EVALUATION OF THE UNITED STATES GEOLOGICAL SURVEY'S THREE-STEP ASSESSMENT METHODOLOGY

A research report
for contract 1434-92-C-30041 in response
to solicitation 7881
Submitted to

Benjamin Morgan, Chief Geologist
United States Geological Survey

by
DeVerle Harris
Principal Investigator

Michael Rieber
Associate Investigator

Conference (Evaluation) Panel:
(alphabetical order)

Doug Cook
Stuart Marsh
Larry Meinert
Don Myers
Richard Nielsen
Brian Skinner
John Sumner
Spence Titley

And

Josef Marlow
Michael Stanley

Mineral Economics Program
Department of Mining and Geological Engineering
College of Engineering and Mines
University of Arizona
Tucson, Arizona
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THE UNIVERSITY OF
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TUCSON ARIZONA

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College of Engineering and Mines
The University of Arizona
Tucson, AZ 85721

ENGINEERING EXPERIMENT STATION
COLLEGE OF ENGINEERING AND MINES
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Evaluation of the United States Geological Survey's Three-Step Assessment Methodology

by

DeVerle Harris[1] and Michael Rieber[1]

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[1] Mineral Economics Program, Dept. of Mining and Geological Engineering, College of Engineering and Mines, The University of Arizona, Tucson, AZ.

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INTRODUCTION AND EXECUTIVE SUMMARY

SCOPE

This report describes research contracted by the U.S. Geological Survey with the University of Arizona (1434-92-C-30041) to evaluate the U.S. Geological Survey's Three-Step assessment methodology. Specifically, solicitation 7881 provided the following statement of work:

"Provide assistance to the USGS by preparing a report that reviews and analyzes the agency's undiscovered mineral-resource assessment methodology and offers recommendations for future method development and applications. The review should (1) examine the legal and administrative obligations of the USGS to provide mineral-resource assessments; (2) examine the evolution and description of current methodologies; (3) include a critique of the presentation of results with respect to sensitivity analysis of the variability of input data and perceived bias of analytical methods; (4) include a comparison of the methods used by USGS with procedures in other organizations; and (5) include logistical requirements of the various assessment methodologies. The report will provide recommendations which the USGS can use in planning future research and product development."

EVALUATION PANEL

Because of the interdisciplinary and predictive nature of assessment, the panel to evaluate the methodology consists of eminent scientists from relevant disciplines or specialties: economic geologists and explorationists, mineral economists, an exploration geophysicist, a geologist with expertise in remote sensing and GIS, and a geostatistician (mathematician). Members of the panel are Brian Skinner, Douglas Cook, Richard Nielsen, Larry Meinert, Spence Titley, DeVerle Harris, Michael Rieber, John Sumner, Stuart Marsh, and Don Myers.

ARIZONA CONFERENCE

Subsequent to contracting for this study and in response to a planning meeting with Chief Geologist Benjamin Morgan, the work was extended to provide a forum for controversies and conflicts concerning resource assessment. This modification reflects the severity of some controversies and the need for resolutions. Accordingly, a conference was held to provide that forum and to inform the evaluation panel on the controversies and issues that relate to the methodology.

STRUCTURE OF REPORT

The report consists of five major parts. The first one examines the USGS assessment program; accordingly, it begins with a description of the legal and administrative requirements for assessments. This is followed by an overview of the Three-Step assessment methodology, which is the primary subject of the study. This part concludes with a survey of users' opinions about the quality of and usefulness of USGS assessments and about perceived bias in assessments.

The second part, which consists of Chapter II, describes the objectives and agenda of the Arizona Conference and summarizes proceedings of the conference by selected methodological- or program-related controversy.

The third part (Chapter III) describes the evolution of assessment concepts and methods, showing where the USGS Three-step method fits historically and conceptually. Moreover, assessment methodologies used by other organizations are described generally, and the USGS methodology is compared and contrasted with them.

The fourth part (chapters IV through IX) investigates selected technical topics that are involved in assessment: a value measure for land use decisions, deposit models, tonnage and grade distributions, geoinformation other than geology, subjective probability in general, and assessment methodology and subjective probability. Each of these can be read independently, however, the foundations for some elements of Chapter IX, Assessment Methodology and Subjective Probability, are established in Chapter VIII, Subjective Probability.

The fifth part consists of Chapter X, Summary and Recommendations. This chapter includes general comments about the assessment program, a description of positive elements of the USGS methodology, and recommendations for modifications of assessment methodology. Recommendations are separated into short-run (those that can or should be initiated immediately) and long-run, those that are major modifications or require a major effort to implement. Although this part stands alone and can be read separately, foundations for evaluations and recommendations are laid in the foregoing chapters, especially those that deal with technical topics.

Appendices to the report include the evolution of recent controversies and unresolved questions or issues of the Arizona Conference (Appendix I), individual reports by some Panel members (Appendix II), vitae of Panel members (Appendix III).

EXECUTIVE SUMMARY

STRUCTURE

This brief summary consists of two major subjects: 1) the USGS assessment program and 2) the USGS assessment methodology.
A more complete summary and discussion of recommendations is provided in Chapter X.

Assessment program topics include administrative responsibilities of the USGS for mineral resource assessment, guiding principles, elements of the three-step methodology, and opinions of users about USGS assessments.

A brief evaluation of the methodology overall follows the discussion of the program. A brief discussion then is presented of major short-run modifications that are recommended to improve assessments. This is followed by summary statements about other specific short-run modifications. The section concludes with a brief listing of long-run modifications.

Short-run modifications are those that either should be made immediately or that could be made without a major effort. Long-run modifications are those that are either major kinds of changes or require considerable time to develop and implement.

THE ASSESSMENT PROGRAM

ADMINISTRATIVE RESPONSIBILITIES

Administrative responsibilities for mineral resource assessments derive from authorizing legislation (U.S. Code) and memoranda of understanding of the USGS with the U.S. Bureau of Mines, U.S. Bureau of Land Management, and the U.S. Forest Service. Authorizing legislation deals with the following mineral surveys: Public Lands, Wilderness Lands, Alaska Lands, National Security Purposes and on Mineral Lands, and National Forest Lands Administered by the Department of Agriculture.

The demands for and the requirements of mineral resource assessments are expected to increase as requirements for optimum land use increase in importance and complexity, reflecting the evolution of societal preferences. Meeting these demands will require improvements in programmatic support and management. As the institution responsible for mineral resources, the USGS needs a dramatic change from a reluctant participant to an enthusiastic supporter and leader of assessment activities and methods. In particular, USGS management needs to 1) send a strong signal that mineral resource assessment is an important professional activity, for many USGS geologists believe otherwise, and 2) take an active role in directing USGS geologists to become involved in assessment activities. Finally, institutional support of research and development of improved assessment methodologies and information support should be increased in magnitude and have greater continuity.

The needs for consistency and accountability suggest that the responsibilities for research and development of methodology, the training of assessors, the monitoring of the assessment process, and the review of assessments should be institutionally centralized, with provision made for oversight of the unit. Moreover, to ensure that the unit remains progressive and opportunities exist for involvement, it is recommended that interested USGS scientists from other units be rotated into the "central" unit for a limited, but appropriate period of time. As methodology for improved assessments evolves, every effort should be made to apply it in a uniform and consistent manner.

Experience has shown that when no mineral resources assessment is available at the time that a decision on land use is made, the value of the land for its mineral resources is considered to be zero. Thus, in order for the USGS to fulfill its administrative obligations, assessments often must be made quickly, with existing geological information, even when the information is much less than that desired for thorough scientific analysis. Naturally, such assessments are highly uncertain and easily criticized. Often, these criticisms fail to recognize that although the best assessment possible for the given circumstances may be uncertain, it is better than no assessment, provided, of course, that the assessment is unbiased.

GUIDING PRINCIPLES

Uncertainty can, of course, be decreased if the decision can be deferred and funds are made available for the acquisition of additional information. Although delay to acquire more information is always better from the scientific point of view, it may not always be in the best interest of society.

Geological maps and data and mineral resource assessments are information which, like all information, has a cost as well as a benefit. At least in concept, there is an optimum level of geological and mineral resource information, one for which the marginal cost to society equals the marginal benefit. Thus, while scientists may always desire more geological information for better assessments of mineral resources, efforts to acquire such must ultimately be bounded by their value to society. On the one hand, this principle constrains the pursuit of ever greater amounts of geological information. On the other hand, it dictates that some level of geological and resource information should be acquired and that geoscientists who understand the geology and genesis of mineral deposits should participate in the use of available or augmented information to provide society with their best estimates of undiscovered mineral resources.

So far, the benefits and costs of resource information for land use decisions have dictated a level of geological information that leaves the true state of undiscovered resources quite uncertain. This will probably continue to be the case for the foreseeable future, at least for those areas typically involved in land use decisions. Therefore, assessment methodologies must be designed that can use meager or incomplete geological information and that quantify uncertainty about the true magnitudes of number of deposits and resources. Accordingly, it is not useful to speak of "accurate assessments" or of "knowing" the number of undiscovered deposits. We can know the number of economically exploitable deposits in an area if we choose to simply by drilling at the required density. But, generally, the cost of that knowledge is far greater than its value for the making of land use decisions.

Similarly, it is not useful to denigrate a methodology because of the meager geological information used when neither time nor funding permit the acquisition of adequate information. Unbiased scientific estimates based upon meager information will always be better for land use decisions than simply assigning a mineral-use value of zero, except of course when the actual value is zero.

THE THREE-STEP METHODOLOGY

The USGS Three-Step assessment methodology consists of the following major activities (steps or parts):

Step 1

Delineation of geologically permissive areas by geologic environment and deposit type;

Step 2

Elicitation of quantiles (at least probability format) for number of deposits by deposit type and permissive area;

Step 3

The computation of the cumulative probability distributions for GIPV (gross-in-place value) and total amount of metal by permissive area and deposit type using Monte Carlo methods to simulate number of deposits and to simulate deposit tonnages and deposit grades for simulated deposits. This is performed by the computer program referred to as MARK3.

Typically, the assessment is reported as a single value and as selected values from an estimated probability distribution. The single value reported is an estimate of the expected GIPV and is computed as an arithmetic average. The estimated probability distribution for GIPV is represented by 90, 50, and 10 percentile GIPVs ($GIPV_{90}$, $GIPV_{50}$, $GIPV_{10}$) i.e. those GIPVs for which the probabilities are 0.90, 0.50, and 0.10 that the true GIPV is at least as large as $GIPV_{90}$, $GIPV_{50}$, $GIPV_{10}$, respectively.

OPINIONS OF USERS OF USGS ASSESSMENTS

A telephone survey of thirty-five users of USGS assessments revealed that the work of the USGS and the USBOM generally is well regarded, although there are a few detractors. The USGS is not viewed as an advocate of mining or anything else; the USGS is generally perceived as unbiased[1].

Based upon this survey, users, with very few exceptions, consider GIPV to be much better than favorability ratings, i.e. high, medium, and low, and some criticize favorability ratings as being useless for land use decisions, especially when multiple uses or multiple commodities must be considered.

When critical remarks were encountered in the survey of users, they usually were that the assessed quantities (metal or GIPV) are too low; the USGS is too conservative; or, that the USGS is too risk averse, i.e., "afraid to stick its neck out". Other criticisms are that the USGS is too academic, that it is too slow in responding to user's needs, that assessments are based upon too little data, and that it should do more to describe and interpret assessed quantities so that they are more easily understood and more useful in making land use decisions. Essentially, the message is that although the USGS earns high marks for professional work, it earns low marks in education of the users, in instruction about the use of its assessment product, and in the geoinformation used in assessments. Of course, the level of geoinformation used in assessments often is beyond the control of the USGS.

OTHER BROAD CRITICISMS

Other broad criticisms are that assessments often are incomplete in that some relevant deposit types are not considered and that sometimes not all available information is used by the USGS. Nonmetallic or industrial minerals usually are excluded, as also are those metal deposits for which tonnage and grade models are not available. In some instances, surveys and evaluations by other federal or state agencies seem to have been ignored. Greater effort should be made to assemble and use all available information when compiling the data base for assessment.

METHODOLOGY OVERALL

When compared with the many techniques and methods that have been developed and employed in some aspect of mineral resource assessment, the USGS three-step methodology

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[1] Note that the meaning of "unbiased" here differs from its technical use as a property of a statistical estimator, e.g. the arithmetic average, although there is a connection between the two meanings.

is based upon sound geological principles in that assessment is performed through the "windows" of geologic environment and geologic deposit model. That others, e.g. British Columbia and the East-West Center, are replacing previous methodologies with new ones that are very similar to the three-step methodology is a kind of certification of the basic soundness of the USGS methodology. Even so, as land use issues become more complex and decisions become more difficult, assessments must continue to improve. Accordingly, there are modifications in methodology that have the potential for improved assessments. These are summarized in a subsequent section, after brief comments are presented on the existing methodology and recent criticisms of it.

Many of the recent criticisms of the methodology are either fundamentally incorrect or exaggerated in terms of their technical merit. **Contrary to recent, widely circulated claims, the three-step methodology does not lead to biased or grossly exaggerated assessments, provided that it is properly applied, the assessors are unbiased[1] and that the product is properly understood:**

- * The use of geologic analogy (including exploration or assessment experience) is appropriate, as it currently is the only feasible method for resource assessment using the expertise of geologists;
- * Tonnage and grade models constructed from discovered deposits are appropriate when the assessment objective is to support land use decisions, given current or recent prices;
- * When tonnage and grade models are properly constructed, their use to constrain/support the estimation of number of deposits is basically a good idea, as it ensures that all geologists assess the same thing;
- * The notion that the number- of- deposits distribution generally should always be exponential is fundamentally incorrect when probabilities are conditioned on geology and size of permissive area;
- * The current elicitation of quantiles is distribution-free, meaning that it does not assume or impose any distribution form or imply anything about clustering;
- * The combining of number of deposits and tonnage and grade distributions by Monte Carlo simulation in MARK3 is basically sound;
- * Improper operations within MARK3 are not the cause of large GIPV values;
- * Although GIPV is not a good measure of social value, its use by the USGS is consistent with other assessed values, e.g. timber, recreation;

SHORT-RUN MODIFICATIONS TO IMPROVE ASSESSMENTS

REPLACE GIPV WITH RGIPV

The panel recommends that the USGS modify GIPV to RGIPV (restricted gross in-place value). Essentially, computing a probability distribution for RGIPV requires extending MARK3 to filter all simulated deposits and to compute GIPV using only those deposits whose simulated tonnages, grades, and depths indicate potential for economic exploitation, given current and recent prices.

Since many users seem to be satisfied with GIPV, this recommendation requires some explanation. First, some of the user satisfaction with GIPV is relative: when compared to high, medium, and low favorability ratings, GIPV generally is seen as a significant improvement. Second, some users take GIPV only as a starting point and perform their own economic analyses. Third, many users may be unaware of the great variation across deposit types of the economic viability of the deposits that comprise the tonnage and grade distributions. Because of this variation, GIPV, as currently computed for a given region, means something different for, say, simulated porphyry copper deposits than it does for, say, simulated podiform chromite deposits.

REPORTING OF ASSESSMENTS

As indicated above, users generally are not satisfied with the reporting of assessments. The Panel concurs with some criticisms made by users and recommends that the USGS provide graphic as well as numerical presentations of the relative frequency histogram (or, a smoothed version) of simulated results (RGIPV). This would replace the reporting of the mean GIPV and the GIPVs for the 0.9, 0.5, 0.10 cumulative (at least) probabilities. Moreover, selected statistics, e.g. arithmetic mean, mode, and 95% confidence limits, should be depicted on this histogram. Each reported assessment should contain "boiler plate" for the interpretation of reported results, both in technical and layman's terms. So that users are aware of uncertainties about assessed values, a histogram for each assessor should be reported, as well as the average (across assessors) histogram. This should be done separately for each deposit type and for the aggregate of deposit types. Finally, reporting of results should be consistent across assessments.

SUMMARIES OF OTHER SPECIFIC SHORT-RUN MODIFICATIONS

The Panel recommends that the following short-run modifications or extensions be made in the USGS methodology for the assessment of undiscovered mineral resources:

* Comprehensive guidelines should be established for:
    the construction of deposit models,

the identification of deposit types,
the delineation of permissive areas, and
the elicitation of subjective probabilities.

* These guidelines should be made easily available to any interested party, and they should be consistently applied;

* Make a permanent (computerized) record for each assessment of the important geological rationale for the identification of deposit types, the delineation of permissive areas, and the assessed number of deposits;

* The number-of-deposits distribution should be elicited as probabilities for specific numbers or for intervals of numbers of deposits, the intervals being specified by the individual providing the subjective probabilities.

* Whenever data and knowledge permit and a specific assessment requires it, the global tonnage and grade distributions should be tailored to account for terrane effects or regional gradients and for differences in economic circumstances.

* Direct elicitation of subjective probabilities should stress extreme events (numbers of deposits) or intervals of events.

* A revised MARK3 should be designed to include uncertainties about deposit type.

* Much greater care must be given to a consistent application of methodology as it pertains to the following:

- delineation of permissive areas
- number of assessors
- composition of assessment team (group)
- elicitation and encoding procedure.

* The minimum composition of an assessment team is the following:

- a regional geologist who is very familiar with the geology of the assessment area,
- an economic geologist who is very knowledgeable about deposit types and models,
- a geophysicist with some exploration experience,
- a remote-sensing/GIS geoscientist,
- an assessment methodology specialist.

* There should be a minimum of three assessors on each team; thus, if the assessment methodology specialist also assesses, the assessment team would have a minimum of 7, with the above composition.

* The primary purpose of the assessment team (group) is to ensure that the necessary expertise is available and to facilitate a thorough discussion of relevant science, data, experience, and analogue areas.

* A short-run strategy for group assessment is the following:

- maintain at least the established minimum composition and number of assessors;
- provide a forum for thorough discussion, as described above;
- subsequent to discussion of science and the delineation of permissive areas, obtain separately and privately an initial assessment of the probability distribution for number of deposits by deposit type and permissive area;
- prior to reconvening the group, each assessor identifies those geological or informational issues to which his assessment is most sensitive by permissive area;
- In group session, each of the geological and informational issues identified collectively is thoroughly discussed, and relevant information is introduced;
- there is no discussion in the reconvened group of number of deposits in the permissive areas;
- subsequent to the thorough discussion of science and informational issues, each assessor privately makes a final assessment of the probability distribution for number of deposits;
- there is no attempt to reach group consensus;
- each assessor's subjective probabilities are submitted to the simulation program (revised MARK3) which produces a relative frequency approximation to the probability density function for RGIPV.

* Increase the emphasis on geophysical and remote-sensing information in assessment.

LONG-RUN MODIFICATIONS OR EXTENSIONS OF METHODOLOGY

Long-run modifications are by definition either major in kind or changes that need time to develop, test, and implement. Here, only the major ideas of these long-run modifications are briefly noted, the reader being referred to Chapter X and relevant specific chapters for a development and rationalization of the ideas:

* redo and add to the deposit models of Bulletin 1693 and provide in computerized format;

* expand the deposit modeling effort to include expertise outside of the USGS;

* explicitly include exploration information in assessments by either developing an exploration data base when requisite information is available or a methodology to estimate (using expert explorationists) intensity of exploration when requisite data are not available;

* develop a formal and structured process for elicitation of judgement and the encoding of probabilities for number of deposits;

* investigate influence allocation by the RCON or similar system as a means for optimum weighting and integrating of different expertise, e.g. geophysics and economic geology, for a group assessment;

* increase the use of geophysical and remote sensing information and their formal integration with geological information in assessment;

* increase the formal representation of all geoinformation with GIS;

* implement formal pattern analysis to support the delineation of assessment areas and the assessment of number of deposits;

* expand applied geologic research on ore deposits, especially the relations of deposits to regional structures, terranes, and rock types;

* continue research for a "metric" for occurrence probabilities;

* selectively integrate objective quantitative methods into assessment methodology;

* continue research and development of PROSPECTOR II and III for the identification of deposit types and the delineation of assessment areas.

DeVerle Harris

DeVerle Harris, Principal Investigator

Michael Rieber, Associate Investigator

Brian Skinner Conference co-chairman, responsible
for deposit models chapter

Doug Cook, Evaluation Panel Member

Stuart L. Marsh

Stuart Marsh, Evaluation Panel Member

Larry Meinert

Larry Meinert, Evaluation Panel Member

Donald E. Myers

Don Myers, Evaluation Panel Member

Richard L Nielsen

Richard Nielsen , Evaluation Panel Member

John Sumner

John Sumner, Evaluation Panel Member

Spence Titley, Evaluation Panel Member

CHAPTER I -- THE ASSESSMENT PROGRAM

THE ASSESSMENT PROGRAM

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AUTHORIZING LEGISLATION AND MEMORANDA

PERSPECTIVE

This section identifies the legal and some administrative obligations to assess mineral resources. It is not, nor is it meant to be, a legal document. It is meant to be descriptive of the current requirements. For this reason the U.S. Code (USC) was relied upon throughout. This section further, by mention, indicates the needs of several government agencies for mineral resource information to fulfill their stewardships and mandated programs.

As the legislation is not always explicit concerning which agency is to do what specific tasks, memoranda of understanding have been signed among those directly affected: the U.S. Geological Survey (GS), the U.S. Bureau of Mines (BOM), the U.S. Bureau of Land Management (BLM), and the U.S. Forest Service (FS). A review of these memoranda follows. They should be recalled in the context of the subsequent code review.

MEMORANDA

The U.S.Geological Survey (GS) has signed a Memorandum of Understanding (MOU) with the Bureau of Mines (BOM)(June 1987) and both the Bureau of Land Management and the Bureau of Mines (January 1991). An Interagency Agreement between G.S., the BOM and the U.S. Department of Agriculture, Forest Service (FS) was signed January 1987. In general, it is the GS that is to assess the mineral endowment of areas and commodities in such form that the BOM can develop economic resource evaluations from these data on undiscovered resources. As the BOM is to conduct mineability and metallurgical studies as well as conducting economic studies and forecasts of needs, it is at least implied that the GS is to provide the data in gross terms to the BOM while the BOM is to use such data as the basis for their own net value estimations. Jointly, their work is to provide the bases for resource considerations in land-use or commodity-related decisions by policy makers.

The 1991 MOU reports a goal of the three agencies to jointly provide current minerals information to support or supplement BLM's existing mineral resource inventory and evaluation responsibilities, especially where 1) land withdrawal from mineral entry is contemplated, 2) the market value of a known or suspected commodity in an area has significantly increased, 3) mineral development is an identified planning issue or, 4) the current mineral inventory is incomplete. This MOU, however, requires only that undiscovered resources are to be: (1) delineated by significant commodity; (2) rated as high, moderate, low, or unknown; and 3) reported as quantitative probabilistic estimates where possible.

The MOU derives its authority from the Federal Land Policy and Management Act (FLPMA) of 1976 (Section 102(a)). Of particular interest here is the assertion that "the national interest will be best realized if the public lands and their resources are periodically and systematically inventoried and their present and future use is projected through a land-use planning process coordinated with other Federal and State planning efforts;" and also that "the public lands be managed in a manner which recognizes the Nation's need for domestic sources of minerals, food, timber, and fiber from the public lands ..." Congress declared specifically that: "when considering public interest the Secretary concerned shall give full consideration to better Federal land management and the needs of State and local people, including needs for lands for the economy, community expansion, recreation areas, food, fiber, minerals, and fish and wildlife ..." (section 206(a)); "the Secretary shall prepare and maintain on a continuing basis an inventory of all public lands and their resource and other values ... This inventory shall be kept current so as to reflect changes in conditions and to identify new and emerging resources and other values." (section 201(a)); and "land-use plans shall be developed for the public lands regardless of whether such lands previously have been classified, withdrawn, set aside, or otherwise designated from one or more uses" (section 202(a)). BLM is responsible for these actions on the public lands, as described in FLPMA and Secretarial Order Number 3087."

"Subsequently, these directives were re-emphasized when the Secretary was directed by Congress in the "National Materials and Minerals Policy, Research, and Development Act of 1980" (30 U.S.C. 1604(e)) to initiate actions to improve the availability and analysis of mineral data in Federal land-use decision making."

(In particular), "The GS is assigned the responsibility to examine, assess, and otherwise survey the mineral resources of the United States. This responsibility is defined under, or results from, a variety of legislative actions and associated documents and agreements, including the: Organic Act of (43 U.S.C. 31(a)); Strategic and Critical Materials Stock Piling Act of 1946 (50 U.S.C. 98); Transfer of Functions From Secretary of Interior to Secretary of Agriculture with respect to exchanges of non-Federal lands for national forest lands or timber (7 U.S.C. 2201(note)); Wilderness Act of 1964 (16 U.S.C. 1131); Mining and Minerals Policy Act of 1970 (30 U.S.C. 21(a)); Materials and Minerals Policy, Research and Development Act of 1980 (30 U.S.C. 1601 et seq.); Forest and Rangeland Renewable Resources Planning Act of 1974 as amended by the National Forest Act of 1976 (16 U.S.C. 1600 et seq.); Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701); and Alaska National Interest Lands Conservation Act of 1980 (16 U.S.C. 3141-3150, 3161).

The Interagency Agreement referred to above adds public lands administered by the Forest Service to those administered by BLM to be surveyed for mineral resource values by the USGS. The objective, authorized in the National Materials and Minerals Policy, Research, and Development Act of 1980 (30 U.S.C. 1604 (e)), is to initiate actions and improve the availability and analysis of mineral data in Federal land decision making. The Forest Service is to recognize and consider the relationship of the mineral resources to renewable resources in the forest planning process. As in the 1991 MOU, the USGS assesses the favorability for the occurrence of undiscovered mineral and energy resources, delineated by significant commodities, as high, moderate, low, or unknown; where possible, resources are to be reported as statistical estimates.

LEGISLATION

MINERAL SURVEYS OF THE PUBLIC LANDS

The traditional tasks of the United States Geological Survey (USGS), those most closely associated with resource identification and quantification (i.e., mapping, geologic, geophysical and mineral surveys and investigations), derive their authority both within the United States and beyond its borders from Title 43 United States Code. The Organic Act of 1879, which established the USGS under the Department of the Interior, directed the USGS to classify the public lands and examine the geological structure, mineral resources, and products of the national domain. [43 U.S.C. 31(a)] Over time Congress extended the authority of the USGS to undertake geological surveys and conduct investigations relating to mineral resources outside the boundaries of the fifty States. Authority to survey and investigate Puerto Rico is granted by 43 U.S.C. 49. The Secretary of the Interior is permitted under 43 U.S.C. 1457 to direct the USGS, or any other entity under his authority, to perform surveys, investigations, and research in geology, biology, minerals and water resources, and mapping in Antarctica and the Trust Territories of the Pacific Islands. The Secretary of the Interior is authorized by 43 U.S.C. 31(b) to direct the USGS to examine the geological structure, mineral resources, and products outside the national domain when the Secretary determines that such actions would be in the national interest. The importance of international surveys and investigations for national security purposes is indicated by the requirement that the Secretary report annually to Congress on the USGS's activities pertaining to areas outside the national domain. [43 U.S.C. 31(c)]

The information obtained from activities of the USGS are important to mining and mineral exploration, geological, geophysical, and other scientific research, and public policy. Therefore, Congress has directed that the publications of the USGS "shall consist of geological and economic maps, illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology." [43 U.S.C. 41]

The importance of geologic mapping by USGS has been recently noted by Congress. The National Geologic Mapping Act of 1992 [43 U.S.C. 31a et seq.] authorized a federal geologic mapping program "whose objective shall be determining the geologic framework of areas determined to be vital to the economic, social, or scientific welfare of the Nation." [43 U.S.C. 31c(d)(1)] It is the finding of Congress that "geologic maps are the primary data base for virtually all applied and basic earth-science investigations," including "exploration for and development of mineral, energy, and water resources" and "land-use evaluation and planning for environmental protection." [43 U.S.C. 31a(a)(2)] Under this Act, the USGS is required to establish a national geologic-map data base, or archive, containing the results from the geologic mapping program and other maps and data as the USGS deems appropriate. States that participate in the geologic mapping program will be required to pay for half the costs in that State. The "State geologic mapping component" will be integrated with other national priorities. [43 U.S.C. 31a(a)(5)] The Secretary of the Interior is required under the Act to report annually to Congress on the status of the program, with recommendations for further legislative actions. [43 U.S.C. 31g]

The integration of land-use evaluation and planning for environmental protection into the framework of the geologic mapping program is a continuation of the public policy objectives that have evolved since enactment of the Wilderness Act of 1964 [16 U.S.C. 1131 et seq.] and the National Environmental Policy Act of 1969. Since the enactment of the Federal Land Policy and Management Act of 1976 [43 U.S.C. 1701 et seq.], the USGS has become much more involved in issues of land-use planning. Between October 1976 and October 1991, the Secretary of the Interior was required under the "Bureau of Land Management Wilderness Study" to determine the suitability or nonsuitability of areas with wilderness characteristics under the authority of the Secretary[1] for wilderness designation. Prior to making his recommendation for each area to the President, he was required by statute to direct the USGS to conduct mineral surveys and the United States Bureau of Mines (USBOM) to determine the mineral values, if any, that may be present in such areas. [43 U.S.C. 1782(a)]

The authority of the Secretary to direct the USGS to conduct mineral surveys in those areas defined under 43 U.S.C. 1782 expired during October 1991. The general land-use planning ideas set forth in the Federal Land Policy and Management Act still remain in effect, however. Congress has declared that "the national interest will be best realized if the public lands and their resources are periodically and systematically inventoried and their present and future use is projected through a land-use planning process coordinated with other Federal and State planning efforts," and that "the public lands be managed in a manner which recognizes the Nation's need for domestic sources of minerals, food, timber, and fiber from the public lands including implementation of the Mining and Minerals Policy Act of 1970 (84 Stat. 1876, 30 U.S.C. 21a) as it pertains to the public lands." [43 U.S.C. 1701(a)(2) and (12)] A land-use planning process is to "use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences." [43 U.S.C. 1712(c)(2)] It is to "rely, to the extent it is available, on the inventory of the public lands, their resources, and other values," and "consider present and potential uses of the public lands." [43 U.S.C. 1712(c)(4) and (5)]

The Secretary of the Interior is required by statute to "prepare and maintain on a continuing basis an inventory of all public lands and their resources and other values (including, but not limited to, outdoor recreation and scenic values), giving priority to areas of critical environmental concern. This inventory shall be kept current so as to reflect changes in conditions and to identify new and emerging resource and other values." [43 U.S.C. 1711(a)] The Secretary shall "provide State and local governments with data from the inventory for the purpose of planning and regulating the uses of non-Federal lands in proximity of such public lands." [43 U.S.C. 1711(b)]

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[1] The public lands administered by the Secretary through the Bureau of Land Management.

The Secretary, with public involvement, is required to develop, maintain, and, when appropriate, revise land-use plans which provide for the use of the public lands. [43 U.S.C. 1712(a)] Congress has declared that the goal and objectives for such plans be the management of the public lands on the basis of multiple use and sustained yield unless otherwise specified by law. [43 U.S.C. 1701(a)(7)] "Land-use plans shall be developed for the public lands regardless of whether such lands previously have been classified, withdrawn, set aside, or otherwise designated for one or more uses." [43 U.S.C. 1712(a)]

The Secretary may withdraw, exchange, or sell units of the public lands to facilitate the land-use plans that have been developed. In executing land-use management decisions, the Secretary, by his own motion or upon request by a department or agency head, may authorize the withdrawal of units of the public lands from existing uses. [43 U.S.C. 1714(a) and (c)] When evaluating the withdrawal of lands aggregating less than 5,000 acres, the Secretary is authorized to make such withdrawals subject to a public hearing. Such withdrawals may be for a period of time as the Secretary deems desirable, but shall not exceed twenty years. [43 U.S.C. 1714(d)] For withdrawals involving 5,000 acres or more, the Secretary must make his recommendation for withdrawal to the President and to Congress. [43 U.S.C. 1714(c)] 43 U.S.C. 1714(c)(2) requires the Secretary to furnish to Congress:

1) a clear explanation of the proposed use of the land involved which led to the withdrawal;
2) an inventory and evaluation of the current natural resource uses and values of the site and adjacent public and non-public land and how it appears they will be affected by the proposed use, including particularly aspects of use that might cause degradation of the environment, and also the economic impact of the change in use on individuals, local communities, and the Nation;
3) an identification of present users of the land involved, and how they will be affected by the proposed use;
4) an analysis of the manner in which existing and potential resource uses are incompatible with or in conflict with the proposed use, together with a statement of the provisions to be made for continuation or termination of existing uses, including an economic analysis of such continuation or termination;
7) a statement of the consultation which has been or will be had with other Federal departments and agencies, with regional, State, and local government bodies, and with other appropriate individuals and groups; and
12) a report prepared by a qualified mining engineer, engineering geologist, or geologist which shall include but not be limited to information on: general geology, known mineral deposits, past and present mineral production, mining claims, mineral leases, evaluation of future mineral potential, present and potential market demands.

Congress may terminate the withdrawal by passing a resolution disapproving of such a withdrawal. If Congress does not disapprove, the Secretary may withdraw such lands from current uses for a period of not more than twenty years.

Congress has declared that "land exchanges are a very important tool for Federal and State land managers and private landowners to consolidate Federal, State, and private holdings of lands or interests in land for purposes of more efficient management and to secure important objectives including protection of fish and wildlife habitat and aesthetic values; the enhancement of recreation opportunities; the consolidation of mineral and timber holdings for more logical and efficient development; the expansion of communities; the promotion of multiple-use values; and fulfillment of public needs." [Public Law 100-409, Sec. 2] Therefore, Congress has authorized the Secretaries of Interior and Agriculture to acquire by purchase, exchange, or donation, eminent domain lands or interests therein that shall become additions to the public lands, or with respect to the Secretary of Agriculture additions to the National Forest System. [43 U.S.C. 1715(a),(c) and (d)]

"A tract of public land or interests therein may be disposed of by exchange by the Secretary of the Interior ... and a tract of land or interest therein within the National Forest System may be disposed of by exchange by the Secretary of Agriculture under applicable law where the Secretary concerned determines that the public interest will be served by making that exchange...." [43 U.S.C. 1716(a)] When considering the public interest the Secretary concerned "shall give full consideration to better Federal land management and the needs of State and local people, including needs for lands for the economy, community expansion, recreation areas, food, fiber, minerals, and fish and wildlife and the Secretary concerned finds that the values and the objectives which Federal lands or interests to be conveyed may serve if retained in Federal ownership are not more than the values of the non-Federal lands or interests and the public objectives they could serve if acquired." [43 U.S.C. 1716(a)]

The values of lands exchanged by the Secretaries either shall be equal[2] or the values shall be equalized by the payment of money, provided that any payment of money by the Secretary concerned does not exceed twenty-five percent of the total value of lands or interests transferred from Federal ownership. [43 U.S.C. 1716(b)] For such exchanges an appraisal of value must be made. The Secretaries of Interior and Agriculture were required by 43 U.S.C. 1716(f) to promulgate comprehensive regulations governing exchanges of lands and interest therein under this section and other applicable law by August 20, 1989. Congress mandated that the rules and regulations reflect nationally recognized standards for appraisals and the costs borne by each party associated with land surveys and appraisals, mineral examinations, title searches, etc.

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[2] Exchanges can be made pursuant to this section if the values of the lands involved are approximately equal and if the Secretary determines that the exchange is in the public interest, provided that the Secretary has set forth regulations that define the meaning of "approximately equal value." [43 U.S.C. 1716(h)]

The Secretary of the Interior is authorized to sell public lands if he determines that (1) the location or characteristics of such lands make it difficult or uneconomic to manage such lands and they are not suitable to be managed by another Federal department or agency, or (2) the lands were acquired for a specific purpose and the lands are no longer required for that or any other Federal purpose, or (3) disposal of such lands will serve important public objectives.[3] [43 U.S.C. 1713(a)] "Sales of public lands shall be made at a price not less than their fair market value as determined by the Secretary." [43 U.S.C. 1713(d)] All conveyances of title to lands issued by the Secretary (except land exchanges pursuant to 43 U.S.C. 1716) shall reserve to the United States all minerals in the lands, together with the right to prospect for, mine, and remove the minerals under applicable law and such regulations as the Secretary may prescribe, unless the Secretary, after consultation with the appropriate department or agency head, determines that there are no known mineral values in the land or that the reservation will interfere with or preclude non-mineral development of the lands and that such development is a more beneficial use of the lands than mineral development. [43 U.S.C. 1719(a) and (b)]

Conveyance of mineral interests shall be made to the existing or proposed owner of the surface rights upon payment of administrative costs and the fair market value of the interests being conveyed. The Secretary shall require the buyer to deposit a sum of money to cover the administrative costs associated with, but not limited to, the "costs of conducting an exploratory program[4] to determine the character of the mineral deposits in the land, evaluating the data obtained under the exploratory program to determine the fair market value of the mineral interests to be conveyed, and preparing and issuing the documents of conveyance." [43 U.S.C. 1719(b)(3)(i)]

MINERAL SURVEYS OF WILDERNESS LANDS

The Wilderness Act of 1964 established the National Wilderness Preservation System. [16 U.S.C. 1131] As a special provision for the use of wilderness areas, surveys for gathering information about mineral or other resources are authorized as long as such activities are carried out in a manner compatible with the preservation of the wilderness environment. The Secretary of the Interior, in consultation with the Secretary of Agriculture, may conduct ongoing surveys consistent with the concept of wilderness preservation through "the United States Geological Survey and the United States Bureau of Mines to determine the mineral values, if any, that may be present" in such areas. [16 U.S.C. 1133(d)(2)] The

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[3] Whenever a tract of land in excess of 2,500 acres has been designated for sale, the Secretary must inform Congress of such a recommendation. Within ninety days, the Congress may adopt a concurrent resolution preventing the sale. [43 U.S.C. 1713(c)]

[4] The exploratory program shall be undertaken in accordance with standards promulgated by the Secretary. [43 U.S.C. 1719(b)(3)(ii)]

"results of such surveys shall be made available to the public and submitted to the President and Congress." [16 U.S.C. 1133(d)(2)] The Secretaries of the Interior and Agriculture are jointly required to report annually to Congress on the status and extent of the wilderness system, regulations in effect, other pertinent information, and any recommendations they may care to make. [16 U.S.C. 1136]

MINERAL SURVEYS OF ALASKAN LANDS

Mineral surveys of Alaskan lands are subject to the authority given the Secretary of the Interior under 16 U.S.C. 3141 through 3151. The Secretary is authorized to "assess the oil and gas, and other mineral potential of all public lands in the State of Alaska in order to expand the data base with respect to the mineral potential of such lands." [16 U.S.C. 3150] "The Secretary may enter into contracts with public or private entities to carry out all or any portion of the mineral assessment program." [16 U.S.C. 3150(a)] Although the USGS is not directed by statute to perform such assessments, the Secretary is required to submit annually to Congress "all pertinent public information relating to minerals in Alaska gathered by the USGS, USBOM, and any other Federal agency." [16 U.S.C. 3151]

The Secretary of the Interior is required to provide a comprehensive and continuing inventory and assessment of the fish and wildlife resources of the coastal plain of the Arctic National Wildlife Refuge (ANWR). The Secretary is also allowed to authorize exploratory activity within the coastal plain in a manner that avoids significant adverse effects on the fish and wildlife and other resources. [16 U.S.C. 3142(a)] After guidelines for exploratory activities have been prescribed by the Secretary, "any person including the United States Geological Survey may submit one or more plans for exploratory activity ... to the Secretary for approval." [16 U.S.C. 3142(e)(1)] The Secretary "shall not approve of any plan submitted by the United States Geological Survey unless he determines that (1) no other person has submitted a plan for the area involved which meets established guidelines and (2) the information which would be obtained is needed to make an adequate report under subsection (h) of this section." [16 U.S.C. 3142(e)(2)] The provisions of 16 U.S.C. 3142(h) required the Secretary to submit a report containing any information that would have been obtained by USGS under 16 U.S.C. 3142(e)(2) by August 1985. Therefore, the statutory authority of the Secretary to allow exploratory surveys by the USGS has expired.

The Secretary was directed by 16 U.S.C. 3141 to carry out a study of all Federal lands (other than submerged lands on the Outer Continental Shelf) in Alaska north of 68 degrees north latitude and east of the western boundary of the National Petroleum Reserve - Alaska, other than lands included in the National Petroleum Reserve - Alaska and in conservation system units established by the Alaska National Interest Lands Conservation Act (Public Law 96-487, December 2, 1980, 94 Stat. 2371). "As part of the study, the Secretary shall review the suitability or nonsuitability for preservation as wilderness" of these North Slope Federal lands and report his findings to the President, who shall make his recommendations to the Congress. [16 U.S.C. 3144]

The Secretary is also authorized to conduct studies or collect and analyze information from permittees of the oil and gas potential of non-North Slope Federal lands. [16 U.S.C. 3148] Permits may be issued for geological, geophysical, and other assessment activities as long as these activities are conducted in a manner that is consistent with the purposes for which the affected area is managed. The Secretary shall encourage the State of Alaska to undertake similar studies on its lands. The Secretary shall integrate information from any State studies with Federal studies. The Secretary is required to report annually to Congress on his efforts regarding the leasing of, and exploration and development activities on, such lands.

MINERAL SURVEYS FOR NATIONAL SECURITY PURPOSES AND ON MINERAL LANDS

The are no explicit statutory requirements concerning the responsibilities of the USGS under the Strategic and Critical Materials Stock Piling Act of 1946 [50 U.S.C. 98], the Mining and Minerals Policy Act of 1970 [30 U.S.C. 21a], and the National Materials and Minerals Policy, Research and Development Act of 1980 [30 U.S.C. 1601 et seq.]. However, either the President or the Secretary of the Interior is directed to perform functions pursuant to each Act.

In enacting the Strategic and Critical Materials Stock Piling Act of 1946, the Congress found that "the natural resources of the United States in certain strategic and critical materials are deficient or insufficiently developed to supply the military, industrial, and essential civilian needs of the United States for national defense." [50 U.S.C. 98a] Congress directed the President to "make scientific, technologic, and economic investigations concerning the development, mining, preparation, treatment, and utilization of ores and other mineral substances that (A) are found in the United States, or in its territories or possessions, (B) are essential to the national defense, industrial, and essential civilian needs of the United States, and (C) are found in known domestic sources of inadequate quantities or grades." [50 U.S.C. 98g(a)(1)] "Such investigations shall be carried out to determine and develop new domestic sources of supply of such ores and mineral substances." [50 U.S.C. 98g(a)(2)] The President is required to submit to the Congress an annual report detailing the research and development activities regarding strategic and critical materials within the United States. [50 U.S.C. 98h(a)]

In the Mining and Minerals Policy Act of 1970, Congress declared "that it is the policy of the Federal Government in the national interest to foster and encourage private enterprise in

(1) the development of economically sound and stable domestic mining, minerals, metal and mineral reclamation industries;
(2) the orderly and economic development of domestic mineral resources, reserves, and reclamation of metals and minerals to help assure satisfaction of industrial, security and environmental needs;

(3) mining, mineral, and metallurgical research, including the use and recycling of scrap to promote the wise and efficient use of our natural and reclaimable mineral resources; and

(4) the study and development of methods for the disposal, control, and reclamation of mineral waste products, and the reclamation of mined land, so as to lessen any adverse impact of mineral extraction and processing upon the physical environment that may result from mining or mineral activities." [30 U.S.C. 21a]

The Secretary of the Interior shall "carry out this policy when exercising his authority under such programs as may be authorized by law other than this section." [30 U.S.C. 21a] In his annual report to the Congress, the Secretary "shall include a report on the state of the domestic mining, minerals, and mineral reclamation industries, including a statement of the trend in utilization and depletion of these resources, together with recommendations for legislative programs as may be necessary to implement this policy." [30 U.S.C. 21a]

In enacting the National Materials and Minerals Policy, Research and Development Act of 1980, Congress declared that "it is the continuing policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well-being and industrial production with appropriate attention to a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs." [30 U.S.C. 1602] The President shall coordinate the responsible departments and agencies to:

- identify materials needs and assist in the pursuit of measures that would assure the availability of materials critical to commerce, the economy, and national security;
- establish a mechanism for the coordination and evaluation of Federal materials programs, including those involving research and development so as to complement related efforts by the private sector as well as other domestic and international agencies and organizations;
- establish a long-range assessment capability concerning materials demands, supply and needs, and provide for the policies and programs necessary to meet those needs;
- promote and encourage private enterprise in the development of economically sound and stable domestic materials industries;
- encourage Federal agencies to facilitate availability and development of domestic resources to meet critical materials needs. [30 U.S.C. 1602]

Congress also directed the Secretary of the Interior to "collect, evaluate, and analyze information concerning mineral occurrence, production, and use from industry, academia, and Federal and State agencies. [30 U.S.C. 1604(f)]

MINERAL SURVEYS OF NATIONAL FOREST LANDS ADMINISTERED BY THE DEPARTMENT OF AGRICULTURE

The Transfer of Functions from the Secretary of the Interior to the Secretary of Agriculture (Public Law 86-509, 74 Stat. 205) transferred the administration of certain public lands in various states from the Secretary of the Interior to the Secretary of Agriculture. The authority of the USGS to determine mineral values was not terminated for most of these lands, however, since the Secretary of the Interior retained certain powers. Section 2 of the Transfer Act required the Secretary of Agriculture to obtain the approval of the Secretary of the Interior whenever the Secretary of Agriculture disposes of certain lands specified in the Act. For an exchange, patent or sale of these lands to occur, the Secretary of the Interior must determine that the lands are non-mineral or give his approval of the valuation and disposition of the minerals in the lands.

In recognition of the vital importance of America's renewable resources of the forest, range and lands administered by the Forest Service, Congress enacted the Forest and Rangeland Renewable Resources Planning Act of 1974 as amended by the National Forest Management Act of 1976. [16 U.S.C. 1600 et seq.] This Act directed the Secretary of Agriculture to prepare a Renewable Resource Assessment (a ten year long-term resources management plan) and a Renewable Resource Program (a five year management plan). [16 U.S.C. 1601 and 1602] To serve the national interest, Congress found that "the renewable resource program must be based on a comprehensive assessment of present and anticipated uses, demand for, and supply of renewable resources from the Nation's public and private forests and rangelands, through analysis of environmental and economic impacts, coordination of multiple use and sustained yield opportunities..." [16 U.S.C. 1600 (3)] "As part of the Assessment, the Secretary of Agriculture is required to develop and maintain on a continuing basis a comprehensive and appropriately detailed inventory of all National Forest System lands and renewable resources. This inventory is to be kept current so as to reflect changes in conditions and identify new and emerging resources and values." [16 U.S.C. 1603] In the development and maintenance of land management plans for use on units of the National Forest System, the Secretary shall use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences. [16 U.S.C. 1604(b)]

The role of the USGS in facilitating the Forest Service's inventory and program requirements is not defined by statute. However, the requirements that the forests and rangelands be managed on a multiple-use sustained-yield basis suggest that the USGS must assist the Forest Service when the Forest Service undertakes its environmental and economic analysis for each unit as required by 16 U.S.C. 1600 et seq. and the provisions of the National Environmental Policy Act of 1969.

Annual evaluation reports for Congress shall set forth progress in implementing the Renewable Resources Program, together with accomplishments of the Program as they relate to the objectives of the Renewable Resources Assessment. "The evaluation shall assess the balance between economic factors and environmental quality factors. Program benefits shall include, but not be limited to, environmental quality factors such as esthetics, public access, wildlife habitat, recreational and wilderness use, and economic factors such as the excess of cost savings over the value of foregoing benefits and the rate of return on renewable resources." [16 U.S.C. 1606(d)]

OVERVIEW OF THE THREE-STEP METHODOLOGY

INTRODUCTION

The USGS currently estimates undiscovered non-fuel mineral resources using what is known as "the three-part quantitative assessment method" (USGS, 1992, Bolivia). This method has evolved since it was first applied in the Alaskan Minerals Resources Assessment Program in the late 1970's. The first suggestions of the parts of the method were by Singer (1975) in a paper urging the presentation of resource estimates in a "disaggregated" form in which estimates are made "of the quality and quantity of the resources available with respect to the factors which affect possible economies and technologies". Singer (1975) suggested delineation of favorable or permissible domains, subjective estimation of the numbers of deposits in an area and the use of statistical models of tonnage and grade based upon known deposits of the same type to estimate undiscovered resources.

Although defined conceptually by Singer in 1975, the methodology was stated succinctly and specifically by Singer and Ovenshine in 1979:

> "The use of deposit types allows resource assessments to be performed in three basic steps. First, areas are delineated according to the kinds of mineral deposits their known geologic character will permit. Second, the number of deposits within each tract is estimated. And third, the amount of metal and the characteristics of the ore in the deposits are estimated by means of models of grades and tonnages based on similar deposits. The relative economic importance of each tract can then be judged on the basis of these last two evaluations."

This definition of the three-part assessment method, which is essentially the same as described by Singer and Cox (1987), has as its final objective the estimation of the amounts of specific metals present in specific deposit types in each delineated permissive tract.

As defined by Menzie and Singer (1990) the three-part assessment method consists of : 1) delineating domains permissive for particular types of deposits, 2) estimating characteristics of deposits with grade and tonnage models and 3) estimating the numbers of undiscovered deposits in the delineated tracts. In this definition, the final objective appears to be the estimation of numbers of deposits of specific types in the delineated tracts.

Most recently, Singer (1992) states: "In three-part assessments; (1) areas are delineated according to the types of deposits permitted by the geology, (2) the amount of metal and some ore characteristics are estimated by means of grade and tonnage models, and (3) the number of undiscovered deposits of each type is estimated." This is similar to the definition offered by Menzie and Singer in 1990 with the addition of "amount of metal" to step 2. The 1992 definition is also very similar in wording to that presented in 1979 by Singer and Ovenshine except that the second and third steps are in reverse order. However, the order has important implications for the assessment objective. In one case the final objective appears to be numbers of deposits and in the other, amounts of metals.

In practice, resource assessments conducted by the USGS present numbers of deposits in some cases (USGS, 1992 Bolivia) and amounts of metals in other cases (Diggles, 1991 Spotted Owl, McCammon, et al., 1991 18 Wilderness Areas, Hodges and Ludington, 1992 EMNSA).

The three-step quantitative assessment method is actually a four-part method. The first three parts are the same as listed by Singer (1992) and the fourth part is a Monte Carlo simulation of deposits to obtain a probability distribution for the amount of metal contained in undiscovered deposits.

The following sections describe important aspects of the three-part quantitative assessment method, drawing upon the following three papers: Menzie, Bagby, Page, 1987, Menzie and Singer, 1990 and Singer, 1992.

USE OF DEPOSIT MODELS IN THE RESOURCE ASSESSMENT METHODOLOGY

Cox and Singer (1986), describe deposit models as the keystone to combining the diverse types of information used in the mineral resource assessment methodology. They define a deposit model as "...systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. The model may be empirical (descriptive), in which instance the various attributes are recognized as essential even though their relationships are unknown; or it may be theoretical (genetic), in which instance the attributes are interrelated through some fundamental concept." Since the release of USGS Bulletin 1693 (Cox and Singer, 1986), deposit models have taken on greater significance in the estimation of mineral resources. The Bulletin contains 87 descriptive deposit models and 67 grade/tonnage curves represent a diverse spectrum of geological environments based upon data from over 3,900 individual deposits located in 110 countries. The compilation of the data and model interpretation are from a series of contributions by authors both within and outside the Geological Survey. Support documentation on the modelling and data support for the bulletin can be found in Orris (1985), Orris and Bliss (1985), Bagby and Berger (1986), Page (1986), Cox and Rytuba (1987), Tosdal and Smith (1987), Bliss and Jones (1988).

Some fundamental terms used in the construction of Deposit Models are defined by Cox and Singer as follows (USGS Bulletin 1693, p.1):

A 'Mineral Occurrence' is a concentration of a mineral (usually but not necessarily, considered in terms of some commodity, such as copper, barite or gold), that is considered to valuable by someone, somewhere, or that is of scientific or technical interest. In rare instances (such as titanium in a rutile bearing black sand), the commodity might not even be concentrated above its average crustal abundance.

A 'Mineral Deposit' is a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential.

An 'Ore Deposit' is a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit. The "profit" decision under some economic regimes may extend beyond the viability of the individual deposit and reflect the gross national economy of that country.

'Mineral Deposit Models' are defined as systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. The model may be descriptive reflecting the various attributes without regard to genetic relationships, or may be theoretical, in which the attributes are interrelated through some fundamental genetic concepts. Although not intuitively apparent it is the genetic modelling that is more easily performed. Given the large number of observations required for the descriptive approach it becomes difficult to distinguish the critical from the incidental attributes. If all information is included, the number of unique features for each deposit yields an unwieldy number of descriptive models approaching the number of deposits.

Cox and Singer (1986) describe the data as consisting largely of ore deposits for which sufficient exposure permits an understanding of the character and features of the mineralization. The authors note the bias towards large, higher grade metal concentrations as many mineral occurrences are unrecognized as mineral deposits.

Geological Attributes (properties) of a mineral occurrence may be considered on two scales. The local scale concerns those features that may be observed upon field examination including mineralogy, zonal patterns, and local chemical halos. At a regional scale, the Geological Attributes must be inferred from modelling of the global tectonic regimes using known rock associations.

CONSTRUCTION OF THE DESCRIPTIVE DEPOSIT MODELS

Menzie, Bagby and Page (1987), in their discussion of the various classification systems for mineral deposits, note that theoretical systems (for example Lindgren, 1933), are based largely upon observation and interpretation from other branches of geoscience. They caution that models based upon theoretical constructs may have too few examples to convey the amount of variability inherent in most geologic processes. Likewise, purely empirical models may contain an abundance of information, some of which is redundant. As a result, the USGS descriptive models are a mix of theoretical constructs and empirical observations. The theoretical aspects are introduced in the consideration of tectonostratigraphic terranes and their associated mineral deposits. Whereas a statistical description based on an analysis of a large number of known deposits maintains a strong empirical base for the models.

Certain types of tectonostratigraphic terranes are associated with classes of mineral deposits. Menzie, Bagby, and Page (1987), focus upon the understanding of the formation of ore deposits within the context of the geologic history of a given terrane. An assessment requires an understanding of the tectonostratigraphic terrane and what deposit types can be expected. Knowing whether a deposit formed pre-, syn-, or post-accretion is the key to linking deposit models with their respective terranes. Thus, the models of Bulletin 1693 are constructed in two parts; the Geological Environment (terrane-related features), and the Deposit Description. The Geological Environment considers Rock Types, Textures, Age, Tectonic Setting, and Associated Deposits, describing the major attributes of the geological environment in which the deposits are found. The Deposit Description concerns itself with the deposit characteristics themselves emphasizing recognition features such as geochemical and geophysical anomalies. Cartoon style maps and cross sections are used to emphasize spatial associations of geological attributes.

NEW DESCRIPTIVE MODELS

Subsequent to publication of Bulletin 1693 a proliferation of both new models and sub-classes of existing models culminated in the release of USGS Bulletin 2004 (Bliss, 1992). Although many of the new deposit models characterize unique and previously unrecognized classes, Bliss (1992), notes that inclusion into the Bulletin is not automatic. Only models for which grade/tonnage relationships can be established are included. Furthermore, subtypes within existing models can be established using 1) the geological attributes of ore type, gangue type, alteration mineral assemblages, emplacement of ore deposition and host rocks (see Heald and Others, 1987), and/or 2) statistical differences based upon grade and tonnage characteristics (see Orris and Others, 1987, Theodore and Others, 1990, and Cox and Singer, 1988).

A significant contribution of Bulletin 2004 is the addition of deposit models that do not readily lend themselves to description by tonnage and grade relationships. Orris and Bliss (1989), define three new model types by:

1. the contained-material model applicable to commodities where the material must meet some minimum level of purity;
2. the impurity model for commodities where the level of impurities affects utilization;
3. the deposit specific model applicable to commodities that are unique as in the case of gem-quality stones.

DELINEATION OF PERMISSIVE DOMAINS

The first part in an assessment is the delineation of tracts that are permissive for the deposit type of interest. As stated by Singer (1992): "Permissive boundaries are defined such that the probability of deposits of the type being delineated occurring outside the boundary is negligible; that is, less than 1 in 100,000 to 1,000,000." Geological environment and deposit feature information contained in the descriptive deposit models is necessary for this step. As suggested by Menzie and Singer (1990), permissive tract delineation can be accomplished in three steps: 1) identify possible deposit types that may occur in the area, 2) identify mapped geological features forming the general controls of a type of deposit, and 3) eliminate parts of domains that are barren of the deposit type based on mineral exploration history and detailed geological studies.

Identification of possible deposit types can proceed through the use of analogy, projection and association (Menzie,Bagby,Page, 1987). The use of analogy entails the examination of deposit types in other geologically similar areas. The presence of deposits in well-explored adjacent areas of similar geology may allow the projection of those deposit types into the study area. A known association between two or more deposit types may be used to suggest a chance of occurrence of one deposit type in an area when an associated type is known or suspected to be present.

Information on geological environment and ore controls present in descriptive deposit models provides a starting point for the delineation of preliminary permissive tracts. Specific host rock types and/or particular structural ore controls are used as the basis for drawing preliminary domain boundaries. The detail of the available geological maps of the study area will strongly affect this step. Geophysical or geochemical information are useful in the extension and modification of the permissive tract boundaries. Of course, known occurrences of the deposit type(s) of interest are very useful in permissive tract delineation. This information is generally available only in explored areas.

Finally, parts of the preliminary permissive domains are eliminated if there is a high degree of confidence that they are barren. An extensively explored area showing no evidence of the deposit type of interest can be excluded from the permissive tract. Detailed information on geology, geophysics and geochemistry can also be used to eliminate parts of permissive areas. After elimination of barren areas, what remains are domains that may contain undiscovered deposits of the type of interest.

TONNAGE AND GRADE MODELS

Singer (1992) states that given the high degree of dependency between the grade/tonnage models and the estimated number of deposits there must be consistency between the two. The estimation of the number of undiscovered deposits requires consideration of deposit grade and tonnage characteristics. The statistical grade/tonnage models in Bulletin 1693 provide the window through which consistent subjective estimation of the number of undiscovered deposits is achieved.

In addition to classifying the known deposits of a region and aiding in delineation of geologic domains, the models provide information about the potential value of undiscovered deposits in this area. Thus, the models provide the key to economic analysis of these resources (Singer and Cox, 1988). Menzie, Bagby, and Page (1987), describe the process of building tonnage and grade models in three steps:

Step 1. Identification of a set of well explored deposits of the type to be modelled. Naturally, the success of tonnage/grade modelling is dependent upon the correct classification of the descriptive models. The authors demonstrate that mis-classification may be identified by a bi-modal sample where separation into two sub-classes of the model may be warranted. By employing an iterative routine statistical outliers may be identified.

Menzie, Bagby, and Page (1987), recognize that in the estimation of undiscovered resources, having data on past production, reserves and resources at some uniform cut-off grade would be ideal. Although this is rarely, if ever achieved, they remind the users of the models that it is important to understand the nature of the data so that the causes of unusual results can be identified. Bliss, McKelvey and Allen (1990), describe the data used to construct the models as being based upon production and reserves of deposits prior to mining. Cox and Singer (1986), describe the data as being pre-mining tonnages and grades from over 3900 well-explored, well-characterized deposits permitting the construction of 60 tonnage/grade models. In the case of multiple tonnages being reported the authors used that tonnage corresponding to the lowest cut-off grade. The estimate of cut-off grade can vary due to regional, national, or operator differences. The tonnage/grade figures are, however, thought to represent the volume of mineralized rock that the operator believed to be economic under some period of production. Cox and Singer (1986), report that 40% of the deposits included were non-economic representing both small and low grade deposits.

Principal data sources for Bulletin 1693 are the Canada Department of Energy, Mines and Resources, 1980; DeYoung and others, 1984; Krauss and others, 1984; Laughlin, 1984; Menzie and Mosier, 1985; Mosier and others, 1983; Mosier and others, 1986; Singer and others, 1980; Yamada and others, 1980. Summary statistics, by deposit type, are listed in the Appendix B of Bulletin 1693 and, where available, accompany the model description of Bulletin 2004. These deposits are also cross-indexed to the descriptive models in Appendix E. Although each point of the grade/tonnage plots are not identified by name, they do represent an individual deposit (or rarely, a district), cumulated in ascending grade or tonnage (Cox and Singer, 1986). Users of the models can use this information to identify points in either tail.

The spatial distribution of the deposits remains an unresolved issue (see Bliss, 1992). Cox and Singer (1986), report individual deposits whenever possible but warn that some district scale data may be mixed into the model. The reader is presented with the list of data used to construct each model and therefore may draw their own conclusions. Likewise, caution must be exercised with by-product grade data for some deposit types for which the information was either erratic or not available.

Step 2. The second step in building the models is to statistically analyze the data. The values for tonnage and grade are transformed to logarithmic space and all plots of the commodity and tonnages are presented at this scale. When a large number of deposits is used for a model, digits are used to represent the number of deposits at each point. Plots are constructed by rank ordering the data by size and the proportion of the deposits that are greater than each deposit are calculated. The logarithms of tonnage and grade are then plotted versus the calculated proportion. Smoothed curves are plotted through array points and intercepts for the 90th, 50th, and 10th percentiles are constructed (Cox and Singer, 1986). In the preface to Bulletin 1693 (p.7) it is stated that "..for tonnages and most grades, the smoothed curves represent percentiles of a lognormal distribution that has the same mean and standard deviation as the observed data; exceptions are the plots where only a small percentage of deposits had reported grades and grade plots that are presented on an arithmetic scale..." Menzie, Bagby, and Page (1987), add to this stating that "...the mean and standard deviation of the logarithm of tonnage, or grade, and a table of areas of the normal curve (Arkin and Colton, 1963), are used to fit a curve to the observed data points." The statistical data used to construct each curve is presented in the appendices of Bulletin 1693.

To construct a grade/tonnage model it is necessary to test for correlation. A plot of the logarithms of tonnage and grade against each other frequently display a wide scatter of points indicating little, if any, correlation (Menzie, Bagby and Page, 1987). Singer and Mosier (1983a,b), state that for most deposit types the tonnage and grade are independent. Likewise, grades of different commodities generally do not display correlation except for those occurring in closely related mineralogical assemblages.

Lastly, the plots are examined for outliers and, if some points can be identified as associated with another deposit type, they are eliminated from the data set.

<u>Step 3</u>. Finally, curves are fit to the remaining tonnage and grade data.

ESTIMATING THE NUMBER OF UNDISCOVERED DEPOSITS

The estimation of the number of undiscovered deposits in a tract is conditional upon the grade and tonnage models by deposit type. These estimates reflect a belief that some fixed but unknown number of deposits exists. There is uncertainty about that number, largely because of incomplete information about the geology of the tract (Singer, 1992). In the three-step quantitative assessment methodology this uncertainty is reflected in the spread of the numbers-of-deposits estimates associated at the 90,50,10 percent quantiles. The larger the difference of the "at least" number estimates - the larger the uncertainty (Singer, 1992). Likewise, the number of deposits estimated for some level of probability reflects the favorability of the tract.

Given the high degree of dependency between the grade/tonnage models and the estimated number of deposits there must be consistency between the two. Singer (1992) explains that approximately one-half of the estimated number of deposits should be larger than the median tonnage and about ten percent of the deposits should be as large as the upper ten percent of the deposits in the tonnage model. For those grade/tonnage models constructed using district data, the estimate of undiscovered resources will be for districts. Likewise, for those grade/tonnage models specially constructed using spatial density rules, such as the 500 m rule for Comstock epithermal gold/silver bearing veins, the estimate of the number of undiscovered deposits reflects this density.

There are no formal rules employed in the three-step method with respect to the estimate of the number of undiscovered deposits. Menzie, Bagby, and Page (1987) have, however, identified: 1) those factors that affect the estimation of undiscovered deposits, 2) methods that have been used to make such estimates, and 3) areas of inquiry which are likely to result with continued research in the field.

FACTORS THAT AFFECT THE ESTIMATION OF UNDISCOVERED DEPOSITS

The authors stress that the intended use of the estimate cannot be overlooked as the foremost influence in the process. The estimate must reflect the strong dependency between grade/tonnage curves and the estimated number of undiscovered deposits as discussed above. Secondly, the estimation must reflect the type and quantity of information used in the estimation. This requires consideration of the distribution and sampling density of the surveys that yielded the information. Given the survey results, statements must be made as to the nature of the responses with regard to the deposit type being considered. Thirdly, the type, amount, spatial distribution, and effectiveness of mineral exploration in the area can have a large influence. Where the exploration information is proprietary, it is difficult to evaluate the amount, spatial distribution and effectiveness of past programs. Menzie, Bagby and Page (1987), suggest that for an exploration history there is a corresponding degree of size-biased sampling of the deposits. If indeed the largest deposits are discovered early in the exploration process, then adjustment can be made to the grade and tonnage model applicable to deposits that remain to be discovered. Using the discovery rates for mercury deposits in California as an example, size-biased sampling is demonstrated but the authors concede that rarely is exploration data sufficient to be useful in the estimation procedure. Furthermore, exploration is characterized by phases of activity reflecting changes in both economic conditions and technology.

FACTORS CONSIDERED IN ESTIMATING UNDISCOVERED DEPOSITS

Identification of the task and the selection of experts are important factors when geologists estimate the number of deposits (Menzie, Bagby, and Page, 1987).

Identification of the task has a large bearing on the type of information elicited. The authors note a simplicity of eliciting quantile estimates over eliciting probabilities for a sequence of numbers of deposits. For simulation-type studies, discrete probabilities are required. It may be necessary to group domains to assist the geologist where the probability estimate is reflecting concern for the small area under consideration.

The selection of experts to make the estimates depends upon finding people with expertise in 1) the type of deposit being considered, 2) the geology of the region being assessed, and 3) the nature of probability and resource assessment. Group consensus is preferred to individual responses. Care must be given to group dynamics and the dominance of one or two personalities. Generally, groups of three to five experts are used in estimating the number of undiscovered deposits. Prior to estimation, the experts should be prepared for the task by reviewing the probability concepts, the geoscience materials to be used, and the characteristics of the deposits considered. This can be aided by preparing a summary document prior to the elicitation as a means of ensuring that all members of the team are basing estimates upon the same information.

MONTE CARLO SIMULATION USING MARK3

The final step of the three-step quantitative assessment method is the combining of the subjective estimates of numbers of deposits together with grade and tonnage data from known deposits. The result is a probability distribution for the amount of metal in undiscovered deposits. This is accomplished through a Monte Carlo simulation implemented in a computer program known as MARK3 (Drew et al., 1986, Root et al., 1992). The following description of MARK3 is taken largely from the Root et al. (1992) article.

The MARK3 simulator program requires two kinds of inputs: 1) three quantiles on the probability distribution for numbers of deposits for a specific deposit type and, 2) grade and tonnage data on known deposits of that type. See Table 1.1. For example, the second entry in Table 1.1, the number 3, indicates the judgement by the geologist that there is a probability of 0.5 that at least 3 deposits are present.

Using the three points on the distribution, MARK3 selects "...a default distribution approximately in the middle of all possible choices"(Root et al., 1992). This default distribution for the number of deposits is used by MARK3 to determine the number of deposits for each Monte Carlo iteration. MARK3 allows a user to indicate a probability for zero deposits if desired. If so, the probabilities for the other numbers of deposits are scaled to maintain a total probability equal to 1.

MARK3 assigns deposit tonnage and grade to each of the n simulated deposits. The deposit tonnage and grade distributions provide the foundation for this simulation and assignment. MARK3 uses empirical data on tonnage and grade from known deposits to construct piecewise linear approximations to the tonnage and grade distributions. In order to avoid unreasonably large grade and tonnage values, the piecewise linear approximations are bounded by selecting the value of the curve at a cumulative (at least) probability of 0 such that the approximate distribution has the same mean value as the empirical data.

Dependencies between grade and tonnage are accounted for through the use of dependent uniform random variables. These are generated from dependent standard normal

Table 1.1

	Probability that at least the tabulated number of deposits is present		
Probability	0.9	0.5	0.1
Number of Deposits	1	3	5

random variables that are linear combinations of independent standard normal random variables. The coefficients in the linear equation are chosen "...so that the mean of the product of a randomly selected grade and ore tonnage is equal to the mean metal content of the deposits in the original data and so that the means of products of grades are preserved as closely as possible" (Root, et al., 1992).

The possibility of the presence of different suites of metals in a particular deposit type is allowed by MARK3. Within any specific deposit type, the empirical deposit data are arranged based on the metal suites they contain. For any simulated deposit, the metal suite is selected at random with the probabilities of each suite being derived from the frequencies of suites in the empirical data.

After construction of the approximate distributions for numbers of deposits, grades and tonnages, the MARK3 simulator generates a probability distribution for the amount of metal in undiscovered deposits using the following general algorithm (Root et al, 1992):

1. Randomly select the number of deposits using the default distribution for number of deposits.
2. Randomly select a metal suite.
3. Randomly select deposit grades and tonnages using piecewise linear approximate distributions based on empirical data, accounting for dependencies, if necessary.
4. Multiply grades by tonnages to calculate amounts of metals and accumulate the amounts for the iteration.
5. If another deposit remains for this iteration, go to step 2, otherwise go to step 6.
6. If 4,999 iterations have not been completed, go to step 1, otherwise go to step 7.
7. Using the totals for each iteration construct a probability distribution for each metal.

The MARK3 simulator has been tested by comparing the mean amount of metal output from MARK3 to the mean amount of metal in the published data for the grade and tonnage models. See Figure 1.1 for a plot of the test.

In cases where a monetary value is required for economic comparison, the gross-in-place-value (GIPV) of a metal, at various quantiles, is calculated by multiplying the amount of metal from MARK3 by some average metal price.

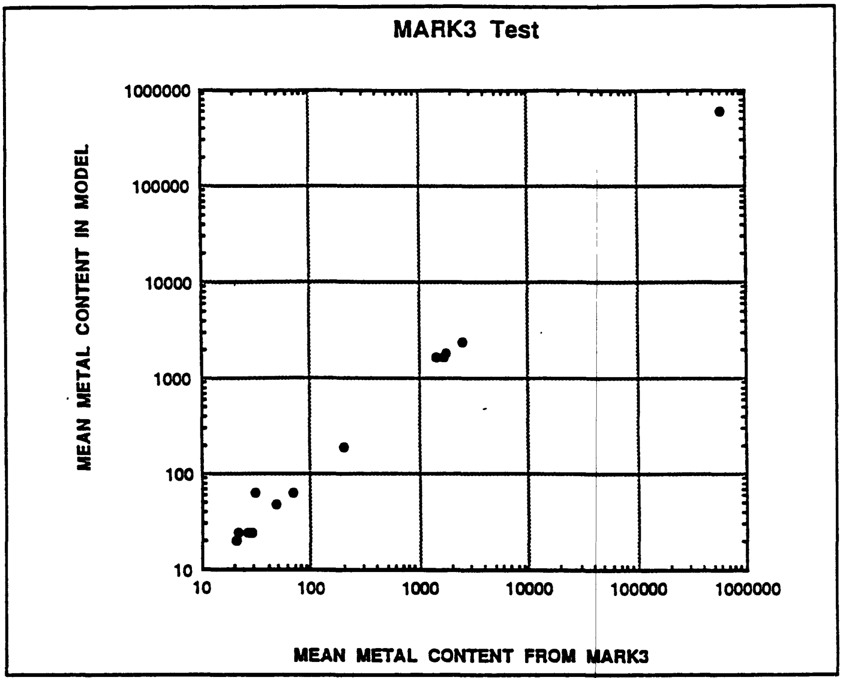

Figure 1.1: A test of the MARK3 simulator.

SURVEY OF USERS' OPINIONS REGARDING USGS ASSESSMENTS

BACKGROUND

MOTIVATION

To gauge user satisfaction with recent USGS assessment activity a telephone survey was undertaken. In order to maintain some consistency and to elicit responses in appropriate areas a generalized format was developed. This outline is appended. It should be noted that the outline is formatted as a checklist of areas to be covered, as cues to a conversational informal questioning. No effort was, or could have been, made to talk anyone through the list.

TOPICS

The survey topics were suggested by a reading of USGS supplied materials, materials supplied by others, and from notes based on discussions of problem areas identified by the project panel and attendees during the scheduled summer meeting. As may be noted from the outline, an effort was made to play devil's advocate with respect to the Survey issues.

INTERVIEWEES

The original source list of interviewees was provided by USGS. This included members of the Congress, BLM, FS, and BOM. Rather than attempt to interview the Senators and Representatives, their legislative assistants or the relevant committee professional staff members were sought. The argument here is that the staff people are usually the actual recipients of USGS materials and apt to be the primary users. It is they who present the results to their legislator or legislative committee.

In some cases legislative assistants undertook the responses directly, in others they suggested alternative names as being more familiar with the area in question. These were then followed up. In almost all cases respondents were asked for the names of additional knowledgeable people. Where names were supplied, they were followed up, if possible. A similar procedure was followed for the Agency people contacted. These included both decision makers and working hands.

To represent the public, representatives of the Sierra Club, the Wilderness Society, the National Resource Defense Council and the American Mining Congress were interviewed. The interview format remained the same. Among environmentalists, two names stand out. They were referred to by several of those contacted: Joanna Wald, Natural Resource Defense Council (California) and Norbert Reidy, Wilderness Society (California). Ms.Wald, unfortunately, suggested that her familiarity with the area was in the past and that she could not be of current assistance. Mr. Reidy, to whom several calls were logged over a three week period, failed either to return calls as promised or to supply promised fax material. These omissions are unfortunate.

MECHANICS

As the individual conversations developed, it became obvious that some of the respondents were unfamiliar with one or more subjects contained in the outline, these were than skipped. Similarly, respondents would cover some outline sections while responding to different sections. There was no need to cover the ground twice. The interviews were not recorded though notes were taken. These notes were then written up in a concise form, eliminating redundancy and extraneous material. Errors in the write-up are the fault of this transcriber. No effort was made to recheck the interview write-up with the original respondents. The interviews have been appended. Thus, if questions arise concerning whether the write-ups properly represent a respondent's views, a direct check can be made. Except for comments identified by squared brackets, all of the material in the interviews as written are from the respondents' viewpoints and represent their expressions.

A problem arises from this; one of interpreting what was said. For example, the word terrane (a group of rocks bounded by some geological features) and terrain (a described area) are homophones. In the reported conversations,however, no effort was made to clarify this matter, all usages were included as "terrain", irrespective of apparent meaning. In this way any possible subjective interpretation was avoided.

ISSUES

Some flavor of the type of issues facing the USGS, excluding the scientific questions, can be gained from the following few paragraphs. No effort was made here to be all-inclusive.

Driving the USGS assessments are the need for land-use planning, including alternative uses, long-term mineral supply considerations, mineral policy requirements, the estimation of mineral values to be used for fair value sales and/or equitable land exchanges, fair payments for land appropriations, and environmental impact statements (EIS). Users, therefore, may be divided into the land and resource decision makers, the Congress; the land and resource planners and managers, the government departments and agencies; professionals in the earth science community; and the public. Principal among the departments and agencies are the USGS, USBOM, USFS, the USBLM, and their equivalents in each of the states.

Mineral appraisal issues arise with respect to resource management plans and the administration of public lands (BLM and FS). These lands, particularly with regard to the Wilderness Act, are subject to rapid withdrawal from entry for minerals. As these applications are expanding, USGS must either expand sufficiently to do the required work, provide quick rather than "accurate" estimates, or have no data to provide those who make land-use decisions.

The resource assessment problem with respect to a given land area is the prediction of the undiscovered mineral inventory and its value. These data are then provided for others to use, perhaps in an economic cost/benefit analysis, an opportunity cost analysis, or with respect to mineral supply issues.

The USGS assessments provide an evaluation of the mineral state-of-nature. To move to the level of economic feasibility on which, later, to base estimates of economic impact arising from the commercial exploitation of the mineralization requires cost estimation. BOM estimates total and operating costs for three sizes of mines (1989$) with interpolations possible. The data may be used with appropriate assumptions (cost of capital, prices, taxes) to yield a cash flow analysis. The economic assumptions may be varied to provide sensitivity analyses, but other variables are not usually so treated. The analyses also provide the requisite metal grades for economic recovery. At issue here is the form and quantification of the USGS data required to adequately underpin the BOM efforts; is high/moderate/low sufficient or is GIPV required?

Potential supply analyses may be used to develop the likely impacts of public lands policies on mining and mineral processing and, with respect to those, on employment, income, and tax revenues within a region vis-a-vis alternative policies on those lands favoring alternative uses. For comparisons to be consistent, however, they must use the same measure (dollars), be appropriately discounted to represent dissimilar time horizons, and reflect relative uncertainties.

SUMMARY OF RESULTS

The remainder of this section is composed of a synthesis of survey responses, section by section, followed by a summary statement of a few modifications which the Survey might wish to consider.

Assessment area choices are politically based, chosen with respect to administrative boundaries and required planning documents, depend on what's hot, but are not commodity driven. The emphasis now is on land-use planning, the resource management plans of the BLM and FS.

Overwhelmingly, respondents indicate that if there is any bias problem with USGS estimates it is that their estimates are understated. This perception is at all levels and across virtually all respondents. More specifically, any bias is attributed to inadequate sampling and misunderstandings (a general USGS representational problem). The USGS output, however, is generally considered credible and scientific.

With respect to HML (High/Medium/Low) reported problems are that it is not sufficiently discriminatory, cannot be translated into useable numbers via economic filters, and may be limited simply to High as Medium and Low tend to be dropped from consideration. Furthermore, High for a low valued commodity may be worth less than Medium for a high valued commodity.

There appears to be little or no discomfort among respondents using Gross In Place Value (GIPV) but the closer they are to being working hands, the less any discomfort. Similar to a corporate preliminary exploration reconnaissance, it is considered a necessary lead into the BOM filters. On the negative side, the large numbers generated are disturbing to some and, like all work on undiscovered resources, it is considered speculative; more credibility would accrue to the estimates if more effort (time and money) were expended.

Comparing HML with GIPV suggests that the former is too qualitative;it says too little and is inadequate for reasonably foreseeable development (RFDs). If it is used, a standard may be needed. While adequate for single parcel land withdrawals, it is less so for evaluations across parcels, commodities and/or alternative uses.

GIPV is considered more useful for cross comparisons (commodities, tracts,and options) and decisions. It still has subjective elements which, with the economic values, lead to controversy, but it is considered a real contribution to potential supply analysis. There are suggestions that GIPT (tonnage) is preferable to GIPV (value).

Given limited time allowances for decisions quick and dirty data are considered better than no data; a lack of data is usually treated as evidence of no resource. In fact, however, it was argued that proof of no resource is more difficult than proof of some resource quantity as it is usually more difficult to prove a negative.

Among the statements of dissatisfaction with USGS, the principal ones appear to be that it is too timid, too research oriented, too aloof, too scientific. Its output is often too late, is not user friendly and is too terse. The Survey needs more people on the ground, better sampling for more detail over smaller areas (all of which requires more money) and more associated industry types.

If the USGS has a problem, it is the failure to educate their clients - from the Agencies through the legislators. They must be able to translate from the supertechnical to the public. They need much more in the way of generic explanations, including all caveats and interpretations.

Furthermore, interagency work needs more development. Turf wars help no one, least of all the clients. Industry and environmentalist data should be accepted if offered and examined like any other even if held to be suspect.

Ultimately, land-use plans and land withdrawals may be political, but more can be done to inform the political debate.

TOPICAL OUTLINE

Telephone Survey

I. Existing and Projected G.S. Surveys
  - A. Results
    - (1) Requested
    - (2) Wanted
    - (3) Used
      - for what commodities
      - what area/region
      - what form of the results/data
  - B. Choices - how made
    - (1) Commodities
      - mineral value now/expected
      - strategic and critical
      - employment
      - other
    - (2) Assessment Areas
      - land swaps
      - withdrawals
      - environmental
      - bill drafting
      - other

II. Perception of Results
  - A. Results Biased
    - (1) how much - (grossly inflated)
    - (2) what reason - (keep mining option, forestall EPA/enviromentalists)
    - (3) form of the bias - what leads to it.
  - B. Data Form HML (High/Medium/Low) for valuation
    - (1) what is understood by this. (S or tons)
    - (2) gross or net - in place or extractable
    - (3) comparable among commodities
    - (4) comparable among alternatives and their estimation (renewables, wilderness, etc.)
    - (5) credibility of estimates

- (6) comfortable with the estimate
- (7) usefulness for potential supply estimation
- (8) is this a first cut estimation - or better
- (9) is more needed or desired

C. Data Form GIPV (Gross In Place Value) for Valuation
- (1) what is understood by this ($ or constant dollars)
- (2) what prices should be used - where or how to get prices
- (3) credibility of the estimate
    - (a) tonnages - in place or extractable
    - (b) prices - gross or net
- (4) How substantiate estimates - are they exaggerated
- (5) comfortable with the estimate
- (6) usefulness for potential supply estimation.
- (7) comparable among commodities
- (8) comparable among alternatives and their estimation (renewables, wilderness, etc.)
- (9) can estimates be improved - how

D. Comparison H/M/L and GIPV
- (1) which one is more
    - (a) useful - in what way
    - (b) credible - why
    - (c) biased - in what way
    - (d) has greater impact ($ vs interpretation)
- (2) for potential supply analysis which is more useful - resource/reserve
- (3) for comparisons which is more useful
    - (a) commodities
    - (b) regions -area
- (4) usefulness - preference
    - (a) first cut
    - (b) cost-benefit or other analysis

III. G.S. Data Supplied

'A. Type
- (1) GIPV/HML
- (2) quantitative rankings
- (3) caveats
- (4) interpretations

B. Time scale - what's useful/desired
- (1) 1-5
- (2)' 6-10

    - (3) 11-20
    - (4) more

IV. Assessment Tradeoffs
  - A. Certainty vs cost (what experience)
    - (1) congressional use
    - (2) agency use
    - (3) legal/environmental/public
  - B. Quick and dirty vs no data
  - C. Economic Conditions re Assessment
    - (1) how important
    - (2) how defined
  - D. Certainty vs Time Period
  - E. USGS estimation validity - GIPV/HML - compared to estimates of
    - (1) scenic values
    - (2) endangered species
    - (3) virgin/wilderness areas
    - (4) renewable resources
    - (5) other
      i.e. - better/worse/how

V. Modifications in USGS results
  - A. Form - What
  - B. Extensions - Type
  - C. Time - What length
  - D. Other

AGENCY

- USGS
  - (1) Research vs Assessment
  - (2) Short vs Long-Term Assessment
  - (3) Comfort Level - GIPV vs HML for geologists
  - (4) Ability to do each - GIPV vs HML - tonnage and price
  - (5) Level of Agency Help.

- BOM/BLM/FS
  - (1) Usefulness of each for their purposes
  - (2) Do they deal with respective state agencies on assessments

- State Units
  - (1) Joint operations with USGS - when, where, satisfaction

    (2) Level of quantification

Congressional Users - how determine
    (1) What minerals
    (2) What area
    (3) What certainty

CLOSE

Any additional, special comments

Suggest anyone else for an interview (knowledgeable)

INTERVIEWS

DEPARTMENT OF THE INTERIOR

Interview: Richard Roddan, Deputy Assistant Secretary, Interior

He prefers GIPV, HML says too little, it's too qualitative; GIPV meets an idea of value. For him, it is necessary to know if in an area a resource is or ever will be economic to mine. E.g., the $5B in Colorado wasn't the trigger for a decision but it gives a better sense than HML for comparisons.

Certainly GIPV is more useful when making cross-comparisons, e.g., natural vs mineral resources. It adds greater specification and makes decisions easier if one must consider numerous options.

For land withdrawals HML is adequate. It's ok for a standard or as if judging a parcel against itself. But if there are many areas and parcels and judgements must also be made among them, against each other, then use GIPV. If you have options GIPV helps to chose among them.

Often the choices of areas are politically based but he is sensitive in judgements with respect to the presence of strategic and critical minerals and with respect to specific minerals - rare earths in the southern California desert.

He has no discomfort using GIPV as he considers its best use to enhance relative rankings. Charges of bias may be due to misunderstanding (gross, in place).

His basic contact with this USGS material came with the wilderness work.

Principal complaint - after 10 years of work in an area with all results in HML, it was not until the end that, for some areas, USGS switched to GIPV. They should have started with it and then people would not have cried foul.

Interview: Dr. Harlan Watson, Principal Deputy Assistant Secretary for Water, Science, and Science Advisor to the Secretary of the Interior.

His principal use of USGS output is for Wilderness Studies (re. FLPMA). USGS data may also be used re. internal disagreements among Bureaus within Interior.

Quick and dirty, "broad brush" is OK for most of the problems he sees. The Wilderness choices are seen as political with respect to the public and to Congress. As these are the drivers of the requests and the area choices, "warm and fuzzy" data are O.K. He notes that there are no $ figures on wilderness values, hence nothing for them to be compared with. At some point in time he thinks the $80M cost of implementing USGS/BOM involvement re. FLPMA may be questioned in Congress as to value given politics.

He thinks that numbers have an impact but he distrusts the very large numbers generated in the GIPV. These he considers to be speculative. He would prefer more credibility even if it took more effort, but not by much as he doesn't think this would be the deciding factor.

He does not consider the USGS to be biased. He does recognize assessment as the largest part of the Survey.

BUREAU OF MINES

Interview: T. Gunther, Potential Supply Analysis, U.S. Bureau of Mines.

The shift to GIPV has made an enormous difference as the quantitative input from the analysis stage prior to the USGS simulation can be fed to the USBOM's own simulation to estimate deposits rather than USGS' resources. From the BOM standpoint, they could get from USGS an enormous gold resource but with all deposits too low grade to be mined and, therefore, the high GIPV does not translate to extractable and impact analysis.

Nevertheless, HML is of no use at all as it can't be translated via filters to useable numbers. In the past BOM has supplied HML evaluations, but they were not used as comparators for BLM and FS.

The split points between BOM and USGS are undiscovered/discovered, no economic analysis/economic analysis, and after the USGS analysis of relevant deposit models (their distributions). At the split BOM uses its simulator to obtain deposit numbers, but finally compares its simulation results with those of USGS. The in place resources are to be a similar number.

As based on deposit models, the numbers are not perfect but are the best descriptions we have available. Furthermore, the methodology, analyses and assumptions are traceable. A similar type of methodology is used formally and informally by the oil and gas companies for exploration decisions. They, however, carry it further to the drilling stage. It is used to create an hierarchy, or ranking of prospective areas which are rescaled as the areas are reduced and eliminated.

When HML was used, ML was often stripped from further consideration. This led to problems as H for, say, moly, might mean only small non-economic deposits even though large tonnages exist throughout the area while M for gold with a couple of good deposits would be economic. The impacts, environmental, economic, etc. are quite different.

Land-use decisions will be made so some logical inputs are required. If USGS did not evaluate the undiscovered resource USBOM could say little about its potential impact for these decisions.

Interview: Robert Hoekzma, Chief, Resource Evaluation Branch, BOM, Spokane

He worked with USGS in Alaska withdrawals (Tongass Forest). USGS developed the terrains and the undiscovered resources. But this was mostly done after the BOM fieldwork so it was not as useful as it might have been. Here the BOM work was useful to USGS.

Interagency cooperation is reasonable, ranging from superb to poor. It is hit or miss and depends on personalities. Winnemucca (for BLM) is a joint BOM/USGS operation and USGS has already done some work here.

USGS does lots of research. It is too timid and afraid to stick its neck out. Its assessments of undiscovered resources are probably on the low side; the numbers are too low, BOM has felt that there was more. USGS results may have been cut back to satisfy the reader (client?).

He sees no bias in USGS, but feels there is a problem with understanding their output. He considers GIPV to be valid and as good a technical approach as is currently available. From this BOM can do interpretations. BOM takes the USGS data and applies economic screens to get RFD. If it makes the cut BOM goes to the socio-economic IMPLAN for impact analysis based, in part, on tonnages and mining method.

GIPV is considered better than H/M/L and, possibly, GIPT is better than GIPV. GIPV is used for rankings across ores and across alternatives. For polymetallic ores care must be used with respect to price times the commodity tonnages. You need to know both what is recoverable as ore and the percent recoverability of each commodity from the ore.

To increase its usefulness USGS should prepare an upfront generic explanation of its methodology and the problems involved. This should be readable.

The type of dollars (constant, current, nominal) used for GIPV are not really important if they are consistent. Besides, they are usually BOM's.

The need for USGS provided caveats and interpretations for the data is variable concerning either or both the number of deposits and their type. They might provide the model and the average for the model. The models are not yet settled out, but he likes the quantitative approach and, here, BOM and USGS go together.

USGS makes a real contribution in potential supply analysis. Its usual clients are BLM and FS with, recently, the Park Service and Fish and Wildlife, with respect to endangered species trade-offs.

Interview: N. Wetzell, BOM, Spokane

BOM takes USGS number of total deposits by deposit types (not GIPV) as given, runs them through the BOM economic screen and throws out those presumed to be uneconomic. But to start they accept their assessment of undiscovered resources.

Wetzell has had many discussions with USGS people including those concerning how to enhance USGS geological work

USGS is typically conservative in its estimates (e.g. gold in the eastern Mojave).

GIPV (GIPT) is alright after BOM evaluation. The analyses are meant for a 10-20 year horizon. If it is not understood, GIPV can be misleading.

HML is not better than GIPV. He would rather deal with numbers if the numbers are real. But there is a question concerning what models and what (±) range on the dollars and tonnages. HML presents problems when comparing across commodities, areas, and alternative uses.

For GIPV the way around some problems is to get other agencies involved sooner, at the beginning. Then USGS and the others will have more time. As it stands now, USGS results are not timely.

There is no bias issue. What bias may exist is due to individuals. This is true in all agencies.

BUREAU OF LAND MANAGEMENT

Interview: S. Allen, Area Manager, Rosewall Resource Area, BLM, N.Mex.

As BLM had nothing in the area to start with it had no way to compare GIPV with HML. They have and are using HML across commodities, areas, and alternate uses. This may not be the best way but they use it to develop EIS impact analyses for NEPA.

GIPV numbers are not overwhelming whether USGS or other based. These values are found for a lot of mineral resources. It is understood that the economics (BOM) in going to the extractable, net basis cuts the numbers down. BLM deals with this a lot so no problems arise.

They have had no reason to question USGS credibility. They like the data support USGS has given this area BLM.

Interview: Victor Dunn, Geologist, Winnemucca District, Nevada, BLM

He is familiar with USGS assessment work on Alaska and Needles as well as other work in Southern California. In the Winnemucca district, with a current assessment, he is working with both USGS and BOM.

In his district the assessment covers everything: base metals, oil and gas, non-metallics and sand and gravel. In fact, all locatable, leasable and saleable. Their brief is everything, no commodity was determining for the assessment. The area/region was chosen with respect to the planning document - administrative boundaries of Nevada BLM and resource areas. The Winnemucca district is only the first for its area.

It is possible that the USGS estimates are too conservative as a first cut. As a check, he is having BOM develop its Reasonable Foreseeable Development for the area (based on USGS' GIPV as a high/Medium/low assessment would not be sufficiently discriminatory). This is a test but could be used for an EIS. But what he really wants, and BOM uses here, is the grade/tonnage and number of deposits rather than gross value.

He wants tons in place and grades rather than dollars, the extractable element he would get from the Bureau. He feels that the USGS data are useful for potential supply estimation when presented as he wants them.

Dunn is familiar with USGS data as supplied as he has been involved with the process all along. With respect to quantitative rankings, caveats and interpretations, therefore, he doesn't need them for his own area but they can be useful for other areas. His time is 10 years.

He wants more credibility, more certainty, but he is forced to the quick and dirty. Policy makers, who want the results don't understand the time and effort problems involved in estimating undiscovered minerals. You simply can't count them like the number of trees, height of grass, or other visible resources.

No dollar estimates accrue to scenic values, endangered species, virgin/wilderness lands so choices are made as policy. The assessments may have little relevance.

Suggested modifications to USGS practice were:

A change in the type of USGS people sent in on the ground - he wants more former industry types.

He has problems with the terminology - In Nevada BLM areas "permissive terrains" might be low (USGS); "favorable" might equal "medium", and "known deposits" might be high.

Interview: Jerry Dutchover; Area Geologist, Roswell Resource Area, BLM (New Mexico)

USGS has already presented a formal document on the area, OFR 92-0261. Study was started several years ago in cooperation with local agencies. The data were presented quantitatively (GIPV) and qualitatively at 90/50/10% which he translates as high/medium/low.

He prefers GIPV as leading to estimation of mineability; it is more useful as if there were to be an operation he could predict type, size and impact.

The study covers a range of minerals. It was not driven by interested concerns but was a joint venture using a history of regional mining. It was total geology and included BLM and FS lands.

He considers USGS unbiased as BOM did a similar report, "Rosewell Report," not yet OFR, at about the same time, with no data sharing and arrived at reasonably close results. He uses both for his (BLM) local Resource Management Plan. He also uses them, re. fair value and geology for land swaps and trades.

BOM and USGS differed in that latter was based on literature and limited field work, former was almost all field work in close cooperation with local BLM.

As he understands the USGS report, it is tonnages (not values). For the required planning documents, HML is OK and specified. For day to day operation, GIPV is used.

What he gets out of this is in place tonnages, gross and general - the generality is needed rather than "nit-picking" the amounts. He wants square miles, thickness, grade/tonnage for use in his own calculations. The mining, extractability is looked at as a separate issue. Cross-comparisons are not made by land-use until someone wants to put out a plan of operations. Then the NEPA analysis needs GIPV.

He sees GIPV as tonnage - not dollars and is less sure of constant or nominal dollars in the estimates. But he is comfortable with the estimates and considers them proper for potential supply estimation. He does seem to consider both GIPV and HML as roughly similar, i.e. 90/50/10 equals H/M/L, and is quite capable of comparing two (say) highs across dissimilar commodities.

Interview: Roger Haskins, BLM, Nevada State Office

A USGS resource assessment is done with a broad sized paint brush, the resources are not extractable. In the past the wilderness study areas were broad brushed and outcomes politically focused.

There was a fight between USGS and BOM (refereed by BLM). USGS did the regional study while BOM went in on the ground and the results were amalgamated. FLPMA ended in 1991 and the appropriations under it ceased. Therefore, USGS wants to restructure towards the quantification of resource values (GIPV) rather than their qualification (HML).

Nevada, fortuitously, is being used as a test site where USGS has been asked to show what it can do. USGS is till trying to figure out how it will all come out. But the formats are to be numerical and digital for an eventual GIS project.

The wilderness land withdrawals were phased out 21 October 1991 (FLPMA started October 1976) and the money ceased. The emphasis now is on land-use planning (BLM and FS) with the withdrawals now part of an RMP process. This included mineral information (values) for an EIS under NEPA as the latter has a disclosure process.

FLPMA itself is endless, only the wilderness withdrawal process ended, with a review of all existing withdrawals. BLM provides the minerals reports but has too few eligible people so the agency gets mineral data from other sources including USGS, or it could go to private sources.

USGS got the work for continuing land-use planning. It must meet some ultimate criteria for format and methodology. BLM may accept one or try to combine several methodologies. There are 1-2 years to decision. Examples include Singer and Cox as well as others.

Politically, it is better to be quantitative. For mangers, numerical with confidence intervals is wanted. Qualitative evaluations are not sufficiently useful. The public also needs (demands) quantification.

USGS sampling is very wide so the results are suspect. A 90/50/10 is like HML until some of the data are checked. He hopes Winnemucca will have good sampling leading to good results.

With respect to estimates, USGS has developed a tool box of methodologies.

Biology is easy to quantify, for example, grass, grazing and timber or vegetation (in animal unit months). Others are not really dollar valued. All need sensitivities. Minerals, a major western factor are not easily valued. Knowing of a high probability of occurrence, however, helps land managers make decisions and appraise economic benefits. The mineral analysis is commodity sensitive.

BOM is participating with USGS (eg, Great Basin) with modeling for production, BOM runs their economic models on USGS data. USGS provides the deposit terrains then BOM provides the economics for impact analysis. Some fieldwork needs to be done but by the summer - fall of 1993 BLM/BOM/USGS will decide on the products and methodologies to be used.

Interview: Jean Juilland, Senior Geologist, BLM, Washington (State) Office, Sacramento CA (location).

USGS works with undiscovered resources, the reports are in common (BLM/BOM/FS/USGS re. the MOUs are cited) but the parts are separate and used by BLM or anyone else.

To BLM the USGS material is useful as BLM may not have the capability (people) to do that type of work or sometimes with the expertise.

He feels that GIPV is not really quantitative as inputs are statistically manipulated subjective estimates. This may not always be understood by users. Statistical probabilities of in place minerals, without detailed studies, though valid, may be misunderstood or misused. Numbers have a mystique and impress people. He suggests that one can operate with the numbers as for rank orderings. Due to the GIPV subjectivity he seems to prefer HML.

Numerical GIPV, however, is useful to BLM for resource management plans covering all resources, mineral and renewable, etc., for which as good a feel for the numbers as possible is desirable. To handle potential resources BLM needs a terrain and/or a commodity, though the latter may be less important, to meet the requirements of the EIS for alternative uses as required by NEPA and CEQ.

These last are asking for reasonable foreseeable development (RFD) for which HML is inadequate.

For the RFD, inferences are required at least in the significant areas, concerning the commodities, and the possible number of deposits that may be there along with grades and tonnages. He seems to imply a GIPT leading to GIPV but notes the problems of high tonnage and low grades or low tonnages and high grades as extremes with a middle ground being commodity dependent for valuation. The solution decided suggests mining method and acres impacted.

He notes that a choice of no potential requires more evidence as proving a negative is more difficult than proving a positive. The result may be resources foregone. The numbers become frightening mainly because of a feeling of false specificity.

More information may not help due to diminishing returns. BLM may use what's available as it cannot wait for another or better survey before making decisions.

USGS needs more knowledgeable people on the ground in each area. They rely too much on theory and need more in the applied area.

Interview: Tom Leshendok, Deputy State Director for Minerals (Nevada), BLM.

BLM is required to use USGS data with respect to BLM wilderness and land-use planning efforts. There is now an attempt to digitize USGS/BLM/BOM data.

There are some difficulties with USGS assessments. For example, for the oil and gas resource assessments USGS was behind the curve with respect to theories and models. Therefore, their rankings were fairly low compared to industry resource assessments and as borne out by more recent developments.

In hard rock, there is a controversy concerning the models and, while USGS results may be a basis for industry looking into an area, they may still be out of date.

USGS is not seen as biased. A perceived problem, however, arises concerning how to treat lack of data (information) versus no information (data) as the latter usually is viewed as no resource.

GIPV leads to a problem in translation - BLM to the public. This is due to language, a translation from the supertechnical. When it doesn't walk away from this problem USGS doesn't help enough. The USGS people are the geologists, they should work more with BLM.

Both commodities and areas of interest are chosen by BLM, not USGS.

There is a gap between the USGS research mission and timetable and local needs. USGS is too slow when data are needed. BLM has received good assistance recently, especially from the USGS Reno group.

Though scales are being worked out, for the Winnemucca district RMP problems of translation arise concerning the 90/50/10 reliability and grade-tonnage relations.

USGS is too research oriented.

Interview: Ron Smith, Division of Minerals Policy Analysis and Economic Evaluation, BLM, Washington, D.C.

BLM wilderness programs are coordinated with USGS and BOM. They used HML until USGS decided to go quantitative (GIPV), to hang dollar figures on the data.

USGS will do the new BLM planning areas. Where there is enough information, they will do a GIPV. There are problems with HML and BLM is satisfied with GIPV, it makes for better comparisons across resources. It will be good to have either tonnage or dollar figures.

The Rosewell project was a pilot. BLM was very pleased with the USGS report. It was used for land-use planning and may well be a model for the future.

Once you know what's behind the models and the statistics you can work with them and be comfortable.

Unlike minerals, other resources are easy to inventory. For HML, H for one commodity may be of less value or use than moderate for another, but ML tracts are not even considered.

USGS tries to provide interpretations, but the reports are terse. They will have to do better in order to extend understanding.

USGS tries for plausibility. Their process is not unlike that of industry - first go to the literature, etc. Industry has used USGS reports in the past for the same opening literature search of an area.

Interview: Dave Stout, Assistant Area Manager, Rosewell Resource Area, BLM (New Mexico).

His area of interest is mainly oil and gas. As he has little staff for inquiry or development, for oil and gas he would like USUSGS to provide the raw data, the scientific aspects with interpretations, so that his office could come up with their own HML estimates.

Their planning horizon, for the Resource Planning Process, is nominally 15-20 years but is often ready for amendment after 3-4 years. Now they tend to look 10-15 years into the future.

Where minerals are concerned, he related them to renewables and to wilderness; pointing out that the comparisons are often subjective and based partly on public perception. For wilderness, he suggested dollar values (possibly) based on such measures as hunting and fishing values (licenses), recreation user days, etc. For renewables the dollar values may be arbitrary as in grazing fees for forage. Other values can be derived from the board feet of timber available or the number of cords of firewood, sometimes validated by bids. [It seems clear that in both of these dollar measures or measureables there is a significant degree of gross valuation rather than net.] For minerals, he would like a dollar value so that if tons of a mineral are to be foregone the cost of this would be known.

FOREST SERVICE

Interview: Charles Frey, Head, Planning Office, FS, Alaska

As applied to the Kootenai, USGS data are basis for trade-off analyses and EISs. To estimate reasonably foreseeable development both USGS and BOM data are required. USGS data are a tool for administration, both for ore deposits and for broad forest planning. The undiscovered resource component is important with respect to new wilderness area delineations.

For land allocation decisions, if HML is used, a handle or standard is needed. The study period may be 2-3 years.

USGS has done lots of good work (e.g., Idaho) but the next round will be even more polarized than before. In the early rounds (1980), locatables allocated themselves, leasables needed allocation, but everything was available for development, from oil and gas through coal to hardrock. Interest groups use total wilderness withdrawal to stop development. Currently, an estimate is made of an area's value, what is it, where is it. Just knowing what's there is of value.

On wilderness decisions mineral potential has had an effect. USGS data were used in Montana for this purpose.

90/50/10 is a good way to go. But USGS should be willing to risk being wrong and take some of the heat like the others.

Excepting wilderness decisions, in the early days FS didn't worry about minerals (except oil and gas). There was no concern about hardrock. If there was no information, there were no minerals. All that counted was a High.

There is no question about USGS credibility, it's there.

Interview: Roger Griffin, Forest Service, Juneau

His USGS contact was with respect to the Tongass Forest and the Panhandle in connection with planning and wilderness areas. A hard look was taken at minerals.

A minerals description was provided (like wilderness and other descriptions). This inventory based description came from BOM, based on their own work and that of USGS.

The Panhandle was a broad brush approach with BOM supplying the hot dogs for more intensive study. The criteria for hot dogs was based on current economics including the type of commodity, its value, and whether of strategic/critical value. They needed something more discrete than broad brush and therefore used BOM. USGS supplied the basics and, later, the inventory of undiscovered mineral resources.

H/M/L was used originally, but they tried to stay away from it. As BOM uses a computer model, they wanted compatibility. He considers the modeling to be a good exercise (both BOM and USGS).

The USGS/BOM record is excellent and unbiased. They do an excellent job. They may or do have opinions. Nevertheless, this is not the issue; the mineral descriptions lead to more mining. USGS/BOM were not challenged by environmentalists in Alaska, even by the Sierra Club Legal Defense Fund.

GIPV is preferred to HML by far. There is a better feel with the numbers and more comfort, among commodities, and across regions and alternative uses. Caveats, interpretations, and qualifications (in cooperation with the FS) are useful.

The FS time horizon is 10 years and their required plans are expensive to produce in both time and money so cooperation is important.

Five years ago there was a BOM-USGS turf war. BOM originally got the Alaska (?) contract. The problems were soothed later. Excellent work was received from the USGS.

USGS is too difficult to understand, the material needs interpretation, they are high science and aloof, and may be too timid with their results. USGS must maintain a service function.

Interview: David Hatfield, Geologist, F.S. Region I.

The Tongass study was open option. Started in 1987, FS did not pick the commodities. It required a land management plan and, therefore, an inventory for trade-offs of values, even if HML.

FS had no mineral map of its own so it started with USGS's OFRs and BOM documents. The terrains were 1:250,000. Four Cox and Singer models were used. FS got involved with BOM for identified as well as undiscovered resources so it ended up with commodities via BOM data bases and field work. (With respect to inferred resources there is a question concerning who is responsible, BOM or USGS, so coordination is required to avoid double counting.) BOM then made a report, including main commodities, from which

FS got High development potentials. Actually, all could be called High but there were three categories to provide a level of certainty. There were about 150 identified mineral tracts, some off the forest boundaries. Within each tract they got the number of prospects. Definitions were kept tight to get away from inferred. Part of the input was professional judgement, part was Cox and Singer for each type of deposit and prospect. They came up with estimates for discovered areas. For planning purposes they needed only a feeling (10±3) rather than a site for a mine.

FS did not want HML from USGS as it is too vague. Low, for example, could be traded off without further consideration so they wanted ounces of identified mineral and estimated ounces of undiscovered mineral to compare with (eg.) wildlife, i.e. how much wildlife could be supported in the area to be removed.

The USGS report was needed, but the bottom line was hot dogs (areas) by commodity, how much, and how do you know From gross tonnages and prices for the past ten with projections for the next ten years (BOM prices) they estimated reasonably foreseeable development (RFD). First the BOM numbers were used (eg. ounces of gold) and then the USGS estimates for undiscovered resources were used, with disclaimers on the price.

If FS hasn't done this for an area then it must be done in order to go through a NEPA process where trade-offs require estimation of direct, indirect and environmental impacts. The last is the EIS portion of the planning process. Assumptions are required and are specified. Areas included are both inside and outside (to get the big picture) the designated boundaries.

USGS involvement stops here, but BOM goes from gross to potential operations via economic analysis (NPV) given the type of mineralization, mining method and tract. The shift is to net from gross to do this and also for sensitivity analysis. Of the 150 tracts (see above) which are the hottest, what is the ranking.

The Alaska Miners Association attended the working groups and reviewed the output for any areas in which they were interested.

Earlier, for FS, minerals constituted use or abuse, there was little mineral understanding.

The state is responsible for extraction, for wildlife as for minerals, habitat is a federal responsibility. A mine is a use, a site; where elk are harvested is a site.

The accuracy of the elk count depends on sightings and poop piles. There is, therefore, a level of certainty. For undiscovered mineral resources all that can be cone is to put out the estimates and, for GIPV, the dollar figure is likely to be large. For Tongass, USGS did a fine job with its 90/50/10 levels of confidence. The USGS report to FS was rewritten to make it more intelligible.

USGS and BOM work related well to the Alaska Mining Association. Enough mineralization was reported to influence a couple of exploration settings.

Across alternative values and areas consistent and equitable measures are desired, so GIPV is desirable. There are lots of assumptions, but it is a useful first cut. Other cuts can be made later by, say, altering the discount rate (NPV).

USGS and BOM are sometimes reluctant to provide data to each other and each seems to want the final say.

He is happy with the output.

Interview: Tom King, Forest Service, Washington, D.C.

Economic values make assessments even more controversial. How do you factor in undiscovered with on the surface resources.

The Forest Plan needs minimal data, it's a zoning type of document and not initially commodity driven, though BOM results and those from USGS are considered. Priorities among areas depend on what's hot; is there exploration there, what are the possible impacts. Where they have the internal capabilities, they take care of their own work.

If there is a USGS bias it may be statistical but not attitudinal.

HML was used until the last two plans; Tongass Forest was GIPV.

The GIPV numbers seem to overwhelm and he is not sure what to do with them, but it is impossible now to make a decision on either GIPV or GIPT.

HML is soft and may be OK, even across alternative values. But High moly versus Moderate (medium) gold requires some market conditions. USGS reports may be enough and might even lead to claims.

Forest plans have a 10-15 years horizon unless reviewed. There is always some data around and, usually, someone on the ground for interpretation. Generally they have too little time.

USGS should be creative, yielding new approaches. No ultimate way has yet been found for their assessments. New approaches are OK even if the data results are not consistent with earlier efforts.

Interview: James Sheldon, Geologist, Saleable Minerals, U.S. Forest Service, Region 1

Commodity choices included locateable and leasable, but excluded saleable minerals. The areas chosen were based on the political boundaries and the areas of controversy, potential and existing, as the sensitive part of a larger effort. There is a possible bias in picking the regions, but none seen otherwise.

GIPV will be in the argument over the Greater Yellowstone from the beginning. For the opposition some will be well meaning, but some will be simply to cast doubt or due to an agenda. Ultimately, it will be a political decision concerning withdrawal.

GIPV is considered more useful than HML with a fairly exact area for the mineral occurrence and a measure of the reliability (90/50/10 percent) given the planning horizon. For planning purposes if you are 60-70% sure that's enough. Therefore, he is not uncomfortable with GIPV as reported.

He feels that USGS doesn't like to make predictions, rather it wants accuracy. They don't like to sound confident and even when daring are conservative.

USGS output is useful for potential supply analysis, given the level of accuracy but cannot be used for mining data [see contra GAO evaluations]. It is a good first approximation and suggests that "yes we can get some out of there." It can also be used for inter-commodity resource comparisons and for assessment trade-offs (e.g., mineral/renewables).

The USGS level of effort for the Greater Yellowstone was good but he feels that some other areas could have used more work on the ground. Most of the time the FS is pushed for results so that given the time constraint quick and dirty is superior to no information.

FS uses state agency people as much as possible, as in Idaho where both USGS and State people were in from the start, but sometimes there are few to work with.

To improve, USGS should do more field work and take the analyses further [but his suggestions would cross USGS into BOM territory, re. economics]. He feels that both forecasts and economics are needed for the undiscovered minerals.

Interview: Robert Thompson, Forest Service, Eureka

HML is good at the informational level, a geologist can make sense of it but management has a problem. For them it doesn't mean too much: "high for what?" Moderate for a megatype deposit may be fine. There is a problem across types of ores.

GIPV is leading in the right direction for evaluating trade-offs. For example, Kootenai where the work was done among FS, BOM and USGS. The numbers arrived at may be problematical but GIPV is still a step in the right direction. One may not need the dollar figure but you do want a significance rating. (An H with significance)

For significance the 90/50/10 estimates are useful. In addition to the dollar amount it also helps to know if the mineral is strategic/critical and the type of mineralization. Some minerals are more important than others.

No bias in the results has been noted. The work was done within the limitations of the data: what is a deposit, what's the implication of extractable and in place, how do these affect probabilities. The problems of dealing with the unknown versus the known are inherent. He has no problem with USGS credibility for either HML or GIPV.

As a first cut he likes GIPV. He makes his own interpretations from this, reading between the lines of the USGS reports. He makes a comparison with timber values for which one can do benefit/cost analyses using computer models.

For minerals his time scale is 10 years, but for decisions minerals are included with the other factors to be considered. Hardrock minerals have not driven the FS process. Economic conditions are not really considered during evaluation, intrinsic value is suggested in place.

If there is a mining claim (locatable mineral) the FS will supply a road, but under suggestions for the new mining law the areas can be cut off even for these.

Suggested modifications for USGS are a rating system (based on dollars or significance). Significance includes type of mineral (e.g. strategic). To evaluate board feet/elk herd versus minerals, high potential goes in one ear and out the other. They would like to have an estimate of possible significant discoveries, something beyond the percents, with respect to identity (not moly but chromium).

There is a need for more people on the ground.

Interview: Charles Wassinger, Director, Lands and Minerals, Forest Service Region 1.

USGS materials are used with respect to mineral inventories and land-use planning. Energy has been, primarily, a USGS domain and hard rock minerals and metals primarily BOM. For wilderness considerations, both BOM and USGS data are used for planning documents.

Problems - he needs more useful data and a better format. He wants small (1:24000 max) rather than large scale. If the data doesn't have enough detail they are of less use. Basically, scale is the number one problem.

It is hard to relate to the USGS terms used. HML is not good enough: what does it mean and how can it be used across minerals. Therefore, FS wants to go to smaller scales, a smaller area for which to predict actual activities likely to occur, as this is more useful for decision makers' choices. The data may be wrong (+/-), but it will help to minimize conflicts.

They have done little with GIPV, but it's a step in the right direction. It may be at the USGS limit of expertise.

GIPV can be used for evaluating trade-offs on a consistent basis, for impact estimation, and for conflict appreciation. Fair value land exchanges are mainly private/public and here mineral value really counts. Mineral development is a legitimate and reasonable land-use. The judgements should be done in a reasonable way, be environmentally sensitive, yet not require zero risk of adverse environmental impact.

The USGS/BOM turf tension has a long history and does not help the customer.

U.S. CONGRESS

Interview: Peter Arapis, Legislative Assistant, Energy, to Senator Harry Reid, (D-NV).

USGS reports are always looked at. This January work will begin on the Spring Mountain National Recreation Area and the USGS material will again be part of the consideration, whether it will be used or not is a different question.

The mining people certainly seem to use the USGS data to buttress their arguments. The maps are used often and often trotted out.

He claims no credibility problem with USGS output but as scientific information it is not always clear what the data mean. It is not always clear how the USGS makes its determinations but the data, like any other forms of data, are subject to interpretation.

The last time he used the USGS material it was in the H/M/L form; simplistic and satisfactory for the layman, but he can't recall what minerals were involved.

He notes that others say the data are not of value as, for example, what does future potential mean, what minerals are under consideration, are they important, who needs more borates.

Based on future needs and prior uses, the more explicit the information the more sensible can be the decisions.

Interview: William Condit, Staff Minority Consultant, House Subcommittee on Mining and Natural Resources; House Mining Caucus. - Assists Barbara Vucanovich, R-NV, Ranking Minority Mining and Natural Resources.

USGS materials are certainly used, as in the House discussions concerning the California desert conservation bills. Both members of Congress and the Agencies have sought the data and prefer that it be at least semi-quantitative.

The Survey was (and is) viewed as too academic, they didn't satisfy their constituents or the constituents of those whom they supplied. Some felt that the USGS results concerning potential in particular areas were too low, principally mining groups.

Because the Survey is felt to be too reticent, their reports are less effective. For this reason they were told to produce more quantitative results. It is understood that this leads to more assumptions, etc., but this is ok (The Singer and Cox work is understood here). Condit feels that he can take USGS work to Rep. Vucanovich for use in legislation and policy making.

He suggests that the Survey "to its credit" doesn't want to be an advocate, they would prefer to be viewed as objective, academic, NAS-like.

Interview: Mike Ford, Legislative Assistant to Senator Pete Dominici, (D) NM.

The USGS data are used primarily with respect to Wilderness bills to determine resource potential lost if an area is locked up. It is felt that the assessments are somewhat projective, but he relies on the data supplied by the agencies and the Senator has great respect for the USGS output,though he also checks with others.

HML is considered fairly subjective but GIPV has not been dealt with enough for them to have an opinion yet.

USGS is not seen as political, their results are usually consistent with those of others (some few exceptions), and in New Mexico they have done good work with respect to potash, oil and gas, and hard rock minerals.

Given quick and dirty versus less data, he would prefer the former.

Comparing across competing claims (wilderness, hard rock, scenic values, etc.) all sides need some numbers for the comparison. They may be seen as components in an EIS. There is also room for loss mitigation but, despite quantification, the results may be only political. If one side demands zero risk this is equivalent to infinite cost so mitigation is impossible or irrelevant.

Interview: Duane Gibson, Legislative Assistant, Senator Ted Stevens, (R) AK

Estimates come in as reports and from other sources, but reports are from BOM/USGS as evaluations and costs. They are useful in the policy arena for authorizing legislation concerning land withdrawals as well as for appropriations.

Nevertheless, they are only part of the data used for policy and are possibly not sufficiently scrutinized.

The data must be credible or won't be utilized. The staff has seen the assumptions and must pass on the accuracy (in some sense).

Quantifiable estimates are sought after and it's understood that this is more difficult for minerals then for renewables.

To estimate potential economic benefit in an area, he wants more than qualitative, needs quantitative and all the information possible.

Interview: Nils Johnson, Legislative Assistant to Senator Larry Craig (R-ID).

USGS supplied information is used, somewhat, for land allocation issues in the sense of what is the situation with respect to mineral resources.

USGS provides a basic resource evaluation. He would like them to be more understandable and to do more with the stats. But all of this needs money.

The levels of reliability for the results leads to credibility problems. For example, 90/50/10 may be a problem and a single number result may also be a problem.

The national mapping bill will yield more mapping, at better levels, and more reliability.

USGS needs more people on the ground and the use of more local surveys.

Interview: C. Lacey, Legislative Assistant to Senator Cranston (D-CA) will be L.A. to Senator Feinstein (D-CA).

Uses mainly BOM and BLM documents as they represent interest on the ground. USGS documents may be late - too late - to be an important resource. They sometimes arrive after Congress has already considered a matter.

Congress is interested in what is real, not what is speculative. Also, government sources sometimes differ with respect to resource magnitudes and in other areas. Some models have been discredited, therefore their numbers are seen as inflated and/or speculative.

For land withdrawals all alternative values are used, including the best mineral information. If the area is outstanding the Senator prefers to err on the side of protection, even if there are mineral occurrences, especially for the California desert.

A timely basis for data acquisition is needed.

Interview: Marian Marshall, Professional Staff, Mineral Resources U.S. Senate, Committee on Energy and Natural Resources, Subcommittee on Mineral Resources Development and Production.

Feels that they may not use USGS data enough and cites the California desert legislation where the U.S. Survey suggested vas resources. In other instances they may not take all information into account and withdraw land prematurely.

USGS should improve the distribution of their results with both legislators and the public.

It is tough to make judgments on HML so GIPV is preferable. [But it is not clear whether a distinction was made here between BOM and USGS output.]

She feels that there is little problem with data, which may exist, but this may be the BOM side.

Interview: E.Rosenberg, Staff Counsel, Mineral Resources, Public Lands Subcommittee, Energy and Natural Resources Committee, U.S. Senate.

They deal with state by state wilderness bills and the respective senators; what do they want, how to satisfy both if there are differences and what to whittle down. It's mainly political. At the level of the subcommittee "great mineral value" may be the level of discussion. A more detailed consideration may exist at the level of the individual senate legislative assistant.

They look at BLM data and listen to opponents. BLM historically understates mineral resource values and were often overridden but the values stated were not too scrutinized.

They are aware of the valuation disputes and aware of the critiques of the methodology. If the methodology is seriously challenged, they don't get to the dollar level of discussion.

Interview: Robert Weidner, Legislative Assistant to Senator Jake Garn (R-UT)

They have done nothing with USGS, the material is ignored, they use private geologists.

In Utah USGS said there was no oil and gas (nil) in various areas. They went to private companies who were paying money for leases on which to drill - 3-4 discoveries were made. GS was wrong on the Overthrust Belt, it erred on the low side. So an area should not be locked up (withdrawn) even though GS says its mineral potential is low.

GS is best in its map making role. As GIPV is done in a fluctuating market it's a waste of time.

Interview: Jim Zoia, Legislative Assistant to Rep. Nick Joe Rahall II, (D) WVA, Chair, House Subcommittee on Mining and Natural Resources.

USGS appraisals are seen primarily in connection with Wilderness Act legislation, for fluids as well as for hard rock minerals. To date there has been a lack of assessment. He finds Congress pushing the BLM and FS to allocate more funds for assessments with respect to RMPs. They want these to be full scale EIS type, as from NEPA.

Politically, the Democratic staff often ignore mineral assessments given the presence of other values (endangered species, scenic, wilderness, etc.) so the issue of credibility doesn't really arise. Besides, the Congressional staff is not really equipped to review the technical aspects and can only compare USGS results with those of others. Republican staff members on the subcommittee pull out the assessments to bolster their claims of mineralization.

The result is that in the House, he feels, the USGS assessments have had no impact whatsoever. The House designates large areas, the more conservative Senate designates smaller areas and it goes to committee for compromise.

ENVIRONMENTAL

Interview: David Albersworth, National Wildlife Federation, Washington, D.C.

Agencies should do land-use plans before set asides. These should be based on all resource data. The mining industry, however, says that it doesn't know what's there, especially for hardrock. The environmental groups say take all surface values (they are easier) and ask what is currently known as an offset. More than just mineral values should be considered.

Agencies should accept the argument that mineral value potential should not necessarily control land-use decisions. The agencies rely on USGS and BOM data and/or industry data at face value, even if they (the Agencies) have doubts.

Interview: David Campbell, National Wildlife Federation, Washington, D.C.

He doesn't really deal with USGS type of data.

A lot of the resource/reserve data based arguments don't really mean anything. To make informed decisions numbers are needed. USGS data have wide confidence intervals. The numbers used for decisions are not based on full economic analyses. [He looks to the BOM level of economic analysis.]

Interview: Kirk Koepsel, Sierra Club, Wyoming.

He is not really acquainted with GIPV.

Respecting oil and gas leasing EISs, USGS was totally arbitrary. The oil and gas leasing program is on a competitive bid basis so we get fair market value. For the coal program, the FS had problems with the few bids.

Based on various EISs, HML, which is descriptive on all areas was inconsistent across areas. He prefers that the agencies skip potential resources and stick with current reserves. [He wants a short-term look at something that is already there.]

USGS studies are arbitrary, a standard is required, possibly an index to be used for ranking tracts.

[He bundles USGS with FS and BLM as decision makers.]

Interview: R. Smith, Sierra Club, Arizona

With respect to desert lands, the politicians did not wait for USGS assessments. Those that were already there were used. The Arizona Mining Association came in with their own mineral estimates, USGS may be lower.

USGS reports are abstract and so may have less punch.

He tends not to question the validity of BLM reports and described a political process where, if anything, USGS merely influences BLM concerning wilderness withdrawals.

USGS materials are often historically based and speculative. He questions when the identified tracts would be mined. All of the USGS materials he has used were HML, not dollar figures, and referred to mineral potential.

The agencies were not advocates of mining or anything else. Others use their data for advocacy purposes, including the Sierra Club.

INDUSTRY

Interview: Keith Knoblock, American Mining Congress, Washington, D.C.

He has no direct experience with the USGS assessment process.

The industry wants the best information possible from USGS. He feels that Congress is not paying attention to the USGS materials and too little is being spent on USGS efforts.

In his view, if you don't know what's there leave the area open. Even where High mineral values or probabilities were estimated, only once or twice were withdrawal boundaries altered.

The USGS reports are well done, but ignored. They are in the nature of a broad reconnaissance, much like the mining industry does privately when determining a new area or areas. The resulting OFRs may be good enough to be used for locatable minerals. This has been successful in some areas: copper in Colorado (?) and gold in Alaska.

Most mining companies tend to stay away from wilderness areas as too troublesome.

Land management plans (FS and BLM) tend to relate to the surface as how do you plan for an unknown resource.

The USGS, and, perhaps, the BOM efforts are strictly a literature search as there are no funds for doing more. This is more useful in known areas. Understandably, the mining companies are reluctant to provide proprietary information. For example, there are no mineral surveys for the California desert.

[Note: at his suggestion D. Ridinger, President, Arizona Mining Association, was contacted. He, however, claimed no experience in this area.]

Interview: William Shepherd, Minerals Exploration Coalition, Colorado.

They use whatever information is available. They have their own problems with undiscovered resources.

USGS assessments were not the in-depth stuff needed for their own work concerning access to public lands and wilderness problems. The coalition looks more to what is excluded if land is alienated.

Extractable is an easier concept then in place, but it's tough to get anywhere with HML. Something hard is needed. Anything to help maintain access is useful.

Interview: T. Wilton, Public Lands Committee, Nevada Mining Association.

He has dealt with USGS and tried to use their data, but the USGS assessments are not really good. The detail is too cursory to assess the mineral potential of the wilderness study areas. It resembles, but is not up to, the level of a corporate preliminary reconnaissance mapping.

The USGS geochemistry is reasonably good, but the stratigraphy is not so good. A major problem is that the sample density is too low. As an exploration manager (geologist) going through USGS data, the data are simply insufficient. Furthermore, USGS has a different view of geochemistry from that of industry.

USGS data are not biased, but they are too thin for real useability. Politics are a part of the USGS process resulting in estimates that are too low. There is some industry interest in providing data to USGS but USGS suspects the data and is unwilling to receive it. The state surveys take the data and a few individuals in USGS are willing to take it.

Partly, the problem is that USGS is too research oriented, too few in the Survey map, and the timing of the mapping and its release can be so long as to be atrocious.

GIPV is meaningless for reasons noted above. So too is HML except that its greater subjectivity allows for compensation. Across areas and report authors, even HML based assessments are inconsistent. Whether GIPV or HML, the USGS estimates for southeastern Utah were too low according to industry sources.

The USGS efforts are a waste of taxpayers' dollars, they might as well not do it at all, although the odd ones (assessments) were really well done.

USGS has too little time, the detail on the maps is insufficient. But the sample locations used were real, not invented as in NURE. Attempts to locate sites reported in NURE was indeterminate. Their contractors' efforts were too little supervised. This is not the problem with USGS.

Land withdrawal is alienation on a permanent basis. Of what use is the value term in GIPV if the price is current and the mineral need may be 40 or more years into the future.

APPENDIX: STATUTORY AUTHORITY OF THE USGS UNDER:

TITLE 16 UNITED STATES CODE - CONSERVATION
TITLE 30 UNITED STATES CODE - MINERAL LANDS AND LEASING
TITLE 43 UNITED STATES CODE - PUBLIC LANDS
TITLE 50 UNITED STATES CODE - WAR AND NATIONAL DEFENSE

TITLE 16 UNITED STATES CODE - CONSERVATION

-- Chapter 23 - National Wilderness Preservation System

16 U.S.C. 1131. National Wilderness Preservation System

(a) **Establishment; Congressional declaration of policy; wilderness areas; administration for public use and enjoyment, protection, preservation, and gathering and dissemination of information; provisions for designation as wilderness areas**
(b) **Management of area included in System; appropriations**
(c) **"Wilderness" defined**

16 U.S.C. 1132. Extent of System

(c) **Review by Secretary of the Interior of roadless areas of national park system and national wildlife refuges and game ranges and suitability of areas for preservation as wilderness; authority of Secretary of the Interior to maintain roadless areas in national park system unaffected**

16 U.S.C. 1133. Use of wilderness areas

(d) **Special provisions**

(2) **Mineral activities, surveys for mineral value**

Nothing in this chapter shall prevent within national forest wilderness areas any activity, including prospecting, for the purpose of gathering information about mineral or other resources, if such activity is carried on in a manner compatible with the preservation of the wilderness environment. Furthermore, in accordance with such program as the Secretary of the Interior shall develop and conduct in consultation with the Secretary of Agriculture, such areas shall be surveyed on a planned, recurring basis consistent with the concept of wilderness preservation by the United States Geological Survey and the United States Bureau of Mines to determine the mineral values, if any, that may be present; and the results of such surveys shall be made available to the public and submitted to the President and Congress.

16 U.S.C. 1134. State and private lands within wilderness areas

(a) **Access; exchange of lands; mineral interests restriction**

In any case where State-owned or privately owned land is completely surrounded by national forest lands within areas designated by this chapter as wilderness, such State or private owner shall be given such rights as may be necessary to assure adequate access to such State-owned or privately owned land by such State or private owner and their successors in interest, or the State-owned land or privately owned land shall be exchanged for federally owned land in the same State of approximately equal value under the authorities available to the Secretary of Agriculture: *Provided, however*, That the United States shall not transfer to a State or private owner any mineral interest unless the State or private owner relinquishes or causes to be relinquished to the United States the mineral interest in the surrounding land.

16 U.S.C. 1136. **Annual reports to Congress**
At the opening of each session of Congress, the Secretaries of Agriculture and Interior shall jointly report to the President for transmission to Congress on the status of the wilderness system, including a list and descriptions of the areas in the system, regulations in effect, and other pertinent information, together with any recommendations they may care to make.

-- **Chapter 51 - Alaska National Interest Lands Conservation**

Subchapter III - Federal North Slope lands studies, oil and gas leasing program and mineral assessments

16 U.S.C. 3142. **Arctic National Wildlife Refuge coastal plan**
(a) **Purpose**
The purpose of this section is to provide for a comprehensive and continuing inventory and assessment of the fish and wildlife resources of the coastal plain of the Arctic National Wildlife Refuge; an analysis of the impacts of oil and gas exploration, development, and production, and to authorize exploratory activity witnin the coastal plain in a manner that avoids significant adverse effects on the fish and wildlife and other resources.
(b) **Definitions**
As used in this section -

> (2) The term "exploratory activity" means surface geological exploration or seismic exploration, or both, for oil and gas within the coastal plain.

(d) **Guidelines**
(1) Within two years after December 2, 1980, the Secretary [of the Interior] shall by regulation establish initial guidelines governing the carrying out of exploratory activities.
(2) The initial guidelines prescribed by the Secretary to implement this subsection shall be accompanied by an environmental impact statement on exploratory activities. The initial guidelines shall thereafter be revised to reflect changes made in the baseline study and other appropriate information made available to the Secretary.
(e) **Exploration plan**
(1) After the initial guidelines are prescribed under subsection (d) of this section, any person including the United States Geological Survey may submit one or more plans for exploratory activity ... to the Secretary for approval. ...
(2) ... The Secretary shall not approve of any plan submitted by the United States Geological Survey unless he determines that (1) no other person has submitted a plan

for the area involved which meets established guidelines and (2) the information which would be obtained is needed to make an adequate report under subsection (h) of this section. The Secretary, as a condition of approval of any plan under this section -

> (B) shall require that all data and information (including processed, analyzed and interpreted information) obtained as a result of carrying out the plan shall be submitted to the Secretary;

(h) **Report to Congress**

Not earlier than five years after December 2, 1980, and not later than five years and nine months after such date, the Secretary shall prepare and submit to Congress a report containing -

> (1) the identification by means other than drilling of exploratory wells of those areas within the coastal plain that have oil and gas production potential and estimate of the volume of the oil and gas concerned;
>
> (3) an evaluation of the adverse effects that carrying out of further exploration for, and the development and production of, oil and gas within such areas will have on the resources referred to in paragraph (2) [fish and wildlife, their habitats and other resources].
>
> (5) an evaluation of how such oil and gas relates to the national need for additional domestic sources of oil and gas; and
>
> (6) the recommendations of the Secretary with respect to whether further exploration for, and the development and production of, oil and gas within the coastal plain should be permitted ....

16 U.S.C. 3144. **Wilderness portion of study**

(a) **Suitability of lands for preservation as wilderness; report to President**

As part of the study, the Secretary shall review the suitability or nonsuitability for preservation as wilderness of the Federal lands described in section 3141 of this title [Arctic National Wildlife Refuge] and report his findings to the President.

(b) **Presidential recommendations to Congress**

The President shall advise the Senate and the House of Representatives of his recommendations with respect to the designation of the area or any part thereof as wilderness together with a map thereof and a definition of its boundaries.

16 U.S.C. 3148. **Oil and gas leasing program for non-North Slope Federal lands**

(b) **Study of oil and gas potential and impact of development and production; permits; consultations; State studies; reports to Congress**

> (1)(A) In such areas as the Secretary deems favorable for the discovery of oil and gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas.

(B) The Secretary is authorized to issue permits for study, including geological, geophysical, and other assessment activities, if such activities can be conducted in a manner which is consistent with the purposes for which each affected area is managed under applicable law.

(3) The Secretary shall encourage the State to undertake similar studies on lands associated, either through geological or other land values or because of possible transportation needs, with Federal lands. The Secretary shall integrate these studies, to the maximum extent practicable, with studies on Federal lands so that needs for cooperation between the Federal Government and the State of Alaska in managing energy and other natural resources, including fish and wildlife, can be established early in the program.

(4) The Secretary shall report to the Congress by October 1, 1981, and yearly thereafter, on his efforts pursuant to this Act regarding the leasing of, and exploration and development activities on, such lands.

16 U.S.C. 3150. **Alaska mineral resource assessment program**

(a) **Mineral assessments**

The Secretary shall, to the full extent of his authority, assess the oil, gas, and other mineral potential on all public lands in the State of Alaska in order to expand the data base with respect to the mineral potential of such lands. The mineral assessment program may include, but shall not be limited to, techniques such as side-looking radar imagery and, on public lands other than such lands within the national park system, core and test drilling for geological information, notwithstanding any restriction on such drilling under the Wilderness Act [16 U.S.C. 1131 et seq.]. For purposes of this Act, core and test drilling means the extraction by drilling of subsurface geologic samples in order to assess the metalliferous or other mineral values of geologic terrain, but shall not be construed as including exploratory drilling of oil and gas test wells. To the maximum extent practicable, the Secretary shall consult and exchange information with the State of Alaska regarding the responsibilities of the Secretary under this section and similar programs undertaken by the State. In order to carry out mineral assessments authorized under this or any other law, including but not limited to the National Uranium Evaluation program, the Secretary shall allow for access by air for assessment activities permitted in this subsection to all public lands involved in such study.... The Secretary is authorized to enter into contracts with public or private entities to carry out all or any portion of the mineral assessment program. This section shall not apply to the lands described in section 3141 of this title.

16 U.S.C. 3151. **Annual report by President to Congress on minerals in Alaska**

On of before October 1, 1982, and annually thereafter, the President shall transmit to the Congress all pertinent public information relating to minerals in Alaska gathered by the United States Geological Surveys, United States Bureau of Mines, and any other Federal agency.

16 U.S.C. 1604. **National Forest System land and resources management plans**

(a) **Development, maintenance, and revision by Secretary of Agriculture as part of program; coordination**

As a part of the Program provided for by section 1602 of this title [Renewable Resource Program], the Secretary of Agriculture shall develop, maintain, and, as appropriate, revise land and resource management plans for units of the National Forest System, coordinated with the land and resource management planning processes of State and local governments and other Federal agencies.

(b) **Criteria**

In the development and maintenance of land management plans for use on units of the National Forest System, the Secretary [of Agriculture] shall use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences.

(k) **Development of land management plans**

In developing land management plans pursuant to this subchapter, the Secretary shall identify lands within the management area which are not suited for timber production, considering physical, economic, and other pertinent factors to the extent feasible ....

(l) **Program evaluation; process for estimating long-term costs and benefits; summary of data included in annual reports**

The Secretary [of Agriculture] shall -

> (1) formulate and implement, as soon as practicable, a process for estimating long-term costs and benefits to support the program evaluation requirements of this subchapter;

16 U.S.C. 1606. **Budget requests by President for Forest Service activities**

(d) **Required contents of annual evaluation report**

These annual evaluation reports shall set forth progress in implementing the Program required to be prepared by section 1602 of this title, together with accomplishments of the Program as they relate to the objectives of the Assessment. Objectives should be set forth in qualitative and quantitative terms and accomplishments should be reported accordingly. The report shall contain appropriate measurements of pertinent costs and benefits. The evaluation shall assess the balance between economic factors and environmental quality factors. Program benefits shall include, but not be limited to, environmental quality factors such as esthetics, public access, wildlife habitat, recreational and wilderness use, and economic factors such as the excess of cost savings over the value of foregoing benefits and the rate of return on renewable resources.

-- Chapter 2 - Mineral Lands and Regulations in General

30 U.S.C. 21. **Mineral lands reserved**
In all cases lands valuable for minerals shall be reserved from sale, except as otherwise expressly directed by law.

30 U.S.C. 21a. **National mining and minerals policy; "minerals" defined; execution of policy under other authorized programs; report to Congress**
The Congress declares that it is the continuing policy of the Federal Government in the national interest to foster and encourage private enterprise in (1) the development of economically sound and stable domestic mining, minerals, metal and mineral reclamation industries, (2) the orderly and economic development of domestic mineral resources, reserves, and reclamation of metals and minerals to help assure satisfaction of industrial, security and environmental needs, (3) mining, mineral, and metallurgical research, including the use and recycling of scrap to promote the wise and efficient use of our natural and reclaimable mineral resources, and (4) the study and development of methods for the disposal, control, and reclamation of mineral land, so as to lessen any adverse impact of mineral extraction and processing upon the physical environment that may result from mining or mineral activities.
For the purpose of this section "minerals" shall include all minerals and mineral fuels including oil, gas, coal, oil shale and uranium.
It shall be the responsibility of the Secretary of the Interior to carry out this policy when exercising his authority under such programs as may be authorized by law other than this section. For this purpose the Secretary of the Interior shall report on the state of the domestic mining, minerals, and mineral reclamation industries, including a statement of the trend in utilization and depletion of these resources, together with such recommendations for legislative programs as may be necessary to implement the policy of this section.

30 U.S.C. 22. **Lands open to purchase by citizens**
Except as otherwise provided, all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, shall be free and open to exploration and purchase, and the lands in which they are found to occupation and purchase, by citizens of the United States and those who have declared their intention to become such, under regulations prescribed by law, and according to the local customs or rules of miners in the several mining districts, so far as the same are applicable and not inconsistent with the laws of the United States.

30 U.S.C. 182. **Lands disposed of with reservation of deposits of coal, etc.**
The provisions of this chapter shall also apply to all deposits of coal, phosphate, sodium, oil, oil shale, gilsonite (including all vein-type solid hydrocarbons), or gas in the lands of the United States, which lands may have been or may be disposed of under laws reserving to the United States such deposits, with the right to prospect for, mine, and remove the same, subject to such conditions as are or may hereafter be provided by such laws reserving such deposits.

-- **Chapter 26 - Deep Seabed Hard Mineral Resources**

30 U.S.C. 1401. **Congressional findings and declaration of purpose**
(a) **Findings**
The Congress findings that -
(1) the United States' requirements for hard minerals to satisfy national industrial needs will continue to expand and the demand for such minerals will increasingly exceed the available domestic sources of supply;
(2) in the case of certain hard minerals, the United States is dependent upon foreign sources of supply and the acquisition of such minerals from foreign sources is a significant factor in the national balance-of-payments position;
(3) the present and future national interest of the United States requires the availability of hard mineral resources which is independent of the export policies of foreign nations;
(4) there is an alternative source of supply, which is significant in relation to national needs, of certain hard minerals, including nickel, copper, cobalt, and manganese, contained in the nodules existing in great abundance on the deep seabed;
(5) the nations of the world, including the United States, will benefit if the hard mineral resources of the deep seabed beyond limits of national jurisdiction can be developed and made available for their use;
(8) it is in the national interest of the United States and other nations to encourage a widely acceptable Law of the Sea Treaty, which will provide a new legal order for the oceans covering a broad range of ocean interests, including exploration for and commercial recovery of hard mineral resources of the deep seabed;
(11) development of technology required for the exploration and recovery of hard mineral resources of the deep seabed will require substantial investment for many years before commercial production can occur, and must proceed at this time if deep seabed minerals are to be available when needed....

(b) **Purposes**
The Congress declares that the purposes of this chapter are -
(4) to accelerate the program of environmental assessment of exploration for and commercial recovery of hard mineral resources of the deep seabed and assure that such exploration and recovery activities are conducted in a manner which will

encourage the conservation of such resources, protect the quality of the environment, and promote the safety of life and property at sea....

30 U.S.C. 1403. **Definitions**

For the purposes of this chapter, the term -

(4) "deep seabed" means the seabed, and the subsoil thereof to a depth of ten meters, lying seaward of and outside -

(A) the Continental Shelf of any nation; and

(B) any area of national resource jurisdiction of any foreign nation, if such area extends beyond the Continental Shelf of such nation and such jurisdiction is recognized by the United States;

(5) "exploration" means -

(A) any at-sea observation and evaluation activity which has, as its objective, the establishment and documentation of -

(i) the nature, shape, concentration, location, and tenor of a hard mineral resource; and

(ii) the environmental, technical, and other appropriate factors which must be taken into account to achieve commercial recovery; and

(B) the taking from the deep seabed of such quantities of any hard mineral resource as are necessary for the design, fabrication, and testing of equipment which is intended to be used in the commercial recovery and processing of such resource;

(6) "hard mineral resource" means any deposit or accretion on, or just below, the surface of the deep seabed of nodules which include one or more minerals, at least one of which contains manganese, nickel, cobalt, or copper.

30 U.S.C. 1411. **Prohibited activities by United States citizens**

(a) **Prohibited activities and exceptions**

(1) No United States citizen may engage in any exploration or commercial recovery unless authorized to do so ....

(2) The prohibitions of this subsection shall not apply to any of the following activities:

(A) Scientific research, including that concerning hard mineral resources.

(B) Mapping, or the taking of any geophysical, geochemical, oceanographic, or atmospheric measurements or random bottom samplings of the deep seabed, if such taking does not significantly alter the surface or subsurface of the deep seabed or significantly affect the environment.

30 U.S.C. 1413. **License and permit applications, review, and certification**

(e) **Other Federal agencies**

The Administrator[5] shall provide by regulation for full consultation and cooperation, prior to certification of an application for the issuance or transfer of any license for exploration or permit for commercial recovery and prior to the issuance or transfer of such license or permit, with other Federal agencies or departments which have programs or activities within their statutory responsibilities which would be affected by the activities proposed in the application for the issuance or transfer of a license or permit. Not later than 30 days after June 28, 1980, the heads of any Federal departments or agencies having expertise concerning, or jurisdiction over, any aspect of the recovery or processing of hard mineral resources shall transmit to the Administrator written comments as to their expertise or statutory responsibilities pursuant to this chapter or any other Federal law. To the extent possible, such agencies shall cooperate to reduce the number of separate actions required to satisfy the statutory responsibilities of these agencies. The Administrator shall transmit to each such agency or department a complete copy of each application and each such agency or department, based on its legal responsibilities and authorities, may, not later than 60 days after receipt of the application, recommend certification of the application, issuance or transfer of the license or permit, or denial of such certification, issuance, or transfer....

30 U.S.C. 1419. **Protection of the environment**

(a) **Environmental assessment**

(2) **Supporting ocean research**

The Administrator also shall conduct a continuing program of ocean research to support environmental assessment activity through the period of exploration and commercial recovery authorized by this chapter. The program shall include the development, acceleration, and expansion, as appropriate, of studies of the ecological, geological, and physical aspects of the deep seabed in general areas of the ocean where exploration and commercial development under the authority of this chapter are likely to occur ....

30 U.S.C. 1469. **Biennial report**

(a) **Submission of reports**

The Administrator shall submit to the Congress -

(1) not later than December 31, 1981, a report on the administration of this chapter during the period beginning on June 28, 1980, and ending September 30, 1981; and

(2) not later than December 31 of each second year thereafter, a report on the administration of this chapter during the two fiscal years preceding the date on which the report is require to be filled.

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[5] 30 U.S.C. 1403(12) defines "Administrator" to mean the Administrator of the National Oceanic and Atmospheric Administration.

(b) **Contents**

Each report filed pursuant to subsection (a) of this section shall include, but not be limited to, the following information with respect to the reporting period:

(2) A description of the exploration and commercial recovery activities undertaken, including, but not limited to, information setting forth the quantities of hard mineral resources recovered and the disposition of such resources.

-- Chapter 28 - Materials and Minerals Policy, Research, and Development

30 U.S.C. 1601. **Congressional statement of findings; "materials" defined**

(a) The Congress finds that -

(1) the availability of materials is essential for national security, economic well-being, and industrial production;

(b) As used in this chapter, the term "materials" means substances, including minerals, of current or potential use that will be needed to supply the industrial, military, and essential civilian needs of the United States in the production of goods or services, including those which are primarily imported or for which there is a prospect of shortages or uncertain supply, or which present opportunities in terms of new physical properties, use, recycling, disposal or substitution, with the exclusion of food and of energy fuels used as such.

30 U.S.C. 1602. **Congressional declaration of policy**

The Congress declares that it is the continuing policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well-being and industrial production with appropriate attention to a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs. The Congress further declares that implementation of this policy requires that the President shall, through the Executive Office of the President, coordinate the responsible departments and agencies to among other measures -

(1) identify materials needs and assist in the pursuit of measures that would assure the availability of materials critical to commerce, the economy, and national security;

(3) establish a long-range assessment capability concerning materials demands, supply and needs, and provide for the policies and programs necessary to meet those needs;

(6) promote and encourage private enterprise in the development of economically sound and stable domestic materials industries; and

(7) encourage Federal agencies to facilitate availability and development of domestic resources to meet critical materials needs.

30 U.S.C. 1603. **Implementation of policies**

For the purpose of implementing the policies set forth in section 1602 of this title and the provisions of section 1604 of this title, the Congress declares that the President shall, through the Executive Office of the President, coordinate the responsible department and agencies, and shall -

(3) provide for improved collection, analysis, and dissemination of scientific, technical and economic materials information and data from Federal, State, and local governments and other sources as appropriate;

30 U.S.C. 1604. **Program administration**

(a) **President; preparation of plan and submission to Congress of report**

Within 1 year after October 21, 1980, the President shall submit to the Congress -

(2) recommendations for the collection, analysis, and dissemination of information concerning domestic and international long-range materials demand, supply and needs, including consideration of the establishment of a separate materials information agency patterned after the Bureau of Labor Statistics;

(e) **Secretary of the Interior; initiation of actions**

The Secretary of the Interior shall promptly initiate actions to -

(1) improve the capacity of the United States Bureau of Mines to assess international minerals supplies;

(2) increase the level of mining and metallurgical research by the United States Bureau of Mines in critical and strategic minerals; and

(3) improve the availability and analysis of mineral data in Federal land-use decisionmaking.

A report summarizing actions required by this subsection shall be made available to the Congress within 1 year after October 21, 1980.

(f) **Secretary of the Interior; collection, evaluation, and analysis activities concerning information**

In furtherance of the policies of this chapter, the Secretary of the Interior shall collect, evaluate, and analyze information concerning mineral occurrence, production, and use from industry, academia, and Federal and State agencies.

-- **Chapter 30 - National Critical Materials Council**

30 U.S.C. 1801. **Congressional findings and declaration of purposes**

(a) The Congress finds that -

(1) the availability of adequate supplies of strategic and critical industrial minerals and materials continues to be essential for national security, economic well-being, and industrial production;

(2) the United States is increasingly dependent on foreign sources of materials and vulnerable to supply interruption in the case of many of those minerals and materials essential to the Nation's defense and economic well-being;

(6) establishing critical materials reserves, by both the public and private sectors and with proper organization and management, represents one means of responding to the genuine risks to our economy and national defense from dependency on foreign sources;

(7) there exists no single Federal entity with the authority and responsibility for establishing critical materials policy and for coordinating and implementing that policy; and

(8) the importance of materials to national goals requires an organizational means for establishing responsibilities for materials programs and for the coordination, within and at a suitably high level of the Executive Office of the President, with other existing policies within the Federal Government.

(b) It is the purpose of this chapter -

(1) to establish a National Critical Materials Council under and reporting to the Executive Office of the President which shall -

(A) establish responsibilities for and provide for necessary coordination of critical materials policies, including all facets of research and technology, among the various agencies and departments of the Federal Government, and make recommendations for the implementation of such policies;

(B) bring to the attention of the President, the Congress, and the general public such materials issues and concerns, including research and development, as are deemed critical to the economic and strategic health of the Nation; and

(C) ensure adequate and continuing consultation with the private sector concerning critical materials, materials research and development, use of materials, Federal materials policies, and related matters.

30 U.S.C. 1801. **Establishment of National Critical Materials Council**

30 U.S.C. 1803. **Responsibilities and authorities of Council**

(a) **Primary responsibilities of Council**

It shall be the primary responsibility of the Council -

(1) to assist and advise the President in establishing coherent national materials policies consistent with other Federal policies, and making recommendations necessary to implement such policies;

(2) to assist in establishing responsibilities for, and to coordinate, Federal materials-related policies, programs, and research and technology activities, as well as recommending to the Office of Management and Budget budget priorities for materials activities in each of the Federal departments and agencies;

(3) to review and appraise the various programs and activities of the Federal Government in accordance with the policy and directions given in the National Materials and Minerals Policy, Research and Development Act of 1980 (30 U.S.C. 1601) [30 U.S.C. 1601 et seq.],and to determine the extent to which such programs and activities are contributing to the achievement of such policy and directions;

(5) to advise the President of mineral and material trends, both domestic and foreign, the implications thereof for the United States and world economies and the national security, and the probable effects of such trends on domestic industries;

(7) to make or furnish such studies, analyses, reports, and recommendations with respect to matters of materials-related policy and legislation as the President may request;

(8)(A) to prepare a report providing a domestic inventory of critical materials with projections on the prospective needs of Government and industry for these materials, including a long-range assessment, prepared in conjunction with the Office of Science and Technology Policy in accordance with the National Materials and Minerals Policy, Research and Development Act of 1980, and in conjunction with such other Government departments or agencies as may be considered necessary, of the prospective major critical materials problems which the United States is likely to confront in the immediate years ahead and providing advice as to how these problems may best be addressed, with the first such report being due on April 1, 1985, and (B) review and update such report and assessment as appropriate and report thereon to the Congress at least biennially; and

(9) to recommend to the Congress such changes in current policies, activities, and regulations of the Federal Government, and such legislation, as may be considered necessary to carry out the intent of this chapter and the National Materials and Minerals Policy, Research and Development Act of 1980.

(b) **Specific authorities of Council**

In carrying out its responsibilities under this section the Council shall have the authority -

(2) to establish and convene such Federal interagency committees as it considers necessary in carrying out the intent of this chapter.

(c) **Collaboration and cooperation of Council and Federal agencies with responsibilities related to materials**

In seeking to achieve the goals of this chapter and related Acts, the Council and other Federal departments and agencies with responsibilities or jurisdiction related to materials or materials policy, including the National Security Council, the Council on Environmental Quality, the Office of Management and Budget, and the Office of Science and Technology Policy, shall work collaboratively and in close cooperation.

TITLE 43 UNITED STATES CODE - PUBLIC LANDS

-- Chapter 1 - Bureau of Land Management

43 U.S.C. 2. **Duties concerning public lands**
The Secretary of the Interior or such officer as he may designate shall perform all executive duties appertaining to the surveying and sale of the public lands of the United States, or in anywise respecting such public lands, and, also, such as relate to private claims of land, and the issuing of patents for all grants of land under the authority of the Government.

-- Chapter 2 - Geological Survey

43 U.S.C. 31. **Director of United States Geological Survey**
(a) **Establishment of office; appointment and duties; examination of geological structure, mineral resources, and products of the national domain; prohibitions in respect to lands and surveys**
The Director of the United States Geological Survey, which office is established, under the Interior Department, shall be appointed by the President by and with the advice and consent of the Senate. This officer shall have the direction of the United States Geological Survey, and the classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain....
(b) **Examination of geological structure, mineral resources, and products outside the national domain**
The authority of the Secretary of the Interior, exercised through the United States Geological Survey of the Department of the Interior, to examine the geological structure, mineral resources, and products of the national domain, is expanded to authorize such examinations outside the national domain where determined by the Secretary to be in the national interest.

(c) **Annual report to Congress**
The Secretary of the Interior shall report to the Speaker of the House of Representatives and the President of the Senate on January 31 of each year on all actions taken pursuant to subsection (b) of this section during the year ending on the December 31 immediately preceding the reporting date and on the results of such actions.

Note to Section 31:

Continental Scientific Drilling and Exploration (P.L. 100-441, Sep. 22, 1988, 102 Stat. 1760) also P.L. 98-473, Oct. 12, 1984, 98 Stat. 1875 which states:

> "The Continental Scientific Drilling Program is an important national scientific endeavor that is vital to the understanding of the geological evolution of the Earth and the economic value of its resources...."

43 U.S.C. 31a. **Findings and purpose**

The Congress finds and declares -

(1) during the past 2 decades, the production of geologic maps has been drastically curtailed;

(2) geologic maps are the primary data base for virtually all applied and basic earth-science investigations, including -

(A) exploration for and development of mineral, energy, and water resources;

(C) land-use evaluation and planning for environmental protection

(4) the combined capabilities of the State, Federal, and academic groups to provide geologic mapping are not sufficient to meet the present and future needs of the United States for national security, environmental protection, and energy self-sufficiency of the Nations;

(5) States are willing to contribute 50 percent of the funding necessary tom complete mapping of the geology within the State;

(7) geologic maps have proven indispensable in the search for needed fossil-fuel and mineral resources; and

(8) a comprehensive nationwide program of geologic mapping is required in order to systematically build the Nation's geologic-map data base at a pace that responds to increasing demand.

43 U.S.C. 31b. **Purpose**

The purpose of sections 31a to 31h of this title is to expedite the production of a geologic-map data base for the Nation, to be located within the United States Geological Survey, which can be applied to land-use management, assessment, and utilization, conservation of natural resources, groundwater management, and environmental protection.

43 U.S.C. 31c. **Geologic mapping program**

(a) **Establishment**

There is established in the United States Geological Survey a National Cooperative Geologic Mapping Program....

(b) **Responsibilities of USGS**

The Survey shall be the lead Federal agency responsible for planning, developing priorities, coordinating, and managing the geologic mapping program....

(c) **Program objectives**

The objectives of the geologic mapping program shall include -

(4) development of public awareness for the role and application of geologic-map information to the resolution of national issues of land-use management.

(d) **Program components**

The geologic mapping program shall include the following components:

(1) A Federal geologic mapping component, whose objective shall be determining the geologic framework of areas determined to be vital to the economic, social, or scientific welfare of the Nation. Mapping priorities shall be based on -

(A) national requirements for geologic-map information in areas of multiple-issue need or areas of compelling single-issue need; and

(B) national requirements for geologic-map information in areas where mapping is required to solve critical earth-science problems.

(2) A geologic mapping support component, whose objective shall be providing interdisciplinary support for the Federal Geologic Mapping Component. Representative categories of interdisciplinary support shall include -

(A) establishment of a national geologic-map data base;

(E) geophysical investigations that assist in delineating and mapping the physical characteristics and three-dimensional distribution of geologic materials and geologic structures, which investigations shall be contributed to a national geophysical-map data base; and

(F) geochemical investigations and analytical operations that characterize the major- and minor-element composition of geologic-map units, and that lead to the recognition of stable and anomalous geochemical signatures for geologic terrains, which investigations shall be contributed to a national geochemical-map data base.

(3) A State geologic mapping component, whose objective shall be determining the geologic framework of areas that the State geological surveys determine to be vital to the economic, social, or scientific welfare of individual States. Mapping priorities shall be determined by multirepresentational State panels and shall be integrated with national priorities. Federal funding for the State component shall be matched on a one-to-one basis with non-Federal funds.

43 U.S.C. 31d. **Advisory committee**

(b) **Duties**

The advisory committees shall -

(3) submit an annual report to the Secretary that evaluates the progress of the Federal and State mapping activities and evaluates the progress made toward fulfilling the purposes of sections 31a to 31h of this title.

43 U.S.C. 36c. **Acceptance of contributions from public and private sources; cooperation with other agencies in prosecution of projects**

In fiscal year 1987 and thereafter the United States Geological Survey is authorized to accept lands, buildings, equipment, and other contributions from public and private sources and to prosecute projects in cooperation with other agencies, Federal, State, or private.

43 U.S.C. 41 **Publications and reports; preparation and sale**

Except as otherwise provided in section 1318 of title 44, the publications of the Geological Survey shall consist of geological and economic maps, illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology....

43 U.S.C. 49. **Extension of cooperative work to Puerto Rico**
The provisions of law authorizing the making of topographic and geological surveys and conducting investigations relating to mineral and water resources by the United States Geological Survey in various portions of the United States be, and the same are, extended to authorize such surveys and investigations in Puerto Rico.

-- **Chapter 6 - Withdrawal from Settlement, Location, Sale, or Entry**
43 U.S.C. 157. **Applications for withdrawal, reservation, or restriction; specifications**
Any application filed on and after February 28, 1958 for a withdrawal, reservation, or restriction, the approval of which will, under section 156 of this title [for Department of Defense projects or facilities], require an Act of Congress, shall specify -

> (7) whether, and if so to what extent, the proposed use will affect continuing full operation of the public land laws and Federal regulations relating to conservation, utilization, and development of mineral resources, timber and other material resources, grazing resources, fish and wildlife resources, water resources, and scenic, wilderness, and recreation and other values ....

-- **Chapter 18 - Survey of Public Lands**

43 U.S.C. 751. **Rules of survey**

> Public Law 100-409, Section 8 (Aug. 20, 1988, 102 Stat. 1091) provided that:
> (a) **Study.**
> The Secretary of the Interior shall conduct an assessment of the need for and cost and benefits associated with improvements in the existing methods of land surveying and mapping and of collecting, storing, retrieving, disseminating, and using information about Federal and other lands.
> (d) **Topics.**
>
> > (5) model standards developed by the Secretary for compatible multipurpose land information systems for use by Federal, State and local governmental agencies, the public, and the private sector.

43 U.S.C. 766. **Geological surveys, extension of public surveys, expenses of subdividing**
There shall be no further geological survey by the Government, unless authorized by law. The public surveys shall extend over all mineral lands; and all subdividing of surveyed lands into lots less than one hundred and sixty acres may be done by county and local surveyors at the expense of claimants; but nothing in this section contained shall require the survey of waste or useless lands.

-- **Chapter 20 - Reservations and Grants to States for Public Purposes**

43 U.S.C. 852 (d). **"Unappropriated public lands" defined; determination of mineral character of land**

(1) The term "unappropriated public lands" as used in this section shall include, without otherwise affecting the meaning thereof, lands withdrawn for coal, phosphate, nitrate, potash, oil, gas, asphaltic minerals, oil shale, sodium, and sulphur, but otherwise subject to appropriation, location, selection, entry, or purchase under the non-mineral laws of the United States; lands withdrawn by Executive Order Numbered 5327, of April 15, 1930, if otherwise available for selection; and the retained or reserved interest of the United States in lands which have been disposed of with a reservation to the United States of all minerals or any specified mineral or minerals.

(2) The determination, for the purposes of this section of the mineral character of lands lost to a State shall be made as of the date of application for selection and upon the basis of the best evidence available at that time. (Selections to supply deficiencies of school lands)

-- **Chapter 25A - Lands Held Under Color of Title**

43 U.S.C. 1068. **Lands held in adverse possession; issuance of patent; reservation of minerals; conflicting claims**

43 U.S.C. 1068a. **Appraisal**

Upon filing of an application to purchase any lands subject to the operation of this chapter, together with the required proof, the Secretary of the Interior shall cause the lands described in said application to be appraised, said appraisal to be on the basis of the value of such lands at the date of appraisal, exclusive of any increased value resulting from the development or improvement of the lands by the applicant or his predecessors in interest, and in such appraisal the Secretary shall consider and give full effect to the equities of any such applicant.

-- **Chapter 29 - Submerged Lands**

43 U.S.C. 1301. **Definitions**

(e) The term "natural resources" includes, without limiting the generality thereof, oil, gas, and all other minerals, and fish, shrimp, oysters, clams, crabs, lobsters, sponges, kelp, and other marine animal and plant life but does not include water power, or the use of water for the production of power...

Subchapter III - Outer Continental Shelf Lands

43 U.S.C. 1331. **Definitions**

(k) The term "exploration" means the process of searching for minerals, including (1) geophysical surveys where magnetic, gravity, seismic, or other systems are used to detect or imply the presence of such minerals, and (2) any drilling, whether on or off known geological structures, including the drilling of a well in which a discovery of oil or natural gas in paying quantities is made and the drilling of any additional delineation well after such discovery which is needed to delineate any reservoir and to enable the lessee to determine whether to proceed with development and production....

(o) The term "fair market value" means the value of any mineral (1) computed at a unit price equivalent to the average unit price at which such mineral was sold pursuant to a lease during the period for which any royalty or net profit share is accrued or reserved to the United States pursuant to such lease, or (2) if there were no such sales, or if the Secretary finds that there were an insufficient number of such sales to equitably determine such value, computed at the average unit price at which such mineral was sold pursuant to other leases in the same region of the outer Continental Shelf during such period, or (3) if there were no sales of such mineral from such region during such period, or if the Secretary finds that there are insufficient number of sales to equitably determine such value, at an appropriate price determined by the Secretary.

(q) The term "minerals" includes oil, gas, sulphur, geopressured-geothermal and associated resources, and all other minerals which are authorized by an Act of Congress to be produced from "public lands" as defined in section 1702 of this title.

43 U.S.C. 1340 **Geological and geophysical explorations**

(a) **Approved exploration plans**

(1) Any agency of the United States and any person authorized by the Secretary may conduct geological and geophysical explorations in the outer Continental Shelf, which do not interfere with or endanger actual operations under any lease maintained or granted pursuant to this subchapter, and which are not unduly harmful to aquatic life in such areas.

43 U.S.C. 1343 **Annual report by Secretary to Congress**

Within six months after the end of each fiscal year, the Secretary shall submit to the President of the Senate and the Speaker of the House of Representatives the following reports:

(1) A report on the leasing and production program in the outer Continental Shelf during such fiscal year, which shall include -

(B) a detailed accounting of all exploration, exploratory drilling, leasing, development, and production activities;

43 U.S.C. 1344. **Outer Continental Shelf leasing program**

(a)(1) Management of the outer Continental Shelf shall be conducted in a manner which considers economic, social, and environmental values of the renewable and nonrenewable resources contained in the outer Continental Shelf, and the potential impact of oil and gas exploration on other resource values of the outer Continental Shelf and the marine, coastal, and human environments.

(2) Timing and location of exploration, development, and production of oil and gas among the oil- and gas-bearing physiographic regions of the outer Continental Shelf shall be based on a consideration of -

(A) existing information concerning the geographical, geological, and ecological characteristics of such regions;

(g) **Information from public and private sources; confidentiality of classified or privileged data**

The Secretary may obtain from public sources, or purchase from private sources, any survey, data, report, or other information (including interpretations of such data, survey, report, or other information) which may be necessary to assist him in preparing any environmental impact statement and in making other evaluations required by this subchapter....

-- Chapter 31 - Department of the Interior

43 U.S.C. 1457.

The authority vested in the Secretary of the Interior, to perform surveys, investigations, and research in geology, biology, minerals and water resources, and mapping is hereby extended to include Antarctica, and the Trust Territory of the Pacific Islands. (See Public Law 85-743, August 23, 1958, 72 Stat. 837.)

-- Chapter 35 - Federal Land Policy and Management

43 U.S.C. 1701. **Congressional declaration of policy**

(a) The Congress declares that it is the policy of the United States that -

(1) the public lands be retained in Federal ownership, unless as a result of the land-use planning procedure provided for in this Act, it is determined that disposal of a particular parcel will serve the national interest;

(2) the national interest will be best realized if the public lands and their resources are periodically and systematically inventoried and their present and future use is projected through a land-use planning process coordinated with other Federal and State planning efforts;
(9) the United States receive fair market value of the use of the public lands and their resources unless otherwise provided for by statute
(12) the public lands be managed in a manner which recognizes the Nation's need for domestic sources of minerals, food, timber, and fiber from the public lands including implementation of the Mining and Minerals Policy Act of 1970 (84 Stat. 1876, 30 U.S.C. 21a) as it pertains to the public lands; and
(13) the Federal Government should, on a basis equitable to both the Federal and local taxpayer, provide for payments to compensate States and local governments for burdens created as a result of the immunity of Federal lands from State and local taxation.

43 U.S.C. 1702. **Definitions**

(c) The term "multiple use" means the management of the public lands and their various resource values so that they are utilized in the combination that will best meet the present and future needs of the American people; making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide sufficient latitude for periodic adjustments in use to conform to changing needs and conditions; the use of some land for less than all of the resources; a combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources, including, but not limited to, recreation, range, timber, minerals, watershed, wildlife and fish, and natural scenic, scientific and historical values; and harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or greatest unit output.
(e) The term "public lands" means any land and interest in land owned by the United States within the several States and administered by the Secretary of the Interior through the Bureau of Land Management, without regard to how the United States acquired ownership, except -

(1) lands located on the Outer Continental Shelf; and
(2) lands held for the benefit of Indians, Aleuts, and Eskimos.

(h) The term "sustained yield" means the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the public lands consistent with multiple use.

(i) The term "wilderness" as used in section 1782 of this title shall have the same meaning as it does in section 1131(c) of title 16.

(j) The term "withdrawal" means withholding an area of Federal land from settlement, sale, location, or entry, under some or all of the general land laws, for the purpose of limiting activities under those laws in order to maintain other public values in the area or reserving the area for a particular public purpose or program; or transferring jurisdiction over an area of Federal land, other than "property" governed by the Federal Property and Administrative Services Act, as amended (40 U.S.C. 472) from one department, bureau or agency to another department, bureau or agency.

43 U.S.C. 1711. **Continuing inventory and identification of public lands; preparation and maintenance**

(a) The Secretary shall prepare and maintain on a continuing basis an inventory of all public lands and their resource and other values (including, but not limited to, outdoor recreation and scenic values), giving priority to areas of critical environmental concern. This inventory shall be kept current so as to reflect changes in conditions and to identify new and emerging resource and other values. The preparation and maintenance of such inventory or the identification of such areas shall not, of itself, change or prevent change of the management or use of public lands.

(b) As funds and manpower are made available, the Secretary shall ascertain the boundaries of the public lands; provide means of public identification thereof including, where appropriate, signs and maps; and provide State and local governments with data from the inventory for the purpose of planning and regulating the uses of non-Federal lands in proximity of such public lands.

43 U.S.C. 1712 **Land-use plans**

(a) **Development, maintenance, and revision by Secretary**

The Secretary shall, with public involvement and consistent with the terms and conditions of this Act, develop, maintain, and, when appropriate, revise land-use plans which provide by tracts or areas for the use of the public lands. Land-use plans shall be developed for the public lands regardless of whether such lands previously have been classified, withdrawn, set aside, or otherwise designated for one or more uses.

(b) **Coordination of plans for National Forest System lands with Indian land-use planning and management programs for purposes of development and revision**

(c) **Criteria for development and revision**

In the development and revision of land-use plans, the Secretary shall -

(1) use and observe the principles of multiple use and sustained yield set forth in this and other applicable law;

(2) use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences;

(4) rely, to the extent it is available, on the inventory of the public lands, their resources, and other values;

(5) consider present and potential uses of the public lands;

(6) consider the relative scarcity of the values involved and the availability of alternative means (including recycling) and sites for realization of those values;

(7) weigh long-term benefits to the public against short-term benefits;

(9) to the extent consistent with the laws governing the administration of the public lands, coordinate the land-use inventory, planning, and management activities of or for such lands with the land-use planning and management programs of other Federal departments and agencies and of the States and local governments within which the lands are located....

43 U.S.C. 1713 **Sales of public land tracts**

(a) **Criteria for disposal; excepted lands**

A tract of the public lands (except land in units of the National Wilderness Preservation System, National Wild and Scenic Rivers System, and National System of Trails) may be sold under this Act where, as a result of land-use planning required under section 1712 of this title, the Secretary determines that the sale of such tract meets the following disposal criteria:

(1) such tract because of its location or other characteristics is difficult and uneconomic to manage as part of the public lands, and is not suitable for management by another Federal department or agency; or

(2) such tract was acquired for a specific purpose and the tract is no longer required for that or any other Federal purpose; or

(3) disposal of such tract will serve important public objectives, including but not limited to, expansion of communities and economic development, which cannot be achieved prudently or feasibly on land other than public land and which outweigh other public objectives and values, including, but not limited to,

recreation, and scenic values, which would be served by maintaining such tract in Federal ownership.

(c) **Congressional approval procedures applicable to tracts in excess of two thousand five hundred acres**

(d) **Sale price**

Sales of public lands shall be made at a price not less than their fair market value as determined by the Secretary.

43 U.S.C. 1714 **Withdrawals of lands**

(a) **Authorization and limitation; delegation of authority**

On and after the effective data of this Act the Secretary is authorized to make, modify, extend, or revoke withdrawals but only in accordance with the provisions and limitations of this section. The Secretary may delegate this withdrawal authority only to individuals in the Office of the Secretary who have been appointed by the President, by and with advice and consent of the Senate.

(c) **Congressional approval procedures applicable to withdrawals aggregating five thousand acres or more**

(1) On and after October 21, 1976, a withdrawal aggregating five thousand acres or more may be made (or such a withdrawal or any other withdrawal involving in the aggregate five thousand acres or more which terminates after such date of approval may be extended) only for a period of not more than twenty years by the Secretary on his own motion or upon request by a department or agency head. The Secretary shall notify both Houses of Congress of such withdrawal no later than its effective date ....

(2) With the notices required by subsection (c)(1) of this section and within three months after filing the notice under subsection (e) of this section, the Secretary shall furnish to the committees [of Congress] -

(1) a clear explanation of the proposed use of the land involved which led to the withdrawal;

(2) an inventory and evaluation of the current natural resource uses and values of the site and adjacent public and non-public land and how that might cause degradation of the environment, and also the economic impact of the change in use on individuals, local communities, and the Nation;

(3) an identification of present users of the land involved, and how they will be affected by the proposed use;

(4) an analysis of the manner in which existing and potential resources uses are incompatible with or in conflict with the proposed use, together with a statement of the provisions to be made for continuation or termination of existing uses, including an economic analysis of such continuation or termination;

(5) an analysis of the manner in which such lands will be used in relation to the specific requirements of the proposed use;

(6) a statement as to whether any suitable alternative sites are available (including cost estimates) for the proposed use or for uses such a withdrawal would displace;

(7) a statement of the consultation which has been or will be had with other Federal departments and agencies, with regional, State, and local government bodies, and with other appropriate individuals and groups;

(8) a statement indicating the effect of the proposed uses, if any, on State and local government interests and the regional economy;

(9) a statement of the expected length of the time needed for the withdrawal;

(12) a report prepared by a qualified mining engineer, engineering geologist, or geologist which shall include but not be limited to information on: general geology, known mineral deposits, past and present mineral production, mining claims, mineral leases, evaluation of future mineral potential, present and potential market demands.

(d) **Withdrawals aggregating less than five thousand acres; procedure applicable**

A withdrawal aggregating less than five thousand acres may be made under this subsection by the Secretary on his own motion or upon request by a department or agency head -

(1) for such period of time as he deems desirable for a resource use; or

(2) for a period of not more than twenty years for any other use, including but not limited to use for administrative sites, location of facilities, and other proprietary purposes; or

(3) for a period of not more than five years to preserve such tract for a specific use then under consideration by the Congress.

(e) **Emergency withdrawals; procedure applicable; duration**

43 U.S.C. 1715. **Acquisition of public lands and access over non-Federal lands to National Forest System units**

(a) **Authorization and limitations on authority of Secretary of the Interior and Secretary of Agriculture**

Notwithstanding any other provisions of law, the Secretary, with respect to the public lands and the Secretary of Agriculture, with respect to the acquisition of access over non-Federal lands to units of the National Forest System, are authorized to acquire pursuant to this Act by purchase, exchange, donation, or eminent domain, lands or interests therein: *Provided*, That with respect to the public lands, the Secretary may exercise the power of eminent domain only if necessary to secure access to public lands, and then only if the lands so acquired are confined to as narrow a corridor as is necessary to serve such purpose.

Nothing in this subsection shall be construed as expanding or limiting the authority of the Secretary of Agriculture to acquire land by eminent domain within the boundaries of units of the National Forest System.

(c) **Status of lands and interests in lands upon acquisition by Secretary of the Interior; transfers to Secretary of Agriculture of lands and interests in lands acquired within National Forest System boundaries**

Except as provided in subsection (e) of this section, lands and interests in lands acquired by the Secretary pursuant to this section or section 1716 of this title shall, upon acceptance of title, become public lands, and, for the administration of public land laws not repealed by this Act, shall remain public lands. If such acquired lands or interests in lands are located within the exterior boundaries of a grazing district established pursuant to section 315 of this title, they shall become a part of that district. Lands and interests in lands acquired pursuant to this section which are within boundaries of the National Forest System may be transferred to the Secretary of Agriculture and shall then become National Forest System lands and subject to all the laws, rules, and regulations applicable thereto.

(d) **Status of lands and interest in lands upon acquisition by Secretary of Agriculture**

Lands and interests in lands acquired by the Secretary of Agriculture pursuant to this section shall, upon acceptance of title, become National Forest System lands subject to all the laws, rules, and regulations applicable thereto.

43 U.S.C. 1716 **Exchanges of public lands or interests therein within the National Forest System**

(a) **Authorization and limitations on authority of Secretary of the Interior and Secretary of Agriculture**

A tract of public land or interests therein may be disposed of by exchange by the Secretary under this Act and a tract of land or interests therein within the National Forest System may be disposed of by exchange by the Secretary of Agriculture under applicable law where the Secretary concerned determines that the public interest will be well served by making that exchange: *Provided*, That when considering the public interest the Secretary concerned shall give full consideration to better Federal land management and the needs of State and local people, including needs for lands for the economy, community expansion, recreation areas, food, fiber, minerals, and fish and wildlife and the Secretary concerned finds that the values and the objectives which Federal land or interests to be conveyed may serve if retained in Federal ownership are not more than the values of the non-Federal lands and interests if acquired.

(b) **Implementation requirements; cash equalization**

In exercising the exchange authority granted by subsection (a) of this section or by section 1715(a) of this title, the Secretary concerned may accept title to any non-Federal land or interests therein in exchange for such land, or interests therein which he finds proper for transfer out of Federal ownership and which are located in the same State as the non-Federal land or interest to be acquired. For the purposes of this subsection, unsurveyed school sections which, upon survey by the Secretary, would become State lands, shall be considered as "non-Federal lands". The values of the lands exchanged by the Secretary under this Act and by the Secretary of Agriculture under applicable law relating to lands within the National Forest System either shall be equal, or if they are not equal, the values shall be equalized by the payment of money to the grantor or to the Secretary concerned as the circumstances require so long as payment does not exceed 25 per centum of the total value of the lands or interests transferred out of Federal ownership....

(d) **Appraisal of land; submission to arbitrator; determination to proceed or withdraw from exchange; use of other valuation process; suspension of deadlines**

> (1) No later than ninety days after entering into an agreement to initiate an exchange of land or interests therein pursuant to this Act or other applicable law, the Secretary concerned and other party or parties involved in the exchange shall arrange for an appraisal (to be completed within a time frame and under such terms as are negotiated by the parties) of lands or interests therein involved in the exchange in accordance with subsection (f) of this section.

(f) **New rules and regulations; appraisal rules and regulations; "costs and other responsibilities or requirements" defined**

> (1) Within one year after August 20, 1988, the Secretaries of the Interior and Agriculture shall promulgate new and comprehensive rules and regulations governing exchanges of land and interests therein pursuant to this Act and other applicable law. Such rules and regulations shall fully reflect the changes in law made by subsections (d) through (i) of this section and shall include provisions pertaining to appraisals of lands and interests therein involved in such exchanges.
>
> (2) The provisions of the rules and regulations issued pursuant to paragraph (1) of this subsection governing appraisals shall reflect nationally recognized appraisal standards, including, to the extent appropriate, the Uniform Appraisal Standards for Federal Land Acquisitions: *Provided, however*, That the provisions of such rules and regulations shall -
>
> > (A) ensure that the same nationally approved appraisal standards are used in appraising lands or interest therein being acquired by the Federal Government and appraising lands or interests therein being transferred out of Federal ownership; and
> >
> > (B) with respect to costs or other responsibilities or requirements associated with land exchanges -
> >
> > > (i) recognize that the parties involved in an exchange may mutually agree that one party (or parties) will assume, without compensation, all or part of certain costs or other

responsibilities or requirements ordinarily borne by the other party or parties; and
(ii) also permit the Secretary concerned, where such Secretary determines it is in the public interest and it is in the best interest of consummating an exchange pursuant to this Act or other applicable law, and upon mutual agreement of the parties, to make adjustments to the relative values involved in an exchange transaction in order to compensate a party or parties to the exchange for assuming costs or other responsibilities or requirements which would ordinarily be borne by the other party or parties.

As used in this subparagraph, the term "costs or other responsibilities" shall include, but not be limited to, costs or other requirements associated with land surveys and appraisals, mineral examinations, title searches, archeological surveys and salvage, removal of encumbrances, arbitration pursuant to subsection (d) of this section, curing deficiencies preventing highest and best use, and other costs to comply with laws, regulations and policies applicable to exchange transactions, or which are necessary to bring the Federal or non-Federal lands or interests involved in the exchange to their highest and best use for the appraisal and exchange purposes. Prior to making any adjustments pursuant to this subparagraph, the Secretary concerned shall be satisfied that the amount of such adjustment reflect the approximate value of any costs or services provided or any responsibilities or requirements assumed.

43 U.S.C. 1719 **Mineral interests; reservation and conveyance requirements and procedures**

(a) All conveyances of title issued by the Secretary, except those involving land exchanges provided for in section 1716 of this title, shall reserve to the United States all minerals in the lands, together with the right to prospect for, mine, and remove the minerals under applicable law and such regulations as the Secretary may prescribe, except that if the Secretary makes the finding specified in subsection (b) of this section, the minerals may then be conveyed together with the surface to the prospective surface owner as provided in subsection (b) of this section.

(b) (1) The Secretary, after consultation with the appropriate department or agency head, may convey mineral interests owned by the United States where the surface is or will be in non-Federal ownership, regardless of which Federal entity may have administered the surface, if he finds (1) that there are no known mineral values in the land, or (2) that the reservation of the mineral rights in the United States is interfering with or precluding appropriate non-mineral development of the land and that such development is a more beneficial use of the land than mineral development.

(2) Conveyance of mineral interests pursuant to this section shall be made only to the existing or proposed record owner of the surface, upon payment of administrative costs and the fair market value of the interests being conveyed.

(3) Before considering an application for conveyance of mineral interests pursuant to this section -

(i) the Secretary shall require the deposit by the applicant of a sum of money which he deems sufficient to cover administrative costs including, but not limited to, costs of conducting an exploratory program to determine the character of the mineral deposits in the land, evaluating the data obtained under the exploratory program to determine the fair market value of the mineral interests to be conveyed, and preparing and issuing the documents of conveyance: *Provided*, That, if the administrative costs exceed the deposit, the applicant shall pay the outstanding amount;and, if the deposit exceeds the administrative costs, the applicant shall be given a credit for or refund of the excess; or

(ii) the applicant, with the consent of the Secretary, shall have conducted, and submitted to the Secretary the results of, such an exploratory program, in accordance with standards promulgated by the Secretary.

(4) Moneys paid to the Secretary for administrative costs pursuant to this subsection shall be paid to the agency which rendered the service and deposited to the appropriation then current.

43 U.S.C. 1720. **Coordination by Secretary of the Interior with State and local governments**

At least sixty days prior to offering for sale or otherwise conveying public lands under this Act, the Secretary shall notify the Governor of the State within which such lands are located and the head of the governing body of any political subdivision of the State having zoning or other land-use regulatory jurisdiction in the geographical area within which such lands are located, in order to afford the appropriate body the opportunity to zone or otherwise regulate, or change or amend existing zoning or other regulations concerning the use of such lands prior to such conveyance. The Secretary shall also promptly notify such public officials of the issuance of the patent or other document of conveyance for such lands.

Subchapter VI - Designated Management Areas

43 U.S.C. 1782 **Bureau of Land Management Wilderness Study**

(a) **Lands subject to review and designation as wilderness**

Within fifteen years after October 21, 1976, the Secretary shall review those roadless areas of five thousand acres or more and roadless islands of the public lands, identified during the inventory required by section 1711(a) of this title as having wilderness characteristics described in the Wilderness Act of September 3, 1964 (78 Stat. 890; 16 U.S.C. 1131 et seq.) and shall from time to time report to the President his recommendation as to the suitability or nonsuitability of each area or island for preservation as wilderness: *Provided*, That prior to any recommendations for the designation of an area as wilderness the Secretary shall cause mineral surveys to be conducted by the United State Geological Survey and the United States Bureau of Mines to determine the mineral values, if any, that may be present in such areas: *Provided further*, That the Secretary shall report to the President by July 1, 1980, his recommendations on those areas which the Secretary has prior to November 1, 1975, formally identified as natural or primitive areas. The review required by this subsection shall be conducted in accordance with the procedure specified in section 3(d) of the Wilderness Act [16 U.S.C. 1132(d)].

(c) **Status of lands during period of review and determination**

During the period of review of such areas and until Congress has determined otherwise, the Secretary shall continue to manage such lands according to his authority under this Act and, other applicable law in a manner so as not to impair the suitability of such areas for preservation as wilderness, subject, however, to the continuation of existing mining and grazing uses and mineral leasing in the manner and degree in which the same was being conducted on October 21, 1976: *Provided*, That, in managing the public lands the Secretary shall by regulation or otherwise take any action required to prevent unnecessary or undue degradation of the lands and their resources or to afford environmental protection. Unless previously withdrawn from appropriation under the mining laws, such lands shall continue to be subject to such appropriation during the period of review unless withdrawn by the Secretary under the procedures of section 1714 of this title for reasons other than preservation of their wilderness character. Once an area has been designated for preservation as wilderness, the provisions of the Wilderness Act [16 U.S.C. 1131 et seq.] which apply to national forest wilderness areas shall apply with respect to the administration and use of such designated area, including mineral surveys required by section 4(d)(2) of the Wilderness Act [16 U.S.C. 1133(d)(2)], and mineral development, access, exchange of lands, and ingress and egress for mining claimants and occupants.

TITLE 50 UNITED STATES CODE - WAR AND NATIONAL DEFENSE

-- Chapter 5 - Arsenals, Armories, Arms, and War Material Generally

Subchapter III - Acquisition and Development of Strategic Raw Materials

50 U.S.C. 98. **Short title**
This subchapter may be cited as the "Strategic and Critical Materials Stock Piling Act."

50 U.S.C. 98a. **Congressional findings and declaration of policy**
(a) The Congress finds that the natural resources of the United States in certain strategic and critical materials are deficient or insufficiently developed to supply the military, industrial, and essential civilian needs of the United States for national defense.

50 U.S.C. 98g. **Minerals development and research**
(a)(1) The President shall make scientific, technologic, and economic investigations concerning the development, mining, preparation, treatment, and utilization of ores and other mineral substances that (A) are found in the United States, or in its territories or possessions, (B) are essential to the national defense, industrial, and essential civilian needs of the United States, and (C) are found in known domestic sources of inadequate quantities or grades.
(2) Such investigations shall be carried out in order to -

> (A) determine and develop new domestic sources of supply of such ores and mineral substances;

(3) Investigations under paragraph (1) may be carried out on public lands and, with the consent of the owner, on privately owned lands for the purpose of exploring and determining the extent and quality of deposits of such minerals, the most suitable methods, and the cost at which the minerals or metals may by produced.

(c) The President shall make scientific, technologic, and economic investigations concerning the feasibility of -

> (1) developing domestic sources of supply of materials (other than materials referred to in subsections (a) and (b) of this section) determined pursuant to section 98b(a) of this title to be strategic and critical materials;

50 U.S.C. 98h-2. **Reports to Congress**
(a) Not later than January 15 of each year, the President shall submit to the Congress an annual written report detailing operations under this subchapter. Each such report shall include -

> (3) information with respect to the activities by the Stockpile Manager to encourage the conservation, substitution, and development of strategic and critical materials within the United States;

(4) information with respect to the research and development activities conducted under sections 98a and 98g of this title;

-- Domestic Minerals Program Extension

50 U.S.C. 2181. **Congressional declaration of policy**
It is recognized that the continued dependence on overseas sources of supply for strategic or critical minerals and metals during periods of threatening world conflict or of political instability within those nations controlling the sources of supply of such materials gravely endangers the present and future economy and security of the United States. It is therefore declared to be the policy of the Congress that each department and agency of the Federal Government charged with responsibilities concerning the discovery, development, production and acquisition of strategic or critical minerals and metals shall undertake to decrease further and to eliminate where possible the dependency of the United States on overseas sources of supply of each such material.

CHAPTER II--THE ARIZONA CONFERENCE

THE ARIZONA CONFERENCE

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THE ARIZONA CONFERENCE

PROCEEDINGS

ROLE OF CONFERENCE

The role of the conference was to 1) formalize the presentation of differing views, 2) provide a forum for rebuttal, discussion, and accountability, and 3) facilitate an independent external (the Panel) evaluation of scientific and methodological issues. Although presentations were invited that dealt with recent assessment controversies, their primary purpose was to inform the evaluation panel, identified below, about possible deficiencies in assessment methodology and in selected assessments and to identify relevant scientific, informational and methodological issues.

SELECTION OF THE REVIEW PANEL

To ensure that the evaluation of the methodology is of scientific merit as well as useful in the assessment work, a small select panel of scientists, varied in both relevant scientific orientation and experience (see Appendix III to the report for vitae), was drawn from both industry (through independent consultants) and academia:

Douglas R. Cook
Consultant
2485 Greensboro Drive
Reno, Nevada 89509

DeVerle Harris (Chairperson)
Room 322D, Mines Building
The University of Arizona
Tucson, AZ 85721

Stuart Marsh
Office of Arid Land Studies
University of Arizona
Tucson, AZ 85721

Lawrence Meinert
Department of Geology
Washington State University
Pullman, Wa 99164

Donald Myers
706 Mathematics
University of Arizona
Tucson, AZ 85721

Richard Nielsen
Geocon Inc.
13741 Braun Drive
Golden, CO 80401

Brian Skinner (Chairperson)
Eugene Higgins Professor
Department of Geology and Geophysics
Yale University
New Haven, Connecticut 06520

John Sumner
Department of Geosciences
Gould-Simpson Bldg.
University of Arizona
Tucson, AZ 85721

Spencer Titley
Department of Geosciences
505 Gould-Simpson Bldg.
University of Arizona
Tucson, AZ 85721

SCOPE AND OVERVIEW OF THE CONFERENCE

A letter outlining 1) the importance of the study, 2) the basis for conflicts and controversies, 3) the role of the study and conference, and 4) perspectives on assessment and methodology, was mailed to the panel on July, 9, 1992. At this time the structure of the conference had changed somewhat from that originally presented to the panel. This change was articulated by Harris as follows:

"I have delayed writing to you until after the planning meeting with the Chief Geologist's (Ben Morgan) staff last week. As a result of that meeting, I have modified the structure of the conference to include the evaluation of some current controversies and conflicts about mineral resource assessment. This modification reflects the severity of these controversies and the need perceived by the Chief Geologist's office and personnel of the Office of Mineral Resources to have them resolved as soon as possible, for they currently are a divisive element within the USGS."

Harris outlined the role of the USGS in providing mineral resource information that is useful in making land-use decisions, and noted that demands for assessments continue to escalate. Moreover, there is a requirement that these mineral resource assessments provide quantitative information that is amendable to economic analysis and facilitates the comparison of land-use for other resources, such as forestry and recreation. The current conflict over the methodology arose from criticisms "circulated without peer review or rebuttal" whereas other criticisms were under review.

To ensure maximum productivity of the panel in reaching these objectives time spent on scientific issues or methodologies only remotely related to quantitative mineral resource assessment was to be minimized. Specific instructions to the panel were:

"Any member of the panel should feel free to disagree with the USGS methodology as his science and experience dictate, but that disagreement should not be based upon the presumption that quantitative assessments can be replaced by qualitative descriptions of favorability."

Furthermore, "...favorability evaluation is of interest in this study only if it is part of a methodology that leads to a quantitative estimate of resources."

The relevant issues for the panel to address were: 1) how well the methodology meets the information needs of user groups, 2) how sound the methodology is scientifically, 3) how well the methodology utilizes available geoinformation, and 4) how acceptable mathematically are the properties of the estimates.

SUPPORTING DOCUMENTATION FOR THE PANEL

METHODOLOGY

To ensure a common understanding of the three-step method the panel was sent a publication by Menzie and Singer (1990) and notes from an assessment course by Menzie, Bagby, and Page prior to the conference. Moreover, at the beginning of the conference a series of formal presentations on the procedure were made by Donald Singer (BORA/Menlo Park) and David Menzie (BORA/Reston). These were to prepare the panel for a review of five previously made assessments so that each one is familiar with: 1) the major elements of the three-step methodology; 2) the kinds and quality of the geological data that are used; 3) the deposit models that are employed; 4) how the models and geological data are employed to delineate favorable areas; 5) how the tonnage and grade models and analogue data support the estimation of number of deposits; and 6) how probabilities for number of deposits are estimated.

Specific Examples of Assessments Employing the Three-step Methodology

The following mineral resource assessments were selected by BORA for panel review:

1) Mineral Resource Assessment of the Republic of Costa Rica. U.S. Geological Survey/Direccion General De Geologia, Minas e Hidrocarburos/Universidad de Costa Rica; Miscellaneous Investigations Series Map I-1865 - Submitted to the panel for critique as an example of a well-done assessment.

2a) Undiscovered Locatable Mineral Resources of the Tongass National Forest and Adjacent Areas, Southeastern Alaska. USGS. OFR 91-10.
2b) Tongass Timber Reform Act Wilderness Areas Supplement to U.S. Geological Survey Open-File Report 91-10. USGS. OFR 91-343.
2c) The Study of the Undiscovered Mineral Resources of the Tongass National Forest and Adjacent Lands, Southeastern Alaska. (manuscript submitted to the Journal of Nonrenewable Resources.)
- Submitted to the panel for evaluation as an assessment under difficult circumstances and meager information.

3) Assessment of Undiscovered Porphyry Copper Deposits Within the Range of the Northern Spotted Owl, Northwestern California, Western Oregon, and Western Washington. U.S.

Geological Survey Open-file Report 91-377. - Submitted to panel review as an example of a recent assessment that is subject to controversy.

4) The Redcloud and Handies Peak Wilderness Study Areas, Colorado as reported in: Quantitative Assessments of the Energy and Mineral Resources within Eighteen Wilderness Study Areas in the States of Colorado, Nevada, Oregon and Utah. U.S. Geological Survey Open-file Report 91-384. - Submitted for panel review because of its role in current controversies.

5) Quantitative Assessment of Undiscovered Metallic Mineral Resources in the East Mojave National Scenic Area, Southern California. U.S. Geological Survey Open-file Report 91-551. - Submitted for panel review as a second example of an assessment that is involved in current controversy.

Each panel member was asked to consider the following questions in his critique of the selected assessments:

1) Is the understanding of depositional environments and genetic processes adequate?

2) Is the understanding of geology sufficient?

3) Are the mineral deposit models sufficiently well described?

4) Are the tonnage and grade distributions appropriate?

5) Is the estimation of undiscovered deposits well founded?

6) Is the estimation of the number of deposits made by a single geologist or by a team?

7) If by a team, how are differences resolved? How is elicitation[1] performed?

Besides an overall evaluation of the selected assessments, panel members were asked to examine and critique specific deposit models. The models were selected to represent three categories: 1) those for which good data exist; 2) those for which good data exist but the model is viewed as being controversial; and 3) those deposit models considered to be problematic and controversial. A preliminary list of prospective models was requested from David Menzie from which a subset was selected that included models that either were in one of the above assessments or were of special interest to the panel. These models are identified below in the summary agenda of the conference.

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[1] elicit 1) To draw out or forth; to educe; as to elicit truth by discussion. 2) To draw or entice forth; to evoke; as to elicit a reply.

COMMUNICATIONS

Pre-conference

Early in this study the Office of Chief Geologist provided documentation on the current controversies. Most of this documentation consisted of memos from which much of the above text was taken. These memos together with several published papers on: 1) the USGS mineral resource methodology; 2) the use of deposit models; and 3) the use of grade/tonnage curves in the estimation task served as supporting documentation for the panel.

The following materials were provided to the panel members prior to the Arizona Conference:

1. Geologic Investigations: Highlights, Applications of Mineral Deposit Models to Resource Assessments, by Donald Singer and Dennis Cox in United States Geological Survey Yearbook Fiscal Year 1987.

2. A course on mineral resource assessment. by Menzie, W.D., and Singer, D.A. in Proceedings of ISME-AI'90, International Symposium on Mineral Exploration: The use of Artificial Intelligence, 1990. vol. 2, Supplements. October, 1990, Tokyo.

3. Computer Monte Carlo Simulation in Quantitative Resource Estimation. by Root, D.H., Menzie, W.D., and Scott, W.A.; in Nonrenewable Resources Vol. 1, Number 2, 1992.

4. Excerpts from: Notes for a course on mineral resource assessment by W.D. Menzie, W.C. Bagby and N.J. Page, unpublished.

5. Comments on the "three-step" method for quantification of undiscovered mineral resources. by Bultman, M.W.; Force, E.R. Gettings, M.E.; and Fisher F.S. Open-File Report 92-xx. Version 1 dated Jan. 21, 1992.

6. Review of the Manuscript by Bultman, Force, Gettings and Fisher: Comments on the Three-step Method for Quantification of Undiscovered Mineral Resources, by DeVerle Harris dated Feb. 12, 1992.

7. Reply to DeVerle Harris' review of the "Comments on the three-step method for quantification of mineral resources" manuscript. Dated March 17, 1992, by Bultman, Gettings, Force and Fisher to Bill Bagby.

8. Comments on: Comments on the three-step" method for quantification of undiscovered mineral resources by Bultman, Force, Gettings (for Open-file Report), by Steve Ludington dated 2/7/92.

9. Reply to Steve Ludington's review of the "Comments on the three-step method" manuscript. To Steve Ludington and Bill Bagby from Bultman, Force, Gettings, and Fisher, dated March 17, 1992.

10. Comments on the "three-step" method for quantification of undiscovered mineral resources, by Bultman, M.W.; Force, E.R. Gettings, M.E.; and Fisher F.S., Open-File Report 92-xx. Version 2 dated March 17, 1992.

11. Review of the revised manuscript by Bultman, Force, Gettings, and Fisher: Comments on the three-step method for quantification of undiscovered mineral resources, from DeVerle Harris to William Bagby dated May 27, 1992.

12a. Reply to DeVerle Harris' second review of the "Comments on the three-step method for the quantification of mineral resources" manuscript, from Bultman, Force, Gettings and Fisher to Bill Bagby. Dated July 2, 1992.

Accompanied by the following two supporting documents:

> 12b. Mineral Resources Appraisal, Mineral endowment, resources, and potential supply: concepts, methods, and cases, by D. Harris, 1984, p. 359-373.
>
> 12c. A first course in probability, Second Edition, by Sheldon Ross, Macmillan Publishing Company

13. Comments on: Comments on the "three-step" method for quantification of undiscovered mineral resources by Bultman, Force, Gettings, and Fisher (for Open-file Report), II, by Steve Ludington, dated 4/2/92.

14. Comments on the "three-step" method for quantification of undiscovered mineral resources, by Bultman, M.W.; Force, E.R. Gettings, M.E.; and Fisher F.S., Open-File Report 92-xx, Version 3 - final dated July 2, 1992.

15. An evaluation of the USGS method of quantitative assessment of mineral resources incomplete draft, Oct. 6, 1991, by Warren Hamilton to Survey mineral-resource assessors.

16. Reply to "An evaluation of the USGS method of quantitative assessment of mineral resources" (incomplete draft, Oct. 6, 1991) by Warren Hamilton, by Don Singer Dated October 28, 1991.

The following memos were released from the files of the Office of the Chief Geologist. Where possible, the posting date of each document is noted to establish for the reader the sequence of events leading up to the current review.

TO: Ben Morgan, Chief Geologist
FROM: H. Wilshire, D. Miller, J. Nielsen, Branch of Western Regional Geology
DATE: Undated
SUBJECT: Misrepresentation of geologic information with regard to assessment of undiscovered metallic mineral resources, East Mojave National Scenic Area (EMNSA).

Accompanied by;

TO: Dave Menzie, Chief, BORA
FROM: Don Singer
DATE: October 17, 1991
SUBJECT: Wilshire, Miller, and Nielsen Memorandum sent on October 10, 1991, to Ben Morgan about the East Mojave National Scenic Area Assessment.

TO: G. Allcott
THROUGH: D. Lindsey
FROM: R. Sanford
DATE: October 17, 1991
SUBJECT: Mineral resource potential in general and Redcloud-Handies in particular.

TO: D. Peck and B. Morgan
FROM: W. Hamilton
DATE: November 15, 1991
SUBJECT: Mineral Assessing

Accompanied by;

TO: D. Peck, B. Morgan, G. Allcott
FROM: R. Sanford
DATE: December 4, 1991
SUBJECT: Smear campaign by Hamilton and Others.

AGENDA OF THE ARIZONA CONFERENCE

Monday Morning, August 3, 9:00 AM

9:00 Overview of the Conference Agenda, Issues and Objectives: DeVerle Harris

9:30 Mineral Resource Information: Joe Briskey USGS

----------Lunch 11:45----------

Monday Afternoon

1:00 PM Economic Analysis: Analysis that can be made of the USGS Assessments to support Land-use Decisions and Policy Evaluation: Tom Gunther, US Bureau of Mines, Washington D.C.

Assessment Methodology

2:30 PM Brief Perspectives: DeVerle Harris
The U.S. Geological Survey's Assessment Methodology

3:10 PM The USGS and the Three-step methodology: David Menzie, USGS, Reston, West Virginia.

3:40 PM The three-step Assessment Method: Donald Singer, USGS, Menlo Park, California.

4:15 PM Panel Questions

----------Adjourn at 5:00 PM ---------

Tuesday Morning, August 4, 8:00 AM

The U.S. Geological Survey's Assessment Methodology (Cont'd)

8:00 AM Donald Singer and David Menzie with Panel Questions

9:30 AM David Menzie: Tin Replacement Study of Alaska

10:50 AM Probability of Occurrence Models: James Bliss USGS, Tucson, Arizona.

---------Lunch at 12:00---------

Tuesday Afternoon

12:47 PM Testing the Ability of Experts in the Estimation of Undiscovered Porphyry Copper Deposits: David Menzie

1:35 PM MARK3 Computer Simulation: David Root, USGS, Reston, West Virginia.

2:30 PM Panel Questions

3:38 PM Mineral Assessment of Costa Rica: Steven Ludington, USGS, Menlo Park, California.

----------Adjourn at 5:00 PM---------

Wednesday Morning, August 5.

8:10 AM Costa Rica continued: Steven Ludington and Donald Singer with questions from the panel.

9:00 AM Critique of the Sado Epithermal Deposit Model (25d): Lawrence Meinert.

9:20 AM Critique of the Sado Epithermal Deposit Model (25d): Douglas Cook.

9:30 AM Panel Questions and Comments

10:40 AM Undiscovered Porphyry Copper Deposits within the Range of the Northern Spotted Owl, California, Western Oregon, and Western Washington: Stanley Church USGS, Menlo Park, California.

----------Lunch at 12:00---------

Wednesday Afternoon

1:15 PM Spotted Owl continued with questions from the panel

2:05 PM Critique of the porphyry copper deposit model (17) by Spence Titley.

2:20 PM Critique of the porphyry copper deposit model (17) by Richard Nielsen.

3:45 PM Full panel discussion.

----------Adjourn at 5:00 PM---------

Thursday Morning, August 6, 8:00 AM

Criticisms of the Current Three-part U.S. Geological Survey Methodology
Perspectives: DeVerle Harris and Brian Skinner

8:10 Eric Force, USGS, Tucson Field Office, Tucson, Arizona.

8:30 Questions from the panel

9:23 Mark Bultman, USGS, Tucson Field Office, Tucson, Arizona.

10:35 Bultman and Force Questions from the panel

11:30 Bultman and Force Questions from the gallery

---------Lunch at 11:50---------

Thursday Afternoon

1:00 PM Warren Hamilton, USGS, Branch of Geophysics, Denver, Colorado.

2:25 PM Questions from the panel and gallery

3:30 PM Rebuttal by Menzie

4:05 PM Rebuttal by Singer

4:20 PM Presentation of the Data Used in the Redcloud and Handies Peak Wilderness Study: Richard Sanford, USGS, Denver, Colorado.

---------Adjourn at 5:00 PM---------

Friday Morning, August 7, 8:00 AM

8:10 AM Mineral Resource Assessment of the Tongass National Forest, Southeast Alaska: Lawrence Drew, USGS, Menlo Park, California.

9:10 AM Questions from the panel

11:10 AM Mineral Resource Assessment of the Tongass National Forest, Southeast Alaska: David Brew, USGS, Menlo Park, California.

----------Lunch at 12:10 PM----------

Friday Afternoon

1:22 PM Questions from the panel and gallery

2:05 PM Evaluation of Deposit Models: General questions and discussion by the panel

2:25 PM Kuroko Massive Sulfide (28a): Brian Skinner

Sedimentary Exhalative (31a): Spence Titley

Creede Epithermal Gold (25b): Richard Nielsen

Mississippi Valley Lead/Zinc (32a): Douglas Cook

Comstock Epithermal Gold (25c): Douglas Cook

Carbonatite Intrusions (10): Brian Skinner

----------Adjourn 4:30 PM----------

Sunday Afternoon, August 9, 3:00 PM
The Arizona Inn
Meeting of the panel to discuss relevant topics and unresolved issues; and assignment of research duties for the final report.

Monday Morning, August 10, 8:00 AM
Meeting for the resolution of important conflicts regarding assessment methodology. Closed to the gallery.

8:10 AM Applications of Expert Systems to Mineral Resource Assessment: Richard McCammon, USGS, Reston, West Virginia.

11:00 Am Questions from the panel

---------Lunch at 12:00 PM----------

Monday Afternoon

1:00 PM General Discussion by the panel of unresolved issues.

2:00 PM Consensus by the panel of duties.

2:10 PM Closing Remarks Harris and Skinner.

POST-CONFERENCE MEMOS SUBMITTED TO THE PANEL

WARREN HAMILTON

As part of his presentation at the Arizona Conference, Warren Hamilton provided the following document to each of the panel members:

An Evaluation of the Quantitative Mineral Resource Assessment Program of the U.S. Geological Survey, *A personal statement for presentation to the Panel for Evaluation of the USGS Assessment Methodology, Tucson, Arizona, 6 August 1992.*

The content of the document is discussed in Appendix I - Evolution of Controversies and Unresolved Questions and Issues.

Subsequent to the conference, Warren Hamilton submitted a memo to Dallas Peck and Benjamin Morgan (copied to conference panel) in which he criticized the Arizona Conference as being misdirected and part of the BORA conspiracy:

> "I believe that the review panel was misdirected in its meeting in Tucson earlier this month. Each panelist was given a thick stack of documents selected exclusively by BORA. These included best-case reports (highly misleading both for what they say and what they omit) and theoretical discussions which have little to do with the methodology practiced."

Hamilton protested the amount of time allotted to his and the Force/Bultman presentations:

> "The meeting was scheduled to have 40 hours of pro-method testimony and only 4 hours of anti-method testimony."

He attempted to discredit DeVerle Harris:

> "Panelists were not informed that Chairman DeVerle Harris is a former teacher and longtime friend of Dave Menzie and others in BORA and a recipient of BORA grants and student support..."

And, Hamilton tried to monitor the flow of information to the panel:

> "Please send copies of the materials to me so that I can keep track of what the panelists have seen..."

CLARIFICATION OF THE PURPOSE OF THE REVIEW BY DEVERLE HARRIS

DeVerle Harris responded to Warren Hamilton's comments about the conference and accusations of personal bias and vested interest in a memo submitted to Dallas Peck and Benjamin Morgan:

TO:	Dallas Peck, Director of the USGS Benjamin Morgan, Chief Geologist
FROM:	DeVerle Harris, University of Arizona
RE:	Warren Hamilton's memo on "Panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program"

There are statements contained therein that clarify the intent of the review, the participants involved and most importantly Hamilton's perception of the issues:

> "The three-step methodology to be evaluated in this study was developed by BORA and is applied by BORA; consequently, it seems quite reasonable that both the personnel and work of BORA are examined in great detail. Except for some variations on the three-step method developed by Warren Finch for uranium resource, there are no other established and routinely applied USGS methodologies. Although Mark Bultman experimented with some variations, Warren Hamilton did not. Moreover, he has not offered an alternative methodology, only criticisms of the established one, unless, of course, one considers total abandonment, as recommended by Warren, a methodology. It is important for the panel to be aware of the themes of major criticisms, and to that end the criticisms by Warren and others help focus on possible deficiencies; however it was not requested or proposed that the panel conduct a survey of opinion as a means to evaluate the USGS methodology. To do so would shift the responsibility, as well as the implied capability, for evaluation to others, some of whom may be relatively uninformed regarding economic geology, mineral resources, and assessment methodology."

> "To my mind both the RFP and my proposal make it clear that the primary objective of the study is an evaluation be the contractor of the USGS three-step methodology for mineral resource assessment. Accordingly, the contractor should have been selected because he and the principals involved in the work are qualified by virtue of their expertise and experience to evaluate the USGS methodology. Neither the RFP nor the proposal stipulate the desirability or necessity for Warren Hamilton, who has limited experience himself in this area, or anyone else, to orchestrate the work of the panel or the information reviewed by the panel."

With respect to panel integrity being compromised in a BORA/OMR conspiracy the following is stated:

> "Warren's comments clearly question my intentions and my capability of providing an impartial scientific evaluation of the USGS methodology. In that regard, I should point out that even if Warren's innuendos were accurate, it is highly presumptuous on his part, given the expertise and stature of the other panel members, to judge the effort as misdirected. Each of these panel members is a highly recognized scientist who is secure in his own knowledge and capabilities and is not going to be led to judgments against his will. That Warren would attempt to discredit these panel members is at the least unprofessional and incredulous."

Lastly, clarification is made on the conference time provided Hamilton, Bultman, and Force:

> "Since Warren makes an issue about the time given to the "pro" versus the "anti" (Warren's words), I think that you, as well as members of the Panel, should know that when I invited Warren, Mark, and Eric (I also tried to get Fred Fisher, but he was on vacation and chose not to return) to participate in the conference, I asked them how much time they wanted. I did not prescribe it! Thus, the amount of time Warren had was exactly what he requested! Had he requested more time he would have received it. Eric and Mark also could have had more time had they requested it. As all three were given the time that they requested, I am left to wonder if Warren's comments about time merely reflect his own recognition "after the fact" that he should have taken the conference more seriously and participated accordingly."

MEMORANDA AND INFORMATION SUBMITTED BY HAMILTON TO SUPPORT ALLEGED CONSPIRACY

Memoranda and information sent to the panel by Warren Hamilton to support his alleged conspiracy include the following:

TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.

FROM: Warren Hamilton
DATE: November 1, 1992
SUBJECT: Additional materials for your consideration

TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.
FROM: Warren Hamilton
DATE: October 18, 1992
SUBJECT: Political goal of the Chief of the Office of Mineral Resources

Accompanied by:

TO: All Personnel, Branch of Western Mineral Resource
FROM: Chief, Branch of Western Mineral Resources
DATE: June 14, 1991
SUBJECT: News from the NAMRAP Program

TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.
FROM: Warren Hamilton
DATE: October 31, 1992
SUBJECT: Document given by BORA to Senate Minority Staff regarding the mineral resources of the East Mojave National Scenic Area

Accompanied by excerpts from:
Undiscovered metallic mineral resources in the East Mojave National Scenic Area, southern California

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TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.
FROM: Warren Hamilton
DATE: October 25, 1992
SUBJECT: Open-file Report 91-551: Fact and Fiction in the Mojave Desert.

Accompanied by:
TO: Ben Morgan, Chief Geologist
THROUGH: Jack Hillhouse, Chief Western Regional Geology
THROUGH: Mitchell Reynolds, Chief, Office of Regional Geology

FROM: Doug Morton, Branch of Western Regional Geology
DATED: November 18, 1991
SUBJECT: East Mojave National Scenic Area Open-file Report 91-551.

And excerpts from:
Quantitative Assessment of Undiscovered Metallic Mineral Resources in the East Mojave National Scenic Area, Southeastern California. By Hodges, C. A., and Ludington, S., editors; U.S. Geological Survey Open-file Report 91-551.

TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.
FROM: Warren Hamilton
DATED: October 25, 1992
SUBJECT: Open-file Report 91-384 and the shape of things to come.

Accompanied by:
Quantitative Assessments of the Energy and Mineral Resources within Eighteen Wilderness Study Areas in the State of Colorado, Nevada, Oregon, and Utah. By McCammon, R. B., Menzie, W. D., Mast, R. F, and Devereux Carter, M., editors; U.S. Geological Survey Open-file Report 91-384.

TO: Chairman and members of the panel to review the BORA/OMR Quantitative Mineral Resource Assessment Program.
FROM: Warren Hamilton
DATED: October 18, 1992
SUBJECT: BORA Statistics

COMMENTS ON SELECTED ASSESSMENTS

MINERAL RESOURCE ASSESSMENT OF THE REPUBLIC OF COSTA RICA USGS MISCELLANEOUS INVESTIGATIONS SERIES MAP I-1865

Panel

The Costa Rica assessment was viewed favorably for the most part by the panel. It is noted in comments that the assessment appears to have had multiple objectives including resource assessment, geologic research and the promotion of mineral exploration in the country. The absence of some deposit types is seen as limiting the completeness of the assessment with respect to the goals.

There was extensive panel discussion concerning the Sado epithermal vein deposit model. Panel members expressed their dissatisfaction with the boundaries of the epithermal sub-models in general and with the criteria employed to select the Sado model for application to Costa Rica. Emphasis was placed on the use of observable geological phenomena.

The large folio format of the assessment is criticized as unwieldy and cumbersome. Panel members note the lack of a table of contents and index.

Comments by panel members emphasize that the foremost contribution of the assessment is the geologic maps. Both the new mapping and the compilation of previous mapping are commended. The addition of geologic cross-sections and stratigraphic sections is suggested, as is a summary analysis of geology and mineral occurrences in adjacent countries.

Suggestions for supplemental data and technology which would have enhanced the usefulness of the assessment include aerial photography, other remote sensing imagery and geochemical data. Additional panel member comments are summarized in the section on Geoinformation.

UNDISCOVERED LOCATABLE MINERAL RESOURCES OF THE TONGASS NATIONAL FOREST AND ADJACENT LANDS, SOUTHEASTERN ALASKA, USGS OFR 91-10

Panel

This assessment was commended mostly for the associated geologic database compilation effort. Panel member comments indicate approval of the approach to the data compilation and standardization of quantitative assessment as presented in OFR 92-307, Decision Points and Strategies in Quantitative Probabilistic Assessment of Undiscovered Mineral Resources (Brew, 1992).

One panel member criticized the fact that appraisal tracts do not cover the entire area, especially those covered by water and ice fields. Also, the judgement by the assessment team that some tracts were too well explored to justify any deposit estimates is criticized on the basis of changing criteria for economic deposits over the last 50 years.

The use of some grade and tonnage models that were constructed using local data is endorsed in panel comments. However, the non-assessment of certain deposit types because of a lack of grade and tonnage models is criticized.

The makeup of the assessment team was criticized as lacking in regional geologist, economic geologists and geophysicists having first hand experience in the assessment areas.

This Report

Additional comments with respect to geophysics and remote sensing imagery are summarized in Chapter VII, Geoinformation Other Than Geology.

ASSESSMENT OF UNDISCOVERED PORPHYRY COPPER DEPOSITS WITHIN THE RANGE OF THE NORTHERN SPOTTED OWL, NORTHWESTERN CALIFORNIA, WESTERN OREGON AND WESTERN WASHINGTON, USGS OFR 91-377

Panel

The panel generally viewed the Spotted Owl terrain assessment unfavorably. Criticism focused on the differences between the world deposit model for porphyry copper deposits and the nature of these deposits occurring in the Cascade Mountains. The geologic differences pointed out included alteration patterns, general host rocks and the absence of chalcocite enrichment blankets in the Cascades. The grade and tonnage model based on the world population is viewed by some panel members as being inappropriate for use in the Cascades.

Additional criticisms include the inadequate consideration of extent and intensity of historical mineral exploration in the area and the non-assessment of other deposit types considered very likely to occur in the area. Panel comments with respect to geophysics and remote sensing imagery are contained in the Geoinformation section.

This Report

Some Panel comments on specific assessments have been incorporated in the Chapter VII Geoinformation Other Than Geology.

SPECIFIC CONTROVERSIES

INTRODUCTION

An objective of the panel was to investigate controversies surrounding specific assessments and to examine those procedures of the current methodology that are contested. To complete this task, USGS personnel having a dissenting opinion of the methodology were invited by DeVerle Harris to speak at the conference. The authors of the Bultman et al. document in the Tucson Field Office and Warren Hamilton of the Branch of Geophysics, Denver were invited to request time before the panel for presentation of alternative quantitative methodologies. This invitation was extended by the committee within the spirit of the RFP and the scope of the contract to:

> "Provide assistance to the USGS by preparing a report that reviews and analyzes the agency's undiscovered mineral-resource assessment methodology and offers recommendations for future method development and applications. The review should (1) examine the legal and administrative obligations of the USGS to provide mineral-resource assessments; (2)examine the evolution and description of current methodologies; (3) include a critique of the presentation of results with respect to sensitivity analysis of the variability of input data and perceived bias of analytical methods; (4) include a comparison of the methods of the USGS with procedures in other organizations; and (5) include logistical requirements of the various methodologies. The report will provide recommendations which the USGS can use in planning future research and product development."

The following controversies were presented to the panel. Many of these controversies have also received treatment in other chapters of the report and are included here to specifically incorporate individual views of panel members.

DESCRIPTIVE DEPOSIT MODELS

Controversies related to descriptive deposit models employed in the three-part methodology derive primarily from the Bultman, et al. (1992, ver.7/2) document and from presentations made at the Arizona Conference by Force. As stated by Bultman, et al. (1992, ver.7/2):

> "The problems associated with using mineral deposit models as a basis for mineral resource assessment include: incomplete deposit models, underrepresentation of unconventional models, arbitrary boundaries between models, omission of some deposit models in most assessments, and necessary but not sufficient conditions for ore deposit occurrence represented by the current models."

Bultman, et al.,(1992, Version 7/2) elaborate further on these five problems: Incomplete deposit models refers to models which " are incomplete or unclear in their description of deposit types" and "factors necessary for deposit formation may or may not be described in a discriminating manner." The lack of unconventional deposit types in Bulletin 1693 will lead to underestimation of resources in an area. The boundaries between deposit types as presented by the geological models are arbitrary and do not adequately represent the importance of the environment of mineralization. The omission of some deposit types from assessments will lead to an underestimation of resources in an area. The lack of information in the deposit models with respect to the sufficient conditions for deposit formation erodes the usefulness of the models for predictive purposes.

These points were emphasized and amplified by Force's presentation at the conference. He pointed out the tremendous temporal and spatial variation across deposits of a single type and stated that deposit variation across crustal blocks seem to result mainly from environmental or source differences. Force stated that worldwide, time-independent mineral deposit models tend to gloss over the differences. He mentioned three unsatisfactory compromises in the descriptive mineral deposit models: 1) mixed populations within deposit models, 2) arbitrary division of deposit classes, and 3) omission of some facies of deposit types.

Panel Comments On General Aspects of the Descriptive Deposit Models

(taken from written panel-member submittals and verbal comments made during the Arizona Conference)

Completeness of Deposit Models

There is general agreement that Bulletin 1693 has been an important contribution but that it now needs to be redone, incorporating some new models, updating some models, and revising others. Two panel members suggest that the models incorporate some ranking or hierarchical listing of deposit recognition criteria in order of their usefulness in deposit identification and discovery. The necessity of inclusion of experience external to the Survey in the development of geological deposit models is emphasized by panel comments, as also is the need for periodical review and revision in order to incorporate new information.

Arbitrary Boundaries Between Models

Comments indicate general agreement of the panel that some deposit models appear to have arbitrary boundaries. Particularly troubling to some panel members is the splitting of the epithermal deposit types. This is discussed more fully in the section on Specific Deposit Models. The uneven treatment of ore deposit types with respect to deposit type boundaries is noted in panel comments. Two panel members would prefer that some deposit model boundaries be based on temporal considerations.

Omission of Some Deposit Models in Most Assessments

The panel generally agree that some assessments have not included consideration of all deposit types that could occur in an area. The lack of consideration of non-metallic deposits, water and energy in some assessments is pointed out.

Necessary But Not Sufficient Conditions for Ore Deposit Occurrence Represented by the Current Models

One panel member suggests the inclusion of necessary and sufficient conditions for deposit occurrence in the geological deposit models. However, panel discussion following Force's presentation highlighted the difficulty of establishing sufficient conditions for deposit occurrence (other than the presence of a deposit).

Panel Comments on Specific Descriptive Deposit Models

These comments are taken from written reports prepared by panel members in response to specific assignments.

Sado Epithermal Veins (25d)

The descriptive model for Sado epithermal veins is criticized by both reviewers as being too narrow a subdivision of the epithermal deposit type. Both reviewers prefer a previously published USGS classification of epithermal deposits as either low-sulfide quartz-adularia or high-sulfide quartz-alunite. The use of basement composition as a distinguishing feature for the deposit type is faulted because it is not field-observable. The deposit description is characterized as containing inconsistencies with respect to mineralogical descriptions and lacking in information about what are the essential features of the deposit type. A final criticism of the model is that one article of the literature cited in the descriptive model is not readily accessible.

Porphyry Copper (17)

One reviewer suggests that the porphyry copper descriptive model should not be separated from the skarn-related porphyry copper, porphyry copper-gold and the porphyry copper-molybdenum models because of certain common features. The separation of deposit types based on Cu/Mo ratios is questioned by one reviewer who indicates that metallogenic differences between deposits may be a function of tectonic setting, wall rock type and composition of intrusions. The omission of characteristic geophysical signatures from the descriptive model is noted as a deficiency. The incorporation of regional structural information in the model is recommended.

Kuroko Massive Sulfide (28a)

This deposit model was considered to be generally well-constructed. A recommendation is made for additional emphasis on alteration, clustering and temporal aspects of the deposit type.

Sedimentary Exhalative Pb-Zn (31a)

This deposit model was criticized as not being constrained to a unique genetic type. The descriptions of tectonic setting were found to be incomplete and unclear.

Creede Epithermal Veins (25b)

The close similarity between Creede and Comstock epithermal vein deposits was noted. Moreover, the descriptive model was judged to not contain enough information to determine permissive areas for the deposit type.

Mississippi Valley (Southeast Missouri) Pb-Zn (32a)

Recommendations for this model include the addition of vein structures as a regional deposit guide and limestone-dolomite interface as an ore control. A complete review of this model is suggested.

This Report

The criticisms by Bultman of: 1) incomplete deposit models; 2) underrepresentation of unconditional models; 3) arbitrary boundaries between models, omission of some deposit models; and 4) necessary but not sufficient conditions for ore deposit occurrence represented by the current models are examined in depth in Chapter V, Deposit Models. The notions of geological process based models proposed by Force during the Arizona Conference are examined further in 1) A Broad Conceptual Framework for Assessment Methodologies, a section of Chapter III, Evolution of Assessment Concepts and Methodology, 2) Philosophy of Science versus Preferred Procedure, a section in Chapter VI, Tonnage and Grade Distributions, and 3) Sound Principles Overall, a section in Chapter X, Summary and Recommendations.

ESTIMATION OF THE NUMBER OF UNDISCOVERED DEPOSITS

Criticisms by Bultman et al.

Bultman et al., (Version 3; 7/2/92) suggest the following geologic problems associated with the estimation of the number of undiscovered deposits in poorly known or covered areas:

- the lack of correspondence between known processes of mineral deposition and the data sets used to predict the occurrence of mineral deposits;
- improper structure of the estimation process, and;
- spatial and temporal variations and clustering in mineral deposits

Correspondence Between Mineral Deposition and Data Sets

The authors state that the occurrence of an undiscovered deposit requires all the same favorable factors in the same sequence as does a deposit of the same type in a similar well-known terrane. Thus, the prediction of the number of undiscovered deposits requires knowledge of the geologic factors and sequence that permitted the known deposit. In poorly known or concealed areas most of the factors are not imprinted on the data sets that form the basis for prediction. They state that where such data are missing, the possibility of useful prediction vanishes.

Bultman et al., suggest that the OMR methodology optimizes personal experience through the involvement of experts. But, if a dominant personality in the group has a great influence on the estimation outcome then much of the expertise of the group is lost. If this dominance is based on a superior knowledge of the BORA methodology then contribution by the local experts can be inhibited. The current structure of the BORA elicitation for the number of undiscovered deposits permits dominant personality bias.

Where the level of geologic information is poor geologic analogy becomes the prime method for estimating the number of undiscovered deposits. The authors note that this requires that the numbers and sizes of mineral deposits are similar in areas with similar geology. They contend that these analogies may or may not embody the sufficient as well as the necessary critical factors for ore deposit formation.

Structure of the Estimation Process

The structure of the current estimation process has been challenged as discouraging discussion of the required factors in sequential order. The authors state that this in turn prevents full and critical utilization of the pertinent geologic information available. They state that the selection of the panel fails to consider the qualifications of individuals, that expertise is regional, experience with different deposit types, and experience with the procedure. The authors suggest that the estimation procedure could be improved if the estimation panel follows a procedure that mimics the formation of the type of mineral deposit in question. In this way the factors involved in mineral formation could be considered sequentially.

Spatial and Temporal Variations

Bultman et al., contend that mineral deposit models tend to ignore the large scale changes in geologic attributes resulting from differences in host rock lithology and crustal blocks. They suggest that most economic geologists embody this factor in their reasoning, and it is contained in the estimate of the number of undiscovered deposits. But, they argue that the Cox and Singer (1986) deposit models ignore these temporal differences, thereby misrepresenting the geologists thinking about undiscovered deposits.

Statistical Problems Associated with the Estimation of the Number of Undiscovered Deposits

Bultman et al., state that the grade and tonnage models are the only available tools used for the visualization of an ore deposit. They contend that asking the assessor to summarize these two distributions into a single unit of measure, the deposit, is difficult, as the contained metal can vary by 4 to 5 orders of magnitude within ore deposits representative of a mineral deposit model. The authors suggest that every geologist estimates from a unique perspective about what a typical ore deposit looks like for a given deposit model. They argue that generally these stereotypical representations contain little, if any, quantitative data on contained metal. They question the ability of the geologist to estimate. given these deficiencies.

The authors state confusion in the reporting of the probabilities from one assessment to another. They note that some assessors report the percentile estimates as if they were providing point estimates of the number of undiscovered deposits at 10-, 50-, and 90-percent confidence intervals. They suggest that an assessor providing a high probability for a small number of deposits expects there to be a high likelihood of a small number of deposits and expects the PMF generated by the simulation procedure to portray this accurately.

Lastly, Bultman et al., discuss the influence of exploration intensity on the number of undiscovered deposits. They state that any exploration in a region leading to deposit discoveries will exhaust the number of remaining yet undiscovered deposits. Estimates of this number must account for previously discovered deposits. They advocate that where the level of exploration cannot be accounted for quantitatively, the assessment of resources cannot be quantitative. The authors charge that the current OMR methodology accounts for the exploration intensity qualitatively based upon rumor and anecdotes.

Criticisms by Hamilton

Hamilton, in his original manuscript, trivialized the estimation of undiscovered deposits to simple 'guesses' that he reported to be extremely optimistic:

> " In the first round of guessing, the range of probability given for the presence of one deposit can be from "90 percent" to "1 percent, if we have to be generous", but group dynamics and authority lead to a single choice. Guesses are made as to the number of deposits of a types present at each of a number of probabilities. The amount of explanation given for the guesses can be large (Brew and Others, 1991) or nonexistent (McCammon and Others, 1991), but they are guesses either way."

Hamilton charges that these guesses are strongly influenced by information on the activity of the exploration industry and higher probabilities are assigned on the flimsiest of evidence to small tracts which industry has examined and dismissed. Hamilton charges that any "non-trivial" possibility that a deposit is present must be expressed by assigning the whole number 1 to a default probability. Thus, a very small area with the minimum of evidence of mineralization will be assigned one deposit in the distribution.

Presentations at the Arizona Conference

Presentations by Bultman and Hamilton of controversies about the estimation of the number of undiscovered deposits were derived from their manuscripts, as reported above. These are not repeated here.

Panel Questions to Bultman and Hamilton

The issue of estimation of the number of undiscovered deposits was not raised during the Bultman question period.

The issue was raised that Hamilton is concerned about the estimation of high numbers but has not reported assessment studies for unreasonably low numbers of undiscovered deposits. Hamilton replied that to him the only time this has occurred in any given area, only a few types of deposits are concerned. Often in this circumstance there could be more deposits of other types. He also replied that he has not felt this type of negative bias in his reviews. Hamilton stated that the examples were selected because of their flagrant results. He admits that it is a valid claim that he has not looked through all of the assessments and has picked out parts that seems particularly outrageous to him. His point is that the assessment team was not tempering the guesses and were not knowledgeable.

Panel Comments on Estimating the Number of Undiscovered Deposits

General

The review panel comments indicate a sensitivity to the apparent intermingling between the team overseeing/conducting the assessment and the panel of experts used to provide the estimates of the numbers of undiscovered deposits. For many of the assessments it was unclear who, and how many experts, made estimations. There should be a reasonably detailed description of 1) what expertise and experience should be represented on the panel, and 2) how and by whom the panel is to be selected.

Since the estimation of the number of deposits is the single most important step and the biggest cause of uncertainty, it is critically important to present some explicit guidelines for selection and operation of the panel. The assessment teams should consist of a minimum of four individuals and a maximum of seven. The minimum configuration consists of a local expert, an economic geologist who is expert in the use of deposit models and associated geochemical signatures, a geophysicist, and a representative from BORA having expertise in the assessment methodology and group dynamics. The BORA representative serves as the group leader for training sessions in the methodology with all members producing individual estimations of the number of undiscovered deposits. Each of the individual estimations is fed to the simulation program, filtered by a cost model, and combined with the other estimates to yield a group estimate, with associated uncertainties.

A larger panel of seven members would include two additional BORA assessment personnel bringing the total to seven persons. Depending on the size of the assessment area and expertise of the local geologists, it may be beneficial to pair each geologist with an experienced BORA assessor.

The estimates should be subjected to a review by an individual who will not produce an estimate of the number of deposits but will file an independent report recording impressions of the assessment process.

Hamilton's use of the word 'guess' drew the criticism from several panel members. They note that a 'guess' has a broad range of probabilities of closing on an answer depending upon the evidence on which it is based and the experience of a 'guesser'. The negative spin given by Hamilton and the semantic games being played with this process by those unfamiliar with it in the world of day to day exploration are at the very minimum born of ignorance and serve no useful purpose to the long term objectives. Done by those who should know better, it is unprofessional.

It was recommended that an objective of the USGS should be to establish a credibility for the estimation process that it currently lacks. Given the degrees of uncertainty in the information used and differing levels of experience, cautious conservatism should be employed. The determination of whether or not undiscovered resources exist in an area of concern should be based upon the best range of judgments of experts on regions, ore styles, ore signatures and commodities. A great number of these experts exist within the USGS. This task requires the highest level of expertise available, and some of this expertise should be drawn from outside the USGS from those having no vested interest in the outcome. Furthermore, Bulletin 1693 should not be the sole document upon which the estimates are based without revision.

Dave Menzie's presentation of the porphyry copper test of the ability of an expert to estimate the number of deposits drew the criticisms that insufficient attention was given to the way in which the subjects performed the estimation task and that the statistical analysis was not appropriate. The results given from the use of regression simply are too erratic to be of any value.

It was suggested from various presentations and panel discussion that the question posed to the geologist about number of deposits is not finalized. Given an inconsistency in the posing of the question there seems to be little recognition of how this variation has affected the results.

Panel Comments on Specific Assessments

Spotted Owl

There was disagreement among panel members about the credibility of the estimated number of undiscovered deposits and the manner in which this number was estimated. The high level of exploration in tract A necessitates that most or all large deposits have been discovered and that new discoveries will be relatively small and cluster on the 'small deposit end' of the tonnage curve. Yet, some areas included in assessment are covered and basically unexplored, meaning that if deposits are present they could be of any size.

The panel of nine experts was probably more than ideal. Each member assessed number of deposits, which was followed by group discussion and a consensus by the entire group. What was not reported is the criteria used by the group to arrive at the number of undiscovered deposits that were derived from the number of known copper prospects. Likewise, it is not clear to the reader how, if at all, the exploration history had been factored into the estimate.

Tongass

Brew reports that the estimation of the number of undiscovered deposits was constrained in this study area by defining those deposits that can be discovered and developed using presently available and appropriate technology. This constraint was viewed as a strength of the estimation process. The estimations of undiscovered deposits in all assessment areas should use this definition to avoid confusion, standardize the estimation procedure, and minimize the credibility issue. However, some panel members consider the assessment to seriously understate the resources of this area, and some are concerned that the assessment seems to reflect primarily the judgments of only one person, David Brew.

This Report

The statistical issues presented by Bultman et al., in estimating the number of undiscovered deposits is examined in depth in Chapter VIII, Subjective Probability, and Chapter IX, Assessment Methodology and Subjective Probability.

GRADE AND TONNAGE MODELS

Statement of the Controversy

Criticism of the grade and tonnage models employed in the three-part methodology are found in: 1) the two Bultman et al. manuscripts - Chapter J and Comments on the Three-step methodology; 2) Warren Hamilton's Evaluation of the USGS Method of Quantitative Assessment of Mineral Resources; and 3) a memo from Wilshire, Miller and Nielsen regarding the East Mojave National Scenic Area.

Chapter J

In Chapter J, Bultman et al. estimate the number of undiscovered mineral deposits based on the expected size of these deposits within the Forest. They employ tonnages of known deposits and occurrences. The authors fault MARK3 in the way it "exaggerates" estimates of the metal contained in inferred undiscovered deposits in Coronado National

Forest. Two of the three factors thought to be contributing to this overestimation are associated with the tonnage models:

1) MARK3 cannot easily accommodate local tonnage models;
2) MARK3 inappropriately uses piecewise log-linear (or log-normal) models to approximate grade and tonnage data contained in Cox and Singer (1986).

The authors state that grade and tonnage models described by Cox and Singer (1986) are not appropriate for the sizes of undiscovered deposits inferred to be present in the Forest. Much of this data is district based, requiring that the estimate produced by MARK3 be divided by the number of deposits believed to be present in the district. But, to their knowledge, there is no published literature on the distribution of deposits in districts.

Bultman et al., state that simulations should be run by extracting random grade and tonnage values from actual deposit data. Neither the lognormal nor piecewise log-linear models fit grade and tonnage data for the Forest in the right hand tail of the distribution. They suggest that this will commonly lead to an over-estimation of the contained metal in the deposits. In the Coronado assessment, grade and tonnage are not modelled, but are sampled directly from the data during simulation.

Bultman et al. Comments on the three-step Methodology

The above notions are elaborated upon in the Bultman et al. document Comments on the "Three-step" method for quantification of undiscovered mineral resources (Version 3, 7/2/92). They identify three sources of error in the grade and tonnage models:

1) a lack of stationarity of deposit tonnages and grade,
2) model biases,
3) model mis-specification.

They claim that the lack of stationarity results from employing the OMR world-wide deposit data characterized by a mix geologic environments in a variety of geologic terranes. Ore deposits are uniquely related to the terrane in which they occur and cannot be viewed as stationary over different geologic terranes. The authors state that application of the OMR data set to a small area makes little sense as the geologic environment is not accurately represented.

Model bias is introduced through size-biased sampling, economic truncation, translation and censorship. In size-biased sampling larger deposits are discovered early in the exploration history as they represent larger exploration targets. Bultman et al. suggest that for a region that is well explored it should be expected that undiscovered deposits will be smaller in size. Sampling from a distribution having a large skew to the right hand tail tends to exaggerate the effect of sampling proportional to size. Truncation results from uneconomic deposits generally not being reported in the literature. This is accompanied by translation of data from the mining of higher grade portions of a deposit. Censorship results from proprietary information on many mining operations not being reported. The authors state that censorship most often will occur for small deposits, leading to contained metal distributions that are biased to large sizes. These effects will all lead to overrepresentation of large deposits in the data set.

Bultman et al. state that the OMR data set is mis-specified by assuming lognormality of tonnage and grade without statistical testing. This assumption is based on a Gaussian shape to the distribution that cannot be statistically tested as the individual deposit types contain too few data. They claim that instead, the Gaussian appearance of the logarithms of tonnage and grade more likely result from the aforementioned sampling biases. A piecewise log-linear cumulative distribution may fit the data better than the lognormal and may more accurately reflect the discrete sets of geologic processes.

The authors fault the use of grade and tonnage data in the MARK3 simulator. One method models the data with a lognormal distribution whereas the other models the data as a set of piecewise lines (Bultman et al., 1992 citing Root, 1992). They state that, although the piecewise method minimizes errors due to model mis-specification, no published assessment contains information on errors due to models not fitting the data.

Bultman et al., performed a test for sensitivity of the lognormal assumption. Making use of the Cox and Singer (1986) porphyry copper data set they examined the following conditions:

Method 1 - random sampling of grade and tonnage from the statistical (lognormal) models for grade and tonnage (Cox and Singer, 1986) and the simulation of deposits;

Method 2 - sampling the actual grade and tonnage data randomly to create simulated deposits;

Method 3 - sampling of the actual data with the 2 largest deposits (tonnage) removed;

Method 4 - sampling the actual data with the 10 largest deposits removed;

They concluded that the results indicate a sensitivity of the lognormal distribution to the fit of the right-hand tail. By removing the largest deposits they demonstrate "a sampling proportional to size".

Warren Hamilton

Many of Hamilton's challenges to the grade and tonnage models are similar to those of Chapter J and Bultman et al. He states that the Cox and Singer (1986) grade and tonnage data sets are biased, having an overrepresentation of large deposits and an underrepresentation of small deposits. He suggests that perhaps half of the worldwide tonnage plotted for deposits of a given type is represented by the largest 10 percent of those deposits, yet in a natural distribution no more than a few percent would likely be of that size. Like Bultman et al., he challenges the inclusion of points representing entire districts fed to MARK3 where they are treated as large deposits. Given the similarity of these criticisms to those of Bultman et al., only points unique to his presentation follow.

Hamilton's manuscript discusses the effect of cutoff grade on the data set. The small tonnage end of each distribution is controlled by an economic-cutoff, sliding window that has little to do with the actual distribution of size of deposits. Furthermore, economic cutoffs lie approximately at median grades (citing Singer, (in press), who cites H. K. Taylor) and that these factors are ignored in the MARK3 hypothetical-resource calculations which, he claims, are for contained and not extractable metal.

Hamilton states that podiform chromite deposits support these criticisms because the data permits the evaluation of low tonnage deposits with variable cutoff grades resulting from changing economics. The subsidized, wartime production of podiform chromite in Oregon and California are an example. In the Cox and Singer model 80% of all deposits from this period of production are included but 60% of these are smaller than the economic-cutoff minimum for the overseas distribution. He concludes that economic variables controlling production result in a biased sample that is not lognormal, where small deposits are truncated from the data set. Hamilton claims that for many types of "real-world" deposits the grade and tonnage are continuous, in the geological sense, down to isolated mineral grains and, unlike the Cox and Singer data set, such deposits are more abundant as their size decreases.

Wilshire, Miller, and Nielson

In the mineral source assessment of the East Mojave National Scenic Area (EMNSA) Wilshire, Miller and Nielsen write "biases occur in the MARK3 treatment of data because the grade and tonnage models overrepresent large deposits and underrepresent small ones; use of arithmetic means of statistical data feeds on that bias." They state grade and tonnage curves overrepresent large deposits and underrepresent smaller ones. This bias in the distribution indicates that median and mean values for grade and tonnage are skewed toward high values. In this distribution the median is less drastically skewed than the mean. During the assessment they stated that mean values should not be used.

Presentations at the Arizona Conference

Bultman

During the Arizona Conference Bultman re-iterated the stand that grade and tonnage models based on a world-wide distribution have:

1) a lack of statistical stationarity of the mineral deposit attributes;
2) sampling biases;
3) problems with models not matching the data, and;
4) a use in district based estimations only.

Panel Questions to Bultman

The panel asked about Bultman's statement that there is no theoretical basis for the lognormal distribution and that this may be true for all distributions. It was suggested that Vistelius' Law of Sequential Process Effect may suggest a theoretical basis leading to a lognormal. Bultman agreed and said he would like to see this applied to a geologic setting. He has not seen it done this way and Vistelius has been cited in the manuscript.

Bultman was asked if modification of the grade tonnage curve made for the Coronado assessment was to reflect the amount of previous exploration and, if so, is this not just a guess? Bultman responded it is a guess, but was justified for two reasons: 1) the Forest is well explored; 2) they have a huge amount of geophysical and geological data in the area together with some very experienced geologists that could find no evidence for the largest deposits to exist. He was asked what basis was used for the removal of the top 5% of deposits from the distribution? Bultman replied it was based upon geologic intuition.

A panel member enquired if by removing these deposits is Bultman saying that the national forest and its boundaries are not part of a broader geologic province in which the forest exists? Furthermore, had he considered that the Forest lies within a domain where other deposits exist. Bultman replied that this was considered but the Forest varies a lot from east to west and there is a difference of deposits across the area within the forest. Second, the tonnages and grades of everything produced in the boundaries of the Forest had nothing that matched the Cox and Singer (1986) data. Maybe these specific individual terranes are restricted to these kinds of deposits and there was no evidence to the contrary. Furthermore, only a small portion of the Forest is under cover and they think that they understand what goes on in this region.

Hamilton

The following sections are unique to Hamilton's presentation.

In the East Mojave Scenic Area the method assumes lognormality in grade and tonnage but the data set, with a few exceptions, are not in the open and cannot be tested. He knows no reason to assume that the tonnages and grades of ore deposits should be lognormal. He suggests that lognormality is a religious conviction by Singer and, as the data are secret, cannot be tested. A deposit grade data set that is economically truncated data cannot be lognormal whether or not tonnage displays these tendencies. Because of a lognormal high-end tail effect the MARK3 program must perform an add-hoc 'diddle' algorithm to avoid assuming the bivariant lognormal assumption. This algorithm is, in Hamilton's words, a cosmetic masking of the lognormality assumption.

The cumulative distribution plots, by Cox and Singer (1986), are misleading. Rather than plotting orders of magnitude along the bottom axis there are five divisions of equal linear size. This makes interpolation impossible for the user and this convention should not be used.

In the Redcloud and Handies Peak area Hamilton reports that there are a multitude of small veins; as none are economic they are dropped from the Mosier model. As a result, estimates at the 90, 50, and 10 percentiles result in deposits larger than anything ever found in Colorado. He knows of only 21 deposits world-wide that passed Mosier's filter.

For the Creede polymetallic vein model, estimates are an artifact of the upper tail values and have no significance what-so-ever. Hamilton reports that mean values are enormously larger than the median values and are driven by the upper-tail because of the assumption of lognormality. These values are fiction and have nothing to do with the real world.

The molybdenum porphyry deposit model estimate has a contained value that is larger than all of three molybdenum porphyry deposits known in the world. Again, the results are inflated because of lognormal bias. The Cox and Singer (1986) Climax molybdenum model displays nothing remotely lognormal about the data. In these data sets the mean is unstable; it is a bi-modal sample, and the left tail doesn't matter to the BORA estimators. The large value right hand tail results in high value estimates. For samples like this, there should be a method that down-weights the outliers and reports the median.

Panel and Gallery Questions to Hamilton

The question session was made open to both the panel and members of the gallery.

Hamilton was questioned on his statement that the methodology, and more specifically MARK3, requires that the grade and tonnage be assumed to be lognormally distributed. He acknowledged to the panel that the simulation algorithm employed an add-hoc sampling from an empirical distribution. But, the erratically stepped character of tonnage and grade for some deposit model distributions does not permit a piece-wise linear fit. Furthermore, he notes that BORA claim grade and tonnage are bivariant but 'diddle' the correlation to make the product looks cosmetically reasonable.

The use of the term 'diddle' was challenged by Root who responded to Hamilton eight months earlier with a paper and letter explaining the algorithm. The paper contains the word 'dependency' more than two dozen times and suggested that Hamilton had failed to read this. Furthermore, the parameters of the lognormal distribution use the mean of the data, not of the fitted distribution. The variance is selected so as to get the same variance as in the data. This is done so that a bias is not introduced. Hamilton replied that this is a cosmetic fit, they should work with contained metal rather than 'shenanigans' with pseudo-independent variables. Root replied it is not enough to discuss contained metal as the Bureau of Mines needs tonnage and grade for the cost models. Hamilton suggested that use of the grade and tonnage distributions leads to such 'stratospheric' garbage that the results have no meaning to the real word.

When queried as to how he knew that grade is not lognormally distributed he replied that it is by definition. The data have an arbitrary cut-off, deliberately and economically truncated. By definition this data represents 'ore'. Whether there are lognormal distributions in nature is unknown, it cannot be proven that this is not sampling bias. There is no genetic reason that ore deposits have lognormal distributions for tonnages and grades. Furthermore, the data is a result of sampling proportional to size. A lot of these distributions are exponential. Implicit in all of these calculations is decrease in tonnage and grade for values below the median. He stated that this has never been rigorously proved.

Panel Comments on the Grade and Tonnage Model

General Comments

In general, the panel suggested consideration should be given to a revision of grade and tonnage data to more fully address and compare certain kinds of deposits in the context of different attributes in different regions, and different metallogenic habits in time. The use of world-wide data to evaluate geographically restricted ores of: 1) specific time of formation; 2) specific and usually constrained settings; and 3) post-ore histories in ore bodies that are believed to occupy only a small and discrete part of the complete world spectrum of deposits.

Frequency distributions for deposit tonnage and grade should reflect, to the extent possible, terrane differences and regional contrasts in enriched and hypogene ores. The credibility of tonnage potential may be seriously damaged when world-wide data that include mineral deposit giants of ages and terranes other than those that occur in the United States are used as a basis for estimation of in-place values. It is apparent that the classification of some deposits used as parts of the distributions could be matters of serious debate, i.e., the Coeur d'Alene as a simple Sb deposit. An early conceptual view of the deposit type and an early definition (Parsons, 1933) holds secondary enrichment as an essential element of the deposit and ores of that time, as well as some ores now, mined rich chalcocite blankets; conversely current mining of hypogene ores at Globe and Sierrita Arizona, mine low-grade hypogene ores. This transition in grades should be reflected in considerations of evaluation of deposits of regions.

Recognizing that there are problems with confidentiality, it is important that the data used to model the grade and tonnage distributions be publicly available. There is a need for providing an independent evaluation of the groupings of deposits. The current grouping of grades and tonnages is not acceptable to all geologists.

Given the importance of grade and tonnage distributions to the assessment methodology more attention should be given to the presentation of data and distributions. In particular the practice of focusing exclusively on the cumulative distribution should be changed or supplemented.

Size Biased Sampling and Randomness

The consideration of size biased sampling in the Coronado National Forest and similar suggestions by Hamilton drew criticism. In the Coronado study the tonnage distribution was modified to discount the probability for very large undiscovered deposits. Although this phenomena has been demonstrated for some petroleum exploration (Arps and Roberts, 1958) and more recently for mercury deposits in California (Chung et al., 1992), there are reasons for questioning whether this is a general case. Other deposit types are significantly different from petroleum or mercury and the presumed essential geologic features may be incomplete or in error. As an example, consider the deposit type for which the ore minerals are not visible to the eye and ore-grade rocks can look identical to non-mineralized rocks. Also consider the deposit types that are discontinuous and not confined to a particular geologic strata. When the effects of technological change are superimposed on deposit models ore deposits result in rocks which were previously not even prospected in known ore districts. These and many other differences suggest that discovery according to size is not a universal phenomena and that tonnage and grade models should only be modified to account for this potential bias when there is a clear and demonstrated understanding of the exploration factors discussed above.

One panelist submits the following factors that can contribute to the discovery as: 1) understanding of the geologic model; 2) visibility of important deposit features; 3) depth of formation and preservation in the crust; 4) size and continuity of ore horizons; 5) extent of exposure in the prospect area; 6) exploration technology and; 7) economics. Changing any one of these parameters may result in a new exploration cycle. Many of these factors are linked, as in the case of a change in price or technology that can allow for mining of an entirely new deposit type for which there was no previous model or exploration.

Another panel member suggests that although a great deal of discussion was given to size biased sampling, randomness is a more important problem. He notes that when various statistical tests (such as for normality or lognormality or for the significance of a correlation coefficient) are applied the use of those tests implies the validity of certain underlying assumptions (some form of random sampling is the most common). It is extremely unlikely that any of the data represents a random sample and this problem should, at least, be acknowledged and caution used in reporting the results of such tests.

Comments Based Upon Specific Models

- Porphyry Copper Deposit Model

In the general, the porphyry copper deposit model (#17) contains bias towards large deposits because of historic high grade production from copper-rich supergene ore zones. This must be considered in the construction and use of these models in local areas.

- Carbonate-Hosted Au-Ag Deposit Model

In the carbonate-hosted Au-Ag deposit model, the descriptive grade and tonnage models need to be revised, principally owing to the large amount of information that is available after publication of Bulletin 1693. One panelist submitted the following list for which new descriptions and grade and tonnage information are available. The Principal source is the Symposium Proceedings and Field Trip Guidebook Compendium for Geologic Association of Nevada Great Basin Symposium (1991).

Chimney Creek, Humboldt Co. USNV (Gold Field)
Rabbit Creek, Humboldt co., USNV (Santa Fe)
Lone Tree, Humboldt Co., USNV (Santa Fe)
Stonehouse, Humboldt Co., USNV (Rayrock et al)
Santa Fe, Mineral Co., USNV (Corona)
Marigold, Humboldt Co., USNV (Rayrock et al.) - 4 deposits
Hilltop, Lander Co., USNV (Placer Dome)
Pipeline, Lander Co., USNV (Placer Dome- Gold Fields)
Gold Bar, Eureka Co., USNV (2 new Atlas operations)
Pan, White Pine Co., USNV (Aspen)
Meikle, White Pine Co., USNV (Barrick) - large and high grade
Post, Eureka Co., USNV (Barrick)
Deep Post, Eureka Co., USNV (Barrick)
East Bullion, Eureka Co., USNV (Teck)
Trout Creek, Eureka Co., USNV (Newmont)
Bald Mountain, White Pine Co., USNV (Placer Dome)
Little Bald Mountain, White Pine Co., USNV (Placer Dome)
White Pine Mountain, White Pine Co., USNV (USMX)
Winrock, White Pine Co., USNV (USMX)
Casino, White Pine CO., USNV (USMX)
Yankee, White Pine Co., USNV (USMX)

Available data on at least 20 additional deposits not listed in Bulletin 1693 will nearly double information on grade and tonnage models.

- Sedimentary Exhalative Deposit Model

No distinction is made in Bulletin 1693 to age and setting of ores, and the model should be tested on that basis. The wide variation in reporting of the nature of grade and tonnage, as in the copper ores, leaves the meaning of the grade-tonnage figures in doubt. One panelist questions how one could compare the 500+M tonne, 5% zinc ores and the 50+M tonne 15% zinc ores of the Selwyn Basin? Are these large, low grade deposits really comparable to the high-grade giants of the Proterozoic?

Panel Comments on Grade and Tonnage Models Used in Specific Assessments

Spotted Owl

It was expressed by several panelists that in the Spotted Owl Assessment the grade and tonnage models for porphyry copper deposits in general are not appropriate for Cascade deposits. These curves are heavily influenced by high grades associated with chalcocite enrichment blankets of southwest porphyries. These are absent in the deposits of the cascades. The use of the general grade and tonnage curves will provide unusually large estimates of expected metal endowment and may be a major credibility issue. One panelist notes that ores of the Cascades appear to be mostly hypogene and near what is conventionally considered as "protore" grade (ie. 0.2-0.3%). At present they constitute resources but of questionable economic recovery with present prices and technology. The methodology of resource assessment should have procedures for modification of the grade and tonnage curves to account for these changes in local geologic conditions.

Tongass

In the Tongass National Forest assessment a strength of the study is the modification of grade and tonnage curves to be applicable to southwest Alaska. Brew is credited, by some, for constructing a subjective grade and tonnage model based upon local information to support a quantitative estimate for undiscovered deposits where data was sparse. However, as these distributions are no better than Brew's judgment, the general use of subjective distributions in place of actual data is problematic and should be avoided whenever possible, as this introduces another dimension of uncertainty and variation among assessments.

This Report

This report considers at length the construction and use of tonnage and grade distributions in the Chapter entitled Tonnage and Grade Distributions.

MARK3 SIMULATION PROGRAM

Statement of the Controversy

The MARK3 simulation program is the center of much controversy. Statements by Hamilton in his memos refer to restricted access to MARK3, confusing descriptions of the program, a bias in MARK3 towards producing high values, and a tendency of the program to increase all estimates to higher probabilities. Comments on the program also are made by Bultman, et al. in their comment paper, in Chapter J of the Coronado National Forest assessment, and in remarks made during the conference. These include criticisms with respect to 1) the use of piecewise log-linear approximations to data, 2) the treatment of secondary metals by the program, and 3) the lack of local grade-tonnage models. In addition, the 10-50-90 percentile method of elicitation is criticized as being counterintuitive and unable to represent deposit number information as intended by geologists.

During the conference, Dave Root presented the workings of the MARK3 simulator and characterized it as a translator of number of deposits and tonnage and grade distributions into contained metal and/or gross in-place value. Given Root's clear presentation, there was little in-depth discussion of the MARK3 simulator program.

Panel Comments on MARK3

The panel generally was satisfied that MARK3 was not the source of great distortion, i.e. Hamilton's "astounding values", or Bultman et al.'s exaggeration factor of 1000, in GIPV. In fact, the truncation of the upper 10% of numbers (the large numbers) so criticized by Bultman et al. works to decrease the resulting GIPV, not increase it. And, what Hamilton describes as "diddling" assures that simulated tonnages and grades honor the available data. Two panel members provided written comments on the MARK3 program. The characterization of the program as merely a translator was both questioned and supported. Suggestions were made that the random number generator employed be tested and that 4,999 simulation runs are not adequate to simulate a lognormal distribution. The panel member recommended that: 1) MARK3 be upgraded to more standard code and made interactive, 2) the algorithm and code for MARK3 should be documented and made available for independent review.

PRESENTATION OF ASSESSMENT RESULTS (GIPV)

Statement of the Controversy

The controversy about the presentation of assessment results is focused on two aspects. The first controversial aspect as outlined by Bultman, et al. (1992, Version 3) is the form of the estimated deposit numbers, specifically the presentation of the 10, 50 and 90 percentiles of the estimated deposit distribution along with its mean. Bultman, et al., feel that end-users of the assessment will use the mean value and may not understand its meaning. They also indicate that this type of presentation does not convey any information about the subjectivity of the decisions employed in generating the estimate.

The second controversial aspect is the use of gross in-place value (GIPV) to represent the mineral value of assessment tracts. GIPV is criticized with respect to its assumptions about metal prices and its lack of consideration of extraction costs. Hamilton characterizes GIPV as overstating mineral values and misleading end-users in its presentation of "astounding" dollar values.

Panel Comments on the Presentation of Assessment Results

The use of GIPV is criticized in panel comments as being unacceptable and misleading. The exclusion of exploration and development costs in the calculation of mineral value is strongly criticized. The suggestion is made that the calculation of GIPV should be modified in order to make the measure more useful. The use of tonnage and grade filters was recommended as one way of achieving this. The panel generally recommended decreasing the number of significant digits in reported statistics of assessments.

This Report

The use of GIPV is examined in depth in the Chapter entitled A Value Measure for Land-use Decisions. This Chapter also describes an improved measure. See also Chapter X, Summary and Recommendations.

ERROR ANALYSIS

Statement of the Controversy

The controversy about error analysis results from similar statements contained in Chapter J and in the Bultman et al. comments paper. The authors state "there has been no analysis of the effects of the uncertainties in the various parameters in the OMR method". They present a table (not present in this report) that lists sources of error and associated error in terms of multiplicative and divisive factors. Based on an analysis of the error table, they state "it is easy to see that the possible errors in the OMR method can be larger than a factor of 10,000". The authors feel that there is a systematic tendency for overstatement of values. They also claim that assessments produced with the three-part method contain less information than properly defined relative estimates such as low, moderate or high mineral resource potential.

These points were also presented at the conference by Force who added that the error should be tracked step-by-step through the assessment process.

Panel Comments on Error Analysis

In the panel discussion following Force's presentation, the notion of assigning error for the various assessment stages was examined. This discussion pointed out the difficulty in implementing such a means of error estimation. Additional panel comments refer to confusion in the Bultman, et al. paper with respect to the concepts of accuracy, error and precision. It is pointed out that error and accuracy are inappropriate terms in a discussion of estimates of unknown quantities. Suggestions are made by three panel members for analyses of precision and uncertainties to be include with the estimates.

This Report

The accuracy notions presented by Bultman et al., and their relevance to assessment are examined in depth in Accuracy and Judgment, a section of Chapter VIII, Subjective Probability.

TESTING OF THE ABILITY OF EXPERTS TO ESTIMATE NUMBERS OF UNDISCOVERED DEPOSITS

Statement of the Controversy

The origin of the controversy over testing the subjective estimation aspect of the three-part methodology is comments made by Bultman, et al. (1992, ver.7/2). They object to the testing being limited to only one deposit type. The basis of their objection is the great differences that exist among deposit types. It is stated that a test for one deposit type is not a test for a genetically unrelated deposit type. In addition, they maintain that the test for porphyry copper deposits has a greater chance of yielding favorable results because of the high degree of correlation between this type of deposit and map information with respect to geology and geophysics. These points were emphasized in Force's presentation at the conference.

Panel Comments on the Testing of Experts

In discussion following Force's presentation, a panel member pointed out that the test presented by Menzie is not a test of model types but of the method used in assigning probabilities. Moreover, according to one panel member, that porphyry deposits give a stronger signature than other deposit types is a presumption by Bultman et al., and does not differentiate between size and strength of anomalies as they relate to sensing technologies, e.g. geophysics.

CHAPTER III -- EVOLUTION OF ASSESSMENT CONCEPTS AND METHODOLOGY

EVOLUTION OF ASSESSMENT CONCEPTS AND METHODS

OUTLINE

PERSPECTIVE
- **ROOTS**
- **STRUCTURE AND SCOPE OF THIS SECTION**

A BROAD CONCEPTUAL FRAMEWORK FOR ASSESSMENT METHODOLOGIES
- **DETERMINISTIC VERSUS STOCHASTIC**
  - DETERMINISM AND SCIENCE
  - A STOCHASTIC WORLD?
- **TWO MAIN APPLICATIONS OF DETERMINISM**
  - PROCESS-BASED ASSESSMENT
  - ASSESSMENT BY GEOLOGICAL ANALOGY
  - MIXED METHODS

A HISTORICAL SKETCH OF MAJOR DEVELOPMENTS
- **PERSPECTIVE**
- **THE STATISTICAL MOVEMENT**
- **THE END OF THE ROMANCE WITH STATISTICAL MODELS**
- **EMERGENCE OF THE USE OF SUBJECTIVE PROBABILITY**
  - LIMITED TIME, AN ADDITIONAL MOTIVATION
  - ELICITATION OF SUBJECTIVE PROBABILITY BY CELL (QUADRAT)
  - ASSESSMENT BY AREAS DELINEATED BY GEOLOGISTS
- **FAITH IN MAN AS AN INTUITIVE STATISTICIAN**
- **THE ENERGY CRISIS--INTENSE DEMANDS AND SCRUTINY**
- **NURE AND POTENTIAL SUPPLY**
  - IMPLICATION OF HIGH PRICES
  - ESTIMATION OF ENDOWMENT
    - Complications
    - Genetic Models and Recognition Criteria
    - Mineralized Rock Density Methodology
    - Control Areas
    - Tonnage and Grade Distributions
    - Subjective Probability
  - POTENTIAL SUPPLY ESTIMATION
    - Cost Factors
    - Probability Distribution for Potential Supply

EVOLUTION OF ASSESSMENT CONCEPTS AND METHODS

PERSPECTIVE

ROOTS

The forerunners of modern mineral resource assessment are those economic and exploration geologists who estimated hypothetical ore reserves, i.e. reserves in undiscovered mining districts. Those resource descriptions or estimates were made by subjective geological analyses and appeared in special studies, such as the Paley Commission's Resources for Freedom or the USGS' Professional Paper 820, Mineral Resources of the United States. Clearly, the main root of resource assessment must lie in the application of metallogeny, economic geology, and mineral exploration to describe the occurrence of yet undiscovered mineral deposits. But, as the number of undiscovered deposits conveys very little about their current or future value to society, another important root of modern assessment is in economic evaluation. The fact that these deposits are undiscovered and must be inferred from indirect geological information makes estimates of their number and of their characteristics uncertain; consequently, another important root of modern assessment is probability theory and methods of estimation.

The study that served to trigger a generation of studies comprising some of the early literature on resource assessment was that by recently recognized Nobel Laureate Maurice Allais (1957), who was asked by the French Government to perform an economic evaluation of exploring the Algerian Sahara. Allais performed the required analysis and reported his results in probability terms, which included a probability distribution for net economic gain. This was a seminal study, for it was the first to apply probability theory to the economic evaluation of exploration and resource potential of a region. Allais used probability theory in three ways, each of which was the topic of considerable subsequent research: 1) a Poisson probability distribution for number of mining districts, 2) a lognormal distribution for district economic value, and 3) a three-stage exploration model.

Major contributions to assessment methods, starting with that of Allais, through the early 1980's are described by Harris (1984) in his book Mineral Resources Appraisal. That reference provides a review of the evolution of concepts and methods, as well as case studies. A more recent consideration of assessment methodology is the proceedings of the Leesburg Conference, under the joint sponsorship of the U.S. and Canadian Geological Surveys (USGS, 1986). A recent (1992) publication by the International Atomic Energy Agency (1993) is a comprehensive description of concepts, methods, and applications for uranium resources assessment and the estimation of uranium potential supply. Much of the discussion in that forthcoming publication is relevant to mineral assessment in general.

STRUCTURE AND SCOPE OF THIS SECTION

This section provides an overview of the evolution of assessment methodology in terms of major relevant concepts and objectives. Since concepts, methods, and case studies through the early 1980's have already been described in considerable detail, they will be described here only as they signal a new methodological development or a shift in perspective or objective. Recent methodological developments are included in this overview of evolution of thought and methods.

An examination of the literature on assessment reveals a wide range of very different methods, ranging from primarily geological to economic and statistical, such as life cycle, exploration process, and crustal abundance models. As the methodologies of interest in this study are those that use geological information in some fashion, this review will be limited accordingly. However, even within the subset of methods that are geological, there is a wide range of methods and approaches. Consequently, it is useful to preface the review of methods with a broad conceptual framework against which the various geological methods can be examined. For, without such a framework, there seems to be little rationality to the great variation in methodology.

A BROAD CONCEPTUAL FRAMEWORK FOR ASSESSMENT METHODOLOGIES

DETERMINISTIC VERSUS STOCHASTIC

DETERMINISM AND SCIENCE

The most fundamental branches of a conceptual framework for assessment methods are two very different philosophies of science regarding the formation, or occurrence, of mineral deposits. The one branch is determinism, which generally depicts the idea that everything, including mineral deposits, is a result of natural law, and that if man knew all of these laws and were provided with complete geological information, all events would be rationalized. Errors in geological analysis to the determinist are merely a reflection of his incomplete understanding of the laws or incomplete geological information about earth processes. As this philosophy is quite conformable with the structure of geoscience and geoscience education, it is naturally appealing to most geologists.

A STOCHASTIC WORLD ?

Contrasting with determinism is the view that mineral deposits are stochastic events. Such a view makes geological information and the geoscience of deposit genesis irrelevant as a basis for prediction (assessment). To most geologists, pure stochasticism is absurd and an affront to field experience and geoscience.

A weaker form of stochasticism obviates the question of natural law by advocating instead that man's knowledge is so limited and based upon so many incorrect premises, that using his knowledge to predict natural events or future states leads to so many errors that he would be better off behaving as though the world were stochastic. John Griffiths' (1966) advocacy of grid drilling is based upon such a view.

Mineral resource assessment based upon a philosophy of a stochastic world would, in its purest form, be made by using nongeological models, concentrating instead on statistical modeling of stochastic processes. For example, if the subject of interest were discoverable deposits, the analyst would strive to model discovery as a stochastic process, geology being considered unimportant.

There are no mineral resource assessments per se that have been made by purely stochastic models, although there are studies that have employed stochastic principles, such as the Engel exploration model (Griffiths 1966). There are, however, some assessments that do not explicitly consider geology and model outcomes directly. Among these are 1) exploration process models which have been used to predict discoveries for specific drilling levels (US Geological Survey, 1980), 2) the statistical models of Barouch and Kaufman (1976) for estimating the size distribution of future discoveries, and 3) the geostatistical models of crustal abundance (Brinck, 1967, 1972; Agterberg and Divi, 1978; Garret, 1978, 1986; Harris et al, 1981; Harris and Chavez, 1984; and Harris, 1984, 1988). Note, however that although crustal abundance models ignore geology and employ statistical concepts, they are conceptually a derivative and special case of process-based geological models, as explained in a subsequent section.

As our interest in this study is in the use of geological information to make assessments, models that do not employ geology directly, are not reviewed here. This does not imply that such models are not useful. In fact, when exploration is well developed within a region and when information on exploration activities and results are available, exploration process models may be very powerful in predicting future discoveries when appropriately constrained. But, they are not useful in unexplored or lightly explored regions or in any region for which good information on exploration is not available.

TWO MAIN APPLICATIONS OF DETERMINISM

PROCESS-BASED ASSESSMENT

Determinism in its purest form leads to process-based assessment, or as referred to by IAEA (1992), assessment by materials balance accounting. This approach requires 1) a fundamental measure of abundance of the element or compound in an initial state, e.g. source, 2) a knowledge of the hierarchy of subsequent processes that lead from source to deposition in mineral deposits and to their preservation, and 3) knowledge of the retention (loss) for each successive process. Suppose that we represent these notions simply in symbolic form: let m_i be the amount of metal present within the region at the completion of the ith process, $\mathbf{x}$ a vector of geological features of the source as it relates to the region of interest, and r_i a coefficient of retention, or equivalently, the fraction of metal present at the termination of the i-1 process that is retained by the ith process.

Then, symbolically,

$$m_0 = f(\mathbf{x}) \,,$$

$$m_i = r_i \,.\, m_{i-1} \,, \quad 1 = 1, 2, \ldots, n$$

And, m_n , the amount of metal at the termination of the last process (amount that currently exists), is defined as the product of initial metal with subsequent coefficients of retention:

$$m_n = r_1 . r_2 \ldots\ldots r_{n-1} f(\mathbf{x})$$

As described above, the concept of process-based assessment is simple and straightforward. However, application of these concepts requires estimation of all terms in the above equation, because none of them are known *a priori*. Naturally, such estimation incurs error, as does assessment by any methodology. Let us represent application by replacing the above terms by their estimates and by adding a combined error term. Accordingly, if a particular retention coefficient, r_i is to be estimated by a geologist, that estimate will be predicated upon geoscience in general and the geological conditions, g_i , within the region that relate to that coefficient:

$$r_i^{est} = h(g_i),$$

$$k(g_0) = \text{estimate of } f(\mathbf{x})$$

And, estimated metal that is now present, m_n^{est} is defined as follows:

$$m_n^{est} = h_1(g_1) \bullet h_2(g_2) \bullet \ldots\ldots \bullet h_{n-1}(g_{n-1}) \bullet k(g_0)$$

Thus,

$$m_n = m_n^{est} + e$$

where e is the combined error due to the use of estimated retention coefficients and source.

The relevant question about process-based assessment is: How large is e? Or, equivalently, how much uncertainty is there about the true value, m_n ? Generally, it is conceded that although process-based thinking is a useful paradigm for the assessor, because of limited information, the errors in estimating the retention coefficients are so large for some of the processes that it is not useful to make assessments by purely process-based analysis. There is some disagreement about the answer to this question, however, as revealed by the comments of Bultman et al (1922).

The only assessments that have been made by this method are those that are referred to as crustal abundance models. As shown by Brinck (1967, 1972), the binomial and lognormal crustal abundance models can be derived from the above relation by imposing the following conditions:

1) $k(g_0)$ or $f(\mathbf{x})$ are replaced by the product of a measure of crustal abundance (proportion comprised by the metal) by the weight of the earth's crust (to some prespecified depth) within the region;

2) replacing each of the n-1 estimated retention coefficients by a single average retention coefficient, referred to as the coefficient of mineralizability;

With these modifications Brinck (1972) derives the binomial crustal abundance model, for which the lognormal crustal abundance model is shown to be a limiting form. To the geologist, these crustal abundance models are uninteresting applications of process-based analysis because the simplifications imposed to derive them suppress geological information, essentially subverting geological analysis to statistical modeling. Consequently, crustal abundance models will not be reviewed in this study. It should be noted, however, that Garret (1986) describes a disaggregated application of a binomial crustal abundance model in which estimated parameters are based upon the grade of the primary ore mineral. Even though such a model is much more specific, geological information other than grade of primary ore mineral is ignored.

Additional commentary on process-based assessment is presented in the section on tonnage and grade distributions; accordingly, the reader is referred to that section. Here, it is noted that except for the highly simplistic crustal abundance form, process-based , or equivalently materials balance, assessments have not been made because of 1) inadequate information, and 2) the great amount of geological analysis that would be required to make such an assessment credible.

As pointed out in the section on tonnage and grade distributions, process-based assessments make for other complications. One of those is that the simplest applications of process-based analysis produce quantity of metal in the aggregate, and this is not useful in economic evaluation unless it is decomposed to a population of deposits which can be subjected to exploration and economic evaluation. Another one is that a credible economic analysis of an endowment population requires that deposit tonnage and grade distributions describe deposits as they occur in nature, or equivalently, the endowment, as contrasted with discoveries. As such information is not available, process-based assessment also requires the difficult estimation of the endowment deposit tonnage and grade distributions. Moreover, for credible economic analysis, ar exploration model would be required to determine which deposits comprising the endowment are discoverable and exploitable for specified economic circumstances.

All methodologies relevant to this study are forms of geological analogy. Accordingly, the following section describes that approach as simply as possible in symbolic form before taking up different ways that analogy can, and has been, employed in resource assessment, and the problems that attend such applications.

ASSESSMENT BY GEOLOGICAL ANALOGY

Assessment by geological analogy bypasses process analysis and materials balance accounting by using the geology and resource descriptors, e.g. density of deposits, of control areas, or equivalently analogue areas, appropriately adjusted for exploration completeness, as a reference for the assessment of an unexplored area. Conceptually, these resource descriptors are a summary substitute for a complete analysis of relevant processes. Clearly, this approach is based upon the premise that regions having similar geology and exploration histories have similar endowment, hence similar resources or discoveries for stated economic circumstances. It should be noted that process-based assessment of two regions having similar geology would also yield similar assessments, everything else being equal. But, apart from that common reference, the two methods differ greatly, not only by philosophy of science but also by the kinds of support each requires and by the ways that each is integrated with economics and probability considerations to support land-use decisions.

Although highly simplistic, a rationalization for using geologic analogy instead of process-based analysis goes like this: The error in assessed measures is far less when made by adjusting resource or endowment descriptors of analogues for geological differences than it is by attempting to use incomplete geological information for materials balance analysis from source to preserved deposits.

Assessment by geological analogy in its purest and simplest form requires the geologist to identify a well explored region that is geologically identical to the region to be assessed. Given geological sameness, the number of deposits would be estimated simply by multiplying some density measure, e.g. number of deposits per spatial unit, by the magnitude of the relevant spatial measure, e.g. area, length, or volume. Letting n_c be deposit density of the control (analogue) area, N_s, the number of deposits in the area to be assessed, is simply the product of n_c with S_s:

$$N_s = n_c \cdot S_s ,$$

where $n_c = N_c/S_c$
N_c = number of deposits in the control area
S_c = Spatial measure for the control area

Thus, $N_s = N_c\,(S_s/S_c)$.

In other words, given the condition that the control and assessment regions have the same geology, the number of deposits in the assessment region is simply the number in the control region scaled for spatial conformity.

In principle, this is straightforward. However, application is confronted immediately by the fact that no two areas (control and assessment) are identical geologically. Therefore, application requires adjustment of n_c, or equivalently N_c/S_c, to reflect these geological differences. In practice, this is much more difficult than it appears, as it requires 1) comparative analysis of the geology of the control area, represented by G_c, with the geology of the assessment area, G_s, 2) the consideration of geological differences with respect to the geoscience of that particular deposit type, and 3) the consideration of spatial dimensions. Conceptually, let us represent this adjustment by a function having as arguments the geology of the two areas, the deposit density of the control area, n_c , spatial measure of the assessment region, S_s, and exploration intensities of the two regions, E_c and E_s:

$$n_s = f(\,G_c, G_s, n_c, S_s, E_c, E_s\,) + e,$$

where e is error in the estimation of n_s

If geoscience were perfect and geological information were complete, e would be zero. Obviously, the greater the geological differences between the control (analogue) and assessment areas, the more difficult the estimation of n_s by adjusting n_c. Clearly, when analogues are inappropriate, e can be very large, making the estimate of n_s inappropriate and not useful.

So far, this description of the method of analogies has used the construct of control or analogue area augmented by comparative geological analysis to describe the elements of the method. This methodology, however, is broader than this depiction. For example, estimation of number of deposits in the assessment area by a multivariate geostatistical equation is basically estimation by geological analogy when parameters of the equation have been estimated from data on geologic variables and number of deposits from one or more control areas. Similarly, estimation of the number of deposits using an expert system which has been calibrated on well explored areas is also assessment by analogy. Finally, the use of exploration experience as a basis for estimating number of deposits is an informal use of analogy. When viewed this way, many seemingly different applied studies are different forms of geological analogy.

MIXED METHODS

The foregoing discussion reveals that process-based and analogy-based methods differ greatly philosophically and in the ways and circumstances of their application. While this classification is useful as a means for examining the collection of methods that have evolved over the years, it should not be considered as a constraint on future methods. Recent methodological developments, e.g. the Arizona Appraisal System --an expert-like system (Harris and Carrigan, 1981) and Intrinsic Sample theory and methods (Harris and Pan, 1991), have combined components of both approaches. Probably, improved methodologies of the future also will employ components of both approaches to an increasing degree.

A HISTORICAL SKETCH OF MAJOR DEVELOPMENT

PERSPECTIVE

The emphasis in this section is on the historical development of thought that is reflected in the methodologies, not on details on the mechanics of the methodologies. Such details can be obtained from the cited literature. As noted above, methodologies of interest here are those that employ geology in some form. Accordingly, comments here are restricted to such methods.

THE STATISTICAL MOVEMENT

An immediate consequence of Allais' (1957) study was interest by mining companies in the use of univariate statistical models of number of deposits and of distributions of value to improve the management of exploration. The comment by Allais (1957, p. 285) that mineral exploration is "par excellence a field to which methods of operations research, economic theory of risk as well as those of the games theory can be applied" was taken seriously. Accordingly, the decade of the 1960's witnessed investigations of formal probability models , e.g. Poisson, negative binomial, exponential, logarithmic, lognormal, as mathematical models of mineral phenomena to support formal analysis and management of regional exploration (Slichter, et al, 1962; Wilmot et al, 1968; Griffiths, 1966a and 1966b).

This period of enchantment with univariate models is a bit strange in view of the strong geologic implications of such models as they were being used at the time. Keying on Allais' work, formal probability models were fitted to various mineral phenomena observed in subdivisions, usually referred to as cells or quadrats, of large regions. The hope of such studies was that once parameters of the appropriate distribution had been estimated, that model could be used to estimate the probability for n deposits in a specific quadrat or in a quadrat of a study region comprised of a number of quadrats. Clearly, such models are useful only to the extent that the region is homogeneous with regard to observable geologic features that relate to mineral occurrence. The larger the region, the less likely that such conditions exist.

As the presence of geological heterogeneities is the prime interest of exploration geologists, interest by geologists in formal univariate, spatial probability models seems curious. Rationalization of this interest "after the fact" is that the 1960's and 1970's was a period of learning about probability and statistics by geologists.

Geologists soon became discontented with univariate probability models because they basically suppressed geological information. Accordingly, it was natural that the next step in statistical learning was to extend probability and statistics to multivariate models which related some measure of mineral resources to quantified geological information (Harris, 1966a, 1966b, 1968; Agterberg and Cabillio, 1969; Sinclair and Woodsworth, 1970; Agterberg, 1971; Singer, 1972 ; DeGeoffroy and Wignall, 1971; Agterberg et al, 1972). Recent years have witnessed additional research on the use of both univariate and multivariate geostatistical models in mineral exploration and resource analysis. Some of these will be commented upon later. Even so, it is important to note that with regard to mineral resource assessment methodologies, the period of the 1960's and early 1970's is marked by an intense investigation of the application of probability and statistical models to various aspects of mineral resources and mineral exploration.

In retrospect, the study by Allais (1957) seems to have stimulated interest in and a desire for the use of probability analysis. That study, as well as others, prompted some geologists to become versed in quantitative methods, some of which are univariate or multivariate probability and statistical methods. Inasmuch as assessment is a form of predictive geoscience, this statistical movement was a necessary stage in the development of assessment skills and methodology.

THE END OF THE ROMANCE WITH STATISTICAL MODELS

It was only natural that after learning to use quantitative models, thereby removing some of their mystique, geologists became more concerned about the information that went into such models and the quality of the estimates that they produced. This concern marked the end of the romance with the casual application of quantitative methods as demonstrations of methods per se. In retrospect, this should have been expected, as it is a natural evolution of learning and scientific inquiry.

Basically, resource and exploration geologists concluded that while those geostatistical models demonstrated at that time had been of initial interest because they were objective and produced quantitative results, the price paid for their use, as measured in terms of geologic credibility, was far too high. They were correct in that judgement, for to satisfy the requirements of standard multivariate statistical models, geology had been quantified by simplistic measures, such as area or percentage of cell (quadrat) occupied by a specific rock type or number of faults and fault intersection within the cell (Harris,1984). No matter how well done the statistical analysis, the model is very simplistic in terms of its geoscience content. Moreover, to make matters worse, some of these demonstrations were commodity or value oriented and not restricted to a single deposit type (Harris, 1966). This fact combined with the fact that all geological measures were of the geology as it relates to the cell, made these models far too simplistic to be of interest to a well informed economic geologist.

EMERGENCE OF THE USE OF SUBJECTIVE PROBABILITY

LIMITED TIME, AN ADDITIONAL MOTIVATION

Excessive simplicity and inflexibility of the geostatistical models demonstrated at that time was sufficient of itself to prompt the examination of alternative methods for assessment. But, the adoption of alternatives was facilitated by a new phenomena, requests for mineral resource information to support societal decision-making and policy evaluation. Except for the deterministic assessments made by the then AEC, the first notable requested assessment was made for the Canadian Government to assist in the determination of the optimum route through British Columbia and Yukon Territory for a new railroad(Freyman et al., 1970). As both of these regions are rich in mineral and forestry resources, the Canadian Government wished to select the route that would contribute most to the economic development of the regions. The time allowed for the description of the resource potentials for the regions was three months. Responding to that request in such a short time required the use of geologic expertise.

Even if desired, the time allowed would not have permitted the quantification of geologic information for the estimation of a multivariate geostatistical model. Moreover, the limitations noted above served to encourage a different approach, especially when high level geological expertise was available: the use of geological expertise and subjective probabilities.

ELICITATION OF SUBJECTIVE PROBABILITIES BY CELL (QUADRAT)

To facilitate this use of expert geologists and at the same time express uncertainty, a format was established for the elicitation of expert judgement as probabilities for number of deposits and for tonnage and grade distributions by cell (Harris et al, 1971). This was a carryover of the use of cells for the quantification of geological information for multivariate geostatistical models.

ASSESSMENT BY AREAS DELINEATED BY GEOLOGISTS

A second study employing subjective probabilities of experts for the assessment of base and precious metals of northern Sonora overlapped the Canadian study, although results were not reported until two years later (Harris, 1973). This study differed from the Canadian study in two important regards, one of which was the use of prospecting zones instead of a grid of cells. This change was made to accommodate the focus of explorationists on combinations of geological features when judging favorability and the desire to provide probability distributions for deposit occurrence for the zone as a geological unit. The second difference was the use of deposit types as opposed to commodities.

In one form or another, the practice of identifying subzones of a region as the areas to be assessed is standard in today's methodologies: the favorable areas of the NURE program for uranium resources(US Department of Energy, 1980), and the permissive areas used by the USGS (Singer et al, 1980). However, the criteria for delineation of prospecting zones, favorable zones, and permissive zones differ considerably, which implies, of course, that the zones themselves also differ.

FAITH IN MAN AS AN INTUITIVE STATISTICIAN

The 1970's witnessed widespread attempts at assessment of mineral resources through the elicitation of probabilities from experts. This was a period marked by great faith in the use of subjective probabilities. Central to this faith was belief in geoscience and geological information as a basis for assessment coupled with the notion that man can function as an impartial observer (sampler) of the real world. Accordingly, ease of recall or conceptualization of an event was considered to be proportional to its relative frequency in the real world.

A second major development during this period of unbridled faith was the widespread use of Delphi groups, of the traditional variety, to provide estimates of uncertain or controversial events. This movement was strongest in technology assessment and forecasting. However, it also was used in mineral resource assessments: 1) a probability distribution of world oil resources at the World Energy Conference by Delphi and 2) probability distributions for number of uranium deposits and for deposit tonnages and grades for selected cells of the state of New Mexico (Ellis et al, 1975).

Delphi, especially the traditional variety, should not be equated to group assessment, even though a Delphi group is obviously a form of group assessment. Proper appreciation of this period of great faith in subjective probabilities requires that assessment by Delphi be considered to consist of iterative assessment, anonymous statistical feedback, and reassessment to a convergence of group judgement. As traditionally applied, Delphi was not structured for scientific discussion or the exchange of information, nor was any consideration given to supporting the assessment of probabilities. There was great faith during this period that when the Delphi group consisted of experts, the simple traditional Delphi format would yield useful results.

Some motivations for using a group of experts are well founded, such as increasing the level of science and information that is considered in assessment and offsetting individual biases. Ways of implementing these are considered in the section on Subjective Probability and Assessment.

THE ENERGY CRISIS--INTENSIVE DEMANDS AND SCRUTINY

The oil embargo and the consequent dramatic increases in oil price focused attention on all energy resources, not just oil and gas. In particular, great attention was given to the future role of nuclear energy and whether or not the U.S. should close the nuclear fuel cycle. At the time, the magnitude of domestic uranium resources seemed to be a paramount consideration in the Breeder decision. Accordingly, the NURE (National Uranium Resource Evaluation) program was established to answer these and other energy questions. The impact of this program was great in that resource assessment, which previously had been of interest to only a few individuals, suddenly became of national interest. Naturally, estimates came under intense scrutiny, and critical questions were raised about assessment methods.

NURE AND POTENTIAL SUPPLY

IMPLICATION OF HIGH PRICES

The questions of national interest with respect to energy resources were cast in terms of economics. In particular, policy makers desired to have estimates of the potential supply of uranium for a wide range of specified prices, prices many times current prices, so that the economic impact of various scenarios could be evaluated. These requirements carry very significant implications for assessment methods and to supportive information. In particular, estimation of potential supply for prices many times higher than traditional prices requires the geologist to estimate number of deposits in the endowment and those characteristics of the deposits that affect cost. This requires the geologist to extrapolate beyond his experience.

Even though the objective in this major section is a "big picture" view of the evolution of thought and assessment methodology, a brief description of the NURE methodology is presented in the following sections. This is purposeful, for many features of the NURE methodology reflect the assessment objective, which was to support the estimation of potential uranium supply. As this objective differs markedly from the support of land-use decisions for current or recent economic circumstances, requirements of NURE and current USGS methodologies also differ greatly. As it is important that these differences be understood, the main features of the NURE methodology are here described to facilitate comparison and contrast. Hopefully, this will clarify why some criticisms drawn from experience with NURE are not appropriate when directed to the USGS methodology as applied to land-use decisions. A detailed review and criticism of the NURE methodology is provided by Harris (1984).

ESTIMATION OF ENDOWMENT

Complications

To support the estimation of potential supply for prices much higher than at the time, the NURE methodology was designed to estimate endowment at an endowment cutoff grade of 0.01% U_3O_8. Purposefully, this endowment cutoff grade was considerably lower than grades of exploration targets, hence reported discoveries, so that the impact of high prices on potential supply could be evaluated.

The density of discoveries and the tonnages and grades of discoveries on well-explored areas underestimate what would be economic and discovered at the very high prices. Consequently, neither simple analogies with control areas nor simple inference from a geologist's exploration experience are sufficient for the estimation of endowment.

Genetic Models and Recognition Criteria

The NURE methodology relied heavily upon 1) the use of genetic models and recognition criteria to identify the deposit types that may occur within a quadrangle, and 2) the use of favorability criteria to delineate favorable areas to delineate areas to be assessed. To support and facilitate the NURE program, DOE identified deposit classes, such as the Wyoming roll-type, and developed what was referred to as recognition criteria for each class. These recognition criteria rationalized the deposit class taxonomy and aided the identification of the kinds of deposits that might be present in a quadrangle (Uranium Resource Assessment Manual, June 1979, p. j-1):

- tectonic setting
- major regional structures
- dominant local structures
- host-rock lithology, texture, mineralogy, age, depositional environment, chemistry, geometry
- associated rocks
- alteration
- uranium and uranium bearing minerals
- related (associated) elements

These deposit classes and their recognition criteria served a role in NURE assessments much like that of the USGS deposit models of Bulletin 1693.

Mineralized Rock Density Methodology

To support endowment estimation, NURE employed what has been referred to as a mineralized rock density methodology (IAEA, 1993). This label refers to the fact that the foundation of the methodology is the estimation of the amount of rock that is mineralized at a concentration above a specified endowment cutoff grade.

The quantity of mineralized rock is the product of projected surface area of favorable ground, A, with F, the fraction of it that is mineralized, and T, the tons of endowed rock per square mile of AF. The quantity of mineralized rock (AFT) is multiplied by an estimate of the average grade (G) of the mineralized part, given the endowment cutoff grade. Finally, this quantity is discounted by the probability that there is at least one deposit of the genetic type within the favorable area to give U, quantity of U_3O_8:

$$U = A \bullet F \bullet T \bullet G \bullet P$$

Control Areas

Extensive use was made of control areas to support the geologists' delineation of favorable areas and his estimates of the factors of the NURE equation. The idea was to compile extensive information on one or more control areas for each deposit type so that the geologist would have a ready reference (Uranium Resources Assessment Manual, 1979, DOE).

Tonnage and Grade Relations

DOE, to aid the geologist, compiled tonnage and grade curves for the inventory of known deposits of each type. It should be noted carefully that these are not at all similar to USGS tonnage and grade distributions, for they describe an aggregate inventory of mineralized rock from all known deposits. The NURE tonnage and grade relations were constructed explicitly to assist the geologist in extrapolating his knowledge to endowment. This has never been the objective of the USGS assessment methodology, and it has not been the motivation for constructing the USGS tonnage and grade distributions.

Inasmuch as DOE had inventories of radiation logs for many of the deposits, each deposit could be depicted in terms of the amount of mineralized rock within specified grade classes. Moreover, an inventory of mineralized rock for all known deposits was described by grade class. From this inventory, a cutoff-average grade curve and a tonnage-cutoff grade curve could be constructed. These were to be used by the geologist as reference for the estimation of the average grade of mineralized rock. Thus, by relating cutoff grade to forward cost, the amount of resources for a specified price, hence cutoff grade, was estimated.

Subjective Probability

The factors F, T, and G were treated as random variables to be estimated by the geologist, with appropriate reference to geologic evidence and data on the control areas. Basically, the most likely (modal) and the 5 and 95 percentile values were elicited from the geologist. Subsequently, these were combined appropriately by a computer program designed to produce a probability distribution for U_3O_8 endowment.

POTENTIAL SUPPLY ESTIMATION

Cost Factors

To complete the analysis of potential supply, cost factors were developed for each deposit type in terms of relevant cost determinants such as thickness of deposit, depth to deposit, and deposit tonnage and grade. These factors, when combined with the tonnage and grade relations, permit the estimation of the amount of uranium for specified forward cost levels.

Probability Distribution for Potential Supply

As each forward cost level was used to infer a cutoff grade, tonnage and average grade were redefined for each forward cost. In turn, these were used to estimate operating and capital costs, and if these were less than the forward cost level (approximately equal to price when deposits are not yet discovered) the quantity of uranium was considered to contribute to potential supply at that forward cost level. Appropriate combination of this economic analysis with probability analysis produced probability distributions for potential supply for each specified level of forward cost.

MAJOR LESSONS TO BE LEARNED FROM THE NURE PROGRAM

The most important lesson to be learned from the NURE program with regard to a historical sketch of assessment concepts and methods is **the great complexity that is introduced when the objective of assessment is the estimation of a potential supply schedule for price (forward cost) levels that are much higher than current and previous experience.** Awareness of these complications and methodological features are important to this study because the assessment objective of the USGS is land-use decisions, which differs greatly from that of potential supply. Accordingly, some of the methodological complications that were necessary for NURE are not necessary for the USGS.

Because the experience of the geologist is not conformable with the assessment requirements, the NURE methodology must rely heavily upon the use of information from control areas and auxiliary relations. Accordingly, 1) control areas were carefully described in terms of their geology, favorable area, and uranium deposits, and 2) cutoff-average grade and cutoff-tonnage relations were developed for the entire inventory of mineralized rock for each deposit type. These were prepared to support the geologist's estimation for a favorable area of the factors of the NURE uranium resource equation.

Providing these supports was a strength of the NURE methodology, particularly because factors required in the NURE resource equation were not easily related to a geologist's experience. This nonconformity of experience with what was required for the NURE equation was, on the other hand, a weakness of the NURE method and undoubtedly detracted from the quality of estimates (see Harris, 1984 for a comprehensive description).

Another important lesson from NURE was that **well designed methodologies can be totally subverted by a geologist who wants to do the geology of the quadrangle but is not willing to, and never intended to, make quantitative estimates of the endowment.** Some USGS geologists spent years doing the geology of quadrangles but were either unprepared or poorly prepared to make quantitative assessments. Particularly problematic was the required estimation of average grade of mineralized rock for a specified cutoff grade. When the geologist had not had any previous experience and had chosen not to prepare himself for the assessment process, his estimates were meaningless.

NURE revealed **the need for geologists to study control areas in considerable depth as preparation for assessment** so that their comparative analysis of control and assessment areas is well done scientifically, as well as statistically.

Finally, NURE revealed **the need for participating geologists to have a basic understanding of probability theory and to have either experience or practice with the assessment methodology** well in advance of the actual assessment.

MODIFIED NURE METHODOLOGY

The (1987) Estimate of the Undiscovered Uranium Endowment in the Solution-Collapse Breccia Pipes in the Grand Canyon Region of Northern Arizona and Adjacent Utah (Finch, Sutphin, Pierson, McCammon, and Wenrich, 1990) is a modified NURE resource assessment using the deposit-size-frequency (DSF) method developed by Finch and McCammon (1987). At the time of the 1980 NURE assessment there was only one high-grade (average grade = 0.43 % U_3O_8), breccia pipe ore body, the Orphan, had been mined. Since that time five new mines, the Hack Nos. 1,2,3, Pigeon, and Kanab North, have gone into production with a least ten more deposits delineated in various stages of exploration. Thus a revision of the NURE mineral assessment was required.

The NURE assessment methodology estimated the uranium endowment (U) as $U = A \circ F \circ T \circ G$ where F is the fraction of area, A, that is favorable for endowment, and T=tons of endowed rock per unit area, and G is the grade. This new methodology replaces factors F and T with a spatial density of deposits established in an analogous control area. Given some level of geologic information on the control area and the previous exploration activity one of three options are selected. The option selected for this study, Option C, requires that the size-frequency distribution of deposits and the relations of the DSF to measurable geologic factors be established in the control area A_c. The resulting endowment equation is:

$$U = A \cdot \left(\sum_{i=1}^{k} \left(\frac{n_{ic}}{A_c} \right) T_i \right) \cdot G \cdot L$$

where

U = unconditional uranium endowment in tons of U_3O_8 above a cutoff grade of 0.01 percent.

A = favorable area in square miles

k = number of deposit classes n_{ic}/A_c= the spatial density(number of deposits / unit area), of deposits of size T_i within control area A_c.

A_c= control area from which estimates of n_{ic}/A_c are taken,

G = grade distribution of endowment, in decimal fraction form, and

L = optional scaling factor that expresses the relation between the endowment in the favorable area and that in either the control area of some designated subarea for which estimates of the number of deposits in different size classes have been made.

The investigator first establishes the number and range of the size classes and then for each size class estimates the lower limit, most likely value and upper limit for the number of deposits in A_c. The favorable area A and grade distribution G is estimated in the study region. Finally, a measure of the endowment of the control area compared to that of the study area is estimated subjectively. These values are input into the TENDOWG computer program that calculates the probability for distribution of undiscovered uranium endowment.

Determination of Favorable Area

The areas assessed in the study were divided into two groups:
1.) the principal group in which the host formations are exposed or are thinly covered
2.) the secondary group in which the host formations are deeply buried beneath a cover of Tertiary rocks.

The favorable areas, ranked A-E, were determined on the basis of the distribution of uranium bearing strata and breccia pipes within the strata and on other geologic factors. The areas were classified as follows:

Favorable area A: most favorable for the endowment of uranium as it contains exposures of the mineralized formations with the occurrence of mineralized pipes.

Favorable area B: contains the full stratigraphic succession favorable to mineralization but is less favorable than A as no known breccia pipes are known.

Favorable area C: has low favorability as those breccia pipes known to exist formed some time after the uraniferous mineralization event and no ore body or other significantly mineralized rock is known to occur in any solution collapse feature in this area.

Favorable area D: a lower favorability than B but still having potential as it lies adjacent to area A. It is expected that the total mineralized body would be smaller than one formed in a full section of strata.

Unfavorable area E: although numerous pipes are present they have been eroded far below the main uranium-ore bearing horizon.

The elicitation for assessment was carried out in two sessions with a team of three experts. Several follow-up discussions were held to review and revise the estimates.

EMERGENCE OF LAND USE DECISIONS AS AN ASSESSMENT OBJECTIVE

An historical event of special relevance to this report was the mandate by the U.S. Congress to the USGS for a mineral resource assessment of Alaska to assist Congress in decisions on land withdrawal. The first reported fruits of the mandated work was a series of open-file reports in 1978, e.g. Grybeck and De Young (1978), Hudson and De Young (1978), Eberlein and Menzie (1978), MacKevett, Singer, and Holloway (1978), and Patton (1978). These were followed by a journal publication by Singer and Ovenshine (1979). These works contain early forms of some of the elements that now comprise what is now referred to as the USGS three-part assessment methodology.

The Alaskan study marked a new era for assessment in that the purpose was not to estimate a potential supply schedule but to assist governmental decision-makers in the decision of whether or not to withdraw lands from mineral exploration and production. Land use decisions are now, and will be in the future, the major source of demand for assessments. However, the tracts of lands at issue are generally much smaller, and the geological information is generally greater and more specific than they were for the Alaskan study. The trend to increased demand for assessments to support land-use decisions and the trend to more specific assessments are expected to continue as societal issues of land-use become more complex.

DEPOSIT MODELS AND TONNAGE AND GRADE DISTRIBUTIONS

IMPORTANT CHANGE IN PHILOSOPHY

The Alaskan study mentioned in the foregoing section is important for another reason, the initiation of an important change in methodology: the use of deposit models and tonnage and grade distributions. Conceptually, deposit models used by the USGS in the Alaskan study are similar in some respects to the deposit classes and recognition criteria developed by DOE to support the NURE assessment program. However, the USGS deposit models are different in some very important respects. One of these is that deposit modeling and the construction of tonnage and grade distributions are intimately related, as described in the section of this report that deals with tonnage and grade distributions.

Perhaps, the most important contribution is the philosophy of assessment that motivated the construction of tonnage and grade distributions:

A geologist cannot make meaningful estimates of number of deposits without consideration of the distribution of tonnages and grades that these numbers determine.

A COMMON REFERENCE--A VERY IMPORTANT METHODOLOGICAL FEATURE

The above philosophy becomes even more important when more than one geologist is participating in the assessment. This is because all geologists should be providing probabilities for number of deposits for the same conception of tonnages and grades. Without a common reference, geologists' estimates may be "noisy" solely because each had a different view of the deposit tonnages and grades: One geologist's estimate may represent large deposits while another's may represent small deposits.

FREEING THE GEOLOGIST FROM PROVIDING PROBABILITIES FOR DEPOSIT TONNAGE AND GRADE

Another important change in methodology that resulted from the formal use of deposit tonnage and grade distributions is the use of these empirical distributions in place of subjective probability distributions for tonnage and grade. All subjective probability assessments prior to the Alaskan had elicited subjective probabilities for deposit tonnage and grade from the geologist. Thus, each geologist had his own subjective distributions of deposit tonnage and grade.

Although deposit tonnage and grade as well as number of deposits are resultants of earth processes, geologists typically feel more capable of inferring number of deposits or deposit density from geological information than they do about inferring deposit average grade and tonnage. Accordingly, to the extent that deposit tonnage and grade distributions can be constructed from hard data, they are preferable to subjective probability distributions estimated by each geologist. Moreover, use of them frees the geologist to concentrate upon that which his science and experience tells him/her should be most useful: Consideration of the geology and its spatial distribution and dimensions to estimate the number of deposits that exist within the area.

DEPOSIT VERSUS INVENTORY TONNAGE AND GRADE DISTRIBUTIONS

Tonnage and grade relations are important elements of both the USGS and the NURE methodologies. However, it is important to note the great differences in these two different kinds of tonnage and grade relations and the ways that they support assessment objective: the USGS distributions of tonnages and grades of discoveries support estimation of number of discoveries and the assessment objective of land-use decisions; the DOE inventory tonnage and grade relations support the estimation of rock density factors for the assessment objective of potential supply, which requires estimates of factors for grades significantly lower than those of known deposits.

Methodologically, it is useful to contrast the USGS deposit tonnage and grade distributions with the inventory tonnage and grade relations used by DOE as support for NURE. Specifically, the NURE methodology was based upon rock density measures, not on the number of deposits. Thus, deposit tonnage and grade distributions would not have provided useful support to NURE without corresponding changes in the NURE resource equation. Conversely, given that number of deposits were to be estimated, the cutoff-average grade and the cutoff-tonnage relations of the aggregate inventory of mineralized rock would not be useful support.

FAITH CHALLENGED--DEFICIENCIES IN MAN'S JUDGEMENT ABOUT UNCERTAIN EVENTS

GENERAL

Although relatively unrecognized during the 1970's by many users of subjective probability in decision analysis, psychometricians had, since the 1960's, been finding evidence that as an intuitive statistician, man exhibits deficiencies. In other words, his judgements and associated probabilities do not conform well with mathematical theory or models. Basically, man (naive subjects) was found in experimental settings to behave as though he knows more (is more certain) than he really does, as his subjective probability distribution is only about one-half as broad as it should be: probabilities for familiar states are overestimated while probabilities for extreme events are underestimated.

In a classic paper, Tversky and Kahneman (1974) identified heuristics that man uses in assessing an uncertain event and showed that in unconstrained experimental settings these heuristics can lead to biases by naive subjects. For example, one heuristic is availability: Man uses the ease of recall from memory of the event as a basis for judging its likelihood, meaning that events that are difficult to remember have low probability for occurrence. If man were an impartial observer, this heuristic would be a useful basis for subjective probability. But, as shown by Tversky and Kahneman, ability to recall an event is strongly influenced by psychological factors and by itself may be a poor basis for subjective probability. A review of the psychometric research during this period is presented in Harris (1984) and in this report, along with more recent research, within the section entitled Subjective Probability and Assessment.

Another blow to casual application of subjective probability was dealt by the comprehensive study of traditional Delphi methods performed by Sachman(1974). Sachman concluded that the evidence adduced in his study clearly indicated that the massive liabilities of Delphi, in principle and in practice, outweigh its highly doubtful assets. Important considerations in his conclusions were 1) the well-documented tendency of individuals to conformity to group norm for purely psychological or social reasons, 2) the fact that seeking consensus or convergence may be counter to scientific inquiry, 3) feedback in traditional Delphi is of estimates only and does not include technical information about the event, 4) difficulties with interacting groups, 5) undue influence of dominant personalities, and 6) only first-round responses are independent and useful in statistical analysis. A discussion of Delphi is also included in the section entitled Subjective Probability and Assessment.

RELEVANCE TO ASSESSMENT

Because of the urgency of some of national energy issues, and particularly those of oil, natural gas, and nuclear energy, the identification by psychometricians of heuristic biases raised considerable concern about DOE's probability distributions for uranium endowment and potential supply, because these were based upon subjective probabilities. Similar concerns were expressed about the probability distributions for petroleum resources and potential supply. A concern of a different, perhaps more important, kind was the possibility for experts to purposefully inflate or discount their best scientific estimates for nonscientific reasons. This purposeful biasing of estimates is referred to as motivational bias or as hedging (Harris, 1981, 1984).

The findings by Sachman (1974) concerning the traditional Delphi process were relevant to assessment during the 1970's. Because of the urgency of mineral and energy issues at the time and because of the uncertainties inherent to assessment of undiscovered deposits, it was natural to involve multiple experts, and in accordance with accepted procedure at the time, some of these experts participated in a traditional Delphi-like setting.

Since most of the psychometric research at that time had been with naive subjects under experimental settings, there were unanswered questions about their relevance to resource assessment. Accordingly, both motivational and cognitive bias were investigated by Harris and Carrigan (1981) using six highly recognized uranium geologists. The basis for evaluation of an expert were estimates made by him when he used his own expert system. In essence, by using his own calibrated expert system, the geologist was forced to use geoinformation and his geoscience exactly the way he described it in his expert system. These estimates were compared with unconstrained subjective probabilities for uranium endowment. This comparison revealed that the unconstrained subjective probability distributions were 1) about one-half as broad as the system distributions, and 2) markedly shifted towards the origin.

If one accepts the assumption that the expert systems accurately depicted the experts' science and its use to make assessments, this study demonstrated that subjective probability distributions of experts obtained by casual, unconstrained, and unsupported elicitation methods 1) possess the same heuristic bias as detected in experimental settings , and 2) exhibit strong motivational bias (hedging).

EXPERT SYSTEMS FOR ASSESSMENT

BEGINNINGS

The experiment described above was part of a larger study performed for DOE in which a prototype expert system was constructed for the assessment of tabular sandstone uranium deposits. Unknowingly at the time this study was contracted with the University of Arizona by DOE (then ERDA), the USGS became a supporter of PROSPECTOR, a rule-based expert system adapted from MYCIN, a medical diagnostic system, by Stanford Research Institute. Both efforts had one thing in common, that was an interest in using computer systems to assist, hopefully to improve, quantitative geological analysis. Apart from that, the two efforts differed greatly in computer system, software, motivations, and results.

THE ARIZONA APPRAISAL SYSTEM (AAS)

One of the motivations for the DOE system, also referred to as the Arizona Appraisal System (AAS) , was cited above, namely the construction of a computerized system that geologists could use to make probabilistic assessments but which could not be abused by the assessor. Moreover, if successful, AAS would demonstrate a means for involving several experts without suffering the liabilities of traditional Delphi groups.

Even prior to the experiment, which documented hedging, DOE had become aware of, and concerned about, the behavior of some geologists who subvert the assessment methodology, particularly those methods and formats that were precursors to the NURE equation. Basically, some geologists would determine what they thought the endowment is and then manipulate the factors of the equation to produce the desired result.

As preparation for the NURE assessment, DOE was examining a number of ways of preserving integrity of assessment methodology, as well as ways of improving numerical estimates. One of those was the construction of a computerized system that could not be gamed and at the same time would be used by all geologists, thereby promoting consistency as well as preventing hedging. Of course, such a system would be no better than the geology-endowment relations that it incorporated. At the time that this research was initiated, there was considerable disagreement among expert geologists whether such a system could be designed and about the credibility of its estimates.

Research and development of the AAS produced a number of interesting results. A few of them are summarized below:

1) An expert-like system can be designed that captures the major logic structure used by the geologist in probabilistic assessment;

2) Although economic geologists identify many geological features as being typical of a particular deposit type, only a relatively small subset of those is actually used in assessment;

3) Experience with assessment is very important: That geologist (of the set of six experts) for which conformity was greatest between system and subjective probability estimates was the geologist with the greatest assessment experience, having also acquired extensive field knowledge about uranium deposits.

4) Contrary to some claims during the 1970's, unconstrained subjective estimates of expert geologists understate mineral resources;

5) Designing, constructing, and calibrating expert-like systems requires great commitment and financial resources.

PROSPECTOR MODELS

When compared to AAS, PROSPECTOR was elegant and sophisticated, as it employed hardware and software especially designed for the computerizing of rule-based expert knowledge . This system facilitated the design of complex rule-based logic structure; however, part of this facility was due to the simplification of structure made possible by the assumption of conditional independence and the use of odds and likelihood ratios as a means for extracting expert judgement. Although PROSPECTOR models (porphyry copper, nickel sulfide, Duda et al, 1978) were by comparison with AAS very complex and scientifically elegant, they were ,as designed, useless for producing a probability distribution for number of undiscovered mineral deposits within a region. Neither the PROSPECTOR system nor the expert models that were developed were designed to produce a probability distribution for number of undiscovered deposits of a region.

That the PROSPECTOR models were not useful in making assessments was, perhaps, a predictable result when expert geologists who are not assessors themselves work together with knowledge engineers who are supported by sophisticated hardware and software and whose objective is promoting the expert system and knowledge engineering technology and service. In part, this is just a different version of a familiar theme: Expert economic geologists are more interested in the science of ore deposits than in producing quantitative estimates of undiscovered deposits. This same phenomenon is well developed in a recent manuscript by Drew and Menzie (1992), who contrasts the "local" focus of the typical economic geologist on the intensive analysis of the deposit with the "global" perception that is required of the assessor to identify relevant deposit types, delineate permissive areas, and to estimate number of undiscovered deposits.

Cooperative efforts of knowledge engineers with economic geologists would naturally gravitate to the intricacies of ore deposit science and the engineering of it to a knowledge structure, instead of the objective of resource assessment. This will always be the case unless the assessment objective is the window through which expert systems are designed.

SEDUCTION BY KNOWLEDGE ENGINEERING

The notion of powerful computer systems combined with the mystique of knowledge engineering and artificial intelligence is seductive. Moreover, such seduction is likely when there are impressive case studies that demonstrate the power of such systems for technically difficult but well understood problems.

The author witnessed this seduction in a recent effort of the World Bank, to which he was a consultant, to construct an expert system for petroleum resource assessment. Even when knowledge engineers were prewarned that the spatial dimensions of geology must be present and that adequate representation of such in the system would be the most difficult task for expert geologists as well as knowledge engineers, they did not appreciate the difficulties until they attempted to adjust the first versions of the knowledge system to accommodate spatial considerations. Then, they did indeed find this to be their most difficult problem. In part, this was because the project was initially approached as a typical knowledge engineering problem, paying little attention to the assessment objective until after capturing the major architecture of geological knowledge. Such an approach will never produce the desired results.

THE GOAL OF KNOWLEDGE ENGINEERING IS INADEQUATE AS A BASIS FOR ASSESSMENT SYSTEMS

The goal stated by knowledge engineers is simply to construct a knowledge system that performs as well as the expert who is the reference for expert knowledge. Given the predictive nature of assessment, such a goal is very anemic and not worthy of pursuit at the level of funding required to create useful expert systems. Granted, the knowledge base can never be greater than that of the expert, but the geoscience knowledge of the expert is not a sufficient basis for the evaluation of the potential of expert systems for assessment.

Future expert systems should be motivated by, designed for, and evaluated by the assessments that they produce. When viewed this way, expert systems have a great potential for assessment, but the emphasis on the design of such systems must be drastically altered.

POTENTIAL OF EXPERT AND AI SYSTEMS EXPLICITLY DESIGNED FOR ASSESSMENT

The great potential for expert systems will be realized only when such systems are designed explicitly for assessment. Accordingly, besides expert knowledge, future systems must be replete with rich geological information banks, including those for well known analogue areas, and appropriate statistical methods to assist the geologist in evaluating geological information from the assessment area. Such systems would be of particular importance in assisting the geologist in areas for which information is meager, for they would have the capability of drawing upon their rich data bases and providing *a priori* statistical information about the states of missing information. Such a capability would be of great assistance to the geologist in his evaluation of the geology of the assessment area, and it would enrich his probabilistic statements about geological states.

The potential for such systems is very great when they are coupled not only with rich statistical data but also with GIS's replete with image analysis techniques to facilitate consideration of spatial relations on analogue and assessment areas. Note carefully that these systems have great potential not so much for their expert knowledge (geoscience) but for their capability of combining expert knowledge with data and information and with interpretation and inference methods. Systems so designed could indeed outperform experts in assessment, not because of greater expert knowledge, but because of the much greater capability of the system to store, access, review, statistically process, and combine evidence with experience (information) and with expert knowledge. When so designed, expert systems have an assessment potential that exceeds any expert. So far, no designed expert system has come close to fulfilling this potential; however, that was the intent of the World Bank effort, but this was terminated after the first year of development as world oil and gas prices declined from their previous highs.

SUBJECTIVE PROBABILITY REVISITED

The decade of the 1980's witnessed intensive research by experts in psychometrics and decision science on the use of subjective probabilities. As this research is described quite thoroughly in the section on subjective probability, only a few summary remarks are presented here.

The research during this period followed two main paths. The first sought to develop ways of improving man's performance as measured by formal probability theory and models. Central to that research is the assumption that the judgement of experts is basically sound and that observed deficiencies in subjective probability are due to improper or inadequate elicitation methods. While some of the research of the 60's and 70's challenged the use of subjective probabilities in decision analysis, subsequent research has softened some of the earlier criticisms, restoring the perception that subjective probabilities of experts can be useful in decision analysis.

Important factors in the softening of criticisms include 1) the unequivocal demonstration that weather forecasters are very well calibrated, meaning that their estimates are well matched with actual events, and 2) the finding that the conservatism previously demonstrated by psychometricians is not ubiquitous, and that it is strongly influenced by elicitation and encoding methodologies, 3) the finding that subjective probabilities by experts for events within their knowledge domain do not exhibit deficiencies to the same degree as do those of naive subjects.

The second path assumes that judgement itself is vague and abandons formal probability theory as the appropriate standard for comparison, choosing instead to consider subjective probability to be simply a statement of degree of belief, unique to the expert, in a proposition. Important developments of the second path include fuzzy probability theory (Zadeh, 1965), Dempster-Shafer theory (Dempster, 1967, 1968; Shafer, 1975, 1976), and the notion of belief functions (Shafer, 1973, 1975, 1976 ; Walley, 1987). While these methods are appealing because they provide great flexibility in expressing uncertainty , no one has demonstrated that they are easier (Lehmann, 1990) or produce more desirable results. On the other hand, for well defined problems, they must, because of the premises underlying their construction, provide a weaker result than do classical probability models. Moreover, the probabilists argue that the need for these "fuzzy" methods could be considerably reduced by proper conditioning of the problem.

THE POST-1980 PERIOD

GENERAL

Developments during this period and to the present reflect a number of different influences. One is that the national concern about mineral and energy resources and the associated funding of assessment research as well as programs evaporated very quickly as concerns about resource scarcity were replaced with the perception that energy is abundant and inexpensive. Concomitant with the decreased interest in national resource adequacy issues was the increase in requests for assessments to support land-use decisions.

Assessments required to support land-use for current or recent prices differ greatly from those that are designed to support the estimation of potential supply for prices considerably higher than current or recent prices. Moreover, the focus of societal interest on specific land tracts required assessments to be more specific as to both geological and economic factors. Thus, change in assessment objectives brought significant changes in assessment programs and methodology.

USGS DEPOSIT MODELS

The publication of the USGS Bulletin 1693 was, without question, a very important event during this period. Assessment by geological analysis requires the geologist to identify the geological environments of the region and the deposit types to which these environments are permissive. This requires some kind of formalization of geological knowledge and information, as well as a procedure to assure some degree of uniformity among geologists. Deposit models are a means to meeting these requirements.

The importance of deposit models extends beyond the formalization of geological knowledge and information to assist the geologist in delineating permissive areas. Some kind of taxonomy of known deposits is required to construct tonnage and grade distributions, which are very important elements of assessment. They aid the geologist in estimating number of deposits, are a basis for cost estimation (as demonstrated by the USBOM, see below), and describe the amount of metal that is subjected to economic analysis. See the section of tonnage and grade distributions for additional discussion.

There are many who take issue with the contents of Bulletin 1693, either with the taxonomy itself or with the identification of specific deposits by type, and advocate that it be redone drawing upon a wider base of geological expertise. Even so, there is a general acknowledgement that 1693 has been a very valuable contribution. At the very least, it has stimulated interest and scientific discussion, both of which should improve future deposit models. Moreover, there is no question about the need for 1693 or an improved version in an assessment program.

COST MODELS AND ECONOMIC ANALYSIS FOR LAND-USE DECISIONS

One very important event during this period was the cooperative effort of the USGS and the USBOM to develop programs and methodologies to support land-use decisions. The usefulness of cooperative efforts was vividly demonstrated on selected lands (Gunther, Arizona Conference) by a description of mineral use of the subject land in comprehensive economic terms. These included not only the probability distribution for value of economically producible deposits but also selected impact measures, such as numbers of jobs expected from mineral development and exploitation. Such analyses required the USBOM to develop simplified cost models (simplified as compared to those of the CES of MAS) by deposit type for the region of interest and the computer software to simulate not only deposit occurrence, as in MARK3, but also the economic decisions to develop and exploit, based upon discounted cash flow analysis. Moreover, output from this analysis was subjected to traditional economic impact analysis through the use of the economist's tool known as input-output analysis.

These developments are important in that they demonstrate the very useful information that can be generated by the combination of geological analysis of mineral potential with cost estimation and comprehensive economic analysis. Moreover, they established a new and very useful USBOM product: simplified cost models for specific deposit types. Such models have been desired for many years by those who are engaged in resource assessment or in the long term planning and management of mineral exploration.

NEW OBJECTIVE METHODS AND ASSESSMENT METHODOLOGIES

The period from 1980 through 1992 witnessed developments of interesting quantitative methods and methodologies. To some degree these developments were motivated by 1) problems found with using expert systems as a basis for assessment, and 2) the desire to predicate assessment on methods that are to some degree more objective. Among these, there are three developments that are especially relevant, either because of the philosophy that they represent or the technical features of their applications: 1) Weights of Evidence-GIS (WEGIS) methods, 2) Intrinsic Sample Theory and Methods (IS), and 3) explicit consideration of multivariate spatial variation. The last of these is not as much a methodology as it is a feature of geology and resources that has been neglected in previous geostatistical methods. At present, it is an important topic of research. This section primarily considers the first two developments. These are of interest in their own right as recent methodologies; however, they also are useful as references for contrasting and conceptualizing important issues and considerations in future methodologies.

The motivations for these two methods differed considerably; however, after the fact, both of them can be seen as alternative methods for delineation of favorable areas, a task that is common to both exploration and resource assessment. Weights of evidence (WE) methods were used by Agterberg et al (1990) for statistical pattern integration for mineral exploration. Intrinsic sample theory was developed expressly for mineral resource assessment; however, a feature of that methodology is the objective delineation of intrinsic samples, which are areas having geology that is consistent with the genetic model for a specific deposit type. To the extent that both methodologies delineate subareas of a larger region, they have some common ground. But, the philosophies underlying the two methodologies contrast markedly, as also do some of their technical features.

WEIGHTS OF EVIDENCE-GIS METHODS (WEGIS)

Elements

This methodology is usually referred to simply as weights of evidence or as pattern integration. Here, it is purposefully combined with geographic information systems (GIS), because its great appeal to explorationists is due in part to 1) its use to combine geostatistically and objectively multiple GIS layers of geoinformation, e.g. outcrop lithologies, geophysics, geochemistry, etc., and 2) the capability of displaying images of the integrated data for the delineation of exploration targets. Representation of various geodata using a GIS system invites the use of image processing software for image enhancements of various kinds in combination with weights of evidence analysis. Together, these methodologies are very appealing to exploration geologists.

Weights of evidence methods (Agterberg et al, 1990; Bonham-Carter et al, 1988) are a natural extension of previous work of the Canadian Geological Survey in the development of 1) automated data bases for geological and resource information, e.g. SIMSAG (Chung, 1983) and GIAPP (Fabbri, 1985), 2) applications of data processing methods (Bonham-Carter et al, 1985) and image processing (Agterberg and Fabbri, 1978; Fabbri, 1985; Fabbri and Kasvand, 1988), and 3) applications of multivariate statistical analysis to exploration and resource assessment (Agterberg and Cabilio, 1969; Agterberg et al, 1972; Agterberg, 1981; Chung and Agterberg, 1980; Bonham-Carter and Agterberg, 1989).

Appealing Features

When considered strictly as a geostatistical methodology for exploration or resource assessment, WE presents the geologist with some advantages over other more traditional multivariate geostatistical methods, e.g. multiple regression or multiple discriminant models:

1) It does not require uniformity of information, meaning that it can be used when a specific kind of geodata is available for part of the area but not for the remainder; When a feature is unknown in parts of the area, no weight is added or subtracted for the unit cell.

2) As adapted and demonstrated by Agterberg et al (1988), it provides a means for evaluating uncertainty due to one or more missing patterns (types of geodata).

3) Given the basic assumption of the method of conditional independence, weights of evidence for each GIS layer can be independently calculated, given co-registration of each evidence (pattern) layer with the deposit occurrence layer.

Everything else being equal, these features are highly desirable, and a coordinated system of GIS, image processing, and weights of evidence presents the exploration geologist with an impressive processing and computational flexibility and capability.

A relevant question is, of course: What does "everything else being equal" mean? While a comprehensive answer to that question is complicated, part of that answer must be that it depends upon analytical objective and the nature of the geological information. An important consideration in answering the above question is the basic assumption implicit to weights of evidence: conditional independence.

The Conditional Independence Assumption

Careful scrutiny of WE relations and methodology reveals a variation on an old, familiar theme: Bayesian probability, given conditional independence. Although Bayes formula is general and does not require conditional independence, many methodologies that involve combinations of variables, e.g. geological conditions, have involved the simplification of conditional independence (Chung and Moon (1990, p. 11): "Most of the combination rules using Bayesian probability formulae (Grosof, 1986; Duda et al, 1976; Spiegelhalter, 1985, among others) in Artificial Intelligence applications such as PROSPECTOR (McCammon, 1990) and Weights Evidence Modelling (Spiegelhalter, 1986) are based on the conditional independence assumption".

The requirement of conditional independence can be illustrated very simply with a binary variable, D, for presence of 0 or at least 1 deposit and two geological variables G_1 and G_2. Simply stated the assumption of conditional independence means that the probability for the joint occurrence of G_1 and G_2, given D is the product of the conditional marginal probabilities:

$$P\{G_1,G_2|D\} = P\{G_1|D\}\ P\{G_2|D\}$$

Accordingly, the posterior probability by Bayes theorem for D, given G_1 and G_2 is:

$$P\{D|G_1, G_2\} = [\ P\{D\}/\ P\{G_1,G_2\}]\quad P\{G_1|D\}P\{G_2|D\}$$

Alternatively,

$$P\{D|G_1, G_2\} = [(\ P\{G_1\}\ P\{G_2\})/(P\{G_1,G_2\}P(D))]\ [P\{D|G_1\}P\{D|G_2\}]$$

Agterberg et al (1988) demonstrated the WEGIS methodology on the Meguma Terrane, eastern mainland Nova Scotia. Various data were quantified for 1 km^2 cells. Patterns that were integrated by weights of evidence included drainage basins classified by lake sediment geochemistry, bedrock geology, proximity to axial traces of Acadian anticlines, proximity to northwest trending lineaments, proximity to Devonian granite, and proximity to the Goldenville and Halifax Formation contact, and gold occurrences. Basically, Bayes equation was employed with weights of evidence to estimate a probability for the occurrence of one or more gold deposits within each cell, given the geological patterns. The final product was a new GIS layer of these probabilities.

An obviously relevant question is: How reasonable is the conditional independence assumption? Agterberg et al (1990) concluded that for the application and demonstration on the Meguma Terrane, the assumption was quite well satisfied. As a general proposition, however, such independence is difficult for a geologist to accept. Clearly, some geological states seem to be highly dependent. Can these opposing views be rationalized?

The answer to the above question is perhaps, in part. First of all, it is conditional independence that is at issue, not independence of geological variables in general. Accordingly, the perception that two geological features are correlated generally does not of itself rule out the possibility that where deposits occur the two conditions are independent. Second, the strength of this assumption depends somewhat upon the quantification of geological information. For example, if geological features that are inherently continuous are discretized to binary variables, the discretization itself may make conditional independence "after the fact" acceptable because important information about dependency has been blunted by the discretizing process. Accordingly, the assumption of conditional independence may "after the fact" appear to be satisfied when the endowment measure is binary (e.g. 0 deposits or at least 1 deposit) and all geological variables are binary.

The unit of reference, e.g. a cell, is also important in determining the acceptability of the conditional independence assumption, especially since the unit of reference interacts with the form of the endowment descriptor and the quantification schemes. For cells so small that at most only one deposit can occur within them, a binary resource descriptor is acceptable. When such a cell size is used along with a binary resource descriptor, the assumption of conditional independence may be acceptable, where as it may not be for larger areas of differing sizes having a cardinal number resource descriptor.

When the resource descriptor and geological variables are continuous, or discrete having several levels, conditional independence is much less likely to be satisfied. Say for example, the resource descriptor is the number of deposits, the unit of observations are generally quite large and of unequal size and shape, and all geological variables are either described by magnitude or intensity. The assumption of conditional independence in this case may be questionable, because scale and dimension, as well as intensities, have become important features of both the resource descriptor and the explanatory variables.

To focus on whether or not the quantified geological variables and the resource descriptor satisfy the conditional independence assumption may be important to rationalize a particular application of WEGIS, but it begs the more important questions: Is this methodology and the associated information strategy optimum for the assessment or exploration objective? And, how well does the methodology capture jointness and spatial relations? The second development, Intrinsic Sample theory and methods, which is briefly described below, is useful in considering the first of these questions. With regard to the second question, Chung and Moon (1990) used an artificial example to compare multivariate regression analysis, Bayesian probability given conditional dependency, and Dempster-Shafer methods. They concluded that all of the methods were deficient because they do not consider the spatial distribution of deposits. Generalization of this criticism would imply that WEGIS, at least as it has been applied so far, has not adequately considered spatial variation. As indicated above spatial variation is the third major movement of this period. Some brief discussion on that subject is presented later in this section.

INTRINSIC SAMPLE THEORY AND METHODS

Background

Intrinsic Sample (IS) theory and methods grew out of research to improve the usefulness of multivariate geostatistical models for quantitative assessment(Harris and Pan, 1990, 1991).

As indicated earlier in this section, even though early demonstrations of quantitative assessment employed univariate and multivariate statistical models, the use of such models to make assessments was later rejected by geologists because of the crude and highly simplistic geological information that they employed. In spite of the fact that multivariate geostatistical models are quantitative and objective and, at least in concept, have the capability of including many variables, geologists turned to the quantification of expert judgement through subjective probabilities. Among the reasons for this was the crudity and simplicity of geological information used in the alternative geostatistical models. Accordingly, the primary motivation for IS theory and methods was to increase the level of geoscience in multivariate geostatistical assessment models. Since the IS research was performed under contract with the USGS and since the USGS has a full report of research results, only a brief, generalized description is here presented.

The Use of Cells Inhibits Geoscience Information

Harris (1986) advocated that one necessary modification for the improvement of multivariate geostatistical assessment (MGS) models was to replace the arbitrary cell, or quadrat, with a natural, or intrinsic, unit of reference, referred to as the intrinsic sample. The rationalization for this change was that the previous cell-based models basically employed variables that described the geology of the cell. And, as the cell is an arbitrary unit, use of the cell to quantify geology serves *a priori* to limit severely the geoscience information that can be expressed in multivariate geostatistical models. In broad terms, the solution to this problem is clear: Replace the quadrat (cell) with an appropriate geologically-based unit of reference. The unit advocated by Harris and Pan (1990) is the Intrinsic Sample.

Intrinsic Sample Concept

Conceptually, an Intrinsic Sample (IS) is considered to consist of genetically related geological objects. Since the IS is explicitly defined as an element of an assessment methodology, the geologic objects that comprise it are either involved in or a product of the earth processes that create the deposit type of interest.

Although conceptually straight forward, an IS-based methodology is at once considerably complicated, when compared to cell-based methodologies. This complication arises from the necessity of delineating the IS's. As these are not known *a priori*, an IS-based assessment methodology must first deal with their delineation. As it turns out, this is a major task.

Delineation of IS's--An Inverse Problem

As is so often the case in geology, we must deal with the inverse problem, which in this case is the use of geoscience and geodata to delineate those spatial locations at which genetically related geological objects are present. This inverse problem is not unlike that currently dealt with by USGS geologists in the delineation of permissive areas. Accordingly, some of the same scientific principles used by USGS assessors are relevant.

Subjectively delineated intrinsic samples are, however, questionable as a foundation for an objective methodology. To serve as units of observation for the construction of multivariate geostatistical models, intrinsic samples must be consistent statistically. One way of satisfying this requirement is to delineate IS's by objective, instead of subjective methods.

While conceptually similar, delineated permissive areas and intrinsic samples may differ considerably: The IS's are more like favorable areas or exploration target areas than permissive areas. For example, as demonstrated on the Walker Lake quadrangle, the IS's are much smaller and more numerous than the permissive areas drawn by USGS geologists. Mainly, this reflects the broader, less discriminating criteria of permissivity, as compared to IS requirements.

Use of Genetic Models

A very important element of the IS methodology is the genetic model for the deposit type of interest. This model serves three basic functions:

1) Identification of one or more critical genetic factors;

2) Identification of useful recognition criteria, meaning observable geologic features that document the genetic processes or factors;

3) Identification of those diverse geodata that carry important information about the recognition criteria and are useful in the delineation of IS's.

Synthesis of Information

Another very important element of the IS methodology is the concept of information synthesis and methods for its implementation. Information synthesis refers to the combining of diverse geodata to form new measures that are enriched in the geoscience information that relates to the objective of analysis. For the delineation of IS's, the essence of information synthesis is to process basic geodata to enhance that information about recognition criteria and to combine enhanced geodata to new measures, referred to as synthesized variables, that reflect the jointness and spatial variation of geoinformation and that are optimally related to the recognition criteria. This requires processing, transformation, filtering, and optimum weighting of diverse geodata.

Control Area--A Requirement

As indicated above, the genetic model is the foundation for the IS methodology, for it guides the identification of the recognition criteria. But, equally important is a control area, a well-explored area in which deposits of the type of interest are known to occur. The control is used to estimate those weights that optimally combine the processed and enhanced geodata to synthesized variables. Moreover, the control area is used to estimate the parameters of multivariate logit models, one for each of the recognition criteria. When estimated on the control area, these models are then used to estimate probabilities for the recognition criteria at each location within the assessment area, resulting in probability maps for recognition criteria.

The control area is used again to estimate the parameters of one or more multivariate logit models that relate probabilities for recognition criteria to probability for genetic factor. Finally, the control area is used to identify the optimum cut of the probability fields for the genetic factors, optimum in the sense that the probability anomalies created by the optimum cut have maximum conformity with known occurrences within the control area. These cut values are used to cut the probability fields on the assessment area, thereby creating probability anomalies for genetic factors. Resolution of these multiple anomalies , e.g. union, intersection, etc. delineates the intrinsic samples within the assessment area.

Walker Lake Demonstration

There has been only one demonstration of the IS methodology, that was by Harris and Pan (1991) on the Walker Lake quadrangle of Nevada and California. In that simplified example, only one critical genetic factor, heat source, was employed; consequently, the intrinsic samples of that study were delineated simply by the optimum cutting of probabilities for heat source. Figure 3.1 is a highly simplified schematic diagram of that analysis, and Figure 3.2 shows the intrinsic samples. These figures do not reveal the extensive analysis of geochemical, geological, structural, and geophysical data that was performed to create the synthesized variables that were employed to delineate the intrinsic samples.

Figure 3.1

SCHEMATIC DIAGRAM OF CONCEPTS

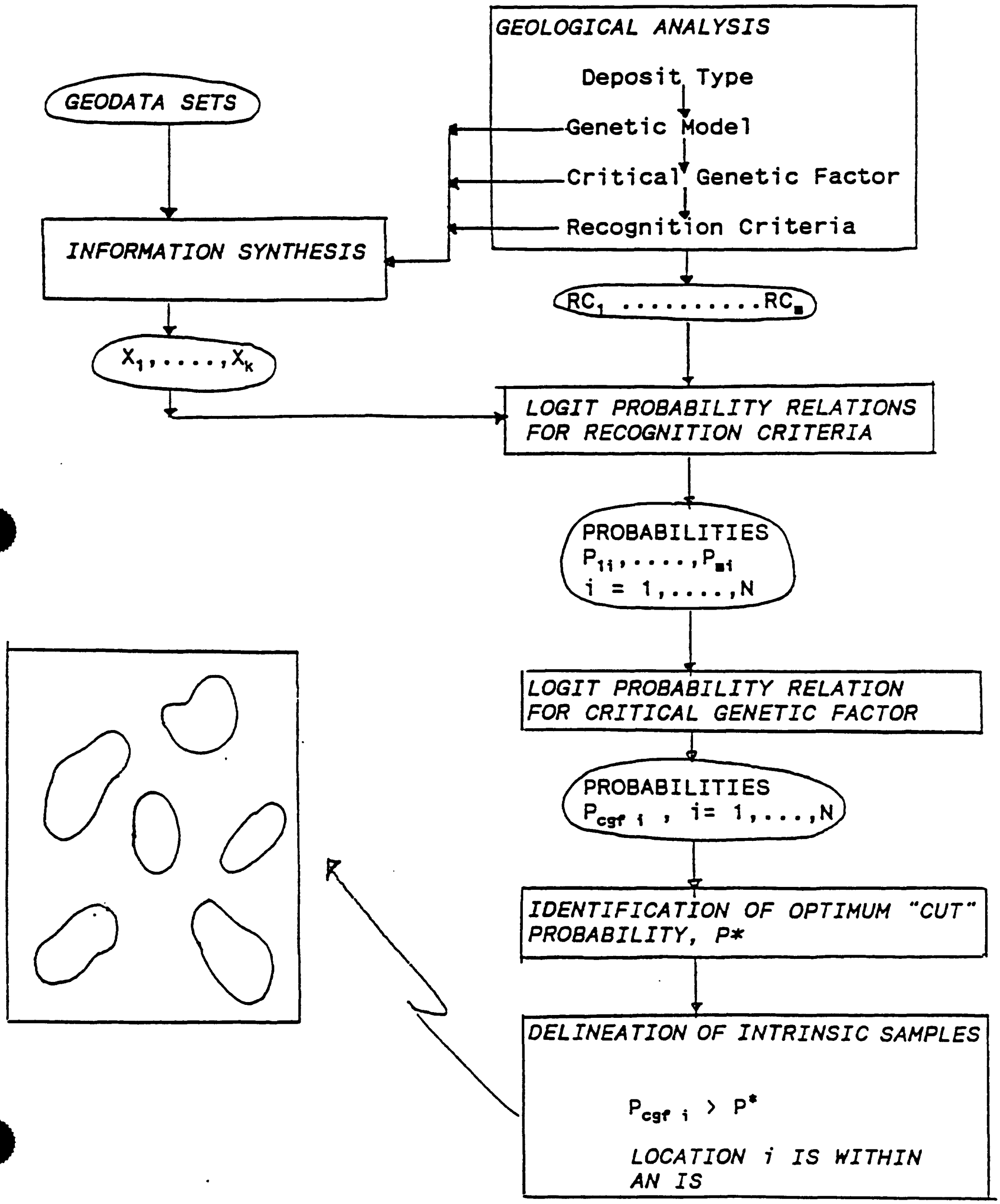
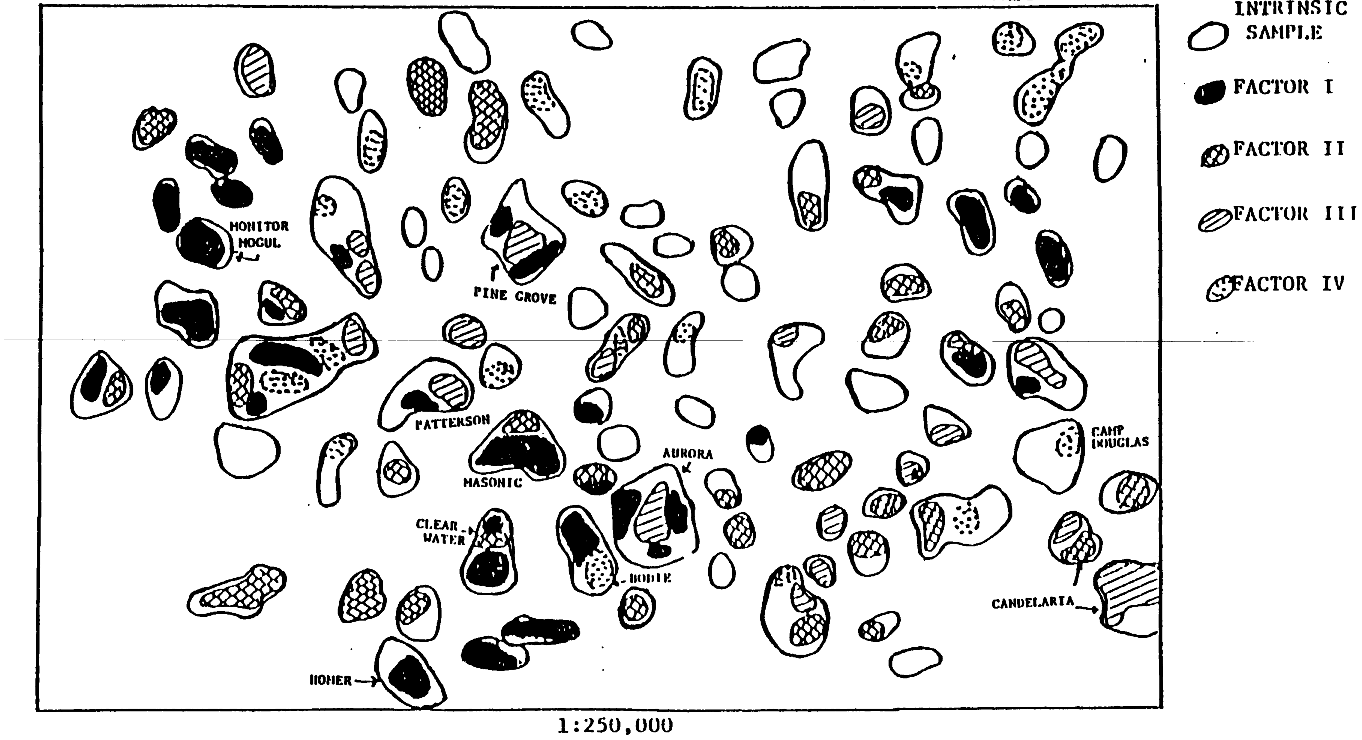


Figure 3.2

INTRINSIC SAMPLES (BY LOGIT) AND "EXCEPTIONALNESS" ZONES



Intrinsic Samples as a Support for the Estimation of Number of Districts (Geologic Deposits?)

Some deposit types, e.g. epithermal veins, present difficulties for an assessment methodology that requires estimates of number of deposits. Difficulties arise over the definition of deposit and the availability of tonnage and grade data. The first issue is the definition of deposit: Is it individual veins, orebodies, the collection of veins that comprise a mine, the mining district, or some measure of rock that has been mineralized by heat-dependent epithermal processes? Although this is an important geological question, the decision usually has been made by the availability of data primarily by district. Accordingly, geologists use the district tonnage and grade distributions to estimate number of deposits (districts).

For these kinds of deposits, the IS methodology could be used to support assessment of number. Suppose, for example, that the Walker Lake demonstration had considered all major genetic factors, instead of just heat source, in the delineation of intrinsic samples. The intrinsic samples delineated by such an analysis would constitute an objective estimation of number of district-size deposits. Some of the these would include known mining districts, but others would constitute unknown deposits that are estimated to exist but have not yet been discovered. At the very least, the geologist could consider this number along with other non-quantified, less tangible, but important geological factors as he provides his probabilities for number of deposits.

As indicated above, the number of IS's delineated in the Walker Lake case study does not constitute an estimate of number of deposits, because they were delineated using only one genetic factor, heat source. Accordingly, it would be useful research on methodology to redo that case study to include additional major genetic factors, thereby generating an estimate of number of undiscovered district-like deposits. This analysis could be compared (contrasted) with the USGS three-part assessment of the same quadrangle.

SPATIAL VARIATION

Most multivariate geostatistical assessment models have not given explicit consideration to spatial variation in the prediction of a resource descriptor. Unless specifically manipulated, these models, as designed, are driven by the co-variation between variables. This contrasts with methods in ore reserve estimation in which spatial variation has been the primary consideration, i.e. variograms of grade.

As indicated above, one of the developments of the post-1980 period is the formal examination of spatial and multivariate variation. One such study is that of Grunsky and Agterberg (1988), who employed spatial factor analysis to study geochemical data for various elements of the Ben Nevis area of Ontario, based upon two-dimensional parabolic auto-and cross-correlation functions on overlapping neighborhoods. In essence, spatial factors utilized spatial relationships of variables as well as the systematic variation of variables that represent geological processes.

To some degree, spatial variation of information is at the heart of the IS methodology. The very delineation of IS's is a resolution of spatial patterns. However, the treatment of spatial variation in the IS methodology as demonstrated on Walker Lake quadrangle is implicit and informal. An interesting extension of IS methodology would be the explicit consideration of multivariate spatial variation for the delineation of IS's. In concept, this seems to call for a wedding in some fashion of the features of regionalized variables with those of multivariate statistical models within the framework of Intrinsic Sample theory and concepts.

There is even a more fundamental step in the Intrinsic Sample methodology in which a more formal and explicit consideration of spatial variation could improve the methodology, that is in the multivariate regionalization of the basic geodata that are subjected to information enhancement and information synthesis. In the Walker Lake quadrangle case study, a pragmatic approach to regionalization was taken so as to facilitate the development and demonstration of the major features of the methodology. Each data set was separately interpolated to a common grid using an inverse distance interpolation scheme. However, as such interpolation ignores the dependency among the data sets, it can not, in general, be optimum. It was rationalized in the case study by the fact that map patterns of interpolated data compared well with map patterns of the original data. As a general methodology, however, the analysis described in the case study should be prefaced with a formal multivariate regionalization, meaning that gridded values would represent multivariate interpolation. This might be achieved by combining the methods of regionalized variables with those of multivariate analysis, perhaps along the lines demonstrated in petroleum resource analysis by Harf and Davis (1990) and Harf, Davis, and Olea (1992).

RECENT BORA INITIATIVES

The Assessment Experiment

There are those who advocate that geologists either should not or cannot assess mineral resources. Of course those who believe that assessment is not acceptable geologically are quick to identify and emphasize problematic assessments or weaknesses in methodology. Moreover, as indicated in an earlier section, there has been, and still is, concern about subjective probabilities. Since assessments, e.g number of deposits, are judgement-based as well as probabilistic, they are subject to criticism both within and outside of the USGS. Consequently, the initiative by BORA to design an experiment that examines the capability of geologists to assess was most appropriate, as well as timely. Generally, the experiment appears to be well designed and executed, and the results are generally positive. (Arizona Conference, 1992).

The experiment has not, however, satisfied all critics. One criticism of it is that porphyry copper is a set up because no other deposit type has such a strong geological signature (Bultman et al, 1992). There may be deposit types for which assessment is more difficult; however, it is doubtful that porphyry copper deposits have any stronger signature than some other deposit types, such as epithermal gold-silver deposits. Perhaps a more useful criticism is that the experiment is fine as far as it goes, but it still leaves somewhat unanswered the question of how well geologists perform when the assessment area contains several or many deposits. The experiment basically tests the capability of geologists to estimate the presence or absence of a single porphyry deposit. While this is important, it is not as difficult as estimating the probability distribution for number of deposits when possible numbers range from zero to at least several.

The assessment experiment was an important event in that it demonstrated a means for training assessors, and it demonstrates a means for simulating feedback to assessors. As documented in the section of subjective probability and assessment, experts can become very well calibrated when they are well trained and when they receive feedback about their estimates. As feedback per se is not possible for mineral resource assessors, an experimental setting in which actual explored areas are disguised and assessed may be useful in simulating feedback and calibrating assessors.

Deposit Density Analysis

Experience has shown that the most difficult task in the assessment of an unexplored area is the association of scale or volumetric dimensions of mineral deposit occurrence with requisite geological conditions. Geologists, by their nature and science, consider the geology of an assessment area and arrive at a general impression of favorability for the occurrence of a specific deposit type. Generally, geologists feel comfortable about performing this "scientific" analysis. Magnitude of the associated mineralization is, however, quite a different matter, one with which they have much less experience. Accordingly, the argument is very strong that one of the most important tasks for the USGS in the support of geological assessment is the thorough analysis of well explored analogue regions to depict magnitude or density of deposit occurrence and its relationship to important geological features. Accordingly, work like that performed by Bliss (1992a, 1992b) should be accelerated and made available to assessors in advance of actual assessments so that they can prepare for the assessment task.

Associated Deposit Types and Their Relations to Broad Geologic Features

The recent work by Drew and Menzie (1992) on associated deposit types and their spatial relations appears to be very important to improvement of future assessments and should be continued and expanded. As pointed out by Drew in the conference, the need for the assessor to identify deposit types and to delineate permissive areas imposes a need for him to have knowledge of how different deposit types are related to fundamental geological features, e.g. volcano-plutonic centers, not just in process terms, but as spatial phenomena: relative frequency of occurrence of different deposit types and spatial associations of deposit types. Although vital to assessment, these are not the central subjects of economic geology. Consequently, this kind of research should be continued by the USGS so that assessors can be trained in the use of such relations to delineate permissive areas and to make assessments.

The formal identification of spatial relations between deposit types and major geological features may ultimately necessitate a change in assessment methodology to accommodate the dependencies of probabilities for number of deposits across some deposit types. When spatial relations exist, the probabilities for at least one deposit of a deposit type within a region is not independent from the probabilities for the occurrence of at least one deposit of an associated deposit type. Obviously, conceptual as well as empirical studies of spatial relations will be important in the improvement of assessments and assessment methodologies.

PROSPECTOR II MODELS

The System

Currently, the selection of deposit types is subjective, often performed in advance of the assessment (Singer and Menzie, Arizona Conference). Alternatively, an expert system referred to as PROSPECTOR II can be used by geologists to either make the selection or to assist the selection of deposit types. Simply stated, PROSPECTOR II consists of formalized descriptions of mineral deposit models and the capability of describing those models whose essential attributes best match observations made by the geologist.

PROSPECTOR II, the successor to PROSPECTOR, was introduced as a frame-based system on a graphics-oriented work station. It featured an expansion of the volunteer mode, a glossary of geological terms, and the explanation facilities featured in PROSPECTOR. This system makes it easy for the geologist to create models or modify existing ones. PROSPECTOR II is much different from PROSPECTOR, which was based upon inference nets relating evidence to hypothesis. Instead, PROSPECTOR II describes how well the observed attributes match the characteristics of the recognized deposit models.

To transform the map information into descriptors, the concept of spatial objects was introduced. Spatial objects are a data-structure for storing items found in the glossary. The map unit Pzg might have chert, argillite, greenstone, and quartzite associated in the spatial object (McCammon, 1989). These spatial objects (airegions) are mouse sensitive on the screen and can be accessed at any time by the user. A tract is an airegion made up of other airegions, where the descriptors in a tract is the union of the descriptors in the airegions. The operations performed on a tract are: 1) to create them; 2) to assign them names; 3) to display them; 4)to add/exclude airegions from a tract; and 5) to select a tract as input to the system (McCammon, 1989).

The system can be queried as to the deposit types most likely to occur within the tract. These tracts are evaluated according to the degree of match between the set of descriptors and the set of essential attributes described for each of the deposit models. The degree of match is a score for each model type. The score is calculated as the sum of weights assigned to each attribute. The models are then ranked according to their scores with the highest being the deposit type most likely to occur (McCammon, 1989).

This system relies on the user to define a set of descriptors that characterize a particular geological setting in an area. The items selected for these descriptors come from a glossary of taxonomic charts called up by the user. The entire system is now object oriented with the user entering data via a mouse on a menu screen. For each item selected from the glossary, the user indicates whether it is: 1) present, 2) present?, or 3) absent. Those items not assigned to one of the three nominal values are assigned the value " missing" (McCammon, 1989). These four states are a simplification of eleven originally present in PROSPECTOR . There are at present 86 deposit models, 1000 geological terms in the glossary, and 800 links. The relative importance of the attributes of each model are represented through weights determined by Paul Barton and Dennis Cox (McCammon, Arizona Conference).

Testing

Numerical deposit modelling has been tested in an experiment: A classification of 124 lode deposits in Alaska by a panel of eight geologists, using Cox and Singer (1986), was compared to a classification of the same deposits using numerical deposit models (McCammon, 1992). The panel of experts classified the deposits using the lode deposit descriptions of Nokleberg and others (1987). Of the 124 deposits classified, 103 were classified the same by PROSPECTOR II for a success rate of 83%. Eight of the deposits not classified the same placed second in the PROSPECTOR ranking. On five of these deposits the panel suggested that the discrepancy resulted from the deposits possibly classifying into two different deposit types (McCammon, Arizona Conference), suggesting that discrepancies in classification result from a matter of personal judgment and are largely not attributable to failings of numerical deposit modelling.

The Need for a Geologic Glossary

Recognition criteria for each deposit type should reflect a common understanding of the deposit models by each of the assessors on a team. This common understanding is dependent, in part, on the choice of terms used to describe the feature. But, the same term may have different meanings to different people. Thus, without standardization, descriptions of some deposit models might lead to different interpretations. Some of this inconsistency can be reduced by requiring the expert system to search a glossary of terms when provided with geoscientific information. When presented with a term, say coarse-grained intrusive, the system must be able to determine if the recognition criteria for porphyritic intrusion have been met. At present PROSPECTOR has available to it 1000 geologic terms linking definitions with concepts. These terms come from Dana's Classification of Rocks, the geochemical elements of the periodic table, and commonly used geophysical terms as used in reports (McCammon, Arizona Conference). The addition of terms to the glossary is essential to reduce the possibility for misclassification because of taxonomic deficiencies.

PROSPECTOR III-A PROTOTYPE GIS-BASED SYSTEM

The evolution to PROSPECTOR III introduces a map-based facility to integrate geologic maps with descriptions of geological settings. The process requires that maps be digitized and stored in bit-map files. These files can then be displayed on the screen and manipulated in ways common to any geographic information system. The combined information is then compared with the attributes of stored mineral deposit models.

PROSPECTOR III currently is a prototype system operating on a Sun work station. The next development task is to transport the code to DOS-based platforms (McCammon, Arizona Conference). McCammon suggested that the evolution away from a Xerox Lisp machine to a work station was a positive step in maintaining interest in the program. He stated that true acceptancc of the program won't be realized until it is ported to desk-top computers where assessors are free to explore the system. PROSPECTOR has been used on those assessments in which McCammon has participated.

REVIEW OF ASSESSMENT METHODS USED BY OTHER INSTITUTIONS

An extensive review of resource assessment literature published in the last decade yielded relatively few examples of complete, integrated mineral resource assessment methodologies. More commonly encountered are descriptions of techniques pertaining to the various stages in assessment, such as spatial data integration or deposit modelling. The following sections present methodologies applied within the last five years in Canada, China, the former Soviet Union, the U.S. and Fennoscandia (Norway, Sweden and Finland).

CANADA

An examination of recently published resource assessments for areas in Canada (Jefferson and Schmitt, 1992; Jones, Jefferson and Morrell, 1992) reveals a methodology yielding qualitative mineral potential ratings for specific geological domains. These assessments were conducted by the Geological Survey of Canada and follow the general approach presented by Scoates, et al (1986) at the Leesburg Resource Assessment Workshop. Current assessments are generally for areas in northern Canada and are conducted in response to native lands claims negotiations or national park proposals.

As presented by Scoates, et al. (1986), the methodology consists of:"(1) definition of the study area, (2) establishment of geologic domains, (3) compilation of geology from existing sources and inventory and appraisal of mineral and energy resources within the study area using the available information base, with emphasis on metallic commodities and hydrocarbons, and (4) application of conceptual deposit models to the study area, followed by qualitative assessment using the rating categories in table 2." (See Table 3.1, below)

Table 3.1 - Rating Categories

Symbol	Potential	Criteria
VH	Very high	Geologic environment very favorable. Significant deposits known. Based on deposit models, presence of additional (undiscovered) deposits very likely.
H	High	Geologic environment very favorable, although significant mineral deposits may not known to be present. Based on deposit models, presence of undiscovered deposits likely.

MH	Moderate to high	Intermediate between moderate and high potential. Reflects greater uncertainty.
M	Moderate	Geologic environment favorable, regardless of whether mineral occurrences are known. Based on deposit models, presence of undiscovered mineral deposits possible.
L	Low	Some aspects of the geologic environment may be favorable but are limited in extent. Few, if any, mineral occurrences known. Probability that undiscovered mineral deposits are present is low.
VL	Very low	Geologic environment unfavorable. No known mineral deposits or occurrences present. Possibility unlikely that undiscovered mineral deposits of the type being assessed for are present.

The study areas are delineated subjectively so as to enclose park or claimed lands and to "include larger, more geologically representative areas" (Scoates, et al., 1986). The study areas are also selected so as to " (1) provide more confidence in the subjective assessments of resource potential, (2) ... fit the National Topographic System grid in a rational way , and (3) allow subsequent adjustments to proposed park boundaries with the compiled data base" (Scoates, et al., 1986). The geologic domains are defined subjectively, based on major geological units and geography (Jefferson and Schmitt, 1992). The compilation of geology and mineral deposit as well as occurrence data is based on existing information.

The conceptual deposit models used for analogues for the subjective qualitative mineral potential ratings (see Table - 4.1) are drawn from Eckstrand (1984) and Cox and Singer (1986) as well as various other sources. The final products of the assessments include maps depicting the assessment domains and written descriptions of mineral potential for specific deposit types including metallics, industrial minerals and hydrocarbons. These descriptions also provide the rationales employed in arriving at the mineral potential ratings.

The proceedings of an assessment methodology workshop conducted in April, 1992 by the British Columbia Geological Survey (1992) indicate that future assessments in BC will employ a procedure very similar to the three-part methodology used by the USGS. The following draws heavily on a report of the proceedings.

The final product of the future BC mineral resource assessments will be maps providing mineral potential information in several different forms including "metal in ground, in place dollar value, exploration activity, mining activity, tax revenue and employment" (MEMPR,MRD,GSB, 1992). The assessments will be broad-based including metals, non-metals, hydrocarbons and geothermal resources. The known mineral resources will be documented and the assessments will include an economic and social impact assessment of mineral potential and known endowment. A description of the methodology will accompany the final product in each case.

The assessment methodology will be based on the three-step methodology of the USGS, including delineation of geologically similar permissive tracts, subjective estimates of numbers of deposits, and the use of Monte Carlo simulation to estimate the expected number, size, grade and mineral content for specific deposit types. The data to be used in the assessments including geology, geochemistry, geophysics, satellite imagery and exploration history, will be maintained in a geographic information system.

EAST-WEST CENTER

An example of a resource assessment methodology employed by the East-West Center (Clark, et al., 1989) is an assessment conducted in China, although the extent and consistency of application of the methodology are not known. The East-West Center assessment is for the Altay Mountains area in northwest China. The project was initiated by local Chinese government officials to more effectively plan future minerals exploration and development activities.

The study had four basic components: 1) an initial resource assessment to estimate the type, quality and quantity of mineral deposits that may occur in the area, 2) a preliminary financial analysis to determine which of the deposits would be economic to develop if discovered, 3) a market analysis of the estimated commodities to assess which commodities would be desirable to develop for local, national and international markets, and 4) an integration of all these data into a comprehensive long-term development plan.

The objectives of the study were a resource evaluation of major non-fuel minerals (copper, nickel, lead, zinc, and iron ore) in the Altay Mountain Region and financial and market analyses of these commodities using information acquired in the resource assessment.

The overall methodology of the assessment was:

1. resource assessment
    a. compilation of a provincial inventory of mines and deposits
    b. estimation and verification of mineral reserves
    c. estimation of the undiscovered resource base

2. Based upon the assessment, the evaluation of the exploration potential of the Altay study area; the timing of the discovery of specific deposit types was predicted.

This in turn was based upon the fundamental assumptions of:
  a. the types of deposits to be discovered first
  b. the relative rates of exploration and discovery of the deposits

3. The creation of 27 financial mine models based upon each deposit type predicted to occur in the resource assessment analysis. For each deposit type three models were developed representing the following scenarios
  a. minimum deposit tonnage, maximum average grade
  b. maximum deposit tonnage, minimum average grade
  c. average deposit tonnage and average grade

A financial model was developed for each deposit type where the resource assessment was able to provide a 'best estimate' of tonnage and grade. The 27 models consist of spreadsheets that estimate the more important categories of cost and revenue. Prices and costs come from Chinese estimates and where not available from outside sources.

4. A market analysis of copper, nickel, lead, zinc, and iron ore was performed. World supplies were studied to indicate the growth in supply and price trends to the year 2000.

RESOURCE ASSESSMENT

The resource assessment method was required to produce a level of disaggregated estimates sufficient for both site-specific and regional studies. Thus, a program of resource assessment that combined elements of the major assessment methodologies and elements of the major assessment methodologies (Unit Regional Value, Integrated Synthesis, Deposit Modelling, and the Delphi Method), was designed to assess the Altay study area's potential mineral resources. The steps involved were:

1. Reserve Resource Inventory

Initial acquisition and compilation of available data on the known deposits of the region. Recognition of the occurrences of major deposit types present. This was followed by a resource assessment technique involving terrane/deposit analysis (Clark 1983):

a. Terrane map compilation. Certain types of mineral deposits are associated with certain geologic attributes, such as chemical and mineralogical composition of rocks. Discrete terranes are delineated and are used to estimate the types of deposits that may occur, based upon known associations of geologic attribute to deposit model.

b. Integration of data. Used to define specific areas of high to low favorability for specific deposit models, this stage utilized a simplified version of Characteristic

Analysis, a procedure developed by McCammon et al. (1983). The resultant ranking of mineral favorability was expressed in map format at the same scale as the terrane maps. Concurrent with these first two stages was the collection of world-wide deposit information and a listing of deposit attributes estimated to occur in the study area.

c. An estimation of the number of deposits estimated to occur in the study area by means of a Delphi method. The experts consisted of geoscientists and planners in the Bureau of Geology and Mineral Resources. Each expert was briefed on the known deposit types of the region and of those not known but inferred to exist based upon geologic analogues. Experts were asked to assess and review both the local geologic data and that collected on a world-wide scale. Then each made an estimate as to the number of undiscovered deposits of specific types to be found in each geologic terrane. The experts were also asked to prioritize the most favorable areas of occurrence for each deposit type, based in part on the results of the characteristic analysis performed in part b.

2. Financial analysis Activities

The results of the resource assessment stage provide estimates of the number of deposits and their size and grades. A mine financial analysis was then used to determine whether these deposits are of sufficient size and grade to be economically viable. The economic measures of Internal Rate of Return (IRR), Net Present Value (NPV), and Discounted Break-even Year (BEY) were estimated for each of the model types. For sensitivity, the following scenarios were used:

1. minimum deposit tonnage and maximum average grade.
2. maximum deposit tonnage and minimum average grade.
3. average deposit tonnage and average grade.

A financial model was developed for each deposit type for which the resource assessment derived a 'best estimate' of tonnage and grade. Prices and cost models were provided by the Chinese government. For those deposit types for which no cost was available the Minerals Availability System (MAS), developed by the U.S. Bureau of Mines was used with conversion from $US to Chinese Y currency. Use of the MAS program required assumptions on the mine life, ore capacity, recovery estimates, degree of processing, transportation costs, capital costs, and working capital. Given the difficulty of applying cost models developed for market economies to the Chinese socio-economic structure, the financial estimates are highly uncertain.

SUMMARY

The resource assessment activities undertaken in the East-West Center study were summarized as (Clark et al., 1989):

1. A compilation of a regional inventory of known mineral deposits and verification of mineral reserves.

2. The selection of the terrane/deposit methodology for evaluating undiscovered mineral resources.

3. The delineation and definition of specific geologic terranes.

4. The estimation of deposit types that may occur within each type of terrane.

5. A ranking of high to low favorability for the occurrence of specific types of mineral deposits within the terranes.

6. A compilation of terrane and mineral resource favorability maps, with the latter including producing and near producing deposits.

7. A collection and interpretation of world-wide data on deposit tonnage, grade, and distribution parameters.

8. A Delphi estimation of undiscovered resources.

9. An estimation of exploration efficiency in the discovery of inferred deposits.

CHINA

OVERVIEW

Chinese scientists and mathematicians have pursued target identification and resource appraisal rigorously for the last two decades. Judged from published literature and first hand contacts in China, most of the Chinese methodologies employ mathematical and multivariate statistical techniques. Some of these have yielded quantitative estimates of resources, e.g. amount of metal, while others delineate targets or favorable resource areas. Since most of their methods are mathematical and statistical, the Chinese scientists have devoted much effort to the structuring of geoscience and resource information and to its quantification.

Besides being heavily quantitative and mathematical, the Chinese methodologies are characterized by a formalized hierarchy for metal occurrence, i.e. provinces, belts, districts, deposits, and orebodies, as a structure for methodology. Generally, this scheme recognizes the need for different quantified variables and mathematical techniques for each level and specifies the means to identifying the variables and the predictive relations that are required for the next hierarchial level.

To some degree, the emphasis on quantification of geodata and the heavy reliance upon mathematical and multivariate statistical methods may be due to an abundance of geodata. When compared to the typical U.S. assessment, the Chinese have usually been very data rich, particularly in geochemistry. Naturally, abundant geodata fosters a greater interest in the use of multivariate statistical methods.

When quantitative resource estimates are made by multivariate methodologies, they often are for amount of metal instead of number of deposits. An interesting feature of some Chinese methodologies is the use of deposit tonnages and grades to weight geodata matrices in the estimation of the mathematical models. Until a few years ago, such weighting was not usually performed in U.S. multivariate models.

There are numerous papers in Chinese about quantification theories and methods and multivariate statistical methods and their applications in resource appraisal, but only a few papers have been translated to or written in English. Two such papers are summarized below, each of which describes quantitative methodologies.

COMPREHENSIVE INFORMATION THEORY AND METHODOLOGY (CIM)

Since 1982 mineral resource appraisal experts have been using a comprehensive information theory and method (CIM) (Wang, et al., 1992) to identify mineral resource domains. Mineral resource appraisal based upon CIM is a systematic approach that accounts for different scales in the information data base. Using large scale geological, geophysical, and geochemical information and medium scale comprehensive information to establish the prospecting model, the following steps are followed:

1) metallogenic maps are compiled and mineral resource targets are predicted by applying a prospecting model;

2) the location, size and margins of individual mineral resource terranes are identified by local characteristics;

3) extraction of the variables, determination of location, and quantitative prediction are made using the mineral resource domain as a unit;

4) after construction of this simplified model, the location of targets and the quantity of contained metal are estimated, and an error is assigned to the estimate.

Mineral Resource Domains

Mineral resource domains (MRD), are geological bodies hosting mineral resources. They may represent a known deposit, ore field or metallogenic belt within a mineral producing area. They are targets for prediction and exploration. The MRD's may be divided into four classes based upon scale:

1) ore body domains (OBD) - comprised of blind ore bodies or promising areas inferred from known deposits;

2) ore deposit domains (ODD) - the set of potential or verified deposits predicted from known ore fields;

3) ore field domains (OFD) - possible or unverified deposit fields inferred from metallogenic belts;

4) metallogenic belt domains (MBD) - potential or verified metallogenic belts inferred from metallogenic zones.

Data Characteristics

The disunity of information states that given a common set of experienced geologists can arrive at different interpretations. Also, complex geology leads to multiple interpretations of geophysical and geochemical information. The authors note that limited information in study areas makes it difficult to use well explored analogue regions.

Method Flow and Main Content

The comprehensive information prospecting model examines the correlation between direct and indirect information and a conversion between the two data types. The main steps are:

1) process the data comprehensively as follows:
    - determine the mineral assemblage indicators of a major metallogenic stage
    - determine the element associations between the ore and the host rock
    - determine the geophysical properties of the ore and host rock
    - correlate the geological, geophysical and geochemical information;

2) expand the model to set up the comprehensive prospecting model for ore field scales;

3) using the models at different scales, forecast at the mineral resource domain scale.

Compilation of Metallogenic Prediction Maps of Comprehensive Information

The construction of metallogenic maps proceeds in stages beginning with a series of basic and intermediate maps. The geophysical interpretations are used to compile the tectonic framework map based upon gravity and magnetic signatures. An interpretation map of the geochemical data is then compiled with the distributions of ore bodies to generate a series of heavy metal associations to deposit maps. Lastly, using all of the above information the metallogenic prediction maps of comprehensive information are compiled. The scale of these maps is determined by the intended use. The following scales are suggested:

- >1:10,000 prediction maps of comprehensive information are intended for OBD, and ODD domains.

- 1:200,000 to 1:50,000 and 1:1,000,000 to 1:500,000 scales are intended for use with OFD and MBD domains.

Unit Division of Mineral Resource Domains

According to metallogenic models of deposits, geophysical, geochemical, and remote sensing data, the domains of OBD, ODD, OFD, and MBD are subdivided as follows:

- deposits hosted in basic and ultra-basic rocks
- diamond deposits
- pegmatite deposits
- skarn type deposits
- porphyry type deposits
- strata bound massive sulfide deposits
- quartz vein deposits
- terrestrial volcanogenic deposits
- metamorphic deposits
- sedimentary deposits

Extraction and Assignment of Geological Variables for Mineral Resource Domains

Broadly, there are two types of mineral resource variables; 1) those reflecting unit features i.e. geophysical and geochemical surveys; and 2) those variables that control the occurrence of the deposit. Assignment and form of the geological variables is directed by the forecasting aim. Locating codes the variable according to the extent to which it exists in the resource domain and is realized by a method of characteristic analysis. Quantitative prediction is assigned on the basis of favorable extent to which the variable controls the scale and grade of mineral resource domains. Generally the method of rank correlation is used to study these variables.

Selection of the Model Unit

The model unit is a representative section of geology upon which the prediction model is based. Use of a model unit helps to mitigate the effects of different levels of information for different units. In large scale domains the geological features differ greatly from those of the moderate to small scale domains.

Location and Quantitative Prediction of the Mineral Resource Target

Generally the location of the ore target can be indicated by the coincidence of special geological variables. By selecting efficient and objective variable associations, on the basis of the prospecting and prediction mapping models, credibility is given to the predicted target areas. Models based upon regression, cluster, and characteristic analysis or quantification theory are frequently used. There exists a two step process where resource potential models are generated from ore belts, ore bodies, ore deposits, and ore fields. Secondly the quantitative model for target prediction of mineral resources is generated from the resource potential estimates for various grades in mineral resource domains.

Generally there exists a much larger data set for the model unit than is available for the prediction unit. A data transformation is required in going to the prediction model. Simplification of the prediction model by comparing various kinds of variable associations can be realized step by step on the premise of satisfying a given prediction accuracy. In an example the authors develop a prospecting model based upon comprehensive information for the district. This produced different ore field and ore prospecting models. Division of these models into domains was implemented using ore control structures interpreted from gravity and magnetic surveys.

LARGE SCALE MINERALIZATION INFORMATION MEASUREMENT

A system for mineral assessment to 1.) classify the statistical units (ore bodies and/or lodes), 2.) select the proper ore controlling information, and 3.) set up varied large scale statistical models (Liu, 1991). Step 1, the classification of ore forming information, considers the following types of information:

1) Background information: a composite of normal geological, geochemical, and geophysical features. Those features associated with Au mineralization are slightly higher in intensity and modified in shape as compared to the background information fields.

2) Non-mineralization superimposed information: these anomalies are associated with concealed strata, intrusions, or structures superimposed on the background information. The relationship to Au mineralization is indeterminant, complicating the research. As this type of information is different from that associated with the Au mineralization it should be excluded from the data set.

3) Blind mineralization: it is necessary to identify and extract from the set of background information those features associated with blind lodes. This superimposed information is an important statistical variable.

4) Apparent mineralization superimposed information: this information is obtained from exposed Au mineralization and its associated geology. This type of information is easily interpreted.

Classification of Statistical Lode Units

The selection of statistical units involves the use of:

1) Random sampling.
2) Representative model units (ore bodies and/or lodes).
3) Independent statistical units defined to be the intersection of the anomalies of the ore controlling information. In general these could be mapped ore bodies, lodes, mineralized alteration zones, mineralized fracture zones, mineralized contact zones, and the minimum range of concentration centers of the ore controlling information. These statistical units are then referred to as the prediction units.
4) direct and indirect mineralization information.

It is interesting to note that the authors suggest the results are broadly similar but differ in detail when compared to consistent geological areas delineated by Harris and Pan (1991).

Selection of Mineralization Information Variables

This is the quantitative selection of the ore controlling information from the known primary data set. The following variables should be considered:

1) Ore controlling structure variables: the most suitable variables are:
    A) long lived fracture zones with early tension and late compression,
    B) intersections of differently oriented structures,
    C) branching and merging portions of faults,
    D) overlapping structures of different origins.

2) Ore controlling host rock variables - selection of the most suitable strata.

3) Ore controlling intrusive complex variables - the spatial distribution and distance between the ore bodies and the intrusions.

4) Mineralization and alteration variables: the temporal sequence and zoning patterns are important.

5) Geophysical variables: the use of shallow, second derivative anomalies, first derivative anomalies, and highs and lows to define co-incident patterns.

6) Petro-geochemical and geochemical prospecting variables: the efficient variables have been found to be ratios and logical combinations of trace elements.

7) Infrared spectrum analysis variables: considers the following:
   A) variables related to the shape of typical spectrum zones,
   B) composition of variables related to the spectrum zones,

8) Fluid inclusion analysis variables: useful in the determination of ore forming temperature, pressure, and component evolution.

Mathematical Models used in the Quantitative Prediction of Gold Lodes

Some of the original mathematical models were originally developed by Pan (1985). The 'multiple dimensional, weighted matrix analysis involves the product matrix for the mineralization information of lodes. Not only the dimension of the model is increased but also a) the relative weight of different types of mineralization, b) the tonnage weight reflecting the size of the ore bodies, c) the grade weight reflecting the mineralization intensity. The following matrices are used:

1) Original data matrix - describing *n* known model ore bodies and *m* selected information variables.

2) Grade weighting matrices by ore species (C^l) - the grade weighing matrix uses the grade of different ore species as the weight where C^l_i is the grade of the *l*th ore species in the *i*th model unit.

3) The tonnage weighting matrices by ore species (D^l) - is the tonnage of the different ore species in a mineralization series for weighting where $\ln d^l_i$ is the natural logarithm of tonnage of the *l*th ore species in the *i*th model unit.

4) The correlation coefficient weighting matrices by ore species (R^l) - is used if a correlation exists between the ore species to be predicted and other ore species where r^l_j is the correlation coefficient between the *l*th ore species and the *j*th variable.

5) Weighting of data by grade and correlation coefficient ($Q^l_{(mxm)}$) - if the grade and correlation coefficient weighting matrices of different ore species are considered at the same time then:

$$Z^l_{(nxm)} = C^l_n X_{(nxm)} R^l_{(m}$$

6) Weighting of data by tonnage and correlation coefficient

$$(P^{l}_{(m \times m)} :- \text{let } Y^{l}_{(n \times m)} = D^{l}_{n} X_{(n \times m)} R^{l}_{m}, \text{ then } P^{l}_{(m \times m)} = Y^{(l)\,T}\, Y^{(l)} = [P_{ij}]_{(m \times m)})$$

Calculation of the weights a^{l}_{qj} and a^{l}_{pj} for the *j*th variable for the *l*th ore species are determined by calculating the square root of the sum of squares of the matrices *Q* and *P* respectively. Using the principal component method to calculate the weights of the multiple dimension variables the characteristic equations are:

$$Q^{l}_{(n \times m)} a^{l}_{q} = \lambda^{l}_{q} \cdot a^{l}_{q}$$
$$P^{l}_{(n \times m)} a^{l}_{p} = \lambda^{l}_{p} \cdot a^{l}_{p}$$

Where λ_q^{l} represent the characteristic vectors.

Calculation of the mineralization degree of the statistical lode units in the Au mineralization series is given by:

$$f^{l}_{qj} = \sum_{j=1}^{m} a^{l}_{qj}\, X_{ij}; \quad f^{l}_{pj} = \sum_{j=1}^{m} a^{l}_{pj}\, X_{ij}$$
$$\text{where}\,(i = 1,2,\ldots\ldots\ldots\ldots,n;\; j = 1,2,\ldots\ldots\ldots\ldots\ldots,m)$$

Here the mineralization degree is an indicator of mineralization intensity of a given unit and it's value can be compared with those of the model units.

FENNOSCANDIA

An assessment of over 210,000 km^2 in northern Norway, Sweden, and Finland (Sinding-Larsen, 1988) provides information on resource assessment methodology in use in Fennoscandia. In this study, multivariate statistical methods were employed for the integration of geological, geophysical and geochemical data. Following data integration, mineral resource potentials were assigned to areas based upon the degree of association with deposit models.

The multivariate assessment was based upon 30 variables selected from over 200 geological, geophysical, and geochemical variables. From each variable 3 new variables of 1) intensity, 2) regional complexity, and 3) statistical complexity were created as follows:

1) A circular window of radius 20 km was drawn from the cell center point.

2) The measure of intensity was the weighted average of all values within the window. The weight of each point is determined by a bell-shaped function of the distance to the window center.

3) Statistical complexity is derived from the distribution of values within the window expressed in quartile differences. For example (P75-P25), where the points for P are the quartiles and M the median.

4) Regional complexity is the average inter-distance of all points having values exceeding the upper quartile, P75.

GEOLOGIC VARIABLES

Geology was depicted by the following 5 variables:

1) dominate rock type within the grid cell (intensity),

2) the rock type at the center of the cell,

3) the number of rock units within the cell (statistical complexity),

4) the age relationship of the rocks in the cell,

5) favorability of the rock type for the occurrence of ore.

GEOPHYSICAL VARIABLES

Gravimetric and magnetic data were used to construct 5 geophysical variables.

1) gravimetric intensity, which is the measured gravimetric value of each cell;

2) local gravimetric expression, which is the residual value from two filters: one high-pass (radius=75km), and one low-pass (radius=10km);

3) magnetic intensity, which was defined to by the weighted average at the center of the cell;

4) regional complexity, which is the average inter-distance of all points having values exceeding the upper quartile P75;

5) statistical complexity, which is the quartile difference not divided by the median.

GEOCHEMICAL VARIABLES

Factor analysis was employed to reduce the geochemical data set from over 200 variables to 20 significant factors:

1) For each sampled material, a factor model was fitted to the raw data and the two most important factors, along with the Mahalanobis distance were selected.

2) Outlier points causing spurious results were removed from the data-set, the data were smoothed and interpolated to the grid.

3) Intensity was expressed by the moving medians of both factors and the Mahalanobis distance.

4) Regional and statistical complexities were computed for the first factor.

CLASSIFICATION BY EMPIRICAL DISCRIMINANT ANALYSIS

A supervised classification was performed on the grid cells using the following steps:

1) Learning of the classes by defining a training set and estimation of class-conditional frequency distribution.

2) Testing by classifying a set of known objects that were not included in the training set. Adjustment of the training set.

3) Classification of unknown objects into classes.

The classification was based upon Bayes rule of minimum expected loss over all classes. The classes were defined by delineating known metallogenic areas, specifying the model objects to be at the grid-points within these areas. The variables were:

1) the major factors and the Mahalanobis distance for geochemical data,

2) the aero-magnetic intensity and statistical complexity,

3) the gravimetric filtered intensity and residual,

4) geological complexity and geological favorability for mineral deposits.

A lack of control data did not allow for the statistical testing of the discriminant analysis. Through trial and error analysis it was determined that the geochemical variables of the stream sediments and the aeromagnetic regional complexity blurred relations, thus these data were removed from the data set.

CHARACTERISTIC ANALYSIS

A characteristic analysis was performed using ternary data. This required the transformation of the variables to a ternary form (-1,0,+1) based on absence, lack of observation and presence, respectively.

For the geological variables, both the dominant rock type and rock type at the center of the cell were transformed into new binary variables for 8 different rock types. Geological favorability had to be transformed using the following rule:

Favorability scores greater than two were considered favorable for mineralization (+1), and favorability scores less than two were considered unfavorable (-1). Those values being equal to two were coded as 'don't know' (0).

Geochemical values were transformed as follows:

1) For each element map, regional features such as plateaus or mountain ridges with steep slopes, were identified.

2) Values within the plateaus or mountain ridges were assigned (+1).

3) Values belonging to steep slopes were assigned (0).

4) Values within the background were coded (-1).

After initial analysis only the maps for geochemical intensity and Mahalanobis distance permitted the identification of the above features.

Geophysical data were transformed in a similar fashion, yielding five new variables. The characteristic analysis was completed over the area divided into 8400 regional cells measuring 5x5 km. Thirteen deposit models were selected for the characteristic analysis by the following procedure:

1) Expanded models were constructed by assigning all regional cells having the same stratigraphic unit and rock type as the model cells to model cells.

2) The characteristic vector was then estimated for this expanded model.

3) Those variables which were better correlated in the original model were then used to recalculate the characteristic vector for the original model.

4) This characteristic analysis vector is then used to compute the degrees of association between the models and each of the regional cells.

THE RESOURCE POTENTIAL

For the 13 deposit types, areas of high favorability were defined. The power of the rock age and stratigraphic position variable lead to the development of a new variable termed geologic favorability. This variable reflects the association of the center point rock with the dominant rock type of each cell. Combinations of the different rock types were assigned subjective favorability measures in an attempt to capture the significance between rock associations in relation to the occurrence of mineral deposits. The 13 deposit models used in the study were chosen according to the following criteria:

1) The model should represent important metal producing provinces within the target area.

2) The model should comprise as many deposit types as possible.

3) The model deposits should represent as many commodities as possible.

Every attempt was made to outline the ore bearing areas using regional information specifically prepared from the study area. This information was used to identify those models most likely to occur in the region.

THE FORMER USSR

OVERVIEW

Relevant published literature in English on the methodologies used by the Soviets for resource assessment (prognostication) is very meager. Judged from these meager publications, occasional conferences and personal contacts, there is a very wide range of methods that have been applied in one way or another to what is termed resource prognostication. Prognostication is not equivalent to assessment, because value of resources was never the stated objective of prognostication. Rather, favorability rating and target identification are the most common objectives of prognostication. Accordingly, prognostication methodologies range widely, from the geological theories and methods of metallogenesis (Shcheglov, A.D., 1979) to the highly multivariate statistical methods of Rodionov (1989)-- similar to those of Harris (1966) and Agterberg (1972) --to the logic structures of Sirontaskaya (1989) --to the intricate mathematical topology of Voronin, et al (1971) for geologic objects and to the mathematical modeling by Zoloratev (1990) of intrusives and their phases, both in time and space, including their mineral deposits.

Judging from some of the translated literature, at least some Soviets have devoted a great deal of thought and effort to designing empirically constructed measures, such as the exceptionalness of Gorelov (1982), as a means to identifying mineral targets and high potential resource areas. This notion and methods for its implementation are described in the next section, Selected Supplemental Techniques.

As of a few years ago, there were two major schools of resource prognostication: those of Voronin and Rodionov. As indicated above, Veronin's school developed intricate and elegant means of describing geologic objects, including mineral deposits, using numerical topology and set notations. But, these were criticized by Rodionov (personal communication, Alma Ata Conference, 1985) as being academic and useless for prediction. Conversely, Rodionov headed a school of geostatistical applications to prediction of deposit occurrences, based upon multivariate statistical models. Sirotinskaya worked with Rodionov to develop logic methods as a tool for prognostication.

This section describes only INTERCRAST, the model constructed by Zolotarev (1990). This model differs greatly from most of those considered in this study because the model is designed for highly specific estimates given considerable highly specific information about the geology, in particularly the magmatic intrusive. However, this model is of interest because 1) it is conceivable that decisions may one day require high-level estimation of a small and very specific area, and 2) a program like INTERCRAST could serve as the basis for a new assessment system, one which simulates the uncertain states of the parameters for INTERCRAST, conditional upon observed geology, as a means to simulating the probability distribution for metal. If this could be successfully done, it would eliminate the need for subjective probabilities for numbers of deposits or for tonnages of metal on small areas deemed permissible for intrusive magma-related deposits.

INTERCRAST

The acronym INTERCRAST stands for INtrusive TEmperature CRystallization ANisotropy STructure (Zolotarev, 1990).

This method is based upon: 1) 2-d models of geologic structures, 2) computer modeling of the thermal process accompanying magma emplacement, and 3) "special techniques of data treatment". The method is intended for use with hydrothermal ore deposits associated with intrusive magmatism. It is oriented "toward the reconstruction of the course of thermal processes in a two-dimensional model which reflect real geological situations". Accordingly, INTERCRAST is small scale and information-intensive when compared to other methodologies described in this section.

Three examples are presented by Zolotarev (1990):

1. REE-Th-U Bear Lodge deposits in Wyoming, USA
2. Vein zinc deposits at Saint Salvy in France
3. Cu-Mo porphyry deposits at Tekhute in the CIS

The authors indicate that there is "linear dependency between metal resources in ore deposits (those mentioned here and others) and energy resources calculated for them", and "when energy resources are established for a new site, potential metal resources can be estimated from the diagram". Also, "The most important feature is the exact linear correspondence of energy/metal dependency among ore deposits of different genetic mineral types".

The predictions of the model are in map form. The location of the ore is predicted as well as the amount.

The method was tested at scales of 1:100 to 1:500000 and was employed in "solving genetic problems of formation and in predicting mineralization of U,Th,REE (granite and alkaline magmatism),Mo,Sn,W,Pb,Zn,Cu,Sb,Au (granite and diorite magmatism), as well as in determining the conditions of preservation of primary massive sulphide ores in thermal fields of younger intrusives and formation of remobilized mineralization".

INTRINSIC SAMPLE METHODOLOGY

The Intrinsic Sample Methodology was reviewed in the section on the evolution of concepts and methods for assessment; consequently, only a few additional remarks are made here regarding it as an assessment methodology. The section on evolution of methods described the delineation of Intrinsic Samples (IS's). As stated there, these can serve as estimated gold-silver district-size metallogenic units when the deposit type does not occur in well-defined deposits, e.g. the vein clusters typical of epithermal gold-silver veins. However, the IS methodology is not restricted to estimating number of mining district-sized deposits.

When number of deposits or amount of metal is known for the IS's of the control area, the IS's serve as sample units for number of deposits and the quantification of explanatory variables (lithology, structure, geochemistry, etc.). These data can be subjected to multivariate statistical analyses to estimate the relationship between number of deposits and the geovariables. Once estimated, these relations can be used to estimate number of deposits in an unexplored IS.

A common problem encountered in the estimation of a multivariate endowment model is the uneven degree of exploration that has occurred across the area and the fact that not all of the deposits have been discovered. To deal with this problem, Harris and Pan (1991) proposed the estimation of a combined model, one which described the relation of number of discovered deposits to the geological and exploration variables.
This model was demonstrated (Harris and Pan, 1991; Pan and Harris, 1992) on the Walker Lake quadrangle using cumulative production and reserves as a proxy for amount of exploration.

Although the demonstration was simplistic, it is sufficient to indicate that the IS methodology could, when data are sufficient and time permits, replace steps one and two of the USGS methodology. Only a minor redesign of MARK3 would be necessary to use the estimated multivariate relationship and its error properties as a basis for simulating number of deposits, and number of deposits could control the simulation of deposit tonnages and grades from the tonnage and grade models. These simulated deposits could be combined to give metal, or they could first be filtered, combining only those that pass the cost filter.

Using number of gold-silver deposits as a proxy for number of deposits, Harris and Pan estimated a multivariate geostatistical exploration-endowment model for discovered deposits.

COMPARISON OF USGS AND OTHER METHODOLOGIES

The form of the assessment products resulting from the assessments varies across the methodologies. The Canadian and Fennoscandian assessment products are qualitative. Both of these methodologies yield maps of indicators of mineral resource potential. These differ from the product of the three-part method of the USGS, as discussed in the overview section, which is gross in-place mineral value. The methodology used by the East-West Center yields mineral potential maps, estimates of numbers of deposits, as well as measures of internal rates of return and net present values. The Chinese methodologies employ an assortment of mathematical and statistical models and produce both qualitative and quantitative assessments. The INTERCRAST methodology produces local assessments of metal for deposits formed by magmatic intrusives.

The Fennoscandia, East-West, Chinese and Intrinsic sample methods characterize favorability using objective statistical means for analysis of quantified geodata. But, the favorability (mineral potential) of areas is assigned subjectively in the Canadian method.

In the USGS and East-West Center methodologies, estimates of numbers of deposits are generated through a group consensus of expert geologists. The East-West method states that a structured Delphi estimation procedure was employed for number of deposits estimation, whereas the USGS procedure is an unstructured group consensus. In contrast with both USGS and East-West Center methodologies, the Intrinsic Sample methodology estimates number of discoveries by a multivariate statistical model in which explanatory variables are 1) variables that synthesize geoinformation, and 2) exploration variables. And, typically, the Chinese mathematical and statistical models either estimate an index of favorability or quantity of metal directly.

The conversion of estimated numbers of deposits into GIPV by the USGS methodology is accomplished through a Monte Carlo simulation using statistical grade and tonnage models, while the East-West Center methodology employs mine financial models based upon a "best estimate" of tonnage and grade. None of the other methodologies estimate a value measure.

Inasmuch as the East-West Center financial models consider costs, the economic analysis per se appears to be a much more comprehensive measure of value than the GIPV computed by the USGS. Of course, when steps 1 and 2 of the USGS methodology are followed by the USBOM economic analysis, value measures are produced that are even closer to social value than those produced by the East-West Center. Differences still exist, however, for the USBOM economic analysis is based upon the expectation for number of deposits and estimates of capital and operating costs of mine, processing, and infrastructure for the entire distribution of deposit tonnages and grades, while the East-West Center performs comprehensive economic analysis on only four scenarios of deposit tonnage and grade.

The attempt by the East-West Center to predict a time profile for the discovery and development of specific deposit types in specific tracts is a great extension of economic analysis that goes far beyond that performed in most assessments. Mineral resource assessments generally have ignored timing of production of predicted deposits in the determination of land values. Of course, timing also is currently ignored in the determination of values for all resources, including recreational and environmental.

The analysis by the East-West Center, while simplistic, is similar in concept to the estimation of dynamic supply (Harris, 1991). Estimation of dynamic supply requires the simulation across time of exploration, development, and production as dictated by projected mineral demands and supplies and by the optimization of economic rent, with consideration given to risk, by those economic agents, e.g. mineral firms, bearing the risk of investment.

Conceptually, land-use decisions would be comprehensively made only if values for each possible use were based upon the social value of the projected costs and benefits. Of course, we must "learn to walk before we can learn to run", meaning that we must first create a sound, comprehensive analysis of land-use without consideration of timing. Then, after construction of the necessary databases and systems, the more complete analysis can be performed.

Resource assessments conducted by the Geological Survey of Canada (federal agency) are shifting from a qualitative final product (mineral potential ratings) to a quantitative final product (future dollar values). According to Chris Findlay of the GSC (pers. comm.), there is now a need for a shift in the methodology from qualitative measures that were used to determine which of a group of areas was best suited for national parks to quantitative measures required to answer questions of optimal land-use .

The trend of the assessments by the East-West Center for China seems to be towards a quantitative final product (value) based on disaggregated deposit estimates. Earlier assessments for areas in China by the East-West Center employed an aggregated approach based on unit regional value (Clark, 1987; Dorian and Clark, 1987). Thus, the recent assessment marks a great change in the Center's methodology, making it similar to that of the USGS.

As revealed by the BC assessment methodology workshop proceedings (MEMPR,MRD,GSB, 1992), future assessments made in BC by the provincial geological survey will employ a methodology closely based on the USGS three-part method. All data of a spatial nature required for the assessments are to be stored in a geographic information system.

When data analysis and support of USGS assessments are compared with the Fennoscandia or the two Chinese analyses, they appear to be very meager. Moreover, when the current USGS assessment program and methodology are compared with the planned program for future BC assessments, the USGS appears to be lagging in the use of GIS and associated data processing. Of course, with today's information technology, GIS and data analyses go together to a great degree.

GIS combined with quantitative analysis of geodata do not of themselves guarantee improved assessments, and their use incurs greater costs. As with the Fennoscandia study, GIS and quantitative analyses may provide interesting patterns for exploration, but unless they are integrated into an assessment methodology, their contribution to quantitative assessment may be marginal. However, judicious employment of them within an integrated assessment methodology could, everything else being equal, contribute to improved assessments and foster greater confidence in the assessment product. Moreover, they facilitate the use of integrated assessment methodologies like Intrinsic Sample Theory and Methods. Of course, preparation for GIS and quantitative analyses are time consuming and costly. Thus, their application would require greater lead time as well as additional manpower.

SELECTED SUPPLEMENTAL TECHNIQUES

INTRODUCTION

An extensive literature search was conducted as a prelude to the review of assessment methodology evolution. The literature review focused on the period from 1980 to the present and included the sources listed in Table 3.2. Although the main purpose of the review was to describe methodologies that produce assessments, a secondary purpose was to identify supplemental methods and techniques which could be useful in a quantitative resource assessment methodology. Excluded from consideration were articles on techniques for basic geoscience applications, such as geochemical and geophysical data analysis, although certainly some of these techniques would be useful for the preparation of basic geodata necessary for assessment.

Table 3.2 Publications reviewed

Mathematical Geology
Economic Geology
Nonrenewable Resources
Resources Policy
Geologische Jarbruch
APCOM proceedings
NATO ASI proceedings
International Geological Review
COGEODATA publications
International Association of Mathematical Geology symposia proceedings
Materials and Society
Resources Forum
Minerala Deposita
Global Tectonics and Metallogeny
Geological Survey of Canada publications
Geoscience Canada
USGS publications
USBOM publications
USDOE publications
All Publications present in the GEOREF database

The following section consists of selected short reviews of articles and papers containing supplemental techniques which could be useful in quantitative assessment.

BRIEF REVIEWS OF SELECTED PAPERS

Gorelov, D.A., 1982, Quantitative characteristics of geologic anomalies in assessing ore capacity: International Geology Review, v. 24, no. 4, p. 457-465

As mineralization is a product of various geologic processes and environments which can be indirectly quantified through the use of geologic variables and geophysical fields, the exceptional and anomalous structure of ore deposits or mineralized zones should, logically, be reflected in some of these variables and fields. Therefore, conversely, areas which exhibit anomalous or exceptional values for several geological variables should coincide with areas likely to contain ore mineralization.

The concept of exceptionalness has been discussed in the Soviet literature since the early 1970's. Gorelov proposed using only geophysical information in exceptionalness analyses because geophysical information is "measurable, reproducible and uniform." He employed eight measures, four each derived from magnetic and gravity fields. The values for these eight variables were determined for each cell (quadrant) of a region. From these values, histograms were constructed. Those measures comprising the least frequent (<20%) values were designated as atypical. That is, the values in the tails of the histograms were designated as atypical. Based upon the ratio of the number of measures whose values were atypical in a particular cell to the total number of measures for that cell, Gorelov arrived at an "index of atypicality" for each cell. The index values were then used to construct a contour map of atypicality. In Gorelov's demonstration, some known mineral deposits were associated with highly atypical areas.

Harris, D.P.; and Pan, Guocheng, 1990, Subdividing Consistent Geological Areas by Relative Exceptionalness of Additional Information, Methods and Case Study, Economic Geology, v. 85, pp. 1098-1083.

This paper extends the expression of exceptionalness to include several different kinds of geoscience information, e.g. lithology, structure, geochemistry, geophysics, alteration and mineralization, whereas Gorelov's exceptionalness was based upon geophysical information only. Moreover, for those kinds of information, e.g. geochemistry, that are represented by multiple measurements, e.g. concentrations of several elements, the multiple measures are synthesized into a single measure, using methods of information synthesis, prior to analysis of exceptionalness. Ten variables were subjected to exceptionalness analysis.

X_1 = filtered geochemistry derived from synthesis of 14 elements sampled from drainage basins,

X_2 = high-pass structure, obtained by synthesis of ten structural descriptors related to faults,

X_3 = band-pass gravity, derived from coherence of high-pass isostatic gravity and filtered synthesized geochemistry,

X_4 = band-pass magnetics, derived from coherence of high-pass magnetics and filtered synthesized geochemistry,

X_5 = ratio of rock density and susceptibility contrasts estimated by Poisson moving window, based upon high-pass gravity fields,and high-pass magnetics,

X_6 = area of hydrothermal alteration,

X_7 = correlation of high-pass gravity and high-pass magnetics estimated by a Poisson moving window,

X_8 = area of host rocks (km^2) for epithermal gold-silver mineral deposits,

X_9 = number of epithermal gold-silver mineral occurrences,

X_{10} = area of Tertiary intrusives that outcrop,

These 10 variables were reduced to four factor scores, which served as the basis for the analysis of multivariate exceptionalness.

The spatial distribution of exceptionalness measures based upon these factor scores may be useful information in an assessment; however, reflecting the objective of this study, which was to subdivide consistent geological areas, the factor scores for each grid location were transformed to relative factor scores. Histograms of the relative scores were constructed and the optimum cut of each histogram was determined. Using these critical values (cuts), the exceptionalness zones were determined for each of the factor scores.

Pan, Guocheng; and Harris, D.P., 1992, Estimating a Favorability Equation for Integration of Geodata and Selection of Mineral Exploration Targets, Mathematical Geology, vol. 24, no. 2, 1992, p. 181-206.

This paper describes the computation of favorability scores computed from favorability equations estimated by two different methods: canonical correlation and weighted canonical correlation.

These methods were demonstrated on the Walker Lake quadrangle of Nevada and California using two vectors of variables, one which included target variables and the other which included geological descriptors:

Target Variables
  hydrothermal alteration
  Tertiary intrusives
  Au-Ag mines or prospects

Geological Descriptors
  synthesized geochemistry
  synthesized structure
  band-pass gravity
  band-pass gravity
  band-pass magnetics
  ratio of density to magnetic susceptibility
  correlation of gravity and magnetics
  host rocks of epithermal gold-silver deposits
  estimated depth to intrusive

This demonstration computed favorability measures, defined favorability measures in terms of the target variables, delineated favorable areas, and compared the results of the canonical and weighted canonical analyses.

Pan, Guocheng, 1992, Estimating a Favorability Equation for the Integration of Geodata and Selection of Mineral Exploration Target: Mathematical Geology, v.24, p. 177-202.

This paper extends the measure of favorability to include spatial variation. It describes a regionalized method for the estimation of a favorability function. The optimal weights for the favorability equation are derived by solving a generalized eigen system established by the maximization of covariances between favorability function and the principal components of a set of preselected target variables. The regionalized favorability analysis can be compared to cokriging in that both use the sample-sample covariances to account for the sample-sample configurations.

The method was demonstrated on a case study, which involved the integration of geochemical, geophysical, and structural data sets for the selection of hydrothermal gold-silver exploration targets. The case study region was subdivided into an equal-area grid with cell size of 200 by 200 feet. All data were interpolated to this common grid prior to variogram analysis. Since the geochemical data are consistent with and provide information on known mineral occurrences, they were used as target variables. The geophysical and structural data were employed as explanatory variables.

Cross variograms were based upon ordinary variograms for sums of pairs of the variables. A total of twenty variogram models were needed, including six for individual target and explanatory variables and fourteen for sums. Four directional experimental variograms were computed for each variable.

Targets identified from the favorability map are consistent with known geochemical anomalies and known mineral occurrences.

Grunsky, E.C. and Agterberg, F.P., 1988, Spatial and Multivariate Analysis of Geochemical Data From Metavolcanic Rocks in the Ben Nevis Area, Ontario. Mathematical Geology, V.20,#7, pp. 825-861.

The article describes the application of a factor analysis technique to spatial auto- and cross-correlation coefficients of lithogeochemical data on metavolcanic rocks. The technique is called *spatial factor analysis.*

One motivation for the study was the desire to delineate areas of hydrothermal alteration which would be significant mineral exploration targets. The data for the study consisted of the results of chemical analyses of 825 rock samples from an area approximately 12.7 x 7.4 km in the Ben Nevis area within the Abitibi Belt of the Canadian Shield. The chemical analyses included tests for CO_2, S, Li, Zn, Si, Al, Fe, Mg, Ca, Na, and K. Various combinations of these elements (& compounds) are known to indicate variation of rock composition, alteration effects, and mineralization.

For purposes of comparison, correspondence analysis was applied to 3 sets of variables: 1) CO_2-S-Li-Zn; 2) Si-Al-Fe-Mg-Ca-Na-K; 3) Si-Al-Fe-Mg-Ca-Na-K-CO_2-Li. The most significant factors derived from each of these analyses were used to construct contour maps of factor scores. These maps revealed spatial patterns which were interpreted to represent lithotype, alteration and mineralization. The patterns exhibited by the maps were consistent with the geology and mineral deposits known to exist in the area.

The next phase of the investigation entailed the estimation of spatial auto- and cross-correlation functions for the data. The particular functional form chosen was the parabola. The function

$$F_D(d_{ij}) = a + bd_{ij} + cd_{ij2}$$

Where:

D = the radius of a circular neighborhood around point i

d_{ij} = the distance between point i and point j was estimated with ordinary least squares after constructing pairs of points composed of point i and the N points j within a radius D of point i. The coefficient "a" in the equation (which is the intercept of the parabola and the y-axis) is an estimate of the auto- or cross-correlation coefficient at lag 0 for the particular value of D. This value (a) allows a comparison with other variables and other neighborhood radii.

The authors acknowledge that the quadratic functions employed (parabolas) are not positive-definite and do not satisfy the Cauchy-Schwartz inequality at all points. It is stated that within neighborhood limits, the values of the functions do stay between -1 and 1 and so the Cauchy-Schwartz inequality is satisfied. The problem of non-positive-definite matrices is eliminated by adjusting the matrices to yield matrices which meet this condition. The method of adjustment is as follows. The eigen values of the matrix (M) to be adjusted are calculated. Any negative eigen value is replaced by a positive number equal to 0.01 x trace (M). Then the new matrix (M) having the new positive eigen values is computed. This matrix is positive-definite. The authors state that the use of this technique resulted in only small adjustments to test matrices which did not change the "fundamental relationships between the variables".

The results of the spatial auto- and cross-correlation analyses are presented in graphs and tables, and their geologic implications are discussed. Exponential-type functions are exhibited by Si and other elements which are chemical constituents of unaltered rocks. The values of these elements tend to change sharply as lithologic boundaries are crossed. As a result of an approximately east-west structural grain to the Ben Nevis area, lithologic boundaries are more closely spaced in the north-south direction. This yields anisotropic spatial correlation functions. However, they are treated in an isotropic manner by the method of estimation. Chemical elements and compounds such as CO_2 and S which are typical of hydrothermal alteration are isotropic in their spatial correlation and exhibit Gaussian-type functions.

The core of the spatial factor analysis method is presented in a demonstration of its application to a 4-variable system (CO_2-Li-S-Zn). To begin, a matrix (R_{01}) is formed with the estimated values of the lag 0 auto- and cross-correlation coefficients (the "a" coefficients of the best-fit parabolas). The off-diagonal elements of the matrix R_{01} are obtained by averaging the "a" coefficients of the two separate cross-correlation functions for each pair of variables (e.g. Si-CO_2 and CO_2-Si). This is allowed because the expected parameters of the two parabolas are equal. It is stated that this matrix "represents the variance-covariance matrix of signal values corresponding to standardized values of the elements." The difference between these values and the corresponding elements of the ordinary correlation matrix represent the "noise" components of the variables and their correlations.

Another matrix is constructed (R_{11}) with the estimated correlation coefficients from parabolas (for the same neighborhood D used for R_{01}) at a specific lag from the origin (e.g. d = 500m). At this point R_{01} and R_{11}, if not positive-definite, must be adjusted as described above.

From R_{01} and R_{11} a non-symmetric transition matrix U is formed:

$$U = R_{01}^{-1}R_{11}$$

The implied statistical model is then:

$$Z_i^T = Z_j^T U + E_{iT}$$

where:

Z_i^T and Z_j^T = row vectors consisting of standardized values for the variables at points i and j
E_{iT} = a vector of residuals.

"Each column of U represents a set of regression coefficients by which the value of the variable z at i can be predicted by using the values of all of the variables at j."

It is proposed to reduce the number (p^2) of coefficients by performing a spectral decomposition of U into p components:

$U_i = £_i V_i T_i^T \quad i = 1,\ldots,p$ where:

$£_i$ = eigen values of U
V_i = eigen vectors associated with $£_i$
T_i^T = an "amplitude vector" consisting of constants of proportionality

The relative magnitudes of the eigen values indicate the relative importance of each spatial factor. The values of T_i^T indicate the relative importance of the respective variables. The spatial factor scores are formed by $Z_i^T V_i$.

The article next presents some statistics which can be used to assess the predictive capabilities of the spatial factors. The multiple correlation coefficient R_{km}^2 is useful for rating the predictive power of the kth spatial factor for the mth variable. R_m^2 is used for assessing the ability to predict the mth variable. The statistic Q_m indicates the relative importance of components of U and allows the choice of the most significant factors. Also, presented is the quantity Q, which is an indicator of the predictive power of the matrix U. With this statistic, one can choose the best neighborhood (D) to employ in the construction of matrix U.

The spatial factor analysis method was then applied to the same 7 and 9-variable systems initially analyzed with correspondence analysis. Spatial factor maps were prepared for each analysis and compared to the maps which resulted from the correspondence analysis. The spatial factor maps compare favorably to expected patterns and to the correspondence analysis results.

The authors' conclusion is that spatial factor analysis is useful for "the delineation of hydrothermal alteration patterns and other geological patterns that are characterized by gradational variation in space."

Harff, J. and Davis, J.C., 1990, Regionalization in Geology by Multivariate Classification, Mathematical Geology, Vol. 22, No. 5, pp. 573-588.

In this article, multivariate classification is combined with the theory of regionalized variables. This results in a technique useful for a classification of geological objects that also accounts for spatial variation. The technique involves two steps, typification and regionalization. Typification is numerical classification based on either an existing model or on intrinsic classes. These equate to supervised and unsupervised classification, respectively. The typification is based only upon the multivariate variation with no consideration of spatial relations. The authors suggest the use of hierarchical agglomerative clustering methods because they mimic geologic reasoning.

Regionalization consists of mapping the types determined in the first step onto the plane. This is accomplished through a consideration of the spatial variation present in the data. The specific formulation presented in the article represents the spatial variability by a cross-semivariogram matrix.

The technique is demonstrated in the detection of favorable areas for petroleum in western Kansas. The classification is based on thickness data for specific stratigraphic intervals from 480 drill holes. The regions delineated approximate geologic terranes, namely, the Central Kansas Uplift, the Pratt Anticline and the western Kansas shelf.

Zhao,P., 1988, Review of Geomathematical Applications for Mineral Resources Evaluation in China,in Chung et al., eds, Quantitative Analysis of Mineral and Energy Resources, Proceedings of the NATO ASI on Statistical Treatments for Estimation of Mineral and Energy Resources II, Lucca, Italy June 22-July 4, 1986, NATO ASI Series C: Vol. 223, D.Reidel, Dordrecht pp.79-88.

The methods of statistical applications for mineral resource evaluation fall into the following three categories:

1. prediction of the total amount of resource over a large region;

2. quantitative prediction for specific regions within an ore bearing zone or metallogenic province;

3. statistical analysis of ore-controlling factors and assessment of ore-bearing environments;

The following two tables taken from Pengda (1988), summarize the status of the work in China to this date (Tables 3.3 and 3.4).

Type of prediction and scale	Commodity of prediction	Prediction area	Method used	Date	Organization
Resources Quantity Estimation (RQE) 1:10,000	Ni	Ore field model for ore-bearing parts of Jilin Province: All Chinese Platform regions	6, 23, 29, 3.	1981-1983	Jilin Geology-Mineral Bureau; Changchun College of Geology
RQE 1:200,000	Cu, Fe, S, Alunite	Single map sheet area	23, 25, 30, 27, 26, 7, 8, 3, 6.	1981-1983	Wuhan College of Geology; Computer Centre of Mineral Geology
RQE 1:50,000	Fe, Cu	Southeastern part of Hubei Province	18, 13, 23, 6, 3.	1981-1983	Hubei Geology-Mineral Bureau
RQE 1:500,000	Cu	Regions along Yangzio River in Anhui Province	12, 29, Delphi method estimation, Zipf law method	1981-1983	Anhui Geology-Mineral Bureau
RQE 1:200,000	W	Single map sheet area	6, 25, 23, 17, 27, Zipf law method	1981-1983	Jiangxi Geology-Mineral Bureau
RQE 1:10,000 1:25,000	V, Ti, Fe	Part of Sichuan Province	17, 6, 23.	1981-1983	Sichuan Geology-Mineral Bureau
RQE 1:200,000 1:50,000 1:10,000	Sn	Western part of Yunnan Province	Delphi estimation 17, 32, 22, Favourability index method	1984-1986	Chengdu College of Geology; Yunnan Geology-Mineral Bureau
Prospective Regions Prediction (PRP) 1:50,000 1:25,000 1:10,000	Fe, Cu	Part of Jiangsu, Anhui, Hebei and Neimeng Provinces	7, 8, 22, 23, 25.	1976-1980	Wuhan College of Geology
PRP 1:200,000	Fe	Part of Fujian Province	22, 23, 25.	1977	Institute of Mineral deposits
Statistical Analysis of Factors (SAF) 1:10,000	Pb, Zn	Ore deposit	21, 8.	1982	Geoexploration Co. for nonferrous metals in Hunan Province
PRP 1:10,000	Au	Ore deposit; ore field	23, 25, 27.	1980-1983	Geoexploration Co. for nonferrous metals in Gansu Province

Table 3.3: A summary of the methodologies in the statistical prediction and assessment of mineral resources in China to 1988. Taken from Pengda (1988).

Indexes can be used to distinguish between different types of mineral deposits. The "Principle of determination of the combination of indexes for the factors controlling the formation of a deposit" suggests that to form a mineral deposit there must have existed a certain number of factors. Index combinations can be used to represent these factors. It is rarely, if ever possible, to define all of the factors essential in the formation of a mineral deposit. Thus, the indexes used represent an incomplete set in what is termed "the principle of uncertainty for the deposit-finding probability". Pengda (1988), defines the following three principles as underlying the statistical estimation of mineral resources:

1. Model Analogy - seeking the common features principle;
2. anomaly definition - seeking the abnormal situation principle;
3. contrast evaluation - an optimization principle.

The author notes that the successful prediction for mineral resources depends upon:

1. the reliability and availability of original data allowing for the construction of weighted, ratio, synthesized, and scoring variables (Yutian, 1985);

2. the suitability and sufficiency of the variables constructed and selected;

3. the accuracy and efficiency of the predictive models;

4. the correct selection of targets.

Type of Data	Qualitative Data														Quantitative Data																					
Methods / Purpose	1. Quantitative I	2. Quantitative II	3. Quantitative III	4. Quantitative IV	5. Logic information	6. Characteristic	7. Rank correlation	8. Quantity of information	9. Conditional probability	10. Markov process	11. Probability distribution	12. Subjective probability	13. Deposit modeling	14. Embedded models	15. Correlation coefficient	16. Canonical correlation	17. Crustal abundance est.	18. Volumetric estimation	19. Geometrical probability	20. Time rate	21. Trend surface	22. Discriminant	23. Multiple regression	24. Logistic	25. Cluster	26. Nonlinear mapping	27. Factor	28. Correspondence	29. Monte-Carlo	30. Fuzzy cluster	31. Fuzzy discriminant	32. Geostatistics	33. Bayesian	34. Decision-making	35. Optimal partitioning	36. Step function
1. Correlation of ore-bearing strata										x																									x	x
2. Classification of igneous bodies, gossans and anomalies		x																				x			x	x	x	x		x	x					
3. Identification of ore hunting indicators					x	x	x	x	x						x						x	x	x		x	x		x							x	
4. Spatial distribution of Mineralization																					x											x				
5. Establishing the relation between mineralization and geological factors	x		x		x	x	x	x	x		x		x		x	x						x	x				x	x								
6. Correlation of ore forming conditions and delineation of prospective regions	x	x	x	x	x	x	x	x	x		x	x	x	x							x	x	x		x	x	x			x	x	x				
7. Estimation of probabilities of known mineral deposits or risk in prospecting	x			x							x			x					x			x	x	x					x				x			
8. Evaluating the scale of mineralization	x	x			x						x	x					x	x					x						x							
9. Evaluation of ore-bearing igneous bodies	x				x							x					x	x					x						x							
10. Prediction of the spatial extent of ore bodies		x										x									x	x														
11. Target selection																				x													x	x		
12. Identification of optimal intervals for ore hunting indicators							x																													

Table 3.4: Methods used for statistical prediction and assessment of mineral resources in China. Taken from Pengda (1988).

To accommodate areas having few known mineral deposits some "zero prediction methods" have been suggested:

1. the favorable degree of mineralization method using geostatistical techniques (Luo Junfeng, 1985);

2. Anomaly finding prediction method using cluster analysis and statistical experimental design techniques (Yuang Ding, 1985);

3. location of probably abnormal cells by simple statistical methods using step-wise regression analysis to predict the frequencies of deposits (Zhao Pengda, Huwangliang, and Li Zijin, 1984). They have also explored the Agterberg model of comparing a single mineralized cell with all other cells in a region.

Target selection is loosely defined but is based upon the following criteria:

1. that area indicated by a majority of the methods;

2. where a maximum occurs in a parameter connected to mineralization;

3. areas of coincident anomalies.

Lan,J. and Cheng, H., 1992, The Grey System and Prediction of Geological and Mineral Resources, Mathematical Geology, Vol.24, #6, pp.653-662.

The Grey interrelationship models the similarity between a parent sequence and a set of subsequences of m factors. The parent sequence is denoted as $\{X_0^{(0)}(i); i=1,2...,N$, whereas the subsequence is denoted as $\{X^0_{(m)}(i)\}$, $i = 1, 2.....,N$. As a practical example there are many factors that affect ore formation such as geological structures, sedimentary environment, and magmatic activities. Because the types of ore are known but the degree of mineralization is not, Grey system theory can be applied to approximate the former.

The method requires the generation of a new subsequence set from the original $\{X^{(0)}_0(i)$ by estimating an average and normalizing each member of the set to this. A measure of the absolute difference between the subsequences and the parent sequence is estimated. A measure of the correlation between the parent sequence and each subsequence is estimated. The relationships of 'closeness' and 'distance' between the parent sequence and the subsequences are defined by the interrelationship degree.

By means of a demonstration, the authors processed information from a number of deposits using the logical information processing method. From this they obtained seven deposits having similar characteristics. On these data the analysis of the Grey interrelationship degree was performed. The order of influence sequence on the degree of mineralization was then determined. This permitted the identification of those conditions most important for Cu deposition. The Grey prediction model is determined by a dynamic relationship that is represented by a differential equation of the form:

$$\frac{d^n X_1^{(1)}}{dt^n} + a_1 \frac{d^{n-1} x_1^{(1)}}{dt^{n-1}} + \ldots + a_{n-1} \frac{dx_1^{(1)}}{dt} + a_n x_1^{(1)}$$
$$= B_1 X_2^{(2)} + B_2 X_3^{(1)} + \ldots\ldots + B_{H-1} X_H^{(1)}$$

A full definition of the parameters is presented in the paper.

Bysigin, B.S., 1992, Man and Machine Technology for the Prediction of Mineral Deposits Using Geophysical Data, Mathematical Geology, V.24, #6, pp.711-717.

This study promotes the idea that the best predictions of mineral resources is achieved with geophysical surveys. The interpretation can be enhanced by implementation of computer processing of the data and the development of adequate interpretational techniques. Classical methods of geological modelling rely upon data that can be observed. But pattern recognition concentrates upon the links of local geological structure and the location of deposits under investigation.

The structural approach is based on the supposition that laws controlling the distribution of the mineral deposits are reflected in the associated geophysical fields. The use of geophysical data reduces the need for a homogenous set of data across the area of interest. It is generally accepted that the coverage by geophysical data is uniform. The authors note a stochastic link between the geophysical fields and the geological features represented in various geophysical frequencies.

Features of Geological Prediction Using Patterns.

The initial geophysical fields are entered into an object-feature table with each line representing a point in the network and each column representing a deduced feature. Given a priori geological information it is possible to define three problems:

1) recognition;
2) ranging;
3) classification.

Learning involves the identification and evaluation of those main features associated with each class of deposits. The learning process first identifies those geophysical signatures over known deposits to determine rules for classification. The process is iterative until a satisfactory pattern recognition set is defined. Voronin (1989), has developed the concept of ranging to detect those anomalous groups and background values that are of no practical use. Ranging places objects or bodies in a series according to their characteristics.

The Technology of Geological Forecasting

The computer program RAPID, developed to establish the relationship between the geophysical data and geological parameters has the following modules:

1) transformation - provides initial data processing;

2) description - computes the:
   - derivative transformation for the data,
   - statistical histograms
   - spatial relations of the point data to geophysical data,
   - anomaly identification
   - morphological methods

3) statistics - calculates the correlation and regression models;

4) decision - evaluates the prospects after recognition, clustering and ranging;

5) Evaluation - provides a qualitative analysis of the prediction results;

6) geologist - represents the output of the result to the person in charge.

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CHAPTER IV -- A VALUE MEASURE FOR LAND-USE DECISIONS

A VALUE MEASURE FOR LAND-USE DECISIONS

OUTLINE

CONCEPTS

GROSS IN-PLACE VALUE AND LAND-USE DECISIONS

RATIONALIZATION OF THE USE OF GIPV

USING GIPV FOR LAND-USE DECISIONS MAY BE A DISSERVICE TO SOCIETY

- GENERAL
- IMPACT OF DEPOSIT SIZE AND LARGE CAPITAL COSTS
- IMPACT OF TONNAGE AND GRADE CURVES

CONCLUSIONS CONCERNING GIPV

RESTRICTED GIPV (RGIPV) AS A PROXY FOR SOCIAL VALUE

CONCEPT IN GENERAL

THE NOTION OF A FILTER FOR MARK3

DISCOUNTED CASH FLOW SUBROUTINE REPLETE WITH SIMPLIFIED COST RELATIONS

USE OF A MATHEMATICAL EQUATION TO IMPLEMENT FILTER -- AN ILLUSTRATION

FILTER ESTIMATION

PARAMETERIZING OF FILTERS FOR REGIONAL VARIATIONS

SUMMARY AND CONCLUSION REGARDING RGIPV

A VALUE MEASURE FOR LAND-USE DECISIONS

CONCEPTS

Identification of the optimum use of land among possible uses, such as mineral production and forestry, that differ greatly in their physical, environmental, and social characteristics, can be intelligently made only when all uses are compared by one or more comprehensive measures of social value. In concept, this social value must include the value of consequent employment, infrastructure development, taxes and licences collected by institutions (local, state, and federal), aesthetic values, recreational values, and net externalities, i.e. environmental pollution, etc. Moreover, these benefits and costs must include not just the first-round effects, but also the multiplier effects, i.e. benefits and costs created in supportive industries.

Determination of social value even for currently existing activities requires formal economic analysis, usually by an input-output matrix of technical coefficients, which permits the calculation of impact and of economic multipliers, i.e. the value of economic activities in all supporting industries that is created by one dollar of output of the basic industry (mineral production). When the social value desired is that of the future exploitation of currently undiscovered mineral deposits, its estimation is considerably more difficult than for existing economic activities, because of the great uncertainties that are involved. In concept, such determination would require 1) the simulation of the uncertain resource, resource exploration and exploitation in a relevant time domain , and 2) the analysis of economic, environmental, and social impacts of the projected activities. Probably, a complete analysis like this has never been performed, but the joint efforts of the USGS and the USBOM have on a few occasions approximated this kind of analysis (T. Gunther, pers. comm.).

GROSS IN-PLACE VALUE AND LAND-USE DECISIONS

RATIONALIZATION OF THE USE OF GIPV

The recent use by the USGS of gross in-place values falls far short of the standards referred to in the foregoing section. As this seems to be common knowledge of at least some of the USGS geologists, there arises naturally the question: Why has such a measure been used? Presentations made at the Arizona Conference cited four rationalizations for its use:

1) Those involved in making land-use decisions desire some kind of value measure, and GIPV seems to satisfy that requirement;

2) A comprehensive estimation of social value would require the joint efforts of the USGS and the USBOM, and such an effort often is not possible, either because time does not permit or because the necessary cooperative efforts can not be arranged;

3) Other competing land uses (e.g. forestry) also use GIPV, so its use by the USGS is at least consistent with practices of other agencies and provides decision-makers with a common measure;

4) GIPV, because it captures the multiplier effect, is closer to social value than is net present value.

As indicated in the foregoing section, intelligent land-use decisions can be made only by considering all uses on a common standard, and conceptually, that standard should be social value. Descriptions of land-use in terms of commodities, i.e. tons of metal, that could be produced is not supportive of land-use decisions, because it requires the decision-makers to , so to speak, compare apples with oranges. The only way to avoid such difficult and indefensible comparisons is to use a measure of social value. Thus, the decision-makers are justified in requesting a measure of value for each land-use. However, the measure with which they have been provided by the USGS is an ambiguous one, especially with regards to mineral resources, and should be replaced by one that is more conformable with social value.

The fact that other land uses are described by GIPV does cloud the issue because of the obvious necessity of comparing all uses on a common basis or criterion. While all land uses should be described by the same measure so as to facilitate objective intelligent land-use decisions, that measure should not be GIPV as it is currently computed. The use of GIPV to make land-use decisions should be discontinued. No natural resource is properly represented in land-use decisions by GIPV.

Clearly, the best solution is for all land uses to be described by a comprehensive measure of social value. For mineral use, this would require both the USGS and the USBOM to subjugate historical interagency "turf" battles for the common cause of improving land-use decisions. Besides removing these obstacles, both agencies would have to be given enough lead time to produce the requisite measures of social value. This would require abandoning the "brush fire" or "panic" approach and adopting a mandated, continuing, cooperative program that would make assessments and economic analyses in advance of their need for specific land-use decisions. For this to take place, there would have to be some very signficant changes made in both the structure of activities and the magnitude of their support. Specifically, personnel and resources would have to be dedicated to resource assessment much like the USGS once supported the national mapping program. Since such changes are not likely to take place immediately, either intra-agency or interagency, there is a need for current and near-future solutions to the support by the USGS of land-use decisions. This necessity is discussed in the following section.

USING GIPV FOR LAND-USE DECISIONS MAY BE A DISSERVICE TO SOCIETY

GENERAL

Suppose we set aside the comprehensive estimation of social value through interagency cooperation as not workable in the short-run or immediate future. What, then, should the USGS do when asked or mandated to supply information for land-use decisions? According to testimony made at the Arizona Conference, this question is a relevant one in that it reflects exactly the circumstances recently faced by the USGS. Moreover, as indicated above, these circumstances are used to defend, at least in part, the computation of GIPV. But, as pointed out above, GIPV is not a good measure of value. In fact, there is strong argument that for mineral use, it is so "noisy" as a proxy for social value that using it for land-use decisions may in some cases be very misleading and produce a disservice to society. Moreover the impacts of the conditions above vary with deposit type, region, etc. leading to additional uncertainty in the GIPV measure.

IMPACT OF DEPOSIT SIZE AND LARGE CAPITAL COSTS

The foregoing thought deserves amplification in light of the fact that other land uses also are described by GIPV : How can doing so for minerals lead to distortions? Are not all uses treated equally? The answer to the latter question is that they are not, although they seem to be. The same measure, GIPV, computed for some mineral deposit types in some regions may differ much more greatly from social value than the same measure computed for other land uses, such as recreation. Consider, for example, a very large (700 million tons of ore) low grade (0.5 % Cu) copper porphyry in interior Alaska. For a copper price of $1.00 per lb., GIPV as currently computed by the USGS would be 7 billion dollars. This is a large value, and if the assessed tract is not large, it most surely will lead to a decision favoring mineral use of the lands. However, for current technology and costs and the price of $1.00/ lb Cu, this deposit has zero social value, simply because it is not economically exploitable!

In fact, this deposit would not be economically exploitable even if it were in Arizona; obviously, being in Alaska makes economic exploitation even further removed from reality.

Because of the very large capital cost for requisite infrastructure, townsite, mine and mill, as well as the higher operating costs, for interior Alaska , GIPV as here computed is badly misleading as a basis for land-use decisions. In reality, there would be no investment because the deposit could not be exploited economically; consequently, there would be no jobs, no taxes, and no supporting services. Accordingly, this deposit would have no social value Considering the social value of the tract for mineral use to be 7 billion dollars could, therefore, lead to nonoptimal land-use decisions. To make this point even more evident, the land tract (permissive area) may be geologically favorable for the occurrence of several porphyries, thereby giving an even larger GIPV , and probably none of these would be economic in the interior of Alaska. The social value of all deposits within the tract may be zero, but the expected GIPV may be very large.

The point to be made with the foregoing discussion is that when potential deposits are of a type such that by their nature they contain a large amount of metal and require larger capital investment, the resulting GIPV can differ greatly from social value because neither capital nor operating costs are considered.

IMPACT OF TONNAGE AND GRADE CURVES

Consider as a second example, a region in Alaska for which permissive areas have been identified for podiform chromite deposits. Suppose further that 1) the region is large and there are many permissive areas and 2) the probability for zero deposits for any one area is negligible, meaning that several deposits are expected to occur within each favorable area. Given these circumstances, the expectation for GIPV for this region could be quite large in spite of the fact that none of the deposits on the tonnage and grade curves for podiform chromite deposits would be economic in the interior of Alaska given recent or likely future prices. In fact, most of them would not be economic even if they occurred in the lower forty-eight states, for the deposits are small, irregular, and have high production costs. Although there are many such deposits in California and Oregon, their contribution to chromite supply has been negligible because of their high costs compared to stratiform chromite deposits.

The point to be made with the above example is: How good or bad GIPV is as a proxy for social value is strongly dependent upon the deposits that comprise the tonnage and grade models. When very few, none being the limiting case, of the deposit population represented by these curves is economic, the GIPV computed by multiplying price by the quantities of metal simulated by MARK3 is very misleading as a measure of social value. As the compositions of the populations of deposits implied by the tonnage and grade curves with respect to economics is highly varied, GIPV as currently computed, is an extremely noisy and uninformative measure of social value.

CONCLUSIONS CONCERNING GIPV

The conclusion is inescapable that GIPV as currently computed should not be used as a measure for making land-use decisions. Since it is computed on the entire population of simulated deposits, irrespective of their grades, tonnages, depths, and location, it is misleading as a measure of social value. In fact, it can result in the inference of a large social value of undiscovered deposits when such value is zero. Predicating land-use decisions upon such a measure is a disservice to society; consequently, the use of GIPV in making land-use decisions should be discontinued. Neither the USGS or any other agency should provide the decision makers with such a noisy and misleading measure of social value.

RESTRICTED GIPV (RGIPV) AS A PROXY FOR SOCIAL VALUE

CONCEPT IN GENERAL

In concept, GIPV could be made a much more useful proxy for social value simply by restricting the population of deposits upon which it is computed to those deposits that have potential for economic exploitation. This modified GIPV still would not be equivalent to social value, but it would not suffer from the two major defects identified above. For example, regions in the interior of Alaska having potential for several large porphyry deposits would be represented by zero GIPV when capital costs for requisite infrastructure, townsite, mine, and mill would be so large that when combined with Alaskan operating costs, none of the deposits could be econmically exploited. Similarly, even if the tonnage and grade populations were constructed entirely of deposits having tonnages and grades such that none of them would be economic, a region having the potential for many such deposits would be represented by zero GIPV. Since none of the simulated deposits would be economic, none of the metal that they contain would contribute to GIPV. Note that RGIPV, as defined here, does not include exploration costs.

THE NOTION OF A FILTER FOR MARK3

While in concept, restricted GIPV (RGIPV) is a much preferrable proxy for social value than GIPV as currently computed, its computation by the USGS with its current system, MARK3, is problematic, for it does not contain the requisite cost relations. Obviously, the USBOM, with its cost systems and economic impact system, could easily compute the required measure. If time and resources permit a cooperative effort with the USBOM, there is no need to approximate social value by RGIPV, for the USBOM could perform an impact (input-output) analysis and provide an estimate of social value that is better than RGIPV.

As indicated earlier, because of the short time often allowed for the USGS to respond to Congressional or other institutional requests for land-use decisions, there is, at least for the short run, justification for seeking an alternative to the full analysis made by a cooperative effort involving both the USGS and USBOM. Accordingly, one such alternative would be to develop economic filters for each deposit type and to include these filters in MARK3, or its replacement, so that each simulated deposit could be tested against the filter and GIPV computed using only those deposits that pass the filter. Here, the filter is a highly simplified proxy for the cost estimating system of the USBOM.

The foregoing discussion employed the notion of a filter to partition the simulated population of deposits into two sets, those that are economic and those that are uneconomic , with GIPV being computed only for deposits of the econmic set. In practice, this notion could be implemented in many different ways. At one extreme, the full CES of the USBOM could play the role of the filter, and only those deposits having a net present value of at least zero would be members of the economic set. This implementation would provide the greatest accuracy as well as the greatest capability for adapting to special cost factors, for example infrastructure costs, factor costs, e.g. fuel, labor, etc, and environmental considerations. But, this level of analysis is the same as that performed by the USBOM and employs a system that is maintained by the USBOM; consequently, analysis at this level is not likely without a cooperative agreement with the USBOM. At the other extreme, the entire cost estimating system is replaced with an equation for each deposit type that relates some measure of value to the principal cost determinants, which for mineral resource assessment for a given deposit type are deposit tonnage, grade, and depth. Between these extremes there is the use of simplified capital and operating costs within a subroutine for discounted cash flow analysis; together, the simplified capital and operating cost relations combined with the discounted cash flow analysis, determine whether a simulated deposit belongs to the economic or non-economic subset. The following sections provide additional comment upon this " in between" analysis and upon the use of an equation to perform the required filtering.

Discounted Cash Flow Subroutine Replete with Simplified Cost Relations

There is an implementation of the filter notion that approximates that of the full CES that could be performed by the USGS. That is the development of an evaluation subroutine that would be an integral part of MARK3 and which would employ simplified pre-feasibility cost relations estimated by the USBOM. Previous work by the USBOM to support mineral resource assessment, as well as economic evaluation of prospects preliminary to feasibility studies in general, led to the development of a set of relations that permit the estimation of capital and operating costs for infrastructure, mine, and mill (Gosling, Camm, Christiansen, Lemmons, and Gillette, 1987; Camm, 1989; Gunther, et al, 1989; US Bureau of Mines/Division of Policy Analysis, 1989, 1992). For example, consider the relations for Kuroko massive sulfides in Alaska, shown in Table 4.1.

Here, capital and operating costs for infrastructure and mine are a function of daily output of waste and ore, and daily output is a function of size and depth of orebody and life, with life being a function of orebody size. Obviously, these are simplified relations, but they are a useful means for implementing the filter notion, for since these deposits are all hypothetical, many of those features that affect cost must be ignored, focusing instead on the major features, such as deposit type, deposit size and grade, and deposit depth. Of course, as deposit types often are associated with generalized morphology, the cost relations developed

Table 4.1: Cost models for Kuroko massive sulfide deposits in Alaska, as estimated by the US Bureau of Mines.

Where Mine Life (L) = $0.2\,(T)^{0.25}$ and Capacity (C)= T/(350 x L)
T = tonnage

Cost Summary - Total Cost Equations
Capital Cost, $:

Infrastructure	$638{,}200.\,8\,(C)^{0.5582}$
Mine	$1{,}606{,}039.5(C)^{0.4532} + [7{,}184{,}000 + 7{,}056(D)]$
Mill	$60{,}753.5(C)^{0.7786}$

Operating Cost, $/mt:

Infrastructure	$293.7(C)^{-0.4704}$
Mine	$394.9(C)^{-0.3703} + [1.81 + 0.0013(D)]$
Mill	$90.3(C)^{-0.3703}$

Infrastructure capital costs, $

Labor	$176{,}546.6(C)^{0.5703}$
Equipment	$94{,}705.5(C)^{0.5703}$
Steel items	$44{,}112.9(C)^{0.0737}$
Fuel and lube	$17{,}418.8(C)^{0.4116}$
Explosives	$56{,}482.5(C)^{0.2875}$
Tires	$1{,}037.4(C)^{0.3146}$
Construction Materials	$314{,}693.4(C)^{0.5632}$
Industrial Materials	$5{,}653.3(C)^{0.5726}$

Infrastructure operating costs, $/mt

Labor	$129.7(C)^{-0.6178}$
Equipment	$35.2(C)^{-0.5065}$
Fuel & lube	$100.0(C)^{-0.5083}$
Industrial materials	$76.8(C)^{-0.3840}$

Cut-and-fill mine capital costs, $

Labor	$17{,}631.9(C)^{0.6815} + 4{,}112(D)$
Equipment	$1{,}695{,}041.6(C)^{0.4271} + [7{,}184{,}000 + 1{,}680(D)]$
Steel items	$1{,}313.0(C)^{0.6858} + 397(D)$
Lumber	$400.9(C)^{0.5855} + 10(D)$
Fuel and lube	$211.2(C)^{0.6284} + 168(D)$
Explosives	$2{,}942.4(C)^{0.6859} + 351(D)$
Tires	$398.2(C)0.5287$

for a given depost type reflect morphology and type of mining associated with that morphology. The milling cost relations include consideration of the typical mineral suite for that deposit type, the processing method, and the typical product, i.e. concentrates.

Clearly, use of these relations to perform the filtering operations would require that they be embedded in an evaluation algorithm, which itself would be a subroutine of MARK3, or its replacement. In essence, each simulated deposit would be subjected to an investment-type of evaluation, meaning the computation of net present value, when capital and operating costs for requisite infrastructure, mine, and mill are estimated by the simplified cost relations: GIPV would be computed only on those that have a non-negative net present value.

USE OF A MATHEMATICAL EQUATION TO IMPLEMENT THE FILTER--AN ILLUSTRATION

An alternative means of implementing the filter notion is to estimate an equation for each deposit type that relates the major cost determinants to the ratio of unit revenue to unit cost. For a given deposit type, those determinants are depth, tonnage, and grades of contained metals. Consider, for example, the following filter for epithermal gold deposits within a Latin American country as developed by Harris (1990):

$$\ln c = f\,(t, q1, q2, h, r, k),$$

where
t = tonnage of ore
q1 = gold grade
q2 = silver grade
h = depth to deposit
r = discount rate
k = multiplier of base prices for gold and silver: base gold price = \$350
base silver price = \$15
c = unit revenue/ unit cost

Thus, ln c = 0 separates the economic set from the uneconomic set, for when revenue exceeds cost, ln c is positive; when revenue and cost are equal, ln c = 0; and when cost exceeds revenue, ln c is negative.

The form utilized by Harris (1990) for f is the following:

$$\begin{aligned} \ln c = {} & -84.7641 + (9.7391 x 10^{-4} (q1) - 1.4292 x 10^{-10} (h) - 5.19 x 10^{-6})\, t \\ & + (2.8413 - 6.8254 x 10^{-4} \ln(h)) \ln t - 1126.1912\,(q1) + 0.4873\,(q2) \\ & + 0.1759 \ln(q1) + 7.3098 x 10^{-2} \ln(q2) - 1.0006 \ln(3.5\,(q1) + 0.15\,(q2)) \\ & + 2.0532 x 10^{-4}\,(h) + 0.27888 \ln(r) + 1.6570 (\ln([1 - e^{-10r}]/r)) \ln(k) \\ & + 48.1914\,(k) - 52.3444 \ln(k) - 21.5181\,(\ln k)^2 \end{aligned}$$

To facilitate a demonstration of the filter, we restrict our interest to the following:

- deposits that outcrop, meaning that h=1
- base price conditions, meaning that k=1
- r = 0.12, meaning a discount rate of 12 %
- gold deposits having silver grades of 0.05 %

Moreover, suppose that we wished to partition the t-q1 space into the economic and uneconomic subsets, meaning that we are interested in that boundary where ln c = 0, i.e. unit costs and revenues are equal. For this purpose, the above equation can be restated in filter form:

$$0 > -t + (-37.3584 - 1126.1912(ql) + 0.1759\ln(ql) - 1.0006\ln(3.5(ql) + 0.0075) + 2.8413\ln t) / (5.1901x10^{-6} - 9.7391x10^{-4}(ql))$$

where $0.00043 < ql < 0.0019$

This filter is shown in Figure 4.1 as the curve farthest from the origin. The second curve is a filter derived from the same cost equation but for higher prices ($420 and $18: k = 1.2) and greater depth to deposit (h = 500 ft.). As shown by the positioning of the second curve closer to the origin, the increase in revenue from higher prices overwhelms increased costs due to deeper mining; the economic

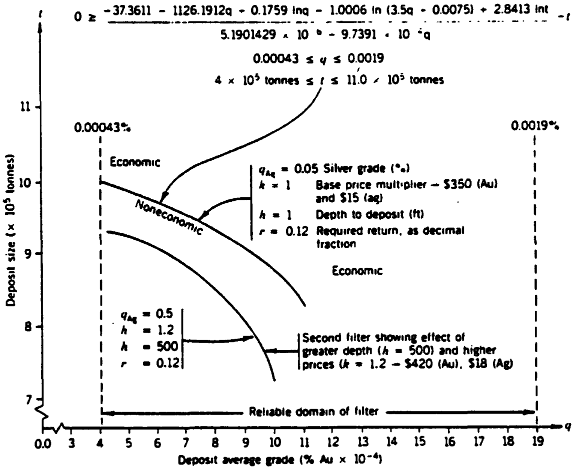

Figure 4.1: Economic filter for epithermal gold-quartz veins. Taken from Harris (1990).

set for the second filter is much larger than for the first, for it includes deposits of smaller size and lower gold grades.

Extending MARK3, or its replacement, to include the use of filters to identify economically exploitable deposits for which GIPV would be computed would be the easiest way to implement the computation of RGIPV, provided that the filters have been estimated previously. Obviously, implementation of RGIPV using formal filters requires an estimation of the filters.

FILTER ESTIMATION

First of all, it should be understood that a separate filter would be required for each deposit type. Filter estimation requires that for a given deposit type there are available either actual data or simulated data on:

- revenue
- prices of major and co- or by-products
- production cost
- deposit tonnage
- deposit grade
- depth to deposit
- discount rate

When actual data required for filter estimation are not available, the only recourse is to use simulated data. Of course, this approach is useful only if the simulation is representative of the real world, at least to some minimal acceptable degree. The epithermal gold filter described above was estimated from simulated data. As consideration of the motivation for the filter and the approach to estimation is instructive generally about the estimation and use of filters for mineral resource assessment and land-use decisions, a brief commentary is presented below.

The objective in the study that yielded the epithermal gold filter was to provide the Ministry of Mines as well as explorationists with a means for making a quick, prefeasibility, judgement about the economic viability of prospects without the implementation of complete cost estimation. As detail on a prospective deposit is meager in the early stages of exploration, there was a desire for some general indications of economic feasiblity without implementing a full mine and mill cost estimating system. In part, the motivation is convenience and cost effectiveness. Of course, the circumstances for mineral resource assessment are even worse with respect to information about those things that affect cost, for the deposits are hypothetical and no information is available about their physical features. Consequently, their economic analysis must, on apriori grounds, be predicated upon only the major cost determinants.

Generation of a filter for epithermal gold-silver deposits in the Latin American country from actual data was impossible because the requisite data were not available. Consequently, as the USBOM was cooperating in this study, the cost estimating system , CES, was used to simulate the data requisite for estimation of the filter equation. Using factor prices relevant to that country and capital and operating costs for infrastructure, mine, and mill estimated by CES, with adjustments as necessry for that country, the USBOM sytem produced net present value, unit revenue, and unit cost for specified gold and silver prices, discount rate, and selected tonnages, gold and silver grades, and depth. As indicated above, the logarithm of unit revenue to unit cost was related statistically by Harris to relevant explanatory variables.

Generally, estimation of filters for the computation of RGIPV by MARK3 or its replacement would have to be quite similar to that described above, meaning that as actual data are not available, cost relations and an economic evaluation program of some kind would have to be used to simulate the data requisite for filter estimation.

In a cooperative effort to support some specific land-use decisions, the USBOM has developed some highly simplified cost models by deposit type. These models could be used in place of the USBOM full CES and in conjunction with an evaluation algorithm to simulate the data necessary to estimate the filter equation. Quite a few filters could be developed using the simplified cost relations already estimated and described either in USBOM publications, open file reports, or reports on special studies. Those that are currently available are identified in Table 4.2. To use these to estimate filters would require a computer program to perform discounted cash flow analysis. For a specific deposit type, the available simplified cost relations would be employed to estimate capital and operating costs for infrastructure , mine, and mill, and these would be submitted to the discounted cash flow analysis program. This program serves as a "black box" that would compute various economic measures or criteria, such as npv and, unit revenue, and unit cost for specified prices (main and by- or co-products). These, along with associated tonnage, grades, and depth, would be written to an appropriate file; this file would contain one record for each combination of depth, tonnage, gold grade, silver grade, discount rate, and prices. Once all identified combinations of the cost determinants have been evaluated and written to file, the file serves as data for the estimation of the parameters of the filter equation.

Table 4.2: Deposit types and associated mine and mill cost models estimated by the US Bureau of Mines. Current to 11/92.

White Mountains National Recreational Area /North Steese National Conservation Area

Deposit Type	Mining Options	Milling Options
Polymetallic vein	Cut and Fill VCR > 2000mt/d	Polymetallic Flotation
Tungsten skarn	Open pit Shrinkage Stoping VCR> 2000 mt/d	W Flotation or gravity
Sediment hosted lead zinc	Open pit Room and Pillar	Pb-Zn Flotation
Alkalic-associated gold	Open pit VCR....?	Heap Leaching or CIP
Tin greisen	Open pit Cut and Fill VCR> 2000 mt/d	Sn Flotation/ gravity
Placer gold	Placer	Placer
Rare earth	Open pit VCR> 2000 mt/d	REO Flotation
Gold vein	Open pit Cut and Fill VCR> 2000 mt/d	Heap Leaching or CIP

Valdez Creek Mining District

Metamorphic gold	Overhand or cut and fill	
Copper Gold Skarns	Overhand, cut and fill	

Valdez Creek Mining District (continued)

Plutonic related vein and replacement gold deposits	Shrinkage, overhand or longhole sublevel
Basalt hosted copper	Longhole sublevel or vertical crater retreat
Carlin-type gold	Open pit
Plutonic related Sn greisen	Open pit
Gold, Silver, copper breccia pipe	Open pit and cut and fill
Deep placer gold	Open pit

Tonopah

Carbonate hosted (Carlin type)	Open Pit or Room and pillar	Heap leaching or Carbon in pulp
Comstock/Sado Epithermal	Cut and fill	Flotation or Merrill-Crowe
Hot Spring Gold	Open pit or Room and pillar	Heap leaching or Carbon in pulp
Polymetallic Replacement	Open pit or Room and pillar	Flotation
Polymetallic vein	Cut and Fill	Flotation

East Mojave National Scenic Area

Carbonatite REE	small open pit or long hole	1 prod. mill
Copper skarn	small/large open pit	1 prod. mill

East Mojave National Scenic Area (continued)

Fe skarn	large open pit or sublevel long hole	Fe crushing
Hot spring Gold	small/large open pit or block caving	Heap leaching
Pb/Zn Skarn	sublevel longhole	2 prod. mill
Low Fluoride Mo	large open pit or block caving	Heap leaching
Polymetallic Replacement and Polymetallic Veins	cut and fill or sublevel longhole	2 prod.Flot.
Porphyry Copper	small/large open pit block caving	1 prod. mill
Tungsten vein	sublevel longhole	1 prod. flot.

Juneau Mining District, Alaska

Alaska PGE (USGS Model #9	open pit 1,000-10,000 mt/d	Flot. 1 prod. Gravity 1 prod.
Cu Skarn (USGS Model #18b)	Open pit 1,000-10,000mt/d Sublevel longhole 500-5000 mt/d	Flot. 1 prod.
Mo Porphyry low F (USGS Model #21b)	Open Pit 10000-50000 mt/d Block caving 5000-25000mt/d	Flot. 1 prod.
Polymetallic Vein (USGS Model #22c)	Overhand stopes 100-500mt/d	Flot. 2 prod.

Juneau Mining District, Alaska (continued)

Kuroko Massive Sulfide	Open Pit	
(USGS Model #28a)	1000-10000mt/d	Flot. 2 prod.
	Cut-and-fill	
	400-4000mt/d	
Sedimentary exhalative	Open Pit	Flot. 2 prod.
(USGS Model #31a)	1,000-10,000 mt/d	
Vein Gold	Sublevel longhole	
(USGS Model #36a)	500-5000 mt/d	Flot. 1 prod.
	Overhand stope	
	100-500 mt/d	
Placer Gold	Placer 20-250 LCY/h	
(USGS Model #39a)		

West Mojave National Scenic Area

Copper Skarn	Small/large open pit	Flot. 1 prod.
(USGS Model #18b)	Block caving	
Hot Spring Gold	Small/large open pit	Heap leach
(USGS Model #25a)	Sublevel longhole	
Iron Skarn	Small/large open pit	Crushing
(USGS Model #18d)		
Lacustrine Borates (new)	Small/large open pit	Wash/
	Room and pillar	crystallization
Polymetallic Vein	Sublevel longhole	Flot. 2 prod.
(USGS Model #22c)		
Porphyry Copper	Small/large open pit	Flot. 1 prod.
(USGS Model #17)	Block caving	
Porphyry Copper-Gold	Small/large open pit	Flot. 1 prod.

(USGS Model #20c)	Cut and fill	

West Mojave National Scenic Area (cont.)

Quartz-alunite (USGS Model #25e)	Small/large open pit cut and fill	Carbon-in-leach(CIL)
Sado Epithermal Vein (USGS Model #25)	Small/large open pit Sublevel longhole	Heap leach
Tungsten Skarn (USGS Model #14a)	Sublevel longhole	Flot. 1 prod.
Tungsten Veins (USGS Model #15a)	Sublevel longhole	Gravity
Zinc-lead Skarn (USGS Model #18c)	Sublevel longhole	Flot. 2 prod.

Needles RMAP Projects, CA

Carbonatite REE (USGS Model #10)	Small open pit Sublevel longhole	REO mill
Comstock Epithermal Vein (USGS Model #25c)	Small/large open pit cut-and-fill	Carbon-in-leach(CIL)
Gold on flat faults (USGS Model #37b)	Small/large open pit Block caving	Heap leach
Hot-spring Gold (USGS Model #25)	Small/large open pit Sublevel longhole	Heap leach
Hot-spring Mercury	Small open pit	Flotation\ rotary kiln
Iron Skarn (USGS Model #18d)	Small open pit	Crushing
Polymetallic Vein (USGS Model #22c)	Sublevel longhole	Flot. 2 prod.
Sado Epithermal Vein (USGS Model # 25d)	Small/large open pit Sublevel long hole	Heap leach

Tin Skarn (USGS Model #14b)	Sublevel longhole	Gravity
Tungsten Skarn (USGS Model #14a)	Sublevel longhole	Flot. 1 prod.
Tungsten Veins (USGS Model #15a)	Sublevel longhole	Gravity

What about filters for other deposit models? For these, the USGS would have to either contract with the USBOM to develop the requisite simplified cost relations, or contract with a private firm for that work. Alternatively, the USGS could contract directly for the generation of the filters as well as simplified cost relations. In that regard, there already exist in the private sector full mine cost systems that could be used to simulate the data requisite for filter estimation, for example Mining Cost Service, Spokane Washington.

PARAMETERIZING OF FILTERS FOR REGIONAL VARIATIONS

A filter estimated for a specific deposit type in the interior of Alaska would not be appropriate to use in MARK3 to compute RGIPV for land-use decisions in California because of the much higher capital and operating costs in Alaska. One solution to this problem is simply to adjust the simplified cost relations for infrastructure, mine, and mill with regional cost indices and then to simulate the data for each region and estimate the filter by region as needed. Obviously, the relevant regional cost indices are an important part of this approach. Such indices are estimated and routinely maintained by the USBOM as part of their support of MAS; consequently, they are available upon request.

An alternative to the above approach, at least in concept, would be to include regional capital and operating cost indexes explicitly in the filter, meaning that the filter is parameterized on regional cost indices. Although estimation of such a filter is more complex and difficult, once satisfactorily estimated, it would be very convenient to use for the estimation of RGIPV. A filter developed for one deposit type could be used, say, for interior Alaska as well as Utah, simply by specifying in the filter equation the numerical values of the cost indices.

SUMMARY AND CONCLUSIONS REGARDING RGIPV

In summary, GIPV, as currently computed and used in land-use decisions should be replaced by RGIPV, which is the GIPV of only economically exploitable deposits.

A useful way to view the computation of RGIPV by the USGS is to envision filtering of the deposits simulated by MARK3 , or its replacement, to retain only those deposits that can be economically exploited, given specified prices. Given such filtering, RGIPV is the GIPV computed on the retained set of deposits, or stated differently, those deposits that are economically exploitable.

The filtering of simulated deposits within MARK3 , or its replacement, can be achieved by two different approaches:

1) estimating a filter equation and including it in MARK3, checking each simulated deposit against the equation to see if it can be exploited economically and computing RGIV on the economic subset;

2) including an evaluation subroutine in MARK3, a subroutine which consists of simplified cost relations -- infrastructure, mine, and mill capital and operating cost relations by deposit type--and processing each simulated deposit through the subroutine, computing RGIPV on those having a non-negative net present value.

As noted above, tne restricted GIPV is not social value, but it is a much more acceptable proxy than the unrestricted GIPV. The full implementation of an economic filter would require accounting for additional costs, such as exploration. Likewise, externalities pertaining to the sequence of development and infrastructure should be included in a more complete filter. Suppose that economic studies have been conducted for the deposit type under consideration and that these have estimated a RGIPV multiplier for the deposit type under consideration. An estimate of social value for that deposit type could be made by multiplying the RGIPV of economically exploitable deposits by the GIPV economic multiplier.

CHAPTER V -- ORE DEPOSIT MODELS

ORE DEPOSIT MODELS

OUTLINE

ORE DEPOSIT MODELS

This Chapter was written by Brian Skinner, with input from Larry Meinert, Richard Nielsen, Spence Titley, and Doug Cook.

INTRODUCTION

There are two steps in a traditional study of an ore deposit; first, the gathering and recording of all factual data both in the field and in the lab, and second, the preparation of a genetic model for the deposit within the bounds of the factual data. As pointed out by Roberts and Sheahan (1988), the two steps, the first empirical, the second conceptual, generate what has, in recent years, come to be called an "ore deposit model".

Because the U.S. Geological Survey assessment methodology is based on ore deposit models, it is helpful to briefly examine the modern history of the concept and to consider the purposes for which the models have been developed plus the tasks to which they have been put.

A BRIEF HISTORY OF ORE DEPOSIT MODELS

The term "ore deposit model" is a new one but the basic concept is an ancient one. For hundreds of years students of ore deposits have been measuring, sorting, recording, and classifying the multifarious data that can be gathered about a deposit. Attempts to group and classify deposits on the basis of the data bank have been numerous. One of the most influential classifications in the twentieth century was that of Lindgren (1932), but the practice of classifying is centuries old.

Those who classified deposits drew the logical conclusion that all deposits in a given class have similar origins. Indeed, the drive and purpose behind an exercise in classification is generally the insight it might provide about genesis. However, while there has long been a measure of agreement concerning the empirical geological features such as host rocks, alteration patterns and mineral assemblages that characterize a given class of deposit, there has commonly been an equally long history of discord concerning the genesis of the class.

The recent drive to sharpen both the empirical and the conceptual components of deposit models arises from two sources: (1), from a growing need to assess the undiscovered mineral potential of untested or partially tested tracts of land, and (2), from exploration geologists who needed help in the selection of places to explore for specific classes of deposits.

DEVELOPMENT OF ORE DEPOSIT MODELS BY THE U.S. Geological Survey

As the need to assess the mineral potential of public lands in the United States became more intense during the 1960's and 1970's, it became increasingly apparent that some kind of codification of the empirical characteristics of the various deposit classes was needed to help the assessors, many of whom were not experts on the geology of mineral deposits. The first major attempt to identify and assemble the essential features of various deposit classes--at least the first of which we are aware--was an internal U.S. Geological Survey document prepared in 1981 under the editorship of R. L. Erickson. The title of the Erickson volume is Characteristics of Mineral Deposits Occurrences and the sub-title is Guide Book for use as an aid in mineral resource assessment studies.

The terms "mineral deposit type" and "mineral occurrence model" rather than ore deposit model are used in the Erickson volume, but the three terms are synonymous. The Erickson volume is a landmark attempt by a large group of experienced survey geologists to sift out the essential characteristics of 48 different deposit classes using their personal knowledge to do so. In his foreword, Erickson made clear what was being attempted, and why. He wrote that the purpose of the guide book is to help "...our scientists to learn the different "languages" of different mineral deposit types. One of the ways to help us learn the "languages" is to develop mineral occurrence models that emphasize the geologic, geochemical, and geophysical environments and characteristics of different types of mineral deposits--and to compile the models into an easily modified and continually expanding working guidebook for project-level geoscientists". The Erickson guide seeks to identify the distinctive characteristics of a class. This goal was chosen because assessors reason that if some of the distinctive characteristics are present in a given area, then the assessor may infer that an orebody also is present at a specified probability. The Erickson volume addresses the empirical component of an ore deposit model and because it was not prepared as an exercise in the conceptual component, the genesis of deposits is rarely mentioned. Nor is the question of the actual probability of an ore deposit being present addressed as a specific issue.

The Erickson volume was followed, in 1986, by the publication of an extremely influential U.S. Geological Survey Bulletin titled Mineral Deposit Models. Edited by D. P. Cox and D. A. Singer, U.S. Geological Survey Bulletin 1693 presents 87 descriptive deposit models based on the combined work of a large group of Survey scientists and a number of outside experts. Bulletin 1693 is at the core of the U.S. Geological Survey assessment methodology so it will be commented on later in this chapter.

Following the appearance of Bulletin 1693 a long list of new models plus a number of updated models have appeared as U.S. Geological Survey Open-File Reports. The most significant publication, however, is Bulletin 2004, edited by J. D. Bliss (1992), titled Developments in Mineral Deposit Modelling. Bulletin 2004 introduces six new descriptive deposit models and nine new or revised grade and tonnage models but, more importantly, the publication of Bulletin 2004 demonstrates that the U.S. Geological Survey is continuing to refine existing models and to develop new ones, albeit rather slowly.

ORE DEPOSIT MODELS IN CANADA

Commencing in the early 1980's, a series of papers discussing individual deposit classes was published in the journal Geoscience Canada. Written by well-known experts, the series was initiated by J. M. Allen during his term as Chairman of the Publications Committee of the Mineral Deposits Division of the Geological Association of Canada. In 1988, the twelve deposits models published up to that time were gathered into a reprint volume under the editorship of R. G. Roberts and P. A. Sheahan (1988).

Entries in the Roberts-Sheahan volume are closer to traditional review papers in which the characteristics and genesis of a class of ore deposits are discussed than to the bare-bones, empirical deposit models published by U.S. Geological Survey They also have a somewhat different purpose in that they are meant to aid in exploration rather than in assessment.

Within the Geological Survey of Canada, deposit modelling had also taken root by the early 1980's. Three years after the appearance of the Erickson volume the staff of the G.S.C. published Canadian Mineral Deposit Types: A Geological Synopsis under the editorship of O. R. Eckstrand (1984). Like the Erickson guide, the G.S.C. volume is a synopsis of deposit types prepared by geologists "as a byproduct of their continuing studies of Canadian mineral deposits". It is hardly surprising that there are many similarities between the Erickson and Eckstrand volumes. However, the purpose of the Eckstrand volume differs markedly from that of the Erickson volume. Where the U.S. Geological Survey volume was designed to aid in the assessment of what might be present in a given area, the G.S.C. volume attempts to set out the features that could be useful in the exploration of new ore bodies wherever they might occur. The G.S.C. volume pays considerable attention to ideas about the genesis of deposit types but the empirical components of both the U.S. Geological Survey and the G.S.C. models are similar.

AN AUSTRALIAN APPROACH

An alternative to ore deposit models as developed in North America was presented by Large at a meeting of the Australian Institute of Mining and Metallurgy in 1992. Large was and is principally concerned with the use of models as exploration tools and he insists that all deposit models should therefore include a genetic model as well as exploration criteria based on geologic, geochemical, and geophysical data. A genetic model, according to Large, should be built on three primary concepts: source, transport, and trap. There are many similarities to the model of a petroleum pool in the Large concept. As Large sees it, an ore deposit model can be derived either from the study of known deposits or it can be based entirely on theoretical considerations. Such a marriage of observational and theoretical data allows for prediction and testing in lesser-known geologic environments where models based solely on observed characteristics and historical production data provide little guidance.

COMMENTS ON HISTORICAL DEVELOPMENTS

As emphasized by Roberts and Sheahan (1988) there are two components of an ore deposit model--the empirical and the conceptual. The empirical component, which is an assemblage of data that characterizes the deposit, can be further subdivided into observational data and statistical data (often referred to as grade-tonnage models). The conceptual component attempts to interpret the data through a unifying theory of genesis.

Depending on the balance between the empirical and conceptual components there can be many types of ore deposit models. There are also many different uses and users for the models. Most users of ore deposit models employ them in guiding their exploration for new deposits. This is particularly effective when new ideas concerning a model are focussed in existing programs; for example, seeing familiar rocks in new ways.

The use of deposit models for resource assessment involves many fewer people than are involved in exploration, but the use-rate is increasing. Resource assessment can be carried out on either a commodity scale or a geographic scale. The use of models in resource assessment on a commodity scale has been carried out for many years, particularly for commodities such as diamonds and gold. The goal of such studies is to estimate worldwide supply and demand.

The employment of ore deposit models in geographic resource assessments, particularly by governmental agencies, is an emerging use. The goal of such programs is to delineate possibilities in a specific area chosen on cultural rather than geologic grounds; it is not to find individual orebodies. It can even be argued that one goal of geographically constrained resource assessment is to identify ore deposits so they will not be mined in a specific geographic area.

The different uses of ore deposit models require different approaches to their construction and, in the extreme, may require different models. As noted earlier, exploration companies use ore deposit models to identify places to look whereas assessment efforts start with the place being defined. It can be argued that exploration practice is additive; the search is for an accumulation of positive features that match important elements of a model. In contrast, assessment practice is at least partly subtractive; areas which lack essential features of a model are removed from further consideration so that attention can be focused on areas which may contain a particular deposit type. This suggests that ore deposit models used primarily for exploration should emphasize features which can be indicative of mineralization whereas ore deposit models used primarily for assessment need to include those features which are essential and would be grounds for elimination of certain regions.

The fundamental difference in end use affects not only model development but also application. Explorationists accustomed to accumulating evidence as a reason for testing a particular target may need guidelines or retraining for the different task of evaluating a region's potential for not containing ore bodies.

THE USE OF ORE DEPOSIT MODELS IN RESOURCE ASSESSMENT

Ore deposit models, when used for geographic resource assessment, must be linked to economic models in order to evaluate potential costs of development and production. Such economic models can vary in sophistication from simple cost filters using empirical estimates of production costs to complex models incorporating databases for complete socio-economic development. Regardless of the sophistication desired, a deposit model must have sufficient depth and extent to meet the demands placed on it.

All ore deposit models, whether used for resource assessment or for exploration, use similar data and have the same need for timeliness. Observations and new data are continually being generated so that a published model is out-of-date the moment the ink dries on the page. Maintenance of the database for deposit models in a traditional venue such as a book or a journal, therefore, has obvious limitations. The first and most obvious difficulty with the models published in Bulletins 1693 and 2004, as well as in Open-File reports, is that they are static.

An obvious solution to the problem of static models is to move to electronic versions of ore deposit models. We recognize that a solution to the timeliness problem may raise questions of access, confidentiality, and sponsorship, but it is a venture that should be commenced. Ideally, a joint venture could be carried out with other geological surveys around the world so that models could be continually updated from a global database.

With respect to the basic deposit model documents used by the U.S. Geological Survey (that is, Bulletins 1693 and 2004, plus numerous Open File reports), a number of questions must be asked. The most important questions are:

1. Is a complete range of deposit classes included?
2. Should existing models be lumped or split to facilitate more effective use?
3. Are the model descriptions adequate?

RANGE OF DEPOSIT CLASSES

The U.S. Geological Survey deposit models for metallic mineral deposits are as complete as is practical. Among the kinds of deposits known to occur in North America we did not find any gaps. Even classes of deposits that have not yet been discovered in North America, such as Noril'sk-type Ni-Cu-PGE deposits are included.

Bulletin 1693 pays little attention to non-metallic mineral deposits. Some deposit classes, such as sedimentary phosphates, bedded barites, and diamond placers are included in Bulletin 1693, but most of the non-metallic deposit models that have been completed have not progressed beyond Open-File Reports (especially Reports 91-11A and 92-437). It is important that the non-metallic deposit models be published as quickly as possible and that the deposit classes be expanded to be as inclusive as possible.

The addition of non-metallic deposit models raises the question of what kinds of natural resources should be evaluated in a resource assessment? Most assessments are done for the purpose of making land use decisions. For exclusive-use restrictions such as wilderness designation it seems important that all alternative uses and resources be evaluated. Most biological and scenic resources are evaluated by other agencies such as the US Forest Service and BLM. Important resources which are within the purview of the U.S. Geological Survey include minerals (both metallic and non-metallic), water, and energy (fossil fuels, geothermal, and hydropower). Current assessments completely ignore the latter two and deposit models for non-metallic and industrial minerals are incomplete. This is a large task but it would appear that in the future the U.S. Geological Survey increasingly will be asked to assess these other commodities. Water resources, particularly groundwater, may become the most important resource questions of the next century and the U.S. Geological Survey should start planning for how assessment methodologies and deposit models can be extended to meet this new challenge.

SHOULD MODELS BE LUMPED OR SPLIT FOR MORE EFFECTIVE USE?

The question of lumping and/or splitting of deposit classes in order to sharpen the models was discussed at length during the conference. The consensus is that it is not a major issue. Lumping and/or splitting can be done as appropriate work indicates the need.

The panel discussed the deposit models in Bulletin 1693 and only seven were singled out as likely candidates for splitting. These are:

Model 17, Porphyry coppers
Model 22, Polymetallic veins
Model 25, Epithermal deposits
Model 28, Volcanic-hosted massive sulfides
Model 29, Quartz-pebble conglomerates
Model 30, Sediment-hosted massive sulfides
Model 34, Iron formations.

In each of the cases listed above panelists pointed out that there are major, sharply defined subgroups within the class and that Bulletin 1693 may well have obscured essential differences by loosely lumping the deposits together. A similar criticism has been levelled by Bultman et al. in their commentary on the "three-step" method of assessment.

ARE MODEL DESCRIPTIONS COMPLETE?

When preparing models for use by assessors, the goal should be, as Barton (1986) pointed out, the specification of the "essential characteristics" of a deposit class. The question whether essential characteristics can be unambiguously and certainly identified is, of course, at the heart of the controversy, because it is a major piece of the question whether or not it is possible to determine both the necessary and the sufficient condition for formation of a given deposit. Panel members are in accord that it is probably not possible to specify essential characteristics with such precision that the sufficient conditions will ever be reliably spelled out. This means that every effort should be made to continually refine and update the data base so that the necessary conditions can be identified. In particular, it important that the issue of scale of the necessary conditions be recognized. For example, some terrains may appear to be permissive on a local scale but when viewed on a broader scale might be seen to be non-permissive. One of the suggestions the panel offers to U.S. Geological Survey deposit modelers is that they broaden the scale of the characteristics looked at to at least the scale of a terrain.

The concept of geologic time also needs to be included systematically in ore deposit models. Many ore deposits, such as BIF, kimberlites, and Ni-komatiities occur in restricted intervals of geologic time. Some deposits have different characteristics during different time periods. Obvious examples include metal ratios (VMS deposits were more copper-rich during the Archean and more lead-rich during the Phanerozoic) and size (sediment-hosted Pb-Zn deposits were notably larger during the middle Proterozoic).

It may be useful to develop a series of "modifiers" such as geologic time, supergene enrichment, etc. which can be used to clarify or interpret individual deposit models. These "modifiers" can be the subject of ongoing research and classification independent of the development of a particular ore deposit model.

A further addition to ore deposit models is a category for ore deposits which do not fit established models or which are not yet well-described (and perhaps undiscovered). This miscellaneous category could be developed to assess terrains which do not appear to have any potential for known types of ore deposits. It may be desirable to evaluate this category qualitatively or at least use a different quantification scheme than applied to deposits with known tonnage-grade distributions.

CONCLUSIONS AND RECOMMENDATIONS

Empirical and conceptual models of ore deposits are powerful tools for both assessment and exploration, but the tools differ in the two cases. Assessment models place a greater reliance on empirical, observational data, while exploration places a greater reliance on conceptual models. Both assessment and conceptual models draw on the same data base, however, and both have a vital need for the data base to be as current and complete as possible. The first recommendation is, therefore, to:

1. Move the U.S. Geological Survey deposit models from hard copy to an interactive electronic system and make that system widely accessible both in and out of the Survey.
   Recognizing that the data-base from which deposit models are built rests in no small part in the cumulative experience of geologists outside the U.S. Geological Survey.

The second recommendation is to:

2. Include a number of industry and academic geologists in the process of refining deposit models. For each model select a small team and charge that team with the task of refining and updating the model. Insofar as possible, try and include members of surveys in other countries in the process.
   The development of good and reliable deposit models needs the best scientists the U.S. Geological Survey can assign to the task. The third recommendation is, therefore, to:

3. Make the development of reliable deposit models a major research effort in the Survey, not just for the roles models play in assessment, but for their great importance in exploration.

Full assessment of the mineral potential of an area requires that many commodities be considered in addition to metallic minerals -- examples are nonmetallics, water and geothermal power. We therefore recommend that:

4. The Survey broaden the range of commodities covered in resource assessments.

CHAPTER VI -- TONNAGE AND GRADE DISTRIBUTIONS (CURVES)

TONNAGE AND GRADE DISTRIBUTIONS (CURVES)

OUTLINE

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TONNAGE AND GRADE DISTRIBUTIONS (CURVES)

PERSPECTIVE

ROLE IN ASSESSMENT

Tonnage and grade distributions are vital components of mineral resource assessment, for they are used in three very important assessment tasks:

1) estimation of number of deposits;

2) converting number of deposits to quantities of metal(s);

3) estimation of costs.

A hallmark of the USGS assessment methodology is the use of tonnage and grade distributions as a window through which a geologist examines the geology of the area for the purpose of estimating number of deposits. Rationalizations for this approach include 1) the geologist's estimate of number of deposits should be consistent with size and grade characteristics of known deposits, and 2) all geologists should estimate number for the same population of deposits, namely the one depicted by the tonnage and grade distributions. In principle, these rationalizations are very appropriate.

Tonnage and grade distributions contribute to the assessment process in two other very important ways: 1) they provide the basis for the estimation of capital and operating costs; and 2) they describe the amount of metal to be associated with each deposit simulated in MARK3, or some similar program. For a given deposit type, the primary determinants of cost are deposit tonnage and grade (grades if multi-metal), along with depth. Generally, capital costs for infrastructure and mine are strongly related to tonnage of waste plus ore, and tonnage of ore is determined by cutoff grade. Of course, cutoff grade, which also determines average grade, reflects all costs, but especially milling operating and capital costs.

Thus, both the number of deposits estimated by the geologist as well as the economics of those deposits are predicated in part, either directly or indirectly, upon tonnage and grade distributions. Because of these important roles in the assessment process, and because of geologic issues regarding the underlying deposit classifications, the distributions themselves are frequent targets of harsh criticisms. Accordingly, one of the specific subjects identified in the RFP for this study is the appropriateness of the tonnage and grade distributions for assessment.

Criticisms are beneficial when they lead to modifications that improve assessments. When judged by this criterion, however, not all criticisms of tonnage and grade distributions are beneficial. Since these distributions are fundamental to assessment and are at the same time inseparable from associated deposit modeling, they receive many different kinds of criticisms. Accordingly, there is a need for a basis for judging the merits of various criticisms. The following section develops this idea.

KINDS OF CRITICISMS

Criticisms of the tonnage and grade distributions fall in the following major classes:

1) taxonomic

2) geologic

3) economic

4) statistical

Given the important roles that these distributions play in mineral resource assessment, they should be, and are, criticized from all four of the perspectives identified above. However, for these criticisms to be useful, they should not be made in total isolation from each other, nor should they be made without regard to the assessment objective.

CONCEPTUAL FRAMEWORK FOR EVALUATION OF TONNAGE AND GRADE DISTRIBUTIONS

PROPOSITION

The proposition made here is important for evaluation of the tonnage and grade distributions:

Judgements about tonnage and grade distributions are of little value except with regard to assessment objective and methodological framework to achieve that objective.

In other words, there are dependencies between the assessment objective (i.e. land-use decision, resource adequacy, potential supply), the components of the assessment methodology , and the required properties of the tonnage and grade distributions (i.e. the properties of the deposits that comprise the distributions). The import of these dependencies is that it is futile to criticize the tonnage and grade distributions without consideration of the roles that they play in achieving the assessment objective.

ASSESSMENT REQUIRES PREDICTIVE SCIENCE

PREDICTION

Perhaps, that perspective most important to making useful criticisms of the tonnage and grade distributions is that

the three-step assessment procedure requires the geologist to use his science, experience, data, and information to predict unseen states, i.e. numbers of deposits and their characteristics.

Recognition, and acceptance, of prediction as necessary, should lead to a second important recognition: Those who have studied subjective assessment of uncertain events, e.g. the presence of n undiscovered deposits, for which related information is available, i.e. geology, have found that:

the best predictions are made by those who formulate a model, a simplification of the real world, as an aid to perception and reasoning and use that model for the evaluation of information and for prediction, and

deposit models with their accompanying tonnage and grade distributions are models that can assist the geoscientist in his prediction, which in this case is the assessment of undiscovered mineral resources.

Forgetting or suppressing the requirement that assessment is predictive and that there are dependencies between deposit models, tonnage and grade models, assessment objective, and methodology may lead to purist positions regarding the above four classes of criticisms. While such criticisms may be technically correct, they may not be useful.

THE UNIQUENESS SYNDROME

Probably, the most obvious and prevalent example of criticisms that are technically correct but not useful are those that arise from the natural inclination of an economic geologist to view each deposit as unique. Unfortunately, while such an inclination may be good descriptive science and scientifically "safe", it obviates the construction and use of models to assist the geologist in prediction.

Another version of the "uniqueness syndrome" is to view deposits within metallogenic provinces as unique, thereby denying their use to predict deposit occurrences within an unexplored area outside of the province. The point here is not that the geoscientist can not justify uniqueness in some regard, nor is it that there are no unique features. Rather, the point is that uniqueness for uniqueness' sake may be an unnecessary, nonuseful complication if those unique features are not useful as a basis for prediction. Furthermore, Fishburn (1983) suggests that it is through generalizations present in models that experts are able to make subjective estimates. With a loss of generality, the ability of an expert to estimate is diminished by the heuristic bias of specificity.

When prediction is the objective, **commonalities that can be used as a basis for prediction are more important than unique features that are scientifically interesting but not useful in prediction.**

FEATURES THAT AID PREDICTION

COMMONALITIES AND SIMPLE STRUCTURE

Assessment is facilitated by identifying a classification of deposits by those features that are in common and which aid prediction. Unique features that can be recognized and used in assessment should be part of the basis for distinguishing deposit types. Unique features that are not useful in that regard should not be a basis for classification.

The study by Harris and Carrigan (1981) demonstrated very dramatically that many geological features identified by expert geologists as characteristic of formation and preservation of tabular sandstone uranium deposits were not used by the experts in the estimation of undiscovered uranium resources. In that study a prototype expert system for the assessment of uranium endowment was constructed for each expert geologist. Subsequent to calibration of his model, each expert assessed undiscovered uranium endowment by responding to questions generated by his expert system.

The final calibrated system employed by each geologist was considerably simplified when compared to his initial specification. Generally speaking, this simplification eliminated from the decision model those processes or conditions which are associated with the uranium deposits but for which the geologist has little understanding about how their presence or intensity influences uranium endowment.

In other words, although feature x may be commonly observed to be associated with a specific deposit type, its role in deposit genesis either may not be known or, if known, it may not be important enough to be one of the criteria used in prediction. This fact was not fully appreciated by the expert geologists until they were forced to describe how variations in the geologic conditions or processes of their decision (expert) model were related to variations in uranium endowment. When prediction of uranium endowment was used as the window through which geological information was evaluated, the number of geologic factors or processes, and their qualifiers, was severely reduced, and in some cases the factors themselves were modified.

TONNAGE AND GRADE DISTRIBUTIONS AS STATISTICAL POPULATIONS AND AS CHECKS ON DEPOSIT CLASSIFICATION

For an assessment to be most useful, it is important that deposit classification be scientifically credible and defensible. And, since assessment is predictive science, based upon subjective probability, it is equally important that the bases for prediction be statistically sound. In that the tonnage and grade distributions represent populations of deposits, it is desirable that the implied population associated with a deposit type exhibit certain features, such as unimodality.

Unimodality itself is not required by the roles that the tonnage and grade distributions play in assessment. Its importance arises from the questions that multimodality raises about the deposit classification used to identify members of the tonnage and grade populations. Generally, the presence of multiple modes reflects either a nonrandom sampling process or the mixing of two or more statistical populations. When a classification of deposit types and the identification of known deposits mixes populations in which the deposits differ considerably in tonnage, grade, or mineral suite and associated grades, this mixing will be manifest by multimodes in either grade or tonnage distributions. Simply stated,

since deposit tonnage and grade(s) are geologic phenomena, the presence of two or more modes in at least one of the distributions may indicate two or more classes of deposits that differ in geologic processes or conditions of deposit formation and preservation.

Thus, when multimodes appear in the process of constructing tonnage and grade distributions (curves), the geologist should re-examine his taxonomy for evidence that two or more geologic populations have been mixed. This can be particularly useful if the unmixing of the population can be related to geological factors that are useful in prediction. If a geological basis for the multimodality can not be found, it may be due to nonrandom sampling by the exploration process.

SCIENTIFIC REFINEMENT VERSUS SIMPLE STRUCTURE--A DIFFICULT BUT NECESSARY TRADEOFF TO AID PREDICTION

Interestingly, the examination of the statistical properties of tonnage and grade distributions, as described above, has been criticized by some geologists as either irrelevant or as placing inappropriate importance on statistical issues, implying that attention should be placed solely on geological issues. Probably, some of these comments fail to appreciate the fact that the statistical properties of the distributions are examined in part as a check against using a taxonomy that is too broad, which would result in the mixing of deposit types that are fundamentally different in some important geological regards. Probably, other criticisms arise from lack of appreciation that predictive science, e.g. assessment of undiscovered deposits, may justify simpler structure, as pointed out in the foregoing.

Obviously, no geoscientist would be satisfied scientifically with a taxonomy that appears to him to be ad hoc geologically, no matter how desirable the associated population of known deposits is in terms of statistical properties. Clearly, the ideal taxonomy would 1) be as simple as possible and at the same time scientifically acceptable and 2) lead to populations of known deposits that exhibit desirable features. Obviously, finding a taxonomy that is ideal to all geologists is virtually an impossibility when trading off scientific refinement with simple structure for prediction. For that matter, deposit taxonomy has always been a subject of scientific disagreement, and still is, as evidenced by the different taxonomies that have been constructed by noted geoscientists.

When taxonomy is simplified to facilitate prediction, it is foregone that there will be considerable scientific disagreement with that taxonomy. Just what the structure of that ideal taxonomy is will be a subject of scientific inquiry for some time, for as we learn more geologically, desirable taxonomies tend to change, at least in some regards. Moreover, when resource assessment is the objective, the taxonomy, and associated tonnage and grade distributions, should be judged not just by scientific credibility and completeness but also by their contribution to quantitative assessment. Generally, this standard of evaluation leads to simpler taxonomy and broader classes. Interestingly, the Conference Panel also suggested that some deposit types, e.g. epithermal gold, had been too highly subdivided and that in general simpler structures are preferred to those that are complex and highly differentiated.

SUMMARY COMMENTS

In summary, 1) the tonnage and grade distributions represent both statistical and geological populations; 2) a deposit type taxonomy must be judged by how useful it is in prediction as well as how credible it is scientifically; and 3) statistical properties of the tonnage and grade distributions are useful checks on the appropriateness of the underlying deposit type taxonomy.

USGS Bulletins 1693 and 2004 were constructed in accordance with the foregoing perspectives. Accordingly, both the deposit models and the tonnage and grade distributions should be evaluated with regard to the objective of scientific prediction.

IMPORTANT DEPENDENCIES

STRUCTURE AND RELEVANCE OF THIS SECTION

This section examines the notion of dependencies between requisite features of tonnage and grade distributions and assessment objective and methodology. This is done by postulating two very different assessment objectives --land-use decisions and potential supply, or long term resource adequacy--and by examining the features of those tonnage and grade distributions, along with assessment methodology, that are necessary to achieve these two objectives. The purpose of this is to establishes a useful reference for the examination of the tonnage and grade distributions of Bulletin 1693 and their current use in assessment. The first circumstance to be examined is a constrained case of land-use decisions, for this is similar in some regards to the current use of assessments, although the circumstances differ in purposefully contrived but revealing ways.

CASE I---LAND-USE DECISIONS

CIRCUMSTANCES

Consider the assessment of a region to assist the making of a decision on land-use. Moreover, so as to more clearly reveal the dependencies, let us make the following assumptions about the circumstances attendant to the assessment:

1) assessment is for a single deposit type and that type occurs in only one geologic environment within the region;

2) permissive areas are easily and unambiguously identified;

3) relevant prices and technologies are similar to those at present and in the immediate past;

4) the region has received little or no exploration;

5) good data on discovered deposit densities and on deposit tonnages and grades are available on numerous explored areas;

6) the well explored analogues are very similar geologically to each other and to the region to be assessed, at least they appear to be so when judged by observed geologic information;

7) exploration intensities of the explored areas are very similar, and exploration is strongly size biased, meaning that the large deposits are discovered early and preferentially;

8) assessment methodology is expert judgement supported by relevant experience and analogue data, and elicited as subjective probabilities.

THE CONSTRUCTION AND USE OF ANALOGUES

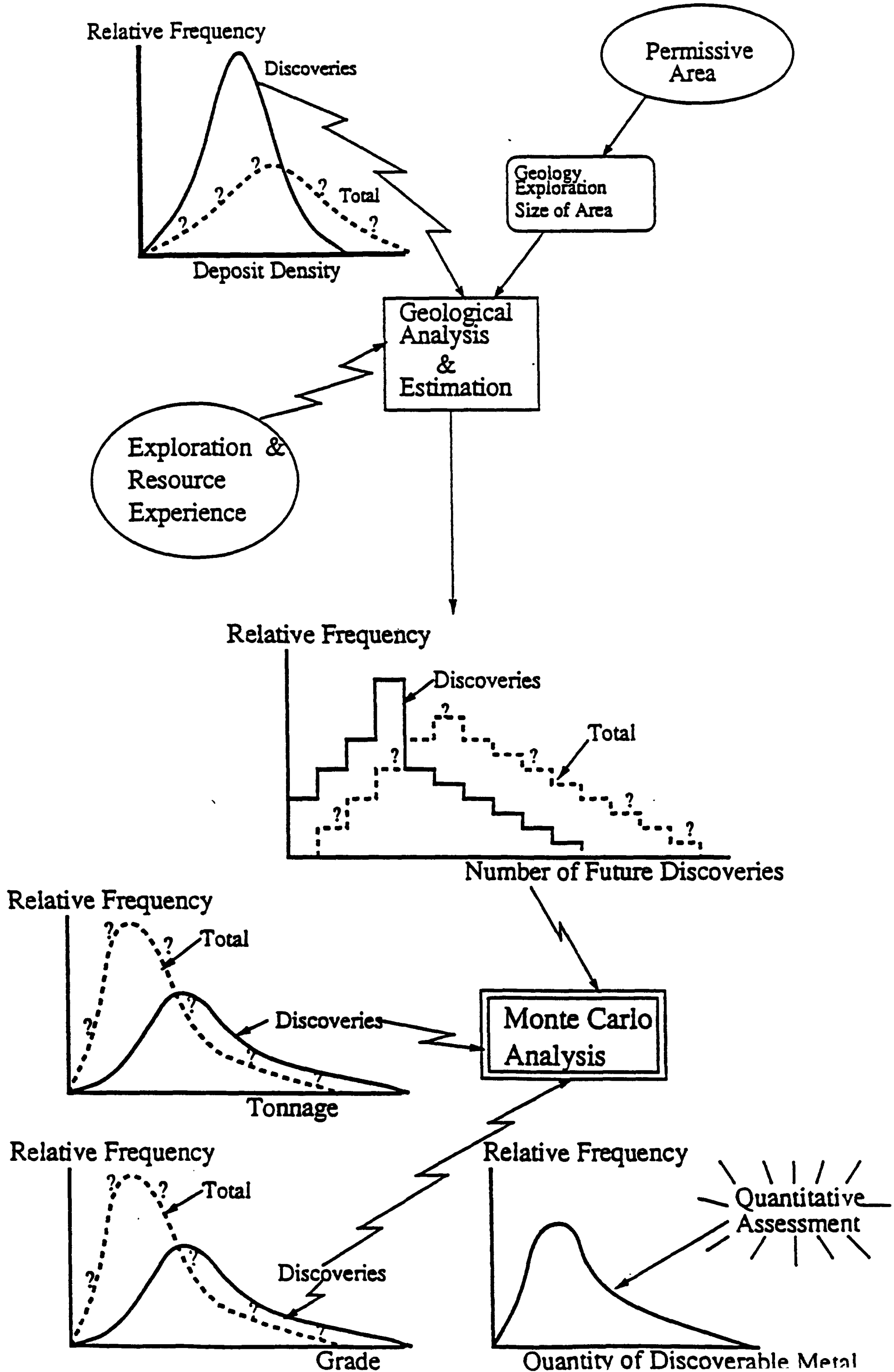
The foregoing circumstances are very favorable for assessment in that they reflect an abundance of information that can be used by the geologist as reference for the estimation of number of deposits in the permissive areas of the region. For example, since the well explored areas do not differ significantly in either observed geology or exploration intensity and since they are all very similar geologically to the unexplored region, at least in terms of observed geology, variation in density of discovered deposits reflects natural variation in endowments. Thus, a histogram of discovered deposit density (e.g. number of deposits per square mile) constructed from the well explored areas would be very useful support of the geologists' estimation of number of deposits in a permissive area of the region.

DENSITIES OF DISCOVERIES VERSUS DEPOSITS IN NATURE (ENDOWMENT)

Consider Figure 6.1, which depicts a smoothed curve (solid line) fitting, labelled discoveries, to the relative frequency histogram for discovered deposit density. Note a second curve (broken line), labelled total. This curve represents the distribution of deposit density if all deposits in the endowments of the explored areas had been discovered. Naturally, as exploration is controlled by economics, the number of discovered deposits differs considerably from the number that exist when exploration is strongly size biased, as hypothesized in this illustration.

Figure 6.1

Analogue Information



NUMBER OF DEPOSITS DISTRIBUTION

Given the specified circumstances, an estimate of the probability distribution for number of discoverable deposits for a permissive area can be created from the density distribution for discoveries simply by multiplying each density by the area of the permissive area and plotting the associated probabilities on the transformed axis. Such a distribution is shown schematically in Figure 6.1. Here, as with deposit density, a second distribution also is depicted, which is the probability distribution for number of deposits in the endowment.

USE OF DISCOVERIES DISTRIBUTIONS TO ESTIMATE GIPV

Suppose that our objective is to determine the probability distribution for GIPV for discoverable deposits, using a specified price for contained metal. As with the current USGS methodology, this requires the simulation of deposit tonnage and grade for each simulated deposit and the multiplication of price times contained metal. In Figure 6.1, this is shown by subjecting the number, tonnage, and grade distributions for discoveries to Monte Carlo simulation, creating the distribution of GIPV of metal contained in discoveries. For the specified circumstances, this is the desired and appropriate distribution.

USE OF DISTRIBUTIONS OF DEPOSITS IN THE ENDOWMENT IS AN INCORRECT PROCEDURE

In contrast, the distributions for deposit tonnage and deposit grades for deposits of the endowment, depicted by broken lines, are not the appropriate distributions for the established circumstances. For many other circumstances, it may be desirable and useful to know the distribution of deposit tonnage and grade in the endowment. Even though generally desirable, those distributions are not appropriate for the circumstances described.

The important point to be made here is that **for the specified circumstances, the desired GIPV distribution is obtained from the number of deposits distribution and tonnage and grade distributions for discoveries. Moreover, it would be incorrect to use tonnage and grade distributions for deposits that comprise the endowment when the number of deposits distribution is for discoveries, given the circumstances specified.**

Suppose that contrary to the foregoing directions, we replace tonnage and grade of discoveries by tonnage and grade distributions for the endowment. Otherwise, the analysis is the same as that depicted in Figure 6.1. Clearly, the GIPV that would be generated with tonnage and grade distributions for the endowment would not represent that of discoveries, which was the stated objective. In this case, the GIPV would severely underestimate the desired objective (GIPV of discoverable deposits), because number of discovered deposits would be incorrectly associated with the full range of tonnages and grades in the endowment, many of which would be too small to be discovered by an exploration process that is strongly size biased.

CRITICISMS OF TONNAGE AND GRADE DISTRIBUTIONS ARE APPROPRIATE ONLY WHEN THEY CONSIDER BOTH THE ASSESSMENT OBJECTIVE AND THE METHODOLOGY

This illustration was purposefully conceived to deal with the issue of tonnage and grade distributions of discoveries versus endowment, because one of the most common criticism of the empirically developed tonnage and grade distributions is that they do not represent deposits as they occur in nature. There can be little doubt that this criticism is accurate. But, these distributions were never intended to represent anything other than discoveries. Moreover, note that whether or not this is important depends upon the objective of assessment and the methodology for achieving that objective. Given the circumstances cited for this illustration, using endowment tonnage and grade distributions in MARK3 would be a serious mistake, as it would introduce an inconsistency between number and the tonnage and grade distributions. Moreover, the resulting estimate of GIPV would be a less desirable estimate than that based upon the tonnage and grade distributions for discoveries.

AN ALTERNATIVE CORRECT PROCEDURE THAT USES DISTRIBUTIONS BASED UPON DEPOSITS THAT COMPRISE THE ENDOWMENT

Procedure

It is instructive to note that the desired distribution could indeed be obtained using the distributions for tonnages and grades in the endowment if:

- the number distribution represented number of deposits in the endowment, and
- the Monte Carlo Simulation program contained a subroutine to simulate exploration and discovery.

Of course, these are demanding circumstances and differ considerably from the simple analysis described in Figure 6.1. As described above, the simulation program does not contain an exploration subroutine and the number distribution is for discoveries, not endowment.

Requirements

In concept, the desired objective, GIPV of discoverable deposits, could be achieved using distributions for number and for tonnage and grade of deposits that comprise the endowment, provided that MARK3, or its equivalent, is replete with a subroutine that generates discoveries that are consistent with the economic allocation practiced by industry. Note, however, that even if this requirement were met, **implementation of this approach requires that the requisite distributions (number of deposits, deposit tonnage and grade(s)) of deposits that comprise the endowment either be known or can be usefully estimated.**

Clearly, this requirement presents great difficulties: Since exploration is generally not exhaustive, we never have the actual data necessary to describe number of deposits or deposit tonnage and grade for deposits that comprise the endowment. At best, we would have to estimate these distributions from data on discoveries. In general, this requires: 1) making strong assumptions about the economic processes (exploration and mining) that produced these data and 2) appropriate statistical processing. One disadvantage of this approach is that it yields, as it must, distributions with which the geologist has had no experience, and, therefore, may be suspect.

Why?

Given the specified circumstances, the obvious question is: Why perform the more complex, unverifiable, analysis when it is not needed to achieve the desired objective? Why not estimate the desired GIPV using data on discovered deposit densities and known deposit tonnages and grades? Moreover, modification of either the number distribution or the deposit tonnage and grade distributions so that they describe deposits of the endowment would result in a GIPV which would not represent discoverable deposits. **Thus, the natural inclination to describe deposits as they occur in nature, i.e. geological phenomena, would in this case be counterproductive.**

As stated above, the desired GIPV could be estimated using distributions based upon endowment, but this would also require a much more complex computer program, one that simulates the economic allocation of exploration and associated discoveries from the endowment. Moreover, as the required distributions are not known, they would have to be estimated from data on discoveries! This last feature predicates much of the credibility of the estimate of GIPV on the assumptions and analyses required to estimate the endowment descriptors from discoveries. Then, why employ the more complex procedure when it is not necessary, although it might be geologically appealing to describe deposits as geological phenomena.

WHAT ABOUT MORE REALISTIC CIRCUMSTANCES?

Geological Differences

The foregoing illustration was contrived so that the desired objective is achievable using "hard" data from analogues so as to reveal in an unequivocal way as possible important dependencies. Suppose that we change just one circumstance: **There are significant geological differences among the analogue areas and between the analogue and permissive areas.** This one change removes the simplistic estimation of the number distribution by simply transforming the deposit density histogram to number of deposits. Now, the geologist must evaluate the implication of these geological differences to number of deposits. Thus, while the analogues are a useful reference, the probability distribution for number of deposits must either reflect judgement or be based upon a formal statistical analysis of the geological differences. Here, our attention is directed to the use of judgement and experience of the geologist.

This one modification of circumstances would require an experienced geologist to evaluate the geology of a permissive area vis-a-vis the geology of the analogue areas and their densities of discovered deposits. Because of incomplete information and uncertainties, the geologist's judgement would be expressed by a subjective probability distribution for number of deposits. Available data on discovered deposit densities for the analogue regions and on their geology combined with geological observations on the permissive areas provide a means for him to exercise his science and experience in the estimation of subjective probabilities for number of deposits. Moreover, given that all of the other circumstances remain unchanged from the idealistic case, the processing through MARK3 of this subjective probability distribution with tonnage and grade distributions constructed from discovered deposits of that type would yield the desired distribution for GIPV.

Tonnage and Grade Distributions of Endowment

Suppose, now for the sake of illustration, that these tonnage and grade distributions receive harsh criticism because they do not describe deposits as they occur in nature. Suppose also that in response to those criticisms, sophisticated analysis of the discovery data is performed to infer the natural distributions of tonnage and grade. Suppose also that this analysis is well done and the results are credible and that the next step is for the geologist to estimate number of deposits , with consideration given to geological differences between analogue and assessment regions.

The assessment task for the geologist has been changed remarkably! Now, in order for his number distribution to be consistent with the tonnage and grade distributions, he must use his science and experience to estimate the distribution of number of deposits as they occur in nature, i.e. those that comprise the endowment.

How does he do this when he has no experience with densities of deposits within the endowment? In this regard, his experience does not prepared him for the assessment task!

The point to be made here is that modifications of tonnage and grade distributions that might be well intentioned and meaningful otherwise, may be counterproductive unless they are coordinated with assessment methodology and assessment objective.

In this illustration, the hypothesized changes would have resulted in imposing a very difficult estimation task upon the geologist. Moreover, his estimated number distribution, no matter how reliable, and the endowment-based tonnage and grade distributions cannot be used in MARK3 to estimate GIPV unless MARK3 also is modified to contain an exploration subroutine that imitates the discoveries that industry would produce when exploration is allocated in an economically optimal way. To say the least, for the stated assessment objective and for the circumstances established for this demonstration, the distribution of GIPV for discoverable deposits generated by this more complex approach would be less credible than that of the straightforward use of data on discoveries. So, what seems to be a priori most desirable, namely distributions of tonnage and grade of deposits as they occur in nature, is not preferable for the circumstances established for this illustration.

Generalizing from the above illustration: Criticisms of tonnage and grade distributions without consideration of the assessment objective and the methodology for achieving that objective can be misplaced, misleading, and counterproductive, even though they are well intentioned.

CASE II ----ASSESSMENT FOR THE ESTIMATION OF A POTENTIAL MINERAL SUPPLY SCHEDULE (CURVE)

CIRCUMSTANCES

The assessment objective is the estimation of the potential supply schedule, meaning the magnitude of potential supply for each of several prices, some of which are much higher than current and recent prices. This objective is similar to that of NURE, the National Uranium Resource Evaluation program, which assessed uranium resources and potential supply for prices up to $100 per unit of uranium oxide, a price that was several times price at the time of the assessment. All other circumstances are similar to those identified for Case I. Even so, the requirements for tonnage and grade distributions and for the estimated number of deposit distribution are changed radically from those for Case I.

CONSEQUENCES OF HIGH PRICES

For Case II, the tonnage and grade distributions constructed from well explored areas having similar geology no longer are adequate. Compared to the economic conditions which produced the discoveries that comprise the tonnage and grade distributions, prices up to several times current and past prices change markedly the economics of exploration and exploitation. Accordingly, data on deposit densities from the well explored areas understate, ceteris paribus, what discovery densities may be on the unexplored permissive areas of the assessment region. This must be, given similar geology, because if such high prices had prevailed in the past, cutoff grades would have been lower, average grades would have been lower, but deposit tonnages would have been higher. Search densities would have been greater , resulting in the reporting of smaller and lower grade discoveries and in higher discovery densities.

For the stated assessment objective and circumstances, the densities of discoveries on currently well explored areas no longer are good estimates of future deposit densities of the permissive areas. It follows, of course, that the use of a number distribution developed from the distribution of densities of discoveries on well explored areas, as was done for Case I, would underestimate the number of deposits for geologically similar regions for the high prices. Moreover, the use of deposit tonnage and grade distributions developed from discoveries on well explored areas would overestimate the amount of metal per deposit for high prices.

ENDOWMENT DISTRIBUTIONS REQUIRED FOR POTENTIAL SUPPLY ESTIMATION

Rationale

The main point to be made here is even stronger: **when the assessment objective is a potential supply schedule for a set of prices, deposit densities and tonnage and grade distributions developed from the well explored areas can never be a satisfactory basis for assessment, except for the unusual case in which the areas are exhaustively explored. The only conceptually acceptable basis for assessment consists of the occurrence densities, tonnages, and grades of the deposits that comprise the endowments of the analogue areas, coupled with a model that simulates the economics of exploration and exploitation.**

Thus, for Case II, the broken-line deposit density curves of Figure I are required for a comprehensive analysis. As for Case I, the assumption of similar geology of the analogues and of the permissive areas makes it possible in concept to generate the desired number distribution, i.e. for the endowment, by transformation (using area of the permissive area). For Case II, the assessment objective would require Monte Carlo simulation of the deposits of the endowments of the permissive areas. Naturally, this would require number, tonnage, and grade distributions of deposits as they occur in nature, i.e, deposits of the endowment. Only then, could the effects of very high prices on exploration and exploitation be appropriately analyzed. As stated above, this analysis also would require that the Monte Carlo analysis by MARK3 or its replacement include subroutines to imitate the economic allocation of exploration and the exploitation of simulated deposits.

Difficult Estimation

Although the concepts and relations required to achieve the assessment objective are clear and straight forward, actual estimation is complex and difficult, for the very foundation of the analysis, the distributions of number, tonnage, and grade of deposits of the endowment, is never known, except for rare small areas that are exhaustively explored. Thus, implementation of the requisite analysis requires estimation by some means of the required distributions. Usually, estimation is made using the discovery data. Generally, this requires either: 1) strong assumptions about the economics of exploration and exploitation, eg. size biased discovery, economic truncation and translation, coupled with sophisticated statistical analysis (see Harris, 1984, Long, 1988; Stanley, 1992), or, 2) strong assumptions about the ability of geologists to extrapolate from discoveries to endowment (Harris, 1984; Harris and Carrigan, 1980).

WHAT ABOUT CIRCUMSTANCES FOR CURRENT USGS ASSESSMENTS?

ASSESSMENT OBJECTIVE

When compared to Cases I and II of the foregoing section, the USGS assessment objective is like Case I in that the primary assessment objective is assessment to support land-use decisions. Only occasionally has language been used in USGS communications that harkens to another assessment objective, e.g. resource adequacy vis-a-vis strategic or critical minerals. Moreover, so far, the USGS has used an average of recent prices as the economic reference for assessment to support land-use decisions. This too is conformable with the circumstances established for Case I. But beyond these, circumstances differ in some regards, and some of these differences are highly consequential.

TONNAGE AND GRADE DISTRIBUTIONS

One of these differences arises from the tonnage and grade distributions employed in USGS assessments. Consider the following proposition:

> **Given that the assessment objective is to support land-use decisions for economic circumstances similar to current and recent past circumstances, the**

simplest and most straightforward assessment would be based upon tonnage and grade distributions that are based solely on economically producible discoveries.

This mirrors the circumstances established for Case I. Given those circumstances and given a number distribution that also is based upon economically producible discoveries, a useful distribution of GIPV could be produced simply by using MARK3, or its replacement, to combine number of deposit and tonnage and grade distributions to a probability distribution for GIPV.

Clearly, the tonnage and grade distributions do not satisfy the requirements for this standard of comparison.

In one sense, the USGS tonnage and grade distributions are compatible with the assessment objective and with the above proposition: The distributions are constructed from data on discovered deposits. However, similarities with the Case I circumstances end there, for **the tonnage and grade distributions of Bulletin 1693 are generally a mix of economic and uneconomic discoveries.** Moreover, this mix varies considerably across deposit types.

GIVEN NONCONFORMITIES, WHAT IS THE PREFERRED PROCEDURE ?

What, then, is the preferred procedure as regards support of assessment? Should the uneconomically exploitable deposits be removed from the distributions? This would make them compatible to the simple, straightforward circumstances established for Case I. Or, should an attempt be made to infer from these data the distribution of deposits as they occur in nature? These questions cannot be answered without identification of assessment objective and without establishing a firm position on how a geologist uses his science and available geoinformation to estimate the number of undiscovered deposits. The reason for this is that the requisite properties of tonnage and grade distributions vary, depending upon the perceived capability of a geologist to estimate number of deposits with or without the use of auxiliary information, e.g. analogue information. Basically, what is at issue is a philosophy of science for assessment. The following is a digression from the theme of this major section; however, it is presented here because the subject bears on the evaluation of the tonnage and grade distributions.

PHILOSOPHY OF SCIENCE VERSUS PREFERRED PROCEDURE

RELEVANCE

The term "philosophy of science" as here used refers to the perception of 1) the completeness of geoscience in knowledge of the formation and preservation of mineral deposits, and 2) the capability of the geologist to employ his science to analyze geological information and predict both the number of deposits and their characteristics. There are two polar philosophical positions: At one pole are the scientists who believe that their science combined with geoinformation gives them direct knowledge about the number of deposits that occur within a region and about their characteristics. At the other pole are those geoscientists who believe that their science, even when combined with good geoinformation, is only weakly informative about the number of deposits that occur within a specific, unexplored, region. The broad spectrum of specific methodologies that have been used to estimate some aspect of mineral resources, can be describe in terms of these two polar philosophical positions:

Process-based geological assessment

Analogue-supported geological assessment

These basic philosophies are important to a criticism of tonnage and grade distributions because the distributions play very different roles in assessments guided by these two philosophies. Such distributions, as well as deposit density distributions, are much less important, at least in concept, to process-based geological assessment than they are to analogue-supported geological assessment. Moreover, the properties of the tonnage and grade distributions that provide the best support of assessments under these two philosophies differ greatly

> **For process-based geological assessment, the tonnage and grade distributions must be based upon the natural population of deposits as geological events, for the number of deposits is determined directly from geological processes and geological information. Otherwise, the tonnages and grades will not be compatible with number of deposits. In contrast, assessment of a region to support land-use decisions under economic circumstances similar to those of the present, can employ directly distributions of discovered ore deposits from well explored analogue areas.**

PROCESS-BASED GEOLOGICAL ASSESSMENT

The Need for Endowment Descriptors

Process-based geological assessment in its purest and most perfect form requires the scientific analysis of information from the assessment region to estimate number of deposits and their characteristics. Clearly, if both geoscience and available geoinformation permitted this approach to assessment, tonnage and grade distributions would not be necessary supports for the estimation of number of deposits, for the deposits could be enumerated and described by their spatial parameters. Moreover, tonnages of deposits would require only a simple transformation of spatial parameters of those deposits identified through the process analysis. However, as even idealized process analysis could not estimate the distribution of grades, deposit tonnage and grade distributions would be required in MARK3 to compute GIPV.

But, to be compatible with the number of deposits that comprise the endowment, as estimated by process-based geological analysis, these distributions should be of tonnages and grades of deposits as they occur in nature, i.e. those that comprise the endowment.

Further elaboration on these points may be useful. If it were possible for a geologist to estimate the number of deposits that occur within an assessment region by identification of the deposits directly or by pure process analysis, this number, or the probability distribution for number, would describe deposits that comprise endowment. Therefore, the tonnage and grade distributions used in MARK3 to associate tonnage and grades with each deposit would have to describe the distribution of deposit tonnages and grades in the endowment. Distributions based upon discoveries would be incompatible with the number distribution. Simply stated, the tonnage and grade distributions in Bulletin 1693 would not be appropriate if the number distribution were to represent deposits of all sizes and grades that comprise the endowment.

Clearly, if number of deposits were estimated solely from process-based geological analysis of the assessment region, tonnage and grade distributions built from discoveries would be inadequate and inappropriate for subsequent analysis, e.g. simulation in MARK3 and the computation of GIPV. What follows from this fact is that evaluation of the USGS tonnage and grade distributions for assessment purposes can not be made without first establishing the way that geologists are going to estimate number of deposits. Accordingly, it is important to determine if geologists could or should employ process-based geological analysis alone for such estimation.

Geoscience Appeal

Process-based assessment has an immediate appeal to geoscientists because it is highly conformable with their scientific education and training. So to speak, it is the way that geologists are taught their science and the way that they are taught to use geoscience. It seems only natural that an assessment methodology should mirror both structure of science and science education. Accordingly, there have been various attempts to construct an assessment methodology based upon the "pure science" approach (Zolotarev, 1990). But, to my knowledge, no assessment has been based strictly upon process analysis of the assessment area without the use of auxiliary information from other well explored and well studied areas. Although many assessments draw upon process analysis, actual assessments have combined process analysis with analogical or statistical relations based upon other areas or experience.

Implementation Difficulties: The Arizona Appraisal System Experience

The experience of Harris and Carrigan (1981) in the construction of the Arizona Appraisal System is a useful commentary on process-based assessment. In that study, which constructed an expert system for each of several expert uranium geologists, each expert started with a process-based architecture of the way that he uses geoscience and geological information to assess uranium endowment. However, because of incomplete scientific understanding or inadequate geological data, these process-based structures developed into inference nets that contained both processes and geological conditions or circumstances. Moreover, every geologist calibrated the linkage of his inference nets to number of deposits by analyzing well explored areas for which he was very well informed and for which mineral deposit data were available.

Either because of incomplete geoscience or inadequate geological data, expert geologists were not able to make an assessment of undiscovered deposits by the use of process-based geological analysis alone. While useful, process-based analysis so far has had to draw upon external information, such as deposit densities of similar areas, to perform quantitative assessment.

Soviet Scientists and Process-based Assessment of Petroleum Resources

As judged from available translated literature and first-hand interaction with resource scientists, Soviet scientists have devoted a great deal of effort to developing process-based assessment, referred to as the volume-genetic method, or the genetic-statistical method (Nalivkin et al, 1976; Nesterov, et al, 1984; Resnick, 1987). Some very strong claims have been made about the power of prediction from process-based analysis combined with selected data. Consider, for example, the comments by Nalivkin, et al (1976, p. 1259):

> "The precision in resolving this problem [estimation of magnitude of initial hydrocarbons] depends only on the completeness of the geochemical information through the section of the sedimentary basin, and even in the poorly studied basins with fragmentary geochemical data, a knowledge of the overall patterns of distribution of the disseminated organic matter (DOM) in the sediments of various types and age, the overall patterns of conversion of the DOM and generation of the hydrocarbons, enables us to solve this problem with complete confidence."

Nalivkin, et al. (1976) go on to say that although the magnitude of initial hydrocarbons can be estimated "with complete confidence", the unreliable part of estimating reserves and resources by the volume-genetic method is the "determination of the migration-route losses and those associated with the disintegration of the segregations already formed" (p. 1259).

Because of the difficulties with process analysis of migration, Nalivkin employs "accumulation coefficients" for various geological features of well studied basins. In essence, Nalivkin, as well as other Soviet scientists, are forced to rely upon empirical or statistical relations developed on other basins, which is a form of analogy. Even the Soviet scientists, who appear to have expended great effort in the development of the volume-genetic and genetic-statistical methods, ultimately have to rely upon empirical relations, hence analogies.

Summary Comments on Process-based Geological Assessment

Although many geologists use process-based reasoning, at least in part, no assessments have been made by purely process-based analysis. That fact reflects inadequacies of either the geoscience or geological information that are required to perform such an analysis. To be credible, such assessments would require greater information than is usually available and greater efforts of the geoscientists. The following points are noted:

> **Mineral resource assessments are not now made by pure process-based analysis, nor are they likely to be so in the near future; consequently, it is not necessary that tonnage and grade distributions be constructed to support such analyses: Tonnage and grade distributions need not describe deposits as they occur in nature, i.e. the endowment when the assessment objective is land-use decisions for economic circumstances similar to those that currently prevail.**

Thus, since available evidence indicates that: 1) geologists cannot estimate number of deposits using pure process-based analysis, and 2) even when geologists do use process reasoning, they ultimately resort to analogue information, tonnage and grade distributions based upon discoveries may be adequate when: 1) the assessment objective is land-use, 2) economic circumstances are similar to those that currently prevail, and 3) GIPV is based upon deposit tonnages and grades that pass an appropriately designed filter.

ANALOGUE-BASED GEOLOGICAL ASSESSMENT

Ideal Circumstances

Contrasted with the pure and perfect form of process-based assessment is the pure and perfect form of geologic analogy: There exists a well explored area that exhibits the same geology and physical and economic features as the area to be assessed. The geologist uses his geoscience and available geoinformation to characterize the geology of the assessment region and to identify the perfect analogue. In its purest and most simple form, all features of the assessment area are so well matched with the analogue area that the best estimate of the number of deposits in the assessment area is that number in the analogue area corrected for differences in area sizes. Moreover, because of the excellent match between the areas, the tonnage and grade distributions on the analogue area would be the best estimate of these distributions in the assessment region.

A Deposit Density Distribution

A more realistic, yet still somewhat idealized, form of analogue-based assessment is that instead of one analogue there are many, all of which have the same geology and physical and economic circumstances, but which differ in deposit density. In this form, a histogram of deposit density constructed from the densities of the analogues could be used directly to generate the probability distribution for number of deposits in the assessment area.

More Realistic Circumstances--Geological Differences

Assessment circumstances never conform with these ideals; consequently, the use of analogues usually is attended by the need of the geologist to analyze the geological differences between analogues and between the assessment area and analogues and to estimate what these differences mean in terms of number of undiscovered deposits. Even though this is a great departure from the idealized circumstances for analogue-based geological assessment, as long as economic circumstances for the land-use decision are similar to those that currently prevail in the analogue and in the assessment areas, the tonnage and grade distributions based upon discoveries are appropriate, provided that GIPV is computed only on those deposits that pass appropriately designed filters.

PREFERRED PROCEDURE FOR LAND-USE DECISIONS RECONSIDERED

PROCEDURE FOR ESTIMATING NUMBER OF DEPOSITS

The foregoing discussion leads to the conclusion that future assessments by geologists will not be made by pure process-based geological analyses. Rather, they will be some mix of process reasoning and geological analogy. Specifically, the connection of observed geology to assessed number will continue to be strongly reflective of the experience of the geologist and of deposit densities of appropriate analogues.

Given Use of Analogues and Given Economic Discoveries

Given that number of deposits is to be assessed by some mix of process thinking with experience and analogue data, tonnage and grade distributions based upon discoveries are compatible with the number distribution that such assessment produces. Moreover, given the assessment objective of supporting land-use decisions for current or recent economic circumstances, the use of estimated endowment tonnage and grade distributions would be improper procedure. It follows that criticisms of the USGS tonnage and grade distributions because they do not describe deposits as they occur in nature may be misleading when the assessment objective is to support land-use decisions for current or recent economic circumstances.

Even if endowment tonnage and grade distributions were available, or reliably estimable, they could not be used without a number of deposits distribution that is compatible, meaning that it would by necessity have to describe the number of deposits that comprise the endowment. Moreover, as this distribution is never known, it too would have to be estimated from the discovery data and appropriate geological and spatial considerations. As such estimation is difficult, the use of such an estimate introduces considerable uncertainty in assessment. Since the objective of supporting land-use decisions for current or recent economic circumstances does not require either deposit density or tonnage and grade distributions for the endowment, there is little justification for undertaking the complex and uncertain analyses that are required to estimate such relations. Probably, discovery densities and discovery tonnage and grade distributions , although imperfect, provide a more robust basis for assessment than inferred endowment distributions when the objective is to support land-use decisions for economic circumstances similar to those of the present or recent past.

Given a Mix of Economic and Uneconomic Discoveries

The foregoing comments are most appropriate when the tonnage and grade distributions are based upon economic discoveries. Although they may also be appropriate when discoveries that comprise the tonnage and grade distributions are a mix of economic and uneconomic discoveries, they lose considerable strength. Moreover, as pointed out in the section of GIPV, the mixing of economic and uneconomic discoveries variously with different deposit types is not acceptable for the computation of GIPV by the current version of MARK3.

Use of a Filter for Economic and Uneconomic Discoveries

Clearly, the presence of economic and uneconomic discoveries in the deposit distributions is undesirable and problematic when these distributions are used to compute GIPV. Even so, probably the best solution to this problem is to include an economic filter in MARK3 and compute GIPV on only those simulated discoveries that pass the filter. This will, in effect, achieve the same result as removing the uneconomic deposits from the tonnage and grade distribution while at the same time preserving the current distributions as depicting all data on discoveries, whether economic or not. Similarly, this approach permits the use of deposit densities computed from the same data.

An advantage of this approach is that it is simple and straight forward, as it employs data with which the geologist has some familiarity. Moreover, it facilitates the construction of the tonnage and grade distributions, for it does not require a deposit-by-deposit decision, of whether or not the deposit is economically exploitable for a specified price. Such a decision would be necessary if MARK3 were not to have a filter. Conversely, as it is not necessary for the tonnage and grade distributions to describe deposits within the endowment, the construction of tonnage and grade distributions does not require, deposit-by-deposit the estimation of the total amount of mineralized material or the description of those deposits that are too small or too low in grade to be targets of exploration.

SOME SPECIFIC PROBLEMS OR ISSUES REGARDING USGS TONNAGE AND GRADE DISTRIBUTIONS

PERSPECTIVE

The foregoing sections established the perspective that when viewed broadly, the use of tonnage and grade distributions based upon discoveries is appropriate, given that the assessment objective is to support land-use decisions for current or recent past economic circumstances. Although this result is important as a reference for evaluation of the USGS assessment methodology, it does not mean that the tonnage and grade distributions based upon discoveries present no problems to assessment. In the detail, these distributions present many problems or issues that become important once the "global" issue of endowment-based or discoveries-based tonnage and grade distribution has been settled. One of these issues is the effect of economic translation on the tonnage and grade distributions and, therefore, the distribution of GIPV computed for the assessment area.

ECONOMIC TRANSLATION

WHAT IS IT?

Economic translation refers to the modification of tonnage and grade that occurs when deposits are exploited so as to optimize their present value. Reported data on tonnage and grade usually describe an ore body, and as such, an ore body is determined only for a specific cutoff grade. This cutoff grade, which reflects economic optimization, determines average grade as well as ore tonnage. When deposits exhibit a wide range of grades and such grades exhibit some regularized spatial pattern, economic optimization results in an ore tonnage that is smaller than the total material in the mineral deposit and an average grade that is higher than the average grade of the total mineral deposit. This effect has been referred to as translation (Harris, 1984).

Translation is not uniformly important for all deposit types. Tonnages and grades for some deposit types may reflect strong translations: reported tonnage is much less than the tonnage of mineralized material that constitutes the deposit, and reported average grade is much greater than the average for all material. On the other hand, translation may be minor to negligible for those deposit types having distinct boundaries and weak spatial patterns in grade.

IS IT IMPORTANT ?

Perspective

This question will be answered at different levels. First, circumstances will be posed for which translation is not important, meaning that either translation itself is minor or the consequence of translation, even when its magnitude is not minor, is not important to the assessment objective. Then, conditions will be posed for which translation is important, and its effects described generally. Finally, translation as a feature of the USGS tonnage and grade distributions is considered, and ways of handling translation so as to achieve the assessment objective, which is the support of land-use decisions, are considered.

Circumstances for Which Translation is Not Important

Deposits having distinct boundaries and little spatial grade variation

Deposits that have distinct boundaries and exhibit very little spatial grade variation do not permit the selective mining of high grade parts and the optimizing of cutoff grade. The entire deposit is either economic or uneconomic for a specified price; consequently, there can be no economic translation to smaller ore tonnage and higher ore grade. This circumstance results in truncation, but it does not give rise to translation. Accordingly, for those deposit types that are characterized by distinct boundaries and little spatial grade variation, tonnages and grades of discoveries do not reflect translation effects.

Truncation

When the assessment objective is to support land-use decisions for current or recent past economic conditions and when this objective is to be achieved using tonnage and grade distributions based upon discoveries, truncation per se is not important. This is because deposits of the truncation size or smaller would not, by definition, be present in the population of discoveries and the associated tonnage and grade distributions. Naturally, if they do not appear in the tonnage and grade population represented by the tonnage and grade distribution, as would be the case for truncation, they would not contribute to the distribution of GIPV generated in MARK3, or its replacement. This result is perfectly acceptable, for the desired GIPV should be computed only on economically producible deposits.

Gradational boundaries and spatial grade variation

Suppose that deposits of the type under consideration have the following characteristics: 1) gradational instead of distinct boundaries, 2) large variations in grade, 3) strong spatial patterns of grade variation (conditions that permit selective mining). Suppose also that the deposits comprising the population of discoveries, which is represented by the tonnage and grade distributions, have been discovered, developed, and exploited under very similar physical, climatic, infrastructure, and economic conditions. Collectively, these circumstances imply that economic translation will have occurred in the analogue areas and that all deposits of a given size and grade will have been translated the same amount, irrespective of where they occur, meaning irrespective of the analogue area in which they occur.

Suppose also that all conditions in the assessment area that affect translation are similar to their states in the analogue areas from which the data originated for the construction of the tonnage and grade distributions. These circumstances and conditions assure that a deposit of a given size and grade that occurs within the assessment area would, if discovered and exploited, be characterized by the same ore tonnage and average grade as it is in any of the analogue areas.

The foregoing circumstances have been contrived so that translation is not important. Given the circumstances specified, GIPV, which ideally should be computed on ore bodies, can be computed using the discoveries-based tonnage and grade distributions. Nothing more is required, for given the conformity of circumstances of the assessment and analogue areas, the undiscovered deposits of the assessment area would undergo the same translation as did those of the analogue areas upon which the tonnage and grade distributions were constructed. In other words, the desired translation for simulated deposits of the assessment area is identical to the translation that took place for deposits of the analogue areas. Clearly, for the specified assessment objective and the specified circumstances, economic translation is irrelevant.

Circumstances for Which Translation Is Important

Gradational boundaries and spatial grade variation

As established above, gradational deposit boundaries and spatial patterns of grade variation are a requirement for the selective mining that results in economic translation. Accordingly, these circumstances are assumed in this section.

Spatial variation in costs

Suppose we change just one circumstance: Those factors that affect cost vary across the analogue areas, i.e. varying climatic, topographic, and infrastructure conditions. This means that a deposit of a given tonnage and grade would yield different ore tonnage and average ore grade in each analogue area. These circumstances lead to a different tonnage and grade distribution than in the previous conformity case, for a specific tonnage and grade occurring in each of several analogue areas now gives rise to several different ore tonnages and average grades, and these deposits may be classified into different histogram classes. Moreover, as the cost factors in the assessment area may be different from each of the analogue areas, simulated deposits in the assessment area should differ from those of the analogue areas because the cost conditions differ. Thus, if translation effects are large, the distribution of GIPV computed for the assessment area is on a priori grounds "noisy" and not a good measure of the actual GIPV.

Spatial variation in physical characteristics of deposits

Suppose that for a specific deposit type there is a natural spatial variation in some deposit features, such as tonnage, grade, and grade variation. Here, this variation is assumed to be geological, not a result of economic optimization, for example, the widely cited trend of porphyry copper deposits of the Western Cordillera to smaller size and lower grades as one proceeds northward from Chile to British Columbia or to Alaska. Naturally, to the extent that spatial variation in physical features of a deposit type can be unequivocally established, this trend should be considered in the assessment of undiscovered deposits of the assessment area.

The point to be made here in this section goes beyond the explicit consideration of spatial variation in physical features to differential economic translation. Specifically, the richer the deposit, the less the economic translation effect. Thus, the impact of spatial variation in physical features may be two-fold: the direct and the indirect, meaning differential economic translation. Of these, the indirect is the most difficult to deal with, for its presence and degree are not easily identified, and even when identified, its effect is difficult to take into consideration in the computation of GIPV for an assessment area.

THE USGS TONNAGE AND GRADE DISTRIBUTIONS

PERSPECTIVE

With the foregoing as background, this section considers the questions: 1) How important is the economic translation effect in USGS tonnage and grade distributions and associated assessments?, and 2) What methodological procedures are indicated when economic translation is important?

First of all, although this point has been well emphasized in the foregoing section, it is of sufficient importance that it merits some repetition: Economic translation effects vary with deposit type, being unimportant for deposits with distinct boundaries and weak spatial grade variation but being important for deposits with gradational boundaries and strong spatial grade variation, particularly those with low overall average grades. Thus, it would be incorrect and nonproductive to consider economic translation an important effect in tonnage and grade distributions of all deposit types. Deposit types can be classified into two or more groups on the basis of the above criteria: type of boundary and strength of spatial grade variation. The following comments are relevant only to those deposit types for which economic translation is important

GLOBAL TONNAGE AND GRADE DISTRIBUTIONS--A MIX OF SOLUTION AND PROBLEM

General principle is sound geologically

The general principle of suppressing political boundaries in the construction of tonnage and grade distributions is sound geologically, for such boundaries have no meaning unless they coincide with geological nonhomogeneities. Exceptions to this include: 1) the presence of global gradients in one or more deposit features as described in the foregoing sections, and 2) differences resulting from metallogenic evolution in space and time. Moreover, to the extent that a given taxonomy is well conceived and there are no significant economic effects, the construction of global tonnage and grade distributions provides greater robustness than those that are regional because of the larger population of tonnages and grades. Problems arise only when there are regional gradients in deposit features or other features that affect costs.

Regional gradients in deposit features

As this feature was discussed in a previous section, no further comment will be made here except to emphasize the notion of direct and indirect affects. Regional gradients have a direct impact if those features having gradients are important cost determinants, such as deposit size and average grade. Regional gradients have indirect affects when the degree of economic translation varies with the magnitude of the physical feature that is a cost determinant.

Purely economic effects

Even when there are no regional gradients in cost determinants, a deposit developed within different economic regimes may be described by different ore tonnage and average grade. These differences generally have more to do with infrastructure and institutional factors, e.g. taxation and labor policies, than they do with technologic factors. As an extreme case, consider those stratiform copper-cobalt deposits of Zambia and Zaire that are reported as ore bodies. Because of the great transportation costs required to serve international markets and because domestic markets are very limited, ore bodies would have to have much higher average grades than the same deposit would in the western U.S. More generally, to the degree that climatic, infrastructure, and institutional factors vary with economic and political regimes, economic optimization of the same deposit in such regimes would result in different ore tonnages and average grades. Of course, this effect may be offset or compounded by natural gradients in physical features.

Methodological implications

Among the possible methodological implications of the foregoing are the following:

- Classify deposits. All deposit types should be examined with respect to the potential that their tonnage and grade distributions could produce a distribution for GIPV that is either very noisy or worse, not credible for the assessment area. Those selected deposit types merit special treatment designed to mitigate to some degree the deficiencies that can be attributed to economic translation.

- Use a common cutoff grade. One way of mitigating translation effects is to modify the tonnages and grades of the discovery population so that they represent a common cutoff grade. Of course, this requires knowledge of, or reliable estimates of, tonnage and grade relations. This approach was employed by Singer (pers. comm.) for some (25) of the copper porphyries that comprise the tonnage and grade distributions for deposit type of USGS Bulletin 1693. Unfortunately, subjecting some deposits to such analysis and not others leads to a state of confusion that is not much different than that with no adjustment, at least in terms of what can be said about the properties of the GIPV produced for an assessment area. This is because the GIPV should be for metal contained in discoverable and economically producible deposits.

Unfortunately ,the common reference created by describing deposit tonnage and average grade at a common cutoff grade may not describe just economically producible ore. Therefore, the tonnage and grade distributions alone, although considerably improved from both the geological and statistical points of view, are not sufficient to produce the desired GIPV distribution for an assessment area. That distribution can not be computed without an economic analysis. While this could be done variously, one approach would be to use an economic filter that had been especially designed for deposits characterized by tonnage and average grade for a common cutoff grade. Of course, an alternative to such an analysis is to perform a discounted cash flow analysis based upon engineering cost relations and supplemented by a subroutine that determines the optimum cutoff grade, given that GIPV is determined only on those deposits that have a nonnegative net present value at optimum cutoff grade.

- Constrain the tonnage and grade populations. To some degree, both the effects of regional gradients in physical parameters and nonuniform economic translation can be diminished by imposing appropriate constraints on the selection of deposits for the construction of tonnage and grade distributions.

A form of this idea is the local tonnage and grade distribution, which has been used in assessment in place of a global distribution when deposits within the assessment area differ significantly from those of the global distribution. This is not a new idea. The USGS assessors have occasionally employed local distributions where they felt it was necessary, for example Bolivia (1992, p.223). Decision criteria for the construction of local distributions are not clear. The reader is referred to the discussion of the Coronado National Forest assessment in the Arizona Conference section of this report.

The notion of this section is broader than the local distribution as it has been used so far. Specifically,
the population of deposits should be constrained not only by gradients in physical features but also by cost factors, some of which may be independent of the physical factors. Knowledge that cost factors in the assessment area are in common with some deposits in the global population but not with others could be used to appropriately partition the global population into subsets, one of which would have commonalities with undiscovered deposits of the assessment area.

When the population has been properly constrained, the tonnage and grade distributions could be very useful in both 1) the estimation of number of deposits that occur in the assessment area, and 2) the generation of the distribution of GIPV. To the extent that discoveries of the constrained distribution are both economic and uneconomic, GIPV should be computed on only those deposits of the constrained distribution that pass the economic filter.

SIZE-BIASED DISCOVERIES

PERSPECTIVE

One criticism made of the USGS tonnage and grade distributions is that the deposits upon which they are constructed are not a random sample of deposits as they occur in nature. Size bias is a statistical sampling term, which when used to describe exploration refers to a probability for discovery which increases with size of the deposit. Sampling by such a process produces a probability distribution for discoveries in which larger deposits occur much more frequently than they do in nature.

SIZE BIAS IS NOT UNIVERSAL

Most assuredly, some discovery distributions are size biased when compared to the distributions of tonnages and grades of the endowment. But, it is very important to note that discoveries of some deposit types do not exhibit size bias.

Exploration by grid drilling is a useful way to examine the phenomenon of size bias, for probability for discovery is strictly determined by geometric considerations: deposit morphology as it relates to size, the geometry of occurrence, e.g. vertical versus flat-lying mineralization, and the properties of the drilling program, i.e. random, square grid, grid spacing etc. Everything else being equal, when surface projected area of the deposit is proportional to size and search is by grid drilling, the conditional probability for discovery is proportional to size, creating a strong size bias in the distribution of discoveries when compared to the endowment distribution. But, even when exploration is only by direct drilling, the degree of size bias is strongly dependent upon the morphology of the deposit, the geometry of deposit occurrence, and the consistency of these as they relate to size. Thus, those deposits that typically have a relative small surface-projected area but a great depth extension will not exhibit significant size bias in the discovery distribution. And, even when deposit morphology is consistently related to size, if geometry of deposit occurrence, i.e. attitude of deposit, is random, size bias may be weak.

When exploration includes detection drilling only to test targets identified by indirect exploration, e.g. geophysics and geochemistry, size bias is a more complex phenomenon. A priori reasoning indicates that size bias will be greatest in those deposits for which anomalies sensed at the surface are proportional to the spatial extent of the deposits. When anomalies of various kinds are used in exploration, e.g. alteration, geochemical, magnetic, gravity, resistivity, electromagnetic, etc., and when these are related to deposit tonnage and grade in complex ways, size bias in discoveries may be weak. Size bias is also weakened when deposits of a given type exhibit varied geometries and occur at various depths, for these variations weaken the relationship of anomaly size and strength as sensed at the surface to deposit size and richness.

Two recent studies are useful commentaries on the complexity of size bias in mineral discoveries: mercury deposits (Chung, Singer and Menzie, 1992) and greenstone gold veins in the Abitibi (Stanley,1992). The study by Stanley (1992) of size bias in gold discoveries of the Abitibi greenstone province demonstrates that a combination of deposit morphology and search economics can result in a set of discoveries for which size bias is not observed.

Examination of 725 mineral occurrences across 80 years of exploration and mining, in the western Abitibi greenstone belt of Ontario, suggests a strong trend to decreasing size of discovery. The trend is amplified by smoothing the data by selecting the largest discovery in each ten year period. The resulting plot is nearly a straight line correlation of decreasing tonnage with time. Similarly, plotting the deposit grade versus year of discovery produced a flatter but nonetheless downward trend. Given such a strong trend it is reasonable to expect that a strong size bias sampling of deposits would occur. Application of the lognormal size bias estimation model, as described by Long (1988) and Forman and Hinde (1986) for oil discoveries, yielded conflicting results that initially seemed to be inconsistent with the observable trends. The size bias sampling parameter was inconclusive, indicating no preference for the discovery of larger deposits. This suggests that discoveries of gold deposits in this area were not characterized by a size bias model although a very clear trend to decreasing size could be observed.

Several steps were taken to improve the model. Considering the largest deposits as geologic centers surrounded by smaller satellite deposits suggested that several economic operations could be aggregated into one geologic entity. Attempts to statistically aggregate economic deposits into geological deposits failed to improve the size bias parameter. Re-examination of the data suggested two populations: the very large deposits yielding greater than 5 million ounces of gold each and remaining smaller deposits in what was termed the ambient population. Much of the strong trend to decreasing size resulted from the presence of these very large deposits. It was thought that their discovery early in the exploration history was overprinting on the ambient population, resulting in an irregular size bias parameter. Removal of the largest deposits and re-estimation of the model not only worsened the size biased parameter but was inconsistent with the intent of the model. The conflict between 1) a decreasing trend in discovery size and 2) a lack of size bias discoveries seems at first to be counter-intuitive and perhaps even impossible!

By examining the discovery data in ten year periods it was observed that, although there is an overall 'trend' to smaller discoveries, the first twenty years of exploration are unique. In this period there are many discoveries in the smaller ambient population prior to the larger deposits. In both of the major gold camps up to one half of all discoveries are made in the first twenty years of exploration. Gold exploration in the western Abitibi exhibits a size biased sampling only after an initial period of exploration. Regression analysis is so greatly influenced by these early years that the exploration parameter is positive and not negative as is expected (Stanley,1992).

What is the influence of the larger deposits? The model attributes all reserve additions to the initial date of discovery for the deposit. But what if the reserve additions come from extensions to depth under improved technology? The surface expression of the initial discovery does not reflect this increased size. If anything, removing the reserve additions from the data set reduces the downward trend in discovery size. Stanley (1992) found that some of the largest deposits (those having 70 years of production) have initial discovery sizes no larger than the ambient population. It is not expected that they would be discovered before any other of the deposits. Furthermore, investigation of the success ratio of occurrence to deposit discoveries reveals a renaissance of exploration coincident with the deregulation of the price of gold. The result is a transformation of previously marginal occurrences into new discoveries helping to establish a trend to smaller deposits late in the history of the belt. Deposits still in production at this time saw large reserve additions under increased prices and technology permitting downward ore extension.

An example of size biased discovery is shown in a study by Chung, Menzie and Singer (1992). They analyzed mine production data and discovery dates for 132 mercury deposits in the California Coast Ranges. The deposits were discovered between 1840 and 1958 and are classified as either the silica-carbonate or hot-spring type. In the study, cumulative deposit production was employed as a surrogate for deposit size. The authors showed that a straight line fit to the natural logs of cumulative deposit production (in flasks of Hg) versus discovery year yields a negative slope that is significant at the 1% confidence level (r = 0.51), indicating size biased discovery.

These two studies are a useful demonstration that size bias is not universal and that it is strongly influenced by the geology of deposit occurrence, exploration technology, as well as the economics of development. The Abitibi study shows that overall trend is different from size biased sampling. Where the data reflect changing technology and economics together with a deposit morphology resulting in near vertical reserve additions, the two cannot be expected to behave sympathetically.

SPECIAL CONSIDERATIONS IN THE DETERMINATION OF SIZE-BIASED SAMPLING IN MINERAL DEPOSITS

Size biased discovery has been most clearly demonstrated in the exploration for oil. The pattern of size bias in oil discoveries is a function of the relationships between:

- exploration technology
- the area of the surface projection of the deposit
- the correlation between the magnitude of the deposit and the area of its associated anomalies.

In the case of metallic mineral deposits, these relationships are highly variable and do not necessarily result in preferential discovery of the largest deposits first. For example, the area of surface projection of steeply dipping zones of mineralization does not vary appreciably with size of deposit. In such a case, exploration technologies may not discriminate between the anomalies of large and small deposits. Furthermore, many exploration methods respond to the volume of mineralized rock as in the case of many geophysical techniques, geological mapping and drilling. But, the volume of mineralized rock is only one of two variables that determine an economic mineral deposit. The grade of mineralization also determines whether a discovery remains an occurrence or becomes an economic deposit. For many deposit types, where size is measured in quantity of metal, it is not clear that grade is a determinant in the discovery.

Changing economics and technology results in translations of uneconomic mineral occurrences to viable mines throughout the exploration history. Thus, determination of size biased discovery must consider non-geological factors when the intended use is in construction of local deposit models. Both the mercury and Abitibi gold studies note that exploration is generally not continuous in an area but occur in periods of activity driven by a changing economy. Any estimation of size biased sampling must be considered as one window through which the data are analyzed representing one history of economic and technologic conditions. This results in the difficult task of normalizing different exploration histories for different commodities so that the local grade/tonnage models reflect only the distribution of deposits as they occur in nature.

Lastly, there is an important point to be taken from research in the discovery of oil pools (Drew, 1980). If the population is characterized by a small set of very large discoveries superimposed on a large base of 'ambient' discoveries then it may be the former dictating the size biased sampling observed. In such a situation care must be taken not to over-estimate the expected decrease in deposit size with increasing exploration history. If the forecasted rate of decrease in size, as determined by the larger deposits, is too high a significant portion of the ambient population may be truncated. In mineral resource assessment this could be more damaging to the local grade/tonnage deposit models than not considering size biased sampling at all.

WHEN IS SIZE BIAS IMPORTANT ?

Deposit Type

As indicated above, there are some deposit types for which size bias is not important. Accordingly, those deposit types should be identified for which size bias is important. But, even for these deposit types, the presence of size bias in a given assessment may or may not be important.

Assessment of an Unexplored Area

Even when exploration is strongly size-biased, when the area being assessed has not received any significant amount of exploration, size bias may be of no consequence. For example, if the assessment objective is to support land-use decisions for current or recent past economic circumstances, size bias is of no consequence when the area has not been explored. The sizes and grades of deposits discovered in analogue areas, as represented by the discoveries-based tonnage and grade distributions should represent well the distribution of tonnages and grades of future discoveries in the assessment area, given similar technology and economic circumstances. Moreover, the densities of discovered deposits on analogue areas should be useful guides to discovery densities for the assessment area unless the areas differ significantly in their geology.

Assessment of a Partially Explored Area

When discoveries of a specific deposit type are typically size biased and when there are known discoveries in the assessment area, the assessment of undiscovered deposits in that area must take into account previous exploration and the size bias effect. Clearly, a strong size bias would indicate that the size distribution of the remaining deposits is different from that prior to any exploration: the probability for large deposits has been decreased by previous exploration. It is also clear that for this circumstance, the GIPV computed in MARK3 for this area should not use the original tonnage and grade distributions, i.e. those that depict discoveries prior to any exploration. To do so would lead to an overstatement of GIPV.

Conceptually, the appropriate procedure is clear: The relevant tonnage and grade distribution for these circumstances is one that has been modified to reflect the discovery depletion of previous exploration. Of course, as always, the way and means to accomplish this are not so clear or simple. Basically, however, what is required is the identification of the size bias effect and a compensation of the distribution of discoveries for that effect. As size bias has been a subject of petroleum exploration and resource estimation, that literature (Wang, 1980; Long, 1988; and Drew, 1980) is relevant; however, the phenomenon is more complex for minerals than for petroleum or natural gas.

The statistical modification of tonnage and grade distributions to reflect size bias is more credible the more specific the tonnage and grade distributions. Accordingly, the modification of global tonnage and grade distributions that are comprised of discoveries from many different regions and economic regimes is far less credible than modification of local distributions, provided that the local distribution is not statistically a small sample. The less variation in geological, physical, and economic circumstances, the more credible the notion of a statistical description of size bias and the modification of the distribution of discoveries to reflect previous exploration and its size bias. Such compensation for global distributions comprised of discoveries from many different world regions is not credible because of the great variation in exploration intensity and technology across these regions. The point to be made here is that if statistical compensation is performed, it should be on a discovery distribution that is as specific and as closely related as possible to the assessment area.

Even when the assessment region has, as a whole, received considerable exploration, resulting in a set of reported discoveries, parts of the assessment area may have received little or no exploration. Clearly, the assessment of those regions does not require consideration of the size bias effect, but the assessment of explored areas does. Where exploration information permits, the assessment region should be partitioned to reflect amount of exploration, and assessment should be made separately of the explored and unexplored areas.

CHAPTER VII -- GEOINFORMATION OTHER THAN GEOLOGY

GEOINFORMATION OTHER THAN GEOLOGY

OUTLINE

PERSPECTIVE

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- A GEOPHYSICIST ON EACH ASSESSMENT TEAM

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- PURPOSE
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    - GEOPHYSICAL STUDIES
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        - Gravity Data Analysis
        - Radiometric Data Analysis

TONGASS NATIONAL FOREST

REMOTE SENSING

INTEGRATION AND ANALYSIS OF REMOTE SENSING DATA

GEOPHYSICAL STUDIES

Geophysical Data Analysis

GEOINFORMATION OTHER THAN GEOLOGY

PERSPECTIVE

The quantity and quality of geological information available to support USGS assessments have varied widely. It is acknowledged that this variation often is beyond the control of the USGS because of limited time and resources. Accordingly, this is not an appeal for more information generally, although that is always desirable for improved geological analysis. As information from geological maps generally has been used well in assessments, this section focuses on two specific kinds of information that could have received greater emphasis in past assessments or that should receive greater emphasis in future assessments: geophysical and remote sensing information.

The comments on these two kinds of information have been taken from the reports prepared by geophysicist John Sumner and Stuart Marsh, a geologist with expertise in remote sensing and GIS systems. Following the general comments on these topics by Sumner and Marsh, brief comments are provided on the analysis of these and other data as part of an assessment program, e.g, pattern analysis, information synthesis, and the use of GIS. Finally, selected assessments are examined with regard to the use, or opportunity for use, of geophysical and remote sensing information. Comments on these selected assessments are primarily those of Sumner and Marsh.

GEOPHYSICAL INFORMATION

USE OF GEOPHYSICS

The reconnaissance aeromagnetic survey method is a powerful means of rapidly obtaining geological and assessment information at a very low cost. Equipment has evolved to the extent that a single-engine fixed-wing airplane with GPS navigational equipment can accomplish what a large twin-engine airplane used to do, and at a much lower cost. Several years ago a group at the University of Utah even successfully developed a system for an ultra-light airplane -- one weighing less than 254 pounds. In days gone by, the USGS was a leader in airborne geophysics; not so at the present time. At the very least, the Survey should sponsor contractors in the assessment program, should review their own contract specifications to be reasonable and up-to-date, and should themselves be up to date in the data processing and interpretive procedures. Some lessons should be learned from Canadian Geological Survey, which is far ahead of the USGS in the field of aeromagnetics.

The second most powerful reconnaissance geophysical survey method is gravity surveying. Here the Survey is to be commended for research in database processing. However, data acquisition, data interpretation and database management have fallen far behind the industry norm. Here again, the USGS should regain leadership in this important assessment field. Without expertise here, and in aeromagnetics, how can the USGS provide the expert personnel to be on mineral assessment teams?

In some instances, other geophysical exploration methods can play an important role in the assessment process: for example, regional electrical surveying such as the audio-frequency electromagnetic surveying, and airborne electromagnetic surveying. An airborne VLF receiver can easily be carried in any aircraft, and thanks to Global Positioning Systems (GPS) important data can readily be gathered.

A GEOPHYSICIST ON EACH ASSESSMENT TEAM

Finally, a knowledgeable geophysicist must be on each and every mineral assessment team. And there must be a portion of the review document, together with supporting references and maps, discussing the geophysical relevance in the assessment interpretation. At the present time, this is not a routine procedure.

REMOTE SENSING DATA

During the past decade, applications research and operational programs using remote sensing data and processing techniques have demonstrated the utility of this information in reconnaissance mineral exploration. Notable examples of this work have been conducted at the USGS, at many Universities, and within the exploration industry. The identification of alteration mineralogy and biogeochemical anomalies can provide important insights into the mineral potential of an area undergoing initial evaluation or mineral resource assessment. In addition, evidence of faulting and fracturing and the structural recognition of intrusions, veins, and dikes can be derived through synoptic structural mapping using airborne or satellite images.

Given the underlying need in mineral resource assessments for reconnaissance geoscience information, it is indeed unfortunate that electromagnetic remote sensing appears to have played so limited a role in the process. Easily available spectral data, such as that from the Landsat Thematic Mapper, coupled with digital information extraction techniques, can be utilized to discriminate areas displaying hydrothermal alteration mineralogy. For example, the minerals limonite, hematite, goethite, kaolinite, montmorillonite, muscovite, illite-sericite, alunite, pyrophyllite, calcite, chlorite, and others display characteristic spectral absorption features in the 0.45 micrometer region (Landsat TM band 1) and 2.2 micrometer region (Landsat TM Band 7). Techniques such as the generation of spectral ratio images can be used to delineate areas where these minerals are present and to supplement lithologic mapping. In densely vegetated terrain, spectral information acquired from the Landsat Thematic Mapper can also be utilized to differentiate anomalous reflectance characteristics of vegetation (Landsat TM bands 3,4, and 5). Additional structural information can also be gleaned from an informed interpretation of enhanced satellite images or aerial photographs.

Obviously, without field verification, the origin of vegetation anomalies, the presence of alteration mineralogy, or the mapping of suggestive geologic structures can not be directly attributable to mineralization. Nevertheless, on a reconnaissance basis, the identification of these areas and the examination of the spatial correlation of these areas with other geoscience indicators, can provide significant insight into the mineral resource potential of a study area. Certainly the first step in the USGS methodology must rely on acquiring and interpreting as much geoscience information as possible. Inherent to the assessment process is the use of converging lines of evidence. Reconnaissance alteration, vegetation, or structural maps derived from Landsat TM data afford low-cost and easily generated data-sets that should serve as additional input to the analysis process.

Implementation of the use of electromagnetic remote sensing data will be constrained by the time and resources available for each assessment. The expertise and resources necessary to successfully utilize remote sensing are available from within the USGS and other Federal agencies, as well as from University and private sector scientists and organizations. Ideally, a geoscientist with remote sensing expertise could provide direct input as a member of, or consultant to, an assessment team. This individual could determine what types of data (i.e. Landsat TM, SPOT, or airborne imaging spectrometer data) would be most appropriate to the area of study, the availability of the data, and the image processing techniques that should be utilized to extract useful information. These decisions would be constrained by the time available for the assessment. As a first step, the remote sensing consultant should be conferred with to determine what might be the contribution of remote sensing data. During the analysis phase of the assessment this individual should also help to rank the significance of remote sensing derived targets/ tracks in relationship to all other geoscience information. This input will be invaluable to the assessment team in terms of understanding and appreciating the significance of the remote sensing input.

PATTERN ANALYSIS

PURPOSE

The current USGS assessment methodology identifies geologic environments and deposit types and delineates areas that are permissive, based upon observed geology and recognition criteria. This is a logical and useful geological approach. Even so, it may be useful to augment current procedures with a strictly empirical (statistical) approach designed to identify general geologic anomalies. The rationalization for this approach is that assessment areas might be missed simply because their geology does not match the recognition criteria of initially selected deposit types and environment. Once delineated, examination of these anomalies may lead to the identification of additional deposit types and their permissive areas. Moreover, these anomalies should be helpful in the delineation of assessment areas of a given deposit type and in the assessment of number of deposits.

In accordance with the foregoing, an important future extension is to augment the traditional maps or images with images of variables especially constructed to delineate anomalous areas by strictly empirical data analysis designed to identify patterns and anomalies.

METHODS

Some Soviet resource prognosticators have developed techniques that may be useful in implementing this notion, for example, the "exceptional " zones of Gorelov (1982). Other similar work includes information synthesis and multivariate relative exceptionalness zones of Harris and Pan (1991), the favorability maps of Liu (1991) and Pan and Harris (1992), the typification areas of Harf and Davis (1990), and the "weights of evidence" probability maps of Agterberg et al (1991).

The idea here is that one or more of these methods would be employed, as is appropriate, and an image of the constructed variable, e.g. exceptionalness, complexity, favorability, etc. would be created and examined for anomalies that had not been identified, or for extensions or subdivisions of already-delineated permissive zones. At the very least, images of these variables could be very useful as information for the geologist to consider in his subjective delineation of assessment areas, checks on his permissive areas, and possibilities for additional deposit types or permissive areas.

This analysis may be especially useful when remote sensing data and geophysical data are included along with the usual geological data and when multivariate pattern integration is performed. Naturally, GIS software would facilitate the implementation of these techniques.

INFORMATION SYNTHESIS AND INTRINSIC SAMPLES

Intrinsic Sample (IS) theory and methods grew out of research, sponsored by the USGS, to improve the usefulness of multivariate geostatistical models for quantitative assessment (Harris and Pan, 1990, 1991). The hallmark of the methodology is that sample units are intrinsically defined by geology, as contrasted to the arbitrary cell or quadrat. Unlike some objective quantitative methodologies, (IS) is similar to the USGS methodology in that it is deposit-type specific and employs the genetic model to direct data analysis, the synthesis of new variables, and the delineation of intrinsic samples (assessment areas).

The synthesis of information variables from sets of basic geodata is an important part of this methodology, for it seeks to identify complex multivariate and spatial inter-relations as they relate to mineral occurrences. Of course, the synthesis of remote sensing and geophysical data with the more usual geological and geochemical data could produce synthesized variables whose images would be very important in the delineation of intrinsic samples and in the assessment of number of deposits.

With regard to the USGS current methodology for assessment, the first step of the Intrinsic Sample methodology can be considered to present an objective means for delineating assessment areas. These assessment areas are the intrinsic samples. While conceptually similar, delineated permissive areas and intrinsic samples may differ considerably: The ISs are more like favorable areas or exploration target areas than permissive areas. Mainly, this reflects the broader, less discriminating criteria of permissivity, as compared to (IS) requirements. Of course, to some degree this is under the control of the analyst. Or alternatively, assessors could assess number of deposits by Intrinsic Sample.

GIS AND DATA ANALYSIS

Whether or not remote sensing data are used as input, the use of digital integration software and analysis techniques (GIS) would be of enormous benefit to the process of mineral resource assessment. Research and demonstration projects during the past decade have amply demonstrated the utility of digital integration of geological, geophysical, and remote sensing data for mineral exploration (Agterberg, 1981; Bonham-Carter et al., 1988; Harris and Pan, 1991; Kowalik and Glenn, 1987; Missallati et al., 1979; Reddy and Bonham-Carter, 1991). The digital and geographic integration of geoscience information coupled with the analytical tools of statistical, boolean, or arithmetic operators provides a means of quickly and efficiently assessing complex data-sets.

The use of GIS software would allow the assessment teams to spend far <u>less</u> time compiling and overlaying data by hand from maps at disparate scales and far <u>more</u> time interpreting the significance of available information. Obviously, time constraints on the resource assessment process again play a major role in what can be implement. Though many geoscience data-sets originate in digital form, it is inevitable that considerable effort would have to be devoted to digitizing maps and interpretations and geographically referencing tabular datasets. These front-end efforts can invariably be handled by technicians. Thus, with sufficient lead time, the geoscience staff can reap the benefits of an integrated digital dataset rather than be overwhelmed with the tasks of creating it.

Once the digital dataset is created, the assessment teams must have access to software that will allow them to easily analyze the data. Most GIS packages currently being utilized by Federal and State agencies (e.g.: ARC/INFO, GRASS, IDRISI) provide a wealth of analysis routines. These include the ability, on a spatial basis, to establish the cross-correlation of all variables, to call upon boolean and arithmetic operators to model user selected layers of geoscience data, and to utilize statistical packages (e.g.: regression, discriminate and factor analysis) to assess the inter-relationships of multivariate data and the predictive capabilities of these data.

A project-by-project implementation could be of use, however, it would be far more efficient to select a GIS package or group of software packages to be adopted and implemented by the Office of Mineral Resources. Ideally, the package(s) selected should be able to integrate both raster and vector data, utilize robust relational database management software, provide appropriate analysis capabilities, include basic image processing routines, and provide a user-friendly interface. This implementation can not be done without a serious commitment of both financial and human resources. GIS personnel would therefore become an integral part of the assessment teams.

The benefits of this commitment would go beyond providing the assessment teams with a more efficient means of analyzing data and producing maps. The more far-reaching benefits would include establishing a complete institutional memory of useful data and successful procedures as well as the ability to effectively document, reproduce, and extend the results of mineral resource assessments. Ultimately the mineral deposit models and MARK 3 program could also be integrated into a complete data integration and analysis workstation. The first priority of the USGS should be to establish these tools on an operational basis for the mineral resource assessment teams. Once implemented, more sophisticated artificial intelligence tools such as expert systems (Prospector II & III) and neural networks could and should be attached to the GIS.

PROSPECTOR III AND GIS

PROSPECTCR III utilizes a GIS interface to explore map areas across several data types simultaneously. This integration into an assessment system would permit the use of recognition criteria constructed from the inter-relationships of several different data types. PROSPECTOR III with GIS offers interesting assessment possibilities:

- A total of 86 descriptive deposit models are currently encoded into PROSPECTOR III with an additional 10 new models to be added this year (McCammon, Arizona Conference; re: USGS Bulletin 2004).

- These models may be modelled numerically and the Survey now includes worksheets in its latest release, Bulletin 2004, to allow interested parties to perform this task.

- Furthermore, numerical deposit modelling techniques have been tested and are shown to be effective in selecting descriptive deposit models as performed by PROSPECTOR II(McCammon, Arizona Conference).

- PROSPECTOR III currently operates on a framework that matches deposit attributes with the geologic environment. A principal limitation of this system is the number of entries and cross-referencing of terms in the geologic glossary of terms.

- PROSPECTOR currently interfaces with a geographic information system allowing for the spatial distribution of tracts (airegions) to be delineated and manipulated.

- PROSPECTOR is structured in a way that allows for the introduction of the RCON vote allocation system to determine the relative weights assigned to the different geologic attributes in numerical deposit modelling.

- Furthermore, the RCON vote allocation process is best implemented through a geographic information system as is currently linked to PROSPECTOR III.

- Integration of a GIS also permits the integration of different data types to derive new variables that might be used in the assessment process.

Expert/AI systems combined with GIS and specific procerssing algorithms offer great potential for facilitating asssessment. The capability to easily process and analyze many layers of information would permit the synthesis of variables having much greater discriminating power than the raw data. This would make the recognition criteria that much more robust. Although not yet implemented on an assessment area, the Intrinsic Sample methodology of Pan and Harris (1990, 1991) would be considerably facilitated using GIS. It is not unreasonable that this methodology might be used to draw 'favorable zones' (intrinsic areas) for deposit types as part of a much larger expert system in the assessment process.

COMMENTS ON GEOINFORMATION ANALYSIS FOR SPECIFIC ASSESSMENTS

COSTA RICA

REMOTE SENSING

Spectral remote sensing data, such as that acquired by the Landsat Thematic Mapper (TM) may have been able to provide additional reconnaissance exploration information. The Landsat TM acquires 30 meter resolution data for an area 185 km on a side from six spectral bands in the visible to shortwave-infrared region of the electromagnetic spectrum. Obviously, the dense vegetation cover in this region of the world is a controlling factor in regard to what information remote sensing data might provide.

Biogeochemical anomalies resulting from elevated metals concentrations have previously been identified in a variety of remote sensing studies, (Birnie and Francica, 1981; Chang and Collins, 1983; Collins et al., 1983; Horler et al., 1980; Labovitz et al., 1985; Lyon, 1975; Milton et al., 1983; Yost and Wenderoth, 1971). Given the nature of many of the target deposits, particularly the epithermal gold, the use of spectral ratios or derived vegetation indices from the TM bands in the green (band 2), red (band 3), near- (band 4) and shortwave-infrared (band 5) could have been utilized to map vegetation reflectance characteristics. Anomalies could have been mapped, field checked, and integrated with other geoscience information.

The successful discrimination of both supergene and hypogene alteration using both coarse- and high- spectral resolution data has also been documented, (Abrams et al., 1983; Abrams et al., 1984; Goetz et al., 1983; Goetz et al., 1985; Hunt, 1979; Hunt and Ashley, 1979; Krohn, 1986; Kruse et al., 1990; Marsh and McKeon, 1983; Podwysocki et al., 1983). Though the extent of vegetation cover presents a significant problem in their recognition in a tropical region of the world. If there are areas where outcrop and soil are visible when viewed vertically, the delineation of hydrothermal alteration is possible using the Landsat TM bands in the blue-green (Band 1) and shortwave-infrared (Band 7) at 2.2 micrometers. Based upon information in the report, the use of remote sensing data to discriminate hypogene alteration (argillic & sericitic) associated with the epithermal gold deposits (or porphyry coppers) would be impossible as tropical weathering has obscured the characteristic mineralogical assemblages in almost all outcrops. Propylitic alteration, we are told, is also widespread but not confined either spatially or genetically to the epithermal gold deposits. However, the report also states that all of the epithermal gold deposits have been weathered to some extent and a suite of alteration minerals characteristic of supergene alteration (limonite, goethite, jarosite, and bleached rocks containing kaolinite) should be easily discriminated using Landsat TM data.

A third potential exploration application of remote sensing in the Costa Rica study would involve structural mapping. The report states that "high-angle faults, particularly where they intersect, are the sites of highest grade ore in most Costa Rica precious-metal epithermal veins." A detailed structural analysis of satellite images, aerial photographs, or most appropriately radar images, could provide additional insights into the location of fracture zones. These synoptic data-sets, might also have provided additional insight into both small- and large-scale structural fabrics in the region.

INTEGRATION AND ANALYSIS OF REMOTE SENSING DATA

The Costa Rica dataset is particularly well-suited to computer based integration techniques. The application of GIS technology would not only have greatly facilitated the production of maps and graphics, but would have provided the authors with analysis techniques that can be prohibitively time consuming when working with paper maps and tables.

The first stage in the application of a GIS would be to put all the <u>geographically</u> referenced data (i.e the 391 rock and soil samples with their rock type and alteration descriptions and elemental analyses) in a digital database. In addition, all the maps (locational, geological, geophysical) would be digitized and stored either as vector or raster data. In addition, each type of feature on the map (e.g.: formation type, faults, etc) would be stored as separate layers or elements. Though entering these data into a digital database would have been time-consuming, there are significant advantages once this front-end work is completed. Quick and efficient analysis of the cross-correlation between any of the map or tabular variables would be easily achieved and certainly a variety of insights may have been gained. In addition, point or contour maps could have been generated from the tabular data. As an example, the author's could have requested a map showing the location of all rock samples displaying argillic alteration or a contour map of the elemental values for any of the 31 elements analyzed. This information could then be displayed along with any other map information, thus, providing the author's with the ability to integrate and overlay any of the variables in their dataset. Given the detail of this dataset, creating a digital GIS database from this information would be of significant value to any future studies.

GEOPHYSICAL STUDIES

Previously existing geophysical data were used in the Costa Rica resource assessment. This procedure apparently was due to the short time-frame imposed for the study and the low budget allowance for the entire program. As a result, both the coverage and the geophysical data analysis are skimpy, both from the viewpoint of future mineral exploration and also for present mineral assessment purposes. The geophysical data assessment study is presented as part of the large map and narrative folio designated as USGS Miscellaneous Investigations Series Map I-1985.

It appears that the principal beneficial use of the geophysical maps was to substantiate and supplement the compiled regional geologic map. However, wherever possible there is discussion of potentially mineralized regions in the geophysical analysis. Some of the surveys were continued offshore, mainly for petroleum exploration. The geophysical maps are quite useful for regional geological mapping purposes.

Because of the sparsity of geophysical survey coverage, the analysis of the existing data was somewhat academic and rather weak from a mineral resource assessment standpoint. However, good-looking colored maps were produced, and these will be useful to future interpreters.

No radiometric, Geographic Information System (GIS), or remote sensing analysis was made in the mineral assessment of Costa Rica. There is a brief mention of seismic work and areal seismicity in the folio.

Aeromagnetic Data Analysis

The quality of the aeromagnetic data appears to be acceptable. It probably was flown under contract for the Costa Rican government. The original data are almost 20 years old, and it might be difficult to obtain the original data for further processing, or for reinterpretation. Only about one-quarter of the country has been covered, so that completion of aeromagnetic surveying should be a high-priority item both for exploration incentives and for mineral assessment.

Several mineral resource targets are indicated on the aeromagnetic maps and are discussed in the folio, which proves the beneficial worth of the aeromagnetic method. References are given for the original surveys, which also contain interpretations. The quality of data interpretation is very good, and the U.S. Geological Survey interpreters are trained and experienced. In this low geomagnetic latitude aeromagnetic anomalies are not readily, correctly interpreted by inexperienced persons.

Gravity Data Analysis

The regional gravity coverage of Costa Rica is about five years old, and it appears to be of good quality. However, the coverage in potentially mineralized areas is so sparse that very little can be said about applications to mineral assessment. The mapped contour interval is 10 milligals, so only major individual anomalies due to large features with strong density contrasts would show up. However, major lineaments that may be indirectly related to mineralization are brought out by the regional gravity survey and are described in the folio, even though their importance to assessment is not emphasized.

Some more dense proprietary gravity coverage along the Atlantic coastal basins is integrated into the regional map.
Also, several offshore gravity traverses were integrated into the mapped areas, rounding out the regional tectonic pattern of the area.

The gravity data reduction process appears to be thorough. The U.S. Geological Survey has applied their terrain and isostatic corrections to the data, giving a professional appearance to the colored Bouguer and isostatic maps.

Rock Properties Studies

As an adjunct to the geophysical surveys, a number of physical properties measurements of rocks were determined by the USGS, and are tabulated along with previously determined rock property values. These values include density and magnetic susceptibility. These properties will prove to be quite useful to future geoscientists studying the region.

Remanent magnetic and electrical properties were not measured in the USGS laboratory, but remanence was noted from the magnetic signature of some airborne anomalies.

NORTHERN SPOTTED OWL

REMOTE SENSING

Spectral remote sensing was not utilized in the Spotted Owl study, and its application could have provided additional insight into this porphyry copper assessment. As in Costa Rica, a dense vegetation cover limits our ability to discriminate characteristic mineral assemblages associated with either supergene or hypogene alteration. However, in areas above tree-line or with limited cover, the Landsat TM sensor could be used to discriminate alteration zones on a reconnaissance basis. More detailed information could be acquired with high spectral-resolution airborne systems which permit the identification of specific alteration minerals (Kruse et al., 1990). In addition to the identification of hydrothermal alteration zones, the relatively dense vegetation cover in the Spotted Owl study areas, again provides the opportunity to search for biogeochemical anomalies. In fact, such an anomaly has previously been recognized in the Spirit Lake Quadrangle of Washington, (Collins et al., 1983). Finally, relatively large scale structures (plutons - lineaments) may be recognized from the small-scale perspective of a satellite image and thus, remote sensing data could have been used in concert with the geophysical anomaly maps.

INTEGRATION AND ANALYSIS OF REMOTE SENSING DATA

The digital integration of the available geological, geophysical, and geochemical data could have greatly facilitated the Spotted Owl study. A study such as this truly demands the use of converging lines of evidence to arrive at a final set of anomalies. The creation of a digital database and the utilization of the analysis capabilities of a GIS would have facilitated the authors' task of identifying Tertiary intrusives.

GEOPHYSICAL STUDIES

For this area only one deposit model was considered from the standpoint of geophysical surveying: porphyry copper systems. Of course, there are several other deposit types such as polymetallic vein systems, massive sulfide replacement bodies, and copper skarn systems that are genetically related to porphyry systems.

The primary method of analysis was to use existing aeromagnetic data, mainly in the form of maps, to delineate the outlines of intrusive igneous bodies from which the porphyries would stem. The description and defense of the operational approach to data analysis is well documented in Open File Report 91-377, the descriptive document assessing the undiscovered mineral deposits in the Spotted Owl study area.

Aeromagnetic Data Analysis

Aeromagnetic maps along the west flank of the Cascades from Northern California to Northern Washington were reviewed by R. Blakely and D. Plouff for the purpose of outlining igneous plutons underlying the blanket of volcanic rocks extruded from the Cascade mountain chain. The logic was that the flat-lying volcanics, although erratically magnetic, would not mask the underlying more homogeneous, somewhat magnetic plutons. It was a satisfactory approach, given the financial and temporal restraints imposed in making the mineral deposit assessment. However, the magnetic nature of porphyry copper deposits together with their plutonic host rocks elsewhere shows that the magnetic contrast approach can be a rather shaky premise.

The 40 known and identified possible porphyry system deposits provided a substantiating guide to the inferred pluton mapping method. The report states that of the 40 known mineral occurrences, 31 are located within 4 km of the edge of a presumed pluton magnetic anomaly.

The aeromagnetic data quality is good, but in the state of Washington the flight line spacing was too large (8 km) to provide more than a regional field representation. The 1:500,000 scale aeromagnetic data are contoured at 50 gamma intervals, but flight lines are not shown. Presumably, the original source maps as prepared by Aero Service Corp. are more complete than those presented in the open file report.

The USGS geophysical data interpreters are very well qualified in their skills. However, industry experience probably would say that this pluton outline estimation method is speculative.

Gravity Data Analysis

Gravity data coverage near the west coast of the United States is fairly good from a regional standpoint, due to past Defense Department support over many years. The gravity data are shaky at 5 milligal intervals, which is too large to identify specific mineral deposits but did serve, when compared with the aeromagnetic maps, to sometimes substantiate the presence of buried plutons. A regional magnetic high, bounded by identified gradients, which is also a gravity low could indeed be a granitic pluton.

The gravity station locations are not shown on the open file report maps, but they are available from source files compiled by the Air Force Chart and Information Center (ACIC) in St. Louis, MO., and from USGS reports referenced in the open file mineral assessment report.

The interpreted gravity data does reveal the presence of lineaments cross-cutting the area. These features may be related to concealed mineralization, a matter alluded to in the assessment report.

Radiometric Data Analysis

Analysis of the National Uranium Resource Evaluation (NURE) airborne spectrometric radiometric data was presented in the assessment analysis. This method is not directly important for mineral assessment in this type of terrain because only a very thin soil cover will prevent any radioactive radiation to be detected by an airborne detector. And ideally the detector system should be flown very close to the ground, which is difficult to accomplish in the mountainous terrain of the subject survey. These facts are not mentioned in the open file assessment report.

The justification in using the airborne radiometric data in the assessment report is that some plutonic outcropping areas may be present, and also there may be a nearby alluvial train of plutonic material that would be identified.

The theory that radiometric signatures may be of importance in porphyry copper resource evaluation is that rather large amounts of potassium are introduced to a region during the mineralization process, and this potassic alteration halo can be identified by the airborne detector.

No mineralized tracts were identified from analysis of the NURE radiometric data; not a surprising finding.

TONGASS NATIONAL FOREST

REMOTE SENSING

Spectral remote sensing data were not used in the Tongass National Forest study. Again, available airborne and satellite systems could have utilized to delimit biogeochemical anomalies, hydrothermal alteration, or geologic structures pertinent to exploration in this large study area.

The large size of this and many other mineral assessment study areas coupled with the time involved in acquisition and digital processing of the Landsat TM satellite data forces a variety of logistical decisions if these type of data is to be successfully integrated into the assessment process. Though each Landsat TM scene covers an area of over 34,000 square kilometers, a large number of scenes would have to be acquired and processed to cover the entire study area. Thus, if time and costs are an administrative constraint, the researchers will have to chose whether to utilizes a sampling of digital scenes which would be processed and analyzed in detail, or to simply purchase photographic products for the entire study area which could then be manually interpreted. Obviously, the type of Landsat photographic product and the scale chosen would depend on the researcher's objectives for the data.

INTEGRATION AND ANALYSIS OF REMOTE SENSING DATA

In addition to the advantages already described for creating geographically referenced digital databases and utilizing GIS technology, the Tongass study points to an additional reason to adopt these techniques. Ten variables were used by the authors' to delineate a series of favorable tracts. Because the entire study was done with paper maps, pens and pencils, it was impossible for the authors' to spend the time to do a detailed evaluation of the importance of each of the ten variables to the creation of a tract. Such an analysis would have been simple and quick with the creation of a digital set of map layers. The Tongass study also made use of the Mineral Resources Data System (MRDS). This USGS database is in digital form and could have been simply integrated into the mapping and analysis procedures if a GIS approach had be utilized.

GEOPHYSICAL STUDIES

The Tongass Forest area comprises all of southeastern Alaska, and mineral assessment of such a large and varied area was a major undertaking. The evaluation process and results are summarized in U.S. Geological Open-File Report 91-10.

The only readily prospectable areas lie between the upper tree line and the snow line, this is observable for only a few weeks in the late summer. From past discoveries in the prospectable areas, the mineral endowment under the forest cover must indeed be quite large.

Geophysical Data Analysis

There is no supporting geophysical data analysis contained in the supporting mineral assessment analysis in the open file report. Figure 5 of the report is a 1:2,5000,000 scale reference map with the caption "Map of southeastern Alaska, showing major sources of gravity and aeromagnetic information". It is an index map showing the location of the 14 1:250,000 quadrangles under study in southeastern Alaska. Outlines of 11 individual study areas are shown, together with the references to the U.S. Geological Survey maps covering this large area.

Judging from the geophysical index map and three references, 1:1,000,000 scale aeromagnetic coverage is available in southeastern Alaska. No mention is made of the gravity coverage, but I suspect that it is available from the ACIC mentioned previously.

No USGS geophysicist served on the mineral assessment team. Perhaps principal author and single assessor D. Brew understood geophysical survey matters sufficiently well to integrate them into his own mineral assessment report. But, it is doubtful.

D. Brew has prepared Open-File Report 92-307 "Decision Points and Strategies in Quantitative Probabilistic Assessment of Undiscovered Mineral Resources", a well written document that goes a long way toward developing an organized quantification procedure. In his paper, a team of geoscientists (page 10) is recommended, along with a leader, to carry out a mineral assessment. However, the Tongass Nation Forest assessment team (OFR 91-10) does not have a geophysicist-member, in violation of the recommendations of OFR 92-307.

The Tongass mineral assessment report appears to be seriously flawed by only fleeting references to geophysical data located elsewhere. Also, there is only a single mineral assessor, putting a heavy load of credibility on Dave Brew's shoulders. Granted, Brew is an unusually experienced and accomplished field geologist, but, this is no way to carry out and report on an important mineral assessment program in a well endowed region.

CHAPTER VIII -- SUBJECTIVE PROBABILITY

SUBJECTIVE PROBABILITY

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SUBJECTIVE PROBABILITY

PHILOSOPHY AND APPROACH

TWO DIFFERENT SCHOOLS

In a very broad sense, there are two generally different philosophies of subjective probability: The first of these considers subjective probability to be a subjective estimate of objective probability or relative frequency (the frequentist school); the second one considers subjective probability to state the degree of belief, or certainty, of the expert in a given proposition.

FREQUENTISTS

The foundation for the frequentists is the classical definition of probability, which according to Laplace (1951) is the ratio of the number of favorable cases to the number of all possible cases. Alternatively, the frequentists employ an empirical generalization of the classical definition, whereby probability is defined as the limiting value of the relative frequency of the event as the number of trials in which the event is a possible outcome increases indefinitely.

DEGREE OF BELIEF

The degree of belief approach is founded on the work of Bruno de Finetti (1964), who viewed subjective probability as an expression of the feelings of an individual. A consequence of this view is that the probabilities have meaning only in relation to the individual. These latter probabilities are also referred to by various other terms, including personalistic probabilities, psychological probabilities, and measures of certainty (uncertainty). Most recent literature on subjective probabilities, much of which is found in mathematical psychology or decision science, frees subjective probability from accountability to "actual" or objective probability, choosing instead to make it accountable only as a useful description of degree of belief.

ASSESSMENT PERSPECTIVE

As a means to emphasizing the essence of these two basic approaches as they apply to resource assessment, consider 1) a block of crustal material of size *S* that has been observed to exhibit geological feature *X* and 2) the question: what is the probability that this particular block contains one or more epithermal gold deposits? Given this simplified world in which only one geological feature is at issue, the desired probability is the proportion of all crustal blocks of size S possessing feature X that also possess an epithermal gold deposit. Of course, in the real world, the geologist would not be able to make that determination objectively because of incomplete information, except for very exceptional circumstances. Even so, the frequentist school of subjective probability would use this as a model for his subjective estimation of the desired probability that the block contains an epithermal gold deposit. Specifically, as a good frequentist, the expert geologist would recall from his memory all such areas of the stated size that exhibit feature X and determine that proportion of the recalled cases that also possess an epithermal gold deposit. This proportion would be his estimate of the desired probability. Clearly, for this to be a good estimate requires first that the areas examined mentally by the geologist are a representative sample of the earth's crust that exhibits feature X and , second, that his ability to recall his experiences is not flawed.

The personalistic approach would ask the question: What is your degree of belief, on a scale of 0 to 1, where 1 represents total belief and 0 represents total disbelief, in the proposition that this crustal block, which exhibits feature X, contains an epithermal gold deposit? Or, alternatively, what is the certainty that you feel about that proposition? Even though both approaches, frequentist and degree of belief, could produce the same probability, they are fundamentally different in philosophy and in what the probabilities are intended to represent. When subjective probabilities are used in mineral resource assessment for societal decisions, that difference is not inconsequential.

Within the personalistic school itself, there are two different interpretations of subjective probability. The first is that subjective probabilities are coherent (obey additive laws); the second interpretation is that they simply represent a real person's opinion, coherent or otherwise (Wallsten and Budescu, 1983). The comments of Dawid (1982) about subjective probability forecasts of precipitation by weather forecasters provide a perspective of a "personalist" about objective versus personalistic probability:

> "In particular, it is rarely appropriate to interpret a subjective probability forecast as an estimate of some underlying 'objective' probability; it is usually better considered as an estimate of the(indicator of) forecast event itself. Thus we do not have to concern ourselves with the "true" probability of rain on a given day. Roberts(1968) has attempted to interpret such a concept by supposing that one could select a subset of all days that could be regarded, at the time of forecast, as identical in all relevant respects, and consider the limiting relative frequency of rain on such days as the 'true' probability for any one of them. However, it is doubtful whether such a selection is practically meaningful, or whether different forecasters would agree on it."

Instead, Dawid (1982) holds that "The probabilities quoted refer to the forecasters' subjective 'degree of belief'". This is in spite of his recognition that the information considered by the forecasters may include 'objective forecast' output from climatological analyses, or a computer forecasting system.

FEEDBACK AND CALIBRATION

The above comments by Dawid (1982) are introductory to a discourse on a general calibration theorem for subjective probabilities by weather forecasters and a discussion of coherence versus calibration. At the risk of oversimplification, the main idea is that when a forecaster has feedback about the event, as does the weather forecaster, it is less important what his probability estimate means, i.e. an estimate of objective probability or degree of belief, because he can learn and calibrate using feedback information. It is possible that someone else can transform the forecaster's biased measures to calibrated measures, provided of course, that he is consistently biased. Is such a position useful for mineral resource assessment? Or, are the two tasks sufficiently different that Dawid's position is not relevant?

ASSESSMENT IS MORE DIFFICULT THAN WEATHER FORECASTING

First of all, the mineral resource assessor can not benefit from real-time feedback information; second, the weather forecaster's task is relatively simple in comparison to that of the assessor. Finally, the event for which weather forecasters provide a probability is a simple binary event: rain or no rain. This event is analogous to a permissive tract containing at least one deposit or no deposit. Clearly, the mineral resource assessor is asked to go far beyond that and provide either a probability distribution or a cumulative probability distribution for number of deposits. A comparable task for the weather forecaster would be the estimation of the probability distribution for the amount of precipitation, or a histogram of probabilities for specified intervals of precipitation.

SOCIETAL DECISIONS CALL FOR OBJECTIVE PROBABILITIES

Philosophically, personalistic probability seems to contrast quite sharply with the objective of mineral resource assessment for land-use decisions. Here, there is little doubt that, at least in concept, the most desirable subjective probability estimates would be unbiased estimates by experts of "objective probabilities". Even though that is clear, there still remain questions about the best approach to making these estimates. Are such estimates better when made through the frequentist window, stressing the data support and encoding format that are consistent with what that approach implies? Do the developing methods for elicitation of personalistic probabilities and their calibration provide better estimates? Can desirable properties of the two approaches be combined? The answer to these questions in general is unclear if judged by the opinions of noted experts: "The personalistic preference-based conception of Ramsey, de Finetti and Savage is of course widely adopted by Bayesian decision analysts while many statisticians remain ardent frequentists and Allais (1979, p. 660-663) holds another subjective position" (Fishburn, 1989). What about mineral resource assessment? Do the objectives and circumstances attendant such assessment differ sufficiently from other events such that a preference for philisophical approach and for methodology is clearly indicated on *a priori* grounds?

DIRECTIONS OF RESEARCH AND DEVELOPMENT

Psychometric research has shown that when man is left to the unbridled exercise of subjectivity, his performance as an intuitive statistician, as required to employ the frequentist approach to estimating objective probability, is not very impressive. This has led to research on the psychology of estimation under uncertainty and on elicitation design and calibration procedures to minimize these undesirable properties. On the other hand, it has also led to the adoption of a personalistic view of subjective probabilities. The motivation for the personalistic approach can be characterized in a highly simplistic fashion as saying "if what individuals estimate are not probabilities, then let us redefine subjective probabilities to conform to what they estimate. A frequentist would say, "if what individuals estimate do not exhibit the required properties to be objective probabilities, then let us develop methods that improve performance or allow transformations so that the individual's estimates are useful as objective probabilities.

SUBJECTIVE PROBABILITY FOR ASSESSMENT

Support of land-use decisions in the name of society strongly suggests that the subjective probabilities desired for mineral resource assessment are unbiased subjective estimates of objective probabilities. As they are currently defined, personalistic probabilities are not sufficiently constrained to be considered estimates of the objective probabilities.

If adoption of the personalistic approach, instead of the more traditional approach, is predicated upon the power of calibration methods to produce good estimates, the resource assessor should remain a frequentist, irrespective of the convenience and greater flexibility provided by the personalistic approach. For, conceptually, those subjective probabilities desired are good estimates of objective probabilities, not degrees of belief or certainty that have meaning only to the individual. Without the "saving grace" of calibration, the personalistic probabilities are not sufficient for the making of societal decisions regarding land-use. Instead, our efforts should be devoted to improving the properties of subjective probabilities as estimates of the desired objective probabilities.

HOW GOOD ARE SUBJECTIVE PROBABILITIES?

HISTORICAL PERSPECTIVE

The decades of the 1960's and 70's witnessed research that challenged previously held beliefs about man as an intuitive statistician. These research results showed that man generally is overconfident about uncertain events, behaving as though he knows more than he really does. Psychometricians (e.g. Slovic, 1972; Tversky and Kahneman, 1974) showed that man employs various heuristics, e.g. anchoring and adjustment, representativeness, availability, etc., to estimate the probability for an uncertain event and that these usually lead to biased subjective probability distributions. Generally, the subjective distributions are about one-half as wide as they should be: Probabilities for events in the tails of the distributions are underestimated, while probabilities for central,familiar, events are overestimated. Man was also found to be a conservative processor of information when compared to Bayes theorem. And, because of the heuristics he employed, e.g. representativeness, man often ignores base rates when considering information about the uncertain event.

Another very important pre-1980 contribution was the thorough critique by Sachman (1974) of the previously accepted standard for group estimation. Traditional Delphi consists of individual estimation, feedback to the group of statistics of the first round estimates, re-estimation by individuals, feedback of statistics of 2nd round estimates, etc., iteration these steps until opinions of the group members converge to a single one. Sachman showed that Delphic convergence can result simply because of a "herding " instinct, i.e. not wanting to be different, even though logic has not been persuaded and evidence has not been modified. He also identified the undue influence of dominant personalities and the critical role of the group leader or facilitator. Overall, Sachman challenged the basic premise of Delphi groups, namely seeking convergence for convergence sake, especially when that convergence can take place for purely psychological reasons, having nothing to do with the exchange of science and technical information.

There is little doubt that these findings plus many others, served to:

1) weaken the blind faith in and dampen the unconstrained use of subjective probability and of traditional Delphi estimates;

2) motivate additional research on subjective probability philosophy, concepts, and methodologies.

While some research of the 60's and 70's challenged the use of subjective probability in decision analysis, subsequent research has softened some of the earlier criticisms, restoring the perception that subjective probability of experts can be useful in decision analysis. Important factors in this development are:

1) the unequivocal demonstration that weather forecasters are very well calibrated, meaning that their estimates are well matched with actual events,

2) the finding that the conservatism demonstrated by psychometricians is not ubiquitous, and that it is strongly influenced by elicitation and encoding methodologies,

3) recognizing that some of the inadequacies of subjective probabilities provided by non-experts are either not present or, if present, are ameliorated considerably when experts provide the subjective probabilities, and,

4) identifying that feedback is very important to good calibration of experts: specifically, when experts have feedback, they can become very well calibrated.

CONSERVATISM RE-EXAMINED

Although conservatism appears to be widely documented, recent literature indicates a revision in the interpretation of its meaning and significance in real world situations (Winkler and Murphey, 1973, as reported by Wallsten and Budescu ,1983, p.160). According to Wallsten and Budescu (1983, p. 159 & 160) recent research on conservatism has been relatively slight for two major reasons:

> Conservatism is no longer seen as a ubiquitous phenomenon,
>
> Conservatism could be due to "misperception of the data, misaggregation of the data, or bias in the response scale (Edwards, 1968).

Wallsten and Budescu (1983, p. 160) state further that

> "A distinguishing feature of the subjective probability revision literature is that more active attention has been paid to the question of response bias. It has been amply documented that responses can be made more or less extreme (and therefore more or less conservative, or possibly even radical) by choice of response mode. For example odds or log-odds, estimated verbally or on a calibrated bar, lead to more extreme responses than do probabilities (Du Charme, 1969; Phillips and Edwards, 1966; Wheeler and Edwards, 1975), and drawing lines whose relative length represents subjective uncertainty leads to more extreme responses than does marking off a line calibrated in probability units (Wallsten, 1972)"

The implication of the foregoing is that conservatism exists but that its consequences may be controlled to some degree by the structure and format of elicitation and encoding. Obviously, this places great importance on elicitation and encoding, for these can be controlled and managed.

CALIBRATION CONCEPTS AND METHODS FOR COMPARISON AND EVALUATION OF SUBJECTIVE PROBABILITY

PERSPECTIVE

To the frequentist, the logical standard for comparison and evaluation of subjective probabilities is the objective probabilities for which the subjective estimates were made, or alternatively actual events. Of course, such comparisons should be made whenever possible to see how well the individual is calibrated with respect to actual events. This is true for the personalist as well as the frequentist; however, the significance of poor calibration has different meaning for these different philosophies of subjective probability.

Often, as for mineral resource assessment, comparisons of subjective probabilities with objective probabilities or with actual events are not possible. Frequently, judgement is sought about unique events, for which relative frequency or propensity can not be defined, or of rare events, for which propensity cannot practically be determined. For these cases, in particular, other means for evaluating judgement are needed. Some useful measures have been developed by psychologists to describe scaling, a topic in psychological measurement. The estimation of subjective probability can be viewed as a special case of the scaling of judgement and feelings to a domain of real numbers. Two measures of scaling that are applied to subjective probability are reliability and validity (Wallsten and Budescu, 1983).

RELIABILITY

Wallsten and Budescu (1983), drawing upon the literature on psychological testing (e.g. Gulliksen, 1950; Lord and Novick, 1968), describe the scale value of an event to be a random variable , x, that consists of a true part, p, and a variable error, e:

$$x = p + e$$

Adaptation of this general scaling relation to subjective probability would be that a subjective probability, x, consists of the true probability, p, and a random error, e. Clearly, this adaptation of psychological scaling fits well the frequentist's perception that a subjective probability is an estimate of an objective probability, the true probability. Although some experts in subjective probability (Fischhoff, Slovic, and Lichtenstein, 1980) employ the notion that an individual's opinion consists of a precise, fixed part to which error is added by the conversion of judgement to probability, Wallsten and Budescu (1983) modify this basic relation somewhat to accommodate the personalistic view of subjective probability. Accordingly, they replace the true fixed part , p, by the expectation for x over a large number of independent estimates.

Consider the following assumptions:

- The expected value of the error is zero;
- The true and error values are uncorrelated;
- For any pair of independent measurements, the errors are uncorrelated;
- The true score in one measurement is uncorrelated with the error in another;

Given these assumptions, $S_x2 = S_p^2 + S_e^2$,

where S_x^2 , S_p^2, and S_e^2 are variances of x, p, and e, respectively.

One measure of reliability is $1 - (S_e^2 / S_x^2)$. Thus, when $S_e^2$is zero, reliability is perfect, having a value of 1, and when S_e^2 equals S_x^2, reliability is zero.

VALIDITY

Consider a binary event for which the proportion of successes, however defined, is p. An individual is said to be well calibrated if his subjective probability for success equals proportion p. Validity (Wallsten and Budescu, 1983, p. 155) is a broader concept than this common measure of calibration. Basically, validity requires only that there be two independent encodings of subjective probability and that if these correlate well, the individual's estimates are valid, or as stated in the literature on psychometrics, the individual is well calibrated. One advantage of this broader measure of calibration is that it permits a description of calibration for unique events for which there are no propensities, meaning actual probabilities, by which to evaluate the subjective probabilities. Employing the assumptions and notion established for reliability, consider two independent encodings of subjective probability and measures of their variances and covariance: S_{x1}^2 , S_{x2}^2, $S_{x1,x2}$. The measure of validity here described , $R_{x1,\,x2,}$ is defined as follows:

$$R_{x1,\,x2} = S_{x1,x2} / (S_{x1} \cdot S_{x2}) \ .$$

Validity, as defined above, is especially important as a measure of calibration for the personalistic school of subjective probability, for by definition subjective probabilities are degrees of belief, not estimates of objective probabilities.

Even though the objective of mineral resource assessment is to estimate objective probabilities, the notion of validity as a measure of calibration may be quite useful, for in some sense, number of deposits occurring within a specific tract can be considered a unique event in that there are no objective probabilities to which the subjective probabilities can be compared. Interestingly, the use of the above definition of validity would require that subjective probabilities for number of deposits for a given tract be elicited and encoded by two different methodologies and that the probabilities be correlated. If the encodings are independent and correlate well, the above definition of validity implies that the individual providing these independent encodings is well calibrated. The value of this approach is that a low measure of validity would suggest either a poor elicitation and encoding methodology or confusion in the mind of the assessor about what was being assessed. This would call for a re-examination of the elicitations, and such examination should improve not only the formal measure of validity but also the value of the assessment for societal decisions regarding land-use.

SUBJECTIVE PROBABILITY SCORING RULES

Stael Von Holstein (1970), has developed mathematical rules to assess and revise subjective probability estimates. If the task permitted feedback to either the implementor of the study or the expert, then a system of scoring rules relates the assessed distribution $\underline{r}$ and the event which eventually turns out to be true. The expert receives a score $Sk(\underline{r})$ if the Kth event occurs. The strictly proper scoring rules define the true probability for the event as Pk and that the subjective expected score is $S(\underline{r}, \underline{P})$ where;

$$S(\underline{r},\underline{P}) = \Sigma\, PkSk(r)\ ,$$

the rule is proper if $S(\underline{P},\underline{P}) \geq S(\underline{r}, \underline{P})$.

The more commonly applied rules are the quadratic:

$$Sk(\underline{r}) = 2r_k - \Sigma\, r_i^2$$

The spherical scoring rule is:

$$SP_k\,(\underline{r}) = \frac{\underline{r_k}}{\sqrt{\Sigma\, r_i^2}}$$

And, the logarithmic scoring rule is:

$$SP_k\,(\underline{r}) = \log r_k$$

Stael Von Holstein (1970) also describes a non-linear utility for risk takers and avoiders where, if u = utility function, then:

$$\Sigma_{pk}\, u\,[\,S_k\,(\underline{p})] > \Sigma\, P_k\, u\,[\,S_k\,(\underline{r})] \text{ for } \underline{r} = \underline{p}$$

To help in choosing among scoring rules the implementor of the survey must consider 1) relevance, where the score does not depend on assignments to events which could have occurred but did not, 2) invariance, where the permutation of the probabilities does not affect the score, and 3) strong discriminability, where the probabilities x and y for two successive trials have s(x) + s(y) as the composite score and therefore should be monotonic, increasing in xy.

To obtain a consensus of subjective probability distributions we can assign the experts weights $\{w_i\}$ in linear combinations. The aggregated distribution function is:

$$F^*(x) = \Sigma\, w_iF_i(x)$$

where the weights may be determined by;

- equal weights
- proportional to self ratings
- weights based upon previous performance
- weights proportional to average scores for previous sessions
- weights proportional to $(m + 1 - R_i)$

where m = # of experts
R_i = rank of expert based on previous performance

A possible response to scoring rules is that this method is not applicable to estimation of the number of mineral deposits where the true distribution is never known. But many aspects of an experts knowledge can be tested for which the true distributions are known. The current research by Menzie (Arizona Conference, 1992) of testing expert geologists using a series of well explored control areas having known porphyry copper deposits holds promise. If the experts level of performance can be established for a related task then, in a relative sense, the performance of that expert can be quantified.

SELECTIVE REVIEW OF EMPIRICAL STUDIES

EXPERTS VERSUS NONEXPERTS

A good selective review of empirical studies has been made by Wallsten and Budescu (1983). The comments provided here are selections from that review that deal with the performance of experts. The reasons for this restriction are obvious in that mineral resource assessment is performed by experts, not naive subjects. As indicated earlier, much of the research of the 60's and 70's dealt with nonexperts, while recent research, as well as some research during the 70's, has examined the performance of experts. As evidenced by the following quote from Wallsten and Budescu (1983, p. 166), there is recognition that subjective probabilities by nonexperts and experts differ in some important regards:

> "The clearest difference to be seen between these two groups is in terms of the calibration studies. When encoding subjective probabilities about events with which they are familiar, experts can be exceedingly well calibrated, whereas a similar degree of goodness has rarely been demonstrated by nonexperts in laboratory contexts. Nonexperts do show relatively rapid, but limited improvement in calibration with training and feedback, and by the same token experts are less well calibrated when required to assess events defined differently from what they are used to considering."

WEATHER FORECASTING

Probabilistic forecasts for precipitation are both extremely well calibrated and more informative than climatological forecasts. The excellent performance of weather forecasters is cited by Wallsten and Budescu (1983, p. 163) as a demonstration that there do exist conditions under which experts can provide subjective probabilities that are relatively free of bias and are well calibrated. An analysis of 17,514 forecasts issued by the National Weather Service (NWS) at Chicago, Illinois (July 1972 through June, 1976) showed a nearly perfect calibration, with a mean square error between forecast probabilities and relative frequencies of 0.028. While this result is widely accepted as an important one for the use of subjective probability in every field, it is premature to conclude that subjectively assessed probabilities in general are equally good. Generally, it is understood that important factors in this excellent performance are experience and feedback. Such circumstances can not be recreated in all applications; moreover, the event for which probabilities were assessed is a relatively simple one.

Probability-for-precipitation is analogous to the probability for the occurrence of at least one deposit. Clearly, the probability for at least one deposit does not give a distribution of probabilities for number of deposits, which is the goal of resource assessment. Thus, we must be careful to not over interpret what this result means with respect to resource assessment. Some other studies which sought to determine how well forecasters could assess fractiles of high and low temperature distributions are more relevant to the analogous capability of geologists to estimate number of deposits. Murphy (1972) had two experienced forecasters assess the 25, 50, and 75 percent fractiles for high and low temperatures during the following day for a period of 30 days. Note the similarity to geologists providing the 10, 50, and 90 quantiles for number of deposits. Murphy found that estimated medians, which are the 50 percent quantiles, tended to be slightly low on average for both the high and low temperature distributions, although the correlation between predicted and observed values was 0.97 and the mean absolute error was only 2.7 degrees Fahrenheit. The subjective probability distributions were well centered, but tended to be too broad: "Of the 55 forecasts, only 18, instead of 27 or 28, fell outside the 50% credible interval" (Wallsten and Budescu, 1983, p. 163). Note here how different this result is from that identified by Tversky and Kahneman (1974) for naive subjects: for them the subjective distributions were too narrow, being only about one-half as broad as they should be.

In another interesting study, NWS forecasters at the National Severe Storms forecast Center in Kansas City, Missouri were asked to assess the following probabilities (Murphy and Winkler, 1979, referenced by Wallsten and Budescu , 1983) :

1) for one or more tornadoes occurring in severe weather areas during the coming day;

2) for ten or more tornadoes occurring anywhere in the U.S. that day;

3) for one or more tornadoes occurring within a given tornado watch;

4) for three or more tornadoes occurring during the watch;

5) for at least one tornado in the watch exceeding specified intensity.

The assessed probabilities for 1) and 3) were rather well calibrated, although with a small, consistent bias to over predict; the other assessed probabilities were less well calibrated, presumably because they required much more effort on the part of the forecasters (Wallsten and Budescu, 1983, p. 163).

MEDICAL DIAGNOSIS

Although the results are somewhat mixed, Wallsten and Budescu (1983, p. 164) summarize the empirical studies on medical diagnosis as showing that physicians can be very well calibrated, although there is a tendency to overestimate the probabilities for serious diseases. The following are brief descriptions of two studies that were summarized by the above authors, one which investigated the reliability of various encoding methods, and the other which investigated calibration.

A study by Ludke, Strauss, and Gustafson (1977) compared test-retest reliabilities of five encoding methods: a ranking procedure, a bisection method, and direct estimates of numerical, log odds, and log-log odds scales. The subjects (nurses and senior nursing students) judged the distributions of six demographic and physiological variables which were selected as left, right, or centrally skewed. All encoding methods were reliable for symmetric distributions and least reliable for left-skewed distributions, for which the log odds method was slightly superior. Generally, the ranking method provided the most reliable judgments, except for the left-skewed distributions. Equally important, Ludke, et al. (1977) found a significant interaction between encoding methodology and distribution type in terms of accuracy. The bisection method gave very poor results for central distributions, while the other methods were less accurate for skewed distributions (Wallsten and Budescu, 1983, p. 163).

Wallsten and Budescu (1983, p. 163) also summarize the results of a massive study sponsored by the American College of Radiology (Lusted, 1977): " Whenever a patient presented with one of seven classes of problems, the physician assessed, prior to ordering an X-ray, the probability (or, at the physicians' option, the odds) of the most important diagnosis (i.e. the one they would not want to miss) and of the most likely diagnosis (which is not necessarily the same as the most important). Calibration curves, based upon the X-ray interpretation as the true diagnosis, were presented by Lusted (1977) for three classes of problems:

- skull fracture,
- extremity fracture, and
- pneumonia.

Wallsten and Budescu (1983) report that calibration for extremity fractures were virtually perfect, but for skull fractures probabilities were overestimated and for pneumonia, they were underestimated. They attribute the poorer performance for pneumonia to the ambiguity of the X-rays, while for fractures, the X-rays are conclusive. The overestimation of probabilities for skull fractures was considered to be "value induced" , meaning that the concern about a possibly serious condition, one which might have severe consequences, resulted in the overestimation of probabilities.

BUSINESS APPLICATIONS

The performance of experts in business applications ranges from very poor for the prediction of stock prices to very good for the prediction of interest rates on certificates of deposits.

Kabus (1975, cited by Wallsten and Budescu, 1983) describes the encodings of probabilities of each of several experts for interest rate on certificates of deposit, using a histogram (approximation to the pdf) format implemented through graphical procedures. From the individual histograms an average histogram was computed. Kabus (1975, p. 105, cited by Wallsten and Budescu, 1983) states that "overall, the histogram [of the] individuals and the group [the average histogram] performed very well". Wallsten and Budescu (1983, p. 165) examined the prediction of 90 day interest rates and concluded that "...they show good predictive validity in that the subjective expected values are close to the actual interest rate. In no case was the actual value outside of the 75% confidence interval, which suggests subjective distributions that were too broad." Note here, as in the study by Murphy (1972) of subjective probabilities for temperatures, the assessed distributions are too broad, not too narrow, as was the usual case described by Tversky and Kahneman (1974) for nonexperts.

Stael von Holstein (1970a, 1972, cited by Wallsten and Budescu, 1983) reports on the performance of 72 experts of various types in predicting prices of shares on the Stockholm Stock Exchange. In spite of the fact that the experts observed the accuracy of their predictions and received intensive feedback, only three of the experts outperformed predictions based on a uniform distribution (Wallsten and Budescu, 1983, p. 165); however, there was evidence that the "experts partially learned to overcome their overconfidence bias (too tight distributions) through training".

To those financial economists who consider the market to be efficient and stock prices to follow a random walk, the inability of experts to predict stock prices would come as no surprise. As an efficient market would not permit experts to improve on a uniform distribution, the von Holstein result may not be an indication of poor performance in the estimation of subjective probabilities. Instead, it may be a validation of the efficiency of the stock market and a verification that when the event being assessed is not structurally related to any causative or precursor information, experts have no relevance as predictors.

SELECTED LESSONS FROM PREVIOUS INVESTIGATIONS

SOME MECHANICS OF JUDGEMENT

EMPIRICAL AND MODEL-BASED REASONING

Koton (1985), suggests that the ability to recall is based in part on the presentation of the information in the current case. Because of the strong influence of presentation model based systems are superior to large-grained compiled databases. He notes that people find it much easier to solve a problem when it is presented as part of a model in a familiar domain. Thus model based reasoning creates a new solution for each problem rather than relying on pre-compiled solutions. The geoscientist often encounters this behavior when faced with a large vector of geological attributes. Rather than attempting to assimilate all data relationships, it is more intuitively appealing to formulate a model characterized by the principle geological attributes of the data set. Having assimilated and incorporated the familiar data in terms of a geological model the uncommon characteristics are then adapted or ignored with respect to the current situation.

CODE-BASED (CASE-BASED) REASONING IN PROBLEM SOLVING

Kolodner et al. (1985), in a study of experts giving subjective estimates to contrived situations identified three processes in problem solving. When presented with a new task people locate and retrieve partially applicable cases from long term memory. Secondly, all applicable cases are evaluated to determine those having the closest degree of similarity. Lastly, there is a transfer of knowledge from the old case to the current one. This stems from the observation that experiences are organized by generalized episodes, commonly referred to as 'stereotypical models, where unique features of a new situation are indexed by differences from the generalized episodes. In the retrieval process the general characteristics of the situation under study are identified, and previous cases are recalled based upon similarity. But it is important to note that previous cases are only identified if they are organized in the same schema and share a common set of features with the situation under consideration.

FISCHLER AND FIRSHIEN'S HYPOTHESES

Fischler and Firshien (1987), have established two hypotheses on probability reasoning. First, subjects expect that a sequence of events generated by a random process will represent the essential characteristics of that process even when the sequence is short. Thus, subjects expect that a sequence will be represented not only globally in the entire sequence, but also locally in each of its parts.

The second hypothesis is that subjects will assess the probability of an event based upon the ease with which instances or occurrences can be brought to mind. This is consistent with Leyton's (1986) notion of searching for prototypical representations in the cognitive process. In a test subjects assessed the risk of heart attack amongst middle aged people by recalling an acquaintance who suffered a heart attack. This is often referred to as the availability heuristic. The estimation of the size of the class, the likelihood of an event, or the frequency of occurrences is decided by the ease with which the mental operations of retrieval, construction, or association can be performed. This however results in systematic errors (Tversky and Kahneman, 1973). Fishler and Firschien (1987), show that human reasoning is context dependent. The difficulty in solving a problem is often not intrinsic to the logical structure of the task, but rather to the mode of presentation.

Three principle reasoning behaviors were used in subjective estimations: deductive, inductive, and analogic. Deductive reasoning is a "chain of valid assertions" leading from statements which are assumed to be true, to some given assertion whose validity we wish to establish. Long reasoning chains of small steps rely on the introduction of additional evidence to derive a new assertion. Each step uses only a subset of the facts. This of course does not allow for probability assertions where conflicting statements may arise.

Inductive reasoning formulates a generalization or abstraction that describes the set of data. Inductive reasoning can accommodate the possibility of erroneous information through short reasoning chains of big steps. Fishler and Firschien (1987) state that to ensure consensus inductive reasoning works on the global problem solving level. This implies that in formulating a generalization to the problem the mind searches for a solution that accommodates the relative effects of both positive and negative solutions.

Analogical reasoning is employed when we desire correspondence between a well understood system and an unknown. This kind of reasoning is used in the estimation of the number of undiscovered mineral deposits and, as Fishler and Firschien (1987) note, is the most difficult kind of reasoning to achieve.

SUBJECTIVE ESTIMATES OF VARIABILITY

In a Ph.D. dissertation, Fike (1987) examined in depth the ability of experts to perceive variability. This work originates in a study by Beach and Scopp (1968) who studied variability perception for paired sets of numbers presented sequentially. Their findings were that variance estimates are inaccurate due to incorrect weighting of the deviations from the sample means. Furthermore, variability estimates decrease as the sample means increase. Consistent with previous results he noted that the sequential effect of the stimulus presented is an important parameter of perceived variability. Fike (1987) found that performance for two-dimensional samples of size 5 was poorer than for one-dimensional samples of size 10.

Of special interest to the estimator of number of undiscovered mineral deposits is Fike's finding that performance for a known distribution is better than for an unknown distribution (the Siegel-Tukey non-parametric test). Optimal performance is for a normal distribution.

When confronted with a combination of variables it was found that when experts make estimates of composite variables they break them down heuristically into components. The heuristic employed results in estimates of excessively large ranges of certainty.

REVISION OF PROBABILITY JUDGEMENTS

Deyoe (1987) investigated weighted averages and the multiplicative rule for revision of subjective probabilities from independent, sequential estimates. Because the model used to elicit the subjective probabilities is important the type of evidence used in the elicitation must be considered (Winkler,1986). Deyoe (1987) considers the following two types of evidence;

- The evidence provided relates to the probability and not to the event itself. In a situation like this the two component probabilities should be averaged.

- The evidence presented relates directly to the event. In this type of situation it is important to employ multiplicative revisions.

The problem then becomes that experts must recognize the type of evidence presented. There are scenarios where revision by the expert must unambigously reflect the *type* of evidence presented. For example, when the component probabilities are both greater or less than the prior probability then a Bayesian multiplicative error leads to a combined probability more extreme than the most extreme component probability. A weighted average yields a combined probability between the two component probabilities.

In the Deyoe (1987), study a number of experts were presented with situations in which both types of evidence were presented. It was found that subjects treat the sample data differently from other types of data. Interestingly, experts used a revision method that was indeterminate whereas the naive subjects used a Bayes revision most often. The experts tend not to change their priors in light of new evidence much more often than naive subjects. The tense of the data i.e. present versus future tense did little to affect results. The most surprising result was a strong correlation to the order of presentation. The initial evidence sets a frame of reference and the additional evidence is fit into that frame.

Finally, there is the issue of momentum. If the second probability is larger than the first then the increasing order might suggest to the subject that the final probability should be even greater, thus continuing the trend. This effect is more prevalent in experts than in naive subjects.

ELICITATION AND ENCODING OF SUBJECTIVE PROBABILITIES

PERSPECTIVE AND IMPORTANCE

Nearly two decades ago, Chesley (1974, p.23) wrote:"These three factors [technique for elicitation, type of data process used, and subjects background] all have affected the elicited results and have been shown to interact in various situations." "The major factor, however, would seem to be the elicitation technique because without it the feelings of the subject cannot be converted into the usable format of subjective probabilities (Chesley, 1973)". Since that time, however, more attention has been given to the behavior of experts, which differs somewhat from that of nonexperts: "When encoding subjective probabilities about events with which they are familiar, experts can be exceedingly well calibrated, whereas a similar degree of goodness has rarely been demonstrated by nonexperts in laboratory contexts" (Wallsten and Budescu, 1983, p. 166). Consequently, when the objective is to obtain subjective probability about a scientific event, the degree of expertise possessed by the assessor obviously is extremely important. Even so, the format for elicitation, or subjective probability encoding, is still recognized as a very important factor that influences the usefulness of the expert's judgements.

Once the expert has been prepared by a careful description of what is to be estimated and has been provided with the necessary background information (scientific issues, relevant data, useful analogues, and perspectives on probability), the important issues are:

1) How well is the expert's judgement or opinion represented in the elicited responses?

2) What are the properties of the judgements (responses)?

3) Are the judgements consistent with a set of axioms guaranteeing that they can be represented by a probability measure (Wallsten, 1974, 1977)?

The importance of the first two of these issues is obvious. The elicitation and encoding of subjective probabilities of an expert presumes that the expertise and knowledge of the expert are important for the decision that is at issue. If this were not the case, the entire effort would be trivialized. Given that presumption, the use of an elicitation and encoding methodology that does not capture well the expert's judgement is counterproductive and a disservice to the expert as well as to society. To the extent that different methodologies for converting expert judgement to subjective probabilities produce different distributions of subjective probabilities, the selection of elicitation and encoding methods is an important task.

Once probabilities have been assessed, an obviously relevant question is: how good are they? This question can be easily answered when there exist external means for comparison, such as objective probabilities or actual events. When these do not exist, other standards for comparison must be used. Some of these are discussed in a later section. The third issue is important when probabilities are used in decision analysis. For example, the estimation of an expected value of a random variable requires that the estimated probabilities conform to the additive axiom. Axiomatization of subjective probability is not dependent upon the approach to subjective probability (Koopman, 1940, p. 270).

LIKELIHOOD VERSUS PREFERENCE SYSTEMS

" There are two classes of axiom systems for rational belief structures, one of which leads to a strictly additive probability measure over events (i.e. one satisfying the Kolmogorov axioms), and the other of which does not necessarily do so" (Wallsten and Budescu, 1983, p. 154). Moreover, of the additive probability axiom systems, the authors (Wallsten and Budescu, 1983; p. 154 & 155) distinguish between two subsystems: 1) likelihood-based(LB) and 2) preference- based (PB) systems:

> "LB systems yield an additive probability measure by specifying conditions that must be satisfied by a set (generally a Σ algebra) all of whose events are put in a single transitive order (i.e. are weakly ordered) by the relation 'is not more likely than' . PB systems specify [sic] conditions that must be satisfied by a set of gambles or lotteries weakly ordered according to the relation 'is not preferred to', and lead simultaneously to a probability measure of events and a utility measure of outcomes".

There seems to be considerable support among decision scientists for the preference-based approach, which basically does not elicit probabilities directly but infers them from betting situations. Moreover, such an approach a priori has some appeal in view of the heuristic biases in subjective probability distributions identified by Slovic(1972) and Tversky and Kahneman (1974). The results of experiments and empirical studies are somewhat mixed, but in general they do not justify the much greater effort required to employ betting constructs to elicit and encode probabilities: "Du Charme and Donnell (1976) found equally conservative inferences using odds, probabilities, and an indirect method similar in concept to, but more complicated than, the reference bet method discussed by Spetzler and Stael von Holstein (1975)" (Slovic, Fishhoff, and Lichtenstein, 1977, p. 18). The following is a summary of relevant investigations reported by Wallsten and Budescu (1983):

> " Beach and Phillips (1967) reported median correlations of 0.92 and 0.90 between direct judgements and objective probabilities, and between 'objective values' and subjective probabilities estimated from bets, respectively, with best-fitting regression lines having median slopes of 0.92 and 0.72, respectively". p. 160.
>
> "Beach and Wise (1969a) manipulated familiarity with events, and obtained mean absolute deviations between judged and 'objective' probabilities of 0.181 and 0.178 for unfamiliar single events and unions, respectively, and of 0.108 and 0.122 for familiar single events and unions. Subjective probabilities inferred from bets were even less accurate "p. 160.

> "Howell (1972) showed that subjective probabilities directly assessed and inferred from bets both consistently overestimate the probability for success, and that overestimation is higher for values inferred from bets and low probabilities." p. 160.
>
> "Probabilities inferred from choices among bets or from bids for bets are less likely to conform to the axioms, probably because they depend on assumptions about utility and on attitudes toward risk". p. 166.

The above evidence does not favor the use of betting or bidding situations as a means for converting judgement to encoded probabilities. This result seems to be indicated on a priori grounds (Chesley, 1975, p.331):

> "To prepare a theoretically correct betting scheme where a subject's probabilities could be inferred from his bets, it would be necessary to know the utility function the subject is using to make his decision. The specification of the utility function is usually considered as difficult as the indirect specification of the probabilities so that a substantial amount of additional effort is required to use the bet method."

Generally, experimental studies on various encoding methods show that probabilities agree more with each other than any one of the methodologies agrees with external probabilities. It should be noted however that none of the above research was performed on experts. There seems to be a dearth of empirical studies that compare direct and indirect encoding of expert judgement as probabilities. Similar results might be expected for experts, but this has not yet been demonstrated.

The foregoing discussion was devoted mainly to direct versus indirect encoding. The following sections investigate specific means for direct encoding.

PROBABILITY OR CUMULATIVE PROBABILITY?

Much of the literature dealing with elicitation or encoding of subjective probability and its calibration treats the probability for a binary event, e.g. rain or no rain. For these events, the distribution of probability is not at issue. But, when the event is not binary, such as number of deposits, the distribution of probability across the possible states of the random variable is at issue. Accordingly, using the best format for the elicitation of the distribution of subjective probabilities is an important issue. One aspect of that issue is whether judgement should be elicited by "at least" (less than) questions, or by "probability for" a specified value or interval of values of the random variable. The first of these is referred to as cumulative probability, the later is loosely referred to in the literature as probability density, even though strictly speaking the term density applies only to continuous as contrasted with discrete random variables. For simplicity, this report uses the acronym pdf, which stands for probability density function, for discrete as well as continuous random variables.

The elicitation of probabilities in cumulative form (cdf, cumulative distribution function) versus interval or density form (pdf, probability density distribution) was reported by Winkler as early as 1967 (p. 785):

> " With regard to the shapes of the curves, the pdf seemed much more intuitively appealing to the subjects than the cdf. Despite the fact that all of the pdf's drawn by the subjects were unimodal, many subjects drew cdf's which implied bimodal pdf's. They apparently did not understand the relationship between the pdf and felt unsure when working with the cdf."

The study referred to above elicited subjective probabilities from 38 subjects for four characteristics by four different methods, two of which were pdf and cdf. Chesley (1974, p. 11) generalizes from Winkler's results and those of Schaefer and Borcherding (1973, p. 128) that "Experimenters have found the probability density function more understandable by subjects than the cumulative density (sic) function". According to Slovic, Fishhoff, and Lichtenstein (1977, p. 19), "Stael von Holstein found that even after four sessions most subjects are inconsistent" when eliciting fractiles for the "less than" form of the cdf.

Spetzler and Stael von Holstein (1975 , p.351) do not recommend using either the pdf or cdf: "Subjects are seldom able to express their uncertainty in terms of a density function, a cumulative distribution, or moments of a distribution". However, they did find that graphical displays of distributions drawn from indirect responses can provide useful feedback to the subject.

The limited research that has been conducted on this subject strongly supports what is indicated on a priori grounds, namely, that when the distribution of probabilities is the objective, elicitation of probabilities for events or intervals of events is preferable to elicitation of cumulative probabilities. As the probability for "at least" is a compound event (in that it implies the summation of probabilities), its estimation a priori should be more difficult than estimating the probability for specified events. Research results confirm that this is the case.

Generally, when there is a wide range of possible values of the random variable, use of the cdf is attractive as it avoids problems with selecting the intervals for which probabilities would be assessed. Moreover, some subjects may prefer the cdf format because it is less precise and less demanding of consistency. But, the down side of this greater ease is that working only with the cdf can provide probabilities that imply a pdf that may not be consistent with the individual's views. In fact, this is one of the reported research results; moreover, when asked to resolve the discrepancies, the subjects modified the cdf to conform more closely to the pdf (Hampton, Moore, and Thomas, 1973, p. 28).

Especially problematic is a cdf that is based upon only a few, e.g. three, fractiles or quantiles and employed without a distribution form, as in the case of many of the applications of the three-step methodology for resource assessment. Not only does such a practice suffer from the general difficulties in the use of the cdf, at least in comparison with the pdf, but it is inadequate in another way. The cdf defined by three quantiles carries very little information about the expert's subjective probability distribution. Stated differently, the expert is provided little opportunity to prescribe the form of the distribution when only three quantiles are selected. It seems clearly indicated that if the individual providing the probabilities is truly expert, he deserves greater opportunity to express his judgement than is provided by the elicitation of three fractiles or quantiles for a cdf. Moreover, given the difficulties identified above with the elicitation of probabilities for a cdf, it also seems clearly indicated that the cdf approach should be replaced with an elicitation and encoding format for the pdf.

WHAT SHOULD BE ELICITED FOR DISTRIBUTIONS?

Scope

This question includes the following:

> Should elicitation be for probabilities or events?
>
> If probabilities are elicited directly, should they be for well-known events first, or for rare or extreme events?

Events versus Probabilities

The two approaches, quantiles versus probabilities, may not be symmetric (Chesley, 1975, p. 327 & 328):

> "The value dimension method has been shown to result in distributions that were too tight if the estimating procedure were started with the subject's best estimate of the value dimension. The probability scale has caused distributions to be too diffuse if the subject started with the equally likely probability".

Probably, it is more important how either of these is elicited than which is elicited. However, when elicitation employs the CDF, there is a logistical advantage to eliciting quantiles for pre-specified probabilities: The probability domain does not change with area, but the domain of relevant numbers of deposits can be vastly different for a rich, large area in comparison with a small, poor area. Thus, everything else being equal, the USGS elicitation of quantiles is a good logistical choice because of the convenience it provides in the design of MARK3, given that elicitation employs the CDF.

As noted above, there is strong preference for eliciting and encoding probabilities using the PDF, based upon a priori reasoning as well as experimental and empirical results. Replacing the CDF with the PDF clarifies the choice for probabilities, instead of quantities.

A more natural sequence of events would be for the expert geologist to examine the geology and spatial features of the area to be assessed, review relevant analogues, and then to specify the range of the random variable and the class intervals for which he would provide probabilities. This would be more natural than the reverse procedure.

Well-known versus Extreme Events

Consider the elicitation of probabilities in the pdf format. The issue considered here is the sequence and content of the elicitation questions. Specifically, in view of the overconfidence documented experimentally on naive subjects (Tversky and Kahneman,1974) and demonstrated by experts in the assessment of uranium resources (Harris and Carrigan, 1981), what is the preferred structure for elicitation?

The answer to this question that emerges from the literature is that probabilities should first be elicited for the extreme events: "Anchoring may result if the questions start with the best estimate for the value dimension, suggesting it might be better to begin at the extremes where subjects have a more certain feel of their estimates" (Chesley, 1975, p. 334). And, "...it is generally unwise to begin the encoding process by eliciting the median, since that value tends to serve as an anchor for subsequent responses" (Spetzler and von Holstein, 1975, p. 351) . These recommendations follow from the findings that in experimental settings man consistently gives subjective probabilities that define a distribution which excludes from 20 to 50% of the range of events (Slovic et al, 1977). According to Tversky and Kahneman (1974), this cognitive bias is due to the use of heuristics for the estimation of the distribution of an uncertain event in place of actual calculation of probability.

ACCURACY AND JUDGEMENT

WHAT ABOUT ACCURACY OF SUBJECTIVE ESTIMATES?

It is useful to contrast the foregoing comments about elicitation procedure with criticisms offered by Bultman et al (1992) about the USGS three-step methodology. In essence, they criticize the elicitation of quantiles in the upper tail of the "at least" cdf, e.g. for 5% and 2% as being meaningless because the geologist can not estimate these with the accuracy implied by the small probabilities, e.g. 5% and 2% error. Acceptance of these criticisms would dictate a format for elicitation that is totally counter to that suggested above, namely avoiding the elicitation of extreme quantiles. Is such a conclusion warranted?

The geologist providing quantiles would probably agree wholeheartedly that he cannot estimate number of deposits accurately; consequently, the argument by Bultman et al may at first glance be met with approval. Because of such a possibility and its implication, the notion of accuracy deserves further consideration.

First of all, the estimation of unseen deposits by virtue of geologic environment and observed geology will always leave the geologist feeling vulnerable to challenges of the credibility of his estimates. Consequently, the argument provided by Bultman et al may be accepted uncritically. While the required estimation is extremely difficult and uncertain, the criticisms by Bultman et al are not nearly as relevant as they seem. Their comments indicate some confusion of concepts. Suppose, as a means to illustration, that an expert has provided 100 deposits as his median estimate and 15 and 185 as his 95th and 5th quantile ("at least" format). If these estimates were to be described in accuracy terms, that description would be that the number of deposits is estimated to be 100 with an error of + or - 85 deposits at the 90 percent confidence level. Alternatively, the number of deposits is estimated to be 100 with an error of + or - 85% (or accuracy of 15%) at the 90% level of confidence. Thus, in this case the accuracy implied by the 5th percentile is an error of 85%, not 5% ! Contrary to Bultman et al., a 5% error (95% accuracy) in the estimate of a quantity is not equivalent to a quantile for which there is a probability of 5% that the actual value of the uncertain event is greater than the stated value.

Even from the frequentist's point of view, the interpretation of the 5% quantile, 185, as a number that can be estimated to 5% error, (as implied by Bultman et al.) is inappropriate, irrelevant, and misleading. Obviously, the notion of accuracy is even more disconnected from subjective probabilities of the personalistic school, for as described elsewhere, these probabilities are considered to be scaled measures of the individual's feelings and are considered to be relevant only to himself, not to any external, objective standard. Accuracy in any sense has no relevance to personalistic probability or quantiles. Furthermore, for the purpose of Monte Carlo simulation, inclusion of the probabilities for extreme events is required. For direct elicitation it is important to define the probabilities of extreme events.

VAGUE JUDGEMENT? OR, VAGUE EXPRESSION OF JUDGEMENT?

There is a notion that is remotely related to that of accuracy: higher order probabilities, i.e. the probability for the probability. A specific formulation of this notion is intervals of probability (Fishburn, 1986) for a specified value of the random number. These intervals represent a range of possible probabilities for a stated event. If this concept is valid, then, analogically, it seems to follow that, at least in concept, for a stated probability there would be a range of possible numbers. Naturally, such a view of subjective probability requires not only a special elicitation procedure but the development of axioms by which these estimates can be used to support decision analysis, as described by Fishburn (1986). This is an active area of current research in psychometric literature.

This notion of intervals of probability is similar to perceptions of probability that constitute the foundation for methods that have been developed, e.g. Dempster-Shafer and Fuzzy theory. These methodologies are based upon the assumption that difficulties in estimating subjective probabilities derive from vague judgement. Generally, the approach of this school to the problem of vague judgement is to replace probability theory and its encoding format with a much looser communication of uncertainty or degree of belief. Naturally, this also results in a less discriminating use of subjective estimates.

Although methods that compromise the rigor of probability theory in an attempt to facilitate the expression by subjects of vague judgement are appealing because of the flexibility that they provide and because they are less demanding of the expert, no one yet has demonstrated that they give better results:

> "Although we know that people have difficulties in expressing their uncertainties using probability, no researcher has presented evidence at the workshops that such expression is easier when subjects use Dempster Shafer Theory or Fuzzy Set Theory"(Lehmann, 1990, p.358)

The assumption of the traditional (probability) school is that it is the scaling of judgement to probability that is vague, not judgement per se. Accordingly, the traditional school maintains that when judgement is vague, this can be treated by appropriate preparation of the expert , conditioning of the event, and support of the elicitation and encoding. A consequence of the traditional view is to place great importance on the elicitation and encoding procedures, because improper procedures create distortions of the original judgement and undesirable properties in subjective probabilities.

A MODEL FOR SUBJECTIVE PROBABILITY AND CALIBRATION

ALPERT AND SPONSLER'S BASIC MODEL

In many fields of science it is possible to obtain an empirical measure of an experts accuracy. This is done by comparing the subjective probability forecast for an event with the actual outcome. Smith (1988), demonstrates that with increasing experience in forecasting, weathermen display a high degree of accuracy and are said to be empirically 'well calibrated'. In these types of situations a measure of reward can be introduced and a scoring rule may be applied to determine the accuracy of the expert. By adjusting each probability to account for accuracy very reliable estimates can be obtained. But what if the outcome of a subjective probability is never known. Then a mathematical model is required to represent how the brain may sub-consciously make subjective estimates based upon prior experiences it deems to be similar.

The following discussion corresponds to Figure 8.1. Consider an expert who is presented with some information and is asked to make a subjective estimate as to the true state of nature based upon his familiarity with the topic. A true expert will recall the full set of prior prediction results and his estimate will equal the frequency of past successful predictions. In Figure 8.1, we denote the full set of prior prediction results as *n*. The true frequency, *b* of past successful predictions is denoted as some measure expressed in percentage along the distribution. The stippled area above the distribution line and starting at

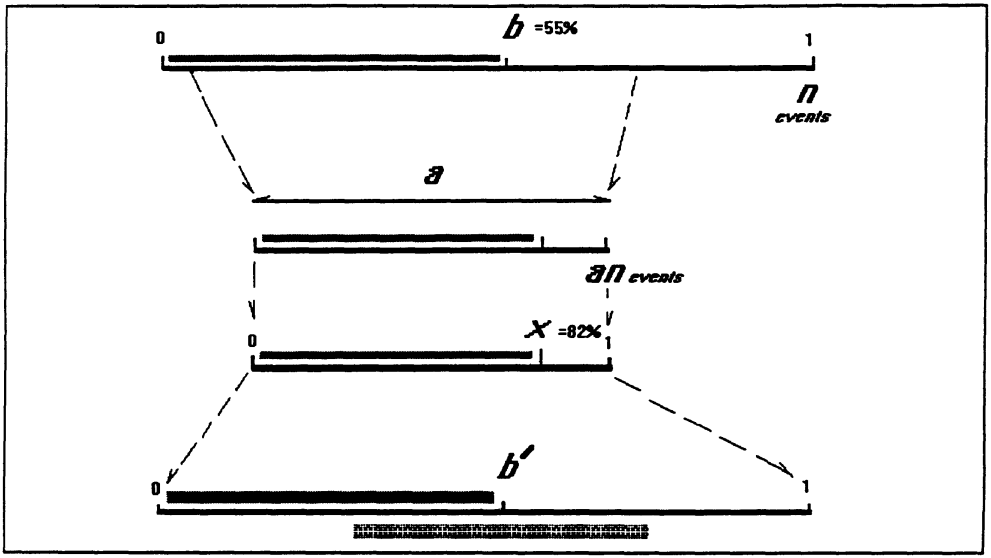

Figure 8.1: The subjective probability estimate by an imperfect expert. The paradigm is constructed after Albert and Sponsler (1989).

zero represents the full set of previous successful predictions. For demonstration purposes let us assume that the level of successful predictions, *b* is some arbitrary value, say 55%. It is unlikely that an expert can recall the full set of prior predictions when *n* becomes large.

Most experts can recall only some subset or partition representing a fraction, *an*, of the full set of prior predictions. That portion recalled in the subset can include a greater or less percentage of the successful previous predictions. Thus, *a* can be greater or less than *b* depending upon the subset recalled by the expert. Here we have arbitrarily assigned x=0.82 (82%), suggesting the common psychometric effect of the expert recalling more favorable successful outcomes than failures. The expert takes the measure *a* from the sub-conscious partition as representative of the true distribution and states that the subjective probability for outcome of the new event is x, where $x=a$.

Calibration attempts to replace the estimate x with the true frequency, *b*, representing the past successful prediction of all events including those which the estimator did not sub-consciously identify (Albert and Sponsler, 1989). In the bottom line of Figure 8.1, we are back to the full distribution n where the actual subjective probability, *b'*, now has a range of permissible values denoted by the stippled line below the distribution line at the bottom of the figure. The range of *b'* is determined by the accuracy of the expert to recall from the full set of *n*. We can thus state that the sub-conscious subset, *an*, reflects an accuracy level of, *a*, in the experts ability to recall. The resulting shape of Figure 8.1, can be termed the 'hour glass' paradigm of subjective probability calibration.

How then does the expert arrive at his estimate of the probability for an event given these sub-conscious processes. The Albert and Sponsler (1989), model considers memory to be divided into two parts; that part identified subconsciously and associated with the success frequency x is the estimate. But that portion not identified sub-consciously and known to contain instances of successes is called the remnant success frequency x^+. If an is the number of events in the identified portion then $(1-a)n$ remains in the unidentified memory trace. Likewise if the frequency of successful predictions in the full memory trace is bn, then it follows that (Albert and Sponsler, 1989):

$$b = ax + (1-a)x^+$$

where the 'actual' subjective probability b is equal to the level of expertise a multiplied by the identified part of the frequency estimate plus the remanent success. This equation can be solved for x, the subjective estimate, in terms of the level of accuracy a, 'actual' subjective probability b, and remnant success x^+ as follows:

$$x = (1/a)\,[b-(1-a)x^+]$$

From this equation Sponsler and Albert (1989), define a set of minimum and maximum values of the estimate as shown in Table 8.1.

Table 8.1: The ranges permitted x for various a and b; after Albert and Sponsler (1989).

Ranges Permitted x for various a and b

	min x	max x	min x	max x
$a \leq b$	0	1	1/a(b-1+a)	1
$a \geq b$	0	b/a	1/a(b-1+a)	b/a

Albert and Sponsler (1989), demonstrate that the brain does not make its estimate based on the subconscious selection of equally likely partitions but instead chooses the midpoint of the range of estimates permitted by the estimators particular accuracy. They show this by fitting a density function, the Beta distribution, that becomes uniform for a=0, and its mean is the midpoint of each x(a) range. Clustering is also observed to be symmetrical about the mid-point.

CALIBRATING THE EXPERT

If we could obtain from the expert a subjective probability estimate *x* and could determine the level of accuracy *a* then it is a simple exercise to determine the estimated 'actual' subjective probability *b*'. Consider the theoretical maximum and minimum values of b' (Albert and Sponsler, 1989):

$$b' \max = 1 - a(1-x)$$
$$b' \min = ax$$

They assume that the 'actual' subjective probability *b*' lies somewhere in a uniform distribution between the maximum and minimum values above. Thus the expectation for *b*' is:

$$Exp\ b' = \frac{1}{2} + \frac{1}{2}a(2x-1)$$

For each subjective estimate that an expert makes the expected subjective probability, Exp *b*', can be determined. This defines a linear relationship that when plotted has a slope equal to the subjects accuracy, *a*.

Albert and Sponsler (1989) have also presented the derivation for that distribution which is not uniform. If anx successes are contained within the sub-consciously recalled subset of an events then the possibly that the unknown number of successes is nb is given by:

$$P(\overline{nb}) = \frac{nb\,{}^{c}\,anx\ n(1-b)\,{}^{c}\,an(1-x)}{\sum_{s=anx}^{n-an(1-x)} S\,{}^{c}\,anx\ (n-s)\,{}^{c}\,an(1-x)}$$
$$= \frac{nb\,{}^{c}\,anx\ n(1-b)\,{}^{c}\,an(1-x)}{(n+1)\,{}^{c}\,n(1-a)}$$

The expected mean, the actual expected subjective probability, is determined by multiplying by *b* and then summing over the permitted values (Albert and Sponsler, 1989):

$$Exp\ \overline{b} = \sum_{anx}^{[1-a(1-\lambda)]n} \overline{b}P(\overline{nb})$$

If a set of values is assumed for the number of total binary events n, then the expectation can be calculated. This value for Exp *b* can then be taken as the calibrated estimate and substituted for *x*. As a demonstration, for $n=5$, $a=0.6$ and $x=0.66$, we obtain Exp $b=0.64$ indicating a modest optimism in the subjective estimate.

GROUP ASSESSMENTS AND RESOLUTION OF MULTIPLE OPINIONS

GENERAL

For studies in which there is a lack of objective data or a desire to incorporate matters of judgement the use of a panel of experts is commonly employed. Historically, panels, or councils, have been used where a decision is desired that reflects a resolution of several points of view. Within the scientific field the use of panels has grown to incorporate a larger collective memory for facts, together with a larger set of judgmental strategies (Ferrell, 1990). If indeed n heads are better than one then a formal system of accounting for differences of opinion and group dynamics must be introduced.

The use of groups is obviously an important subject for resource assessment. It is the composition, structure, and dynamic interactions of the group that has been subject to the most criticism. What then are preferred circumstances under which the assessment team can effectively complete the estimation task? The following discussion examines the issue of decision making through group judgment followed by an examination of techniques that combine individual judgements into a group response.

USE OF GROUPS IN DECISION ANALYSIS - A BRIEF REVIEW

Determining a set of optimum group characteristics for collective estimations can lead to improved judgments (Ferrell, 1990). To enhance the performance of a group the individuals should: 1) be experts in the field of study, 2) exhibit a flexibility in judgment, 3) possess an ability to reduce a complex problem to its essentials, and 4) have a willingness to accept responsibility for the group's decisions (Shanteau, 1986; as cited by Ferrell, 1990). Participants should be aware of factors that inhibit group potential and ways to deal with conflicts when they arise. Each member of the group should be familiar with the strengths and weaknesses of all participants and their effect on the group judgment.

Successful groups are characterized by a leader who directs the process keeping the group focused, explores difference of opinion, summarizes points effectively, and can articulate the consensus. Recording of the group discussions, conflict resolution, and supporting documentation is essential for review at a later time. Group communication is easiest through face to face meetings with the requisite level of computer and communications technology to support the estimations.

It is useful to begin a session by defining for the group the purpose of the estimation, deciding upon acceptable error limits associated with the task. There are some useful activities that, when applied, facilitate the extraction of relevant knowledge. Listing the relevant factors and variables and specifying all models to be used reminds the participants of the points at which heuristic biases may be introduced. Making a list of the variables or parameters that must be estimated to complete the task and noting the sources of potential bias allows for discussion of strategies to counter their effects. The group will benefit from quantifying the impact of variables used on the task. And, when several models are employed make group forecasts using each of the models for comparison.

Computers have been employed to assist the group in the estimation procedure, performing complex calculations and providing graphic user interfaces for the presentation of data. Early attempts at linking the computer technology with the group were perhaps unjustly labeled as failures. The failure is not on the part of the technology itself but rather with the man-machine interface. The central problem remains enhancing the group process so that their outputs become inputs for the computer process and vice versa (Ferrell, 1990). Several studies have been made of the capability of the computer to explore a groups multi-dimensional decision space (Rouse, 1973; Rouse, 1974) or to aid in the aggregation of members opinions (Lemelstrich, 1973; Pizano, 1974) have been performed. Perhaps the most interesting results were obtained using a computer polling method where individuals in the group would enter their opinions as votes into the system. The ability to present and discuss results in real time permitted the groups to explore previously unquestioned avenues of thought. As a result, the polling technique was found to be highly effective in structuring an agenda and in focusing on important issues (Ferrell, 1990).

Decision conferencing, a computer based decision analytic tool, is helping to assist groups in arriving at a better understanding of a problem and to generate new and synergistic options for action (Phillips, 1987 as cited by Ferrell, 1990). Like computer polling the system focus is on defining the common model of the problem and then emphasizing strategies to assist in the groups decision making process.

If the full potential of the group is to be realized where the collective effort is better than the best individual judgment then: 1) the nature of the judgment is important, 2) the process must employ experts in the field, 3) the group decision must reflect the dynamics of different opinions expressed during the process. Ferrell (1990, p. 217) states that ".. If the individuals have no more to contribute than noisy, possibly biased and intercorrelated approximations to the "true" value, then the group can do no better, perhaps even worse, than a mathematical combination of those individual judgements." He goes on to state that "On the other hand if there is an underlying reality, a view of which can be pieced together from the contributions of the group, then there is a possibility that a more complete understanding of it will emerge than is held by any one individual, leading to a group judgment better than that of any single member. This will most likely be the case when the individuals have significant knowledge about the matters at hand and a grasp of the context, causal factors, etc.

And the individuals' commitment must be to a group process that seeks to arrive at images of this reality that represent true synthesis of their collective knowledge."

COMBINING OR RESOLVING MULTIPLE OPINIONS (SUBJECTIVE PROBABILITIES)

Kinds of Aggregation

Ferrell (1985) notes that there are two kinds of aggregation of opinion - mathematical and behavioral. Mathematical techniques are largely algebraic manipulations of weights that seek to assign greater emphasis to an individual or outcome. Simple averaging of individual outcomes is a common technique whereby the group arrives at a single estimate to represent the group of participants. Behavioral aggregation is less passive, where the group actively discusses individual differences and strives to identify an outcome that all can agree upon.

Mathematical Aggregation

The simplistic appeal of mathematical aggregation makes it a convenient solution to an age old problem - combining very different subjective estimations into a single estimate. But, as Ferrell (1985, p. 112) points out "..two opposed zealots do not combine into bland indifference." Likewise, it is simple to demonstrate that given subjective estimates of a situation accompanied by utilities for the outcomes, rank ordering by preference and taking an average produce two very different courses of action (Raiffa, 1968). Thus, the simplicity of mathematical aggregation is clouded by the difficult selection of an algorithm reflecting the preferences of the individuals in the group. In the complicated world of mineral resource appraisal this might include differences in opinion as to what pieces of evidence have the greatest influence on the estimation and proper accounting of this influence in the final aggregated estimate.

If the estimate of each individual were modelled as being a true value with an added zero-mean and independent random error, then the best aggregation technique is a simple average. In this model, the expectation is the true value, and the standard deviation is a minimum. Testing the model in a group situation yields encouraging results: Ferrell (1985, p.115) reports "Group averages consistently outperformed individuals, and for such judgments the zero-mean error model is probably quite good. For judgements involving more complex information, this was not always the case (Rohrbaugh, 1979)."

The critical assumption is whether two experts faced with the same piece of geoscience information will form independent estimates. With dialog during the estimation process as to the interpretation of information and its impact on assessment, it is expected that estimates of the number of undiscovered deposits converge to some degree. Correlation is influenced by the number of members in the group.

When the average individual accuracy is low but the average intercorrelation of the group is even lower, then performance of the group is improved with a larger number of members. This is the old adage that small amounts of independent knowledge do add up (Hogarth, 1978; following Ghiselli, 1964; as cited by Ferrell, 1985). When the correlation of the group is high, the limit to group performance is attained with a small number of members. An interesting result is that the introduction of a less expert participant having lower correlation to the group can be preferred to a correlated, highly informed expert.

When some degree of bias is present in estimates, then averaging will yield an estimate with a smaller variance but it will not eliminate the mean error. Thus, in this case it is better to identify the estimator having the smallest error and to use his estimate for the group. The larger the group, the better the best response can be expected to be (Ferrell, 1985).

Weighting Individual Judgments

There are many schemes for assigning weights to individuals through self rating, group rating or performance rating. For the same reason that feed-back cannot be provided, performance rating schemes are not highly relevant to mineral resource estimators, except for simulated circumstances. When feedback and performance rating are not possible or have limited usefulness, influence allocation schemes may be a useful way of weighting judgements, particularily when the experts different but relevant scientific disciplines.

Influence Allocation Processes

Influence allocation employ voting methods that allow members of a group to allocate some or all of their decision making influence to others in the group. This draws not only upon the other members knowledge of the alternatives but also on their knowledge of the science (Ferrell, 1992). Self and group ratings can apply only when the members of the group have a familiarity of each other's talent as estimators. The SPAN and RCON methodologies are increasingly being used because of their flexibility in the assignment of weights.

SPAN

SPAN (Social Participatory Allocation Network) is a method of weighted voting that permits the individual to divide votes among alternatives and individuals (McKinnon, 1966). An individual thought to be more expert for the specific task at hand or with a long history of mineral resource estimation can receive votes from the other team members. The votes that a member receives from others are passed on according to the same initial allocation as his original votes. Stability is achieved through iteration of the process with all of the votes being assigned to the alternatives. The result is a set of alternatives ranked according to the data and reflecting the relative expertise of the members of the panel. The objective of group resolution is met provided that every member assign at least some proportion of votes to at least one alternative (Ferrell, 1992).

Consider the following scenario: three experts are assembled to decide if a volcano is displaying activity indicating that an explosion is imminent. The three assembled experts have the following profiles: 1) the first expert is a specialist on the frequency of volcanic explosions and has performed several mathematical models to quantify the process, 2) the second is a geophysicists trained to recognize changes in the gravity profile and seismic activity prior to explosions, 3) the third is a volcanologist who observes the type and quantity of volcanic emissions leading up to the main event. The group represents a cross section of relevant science and has the desirable characteristic of heterogenous levels of expertise. If the volcano has yet to emit any eruptive leading up to the main event and geophysical signatures have changed little, then the second and third experts may be inclined to pass some votes to the statistician. Those votes will in turn be applied to the alternatives of 1) high danger of explosion, 2) moderate danger and 3) low danger according to the preference of the first expert. That expert may have determined, however, that the second expert has a high level of expertise in prediction and will pass some votes to him. In this case the passing of votes is based upon the second expert's ability to predict and is somewhat irrespective of the current data. Those votes pass through the second expert, the transient state, and on to the various alternatives, the absorbing state, consistent with how he had applied his own votes. The SPAN system performs an accounting of the vote passing, maintaining anonymity, and calculates the probability for the alternative states.

The simple SPAN methodology can be extended to allow members to designate how the recipients may use the influence allocated to them. Thus the passing of votes may carry the condition that 1) they be passed on to others to use with the same restrictions as were applied to the passers own allocation, 2) votes are cast according to some combination of the passers and recipient allocations, or 3) votes are not restricted. This has the utility of allocating influence to others but ensuring the votes are used as the passer sees fit.

RCON

A second method similar to SPAN but more complicated and flexible is RCON (Rational Concensus). In RCON the process of allocation to members and to alternatives that is done all at once in SPAN is performed in two steps. Step 1 allows the members to assign votes to the various alternatives, Step 2 requires that the members pass votes based on the relative expertise of the others in the group to make subjective estimates. First, consideration of the alternatives by each member i leads to a matrix of weights **A** representing the probability of correctness of that alternative or some other measure of utility. Second, group members create a matrix **P** of the weights assigned by member i to member j. These weights may be thought of as "respect" measures reflecting the respect of one expert of the opinions of the other (Ferrell, 1992). The allocation **P** among members can be modelled as a regular Markov chain where the relative weights are viewed as representing the transition probabilities. The consensus weighting, **w**, is obtained by determining the limiting value of any row of P^n, as n increases. Thus the vector of final votes for the alternatives is estimated by **wA** = **v** (Ferrell, 1992).

The implementation of RCON is really quite similar to SPAN. The iterative process of allocating votes among experts is completed before the single round allocation of votes to the alternatives. In SPAN, the allocation of votes is a single step operation. Ferrell (1992, p. 3) notes "...SPAN can be likened to a 'leaky' RCON process in which the votes passed among the members leak out to the alternatives on each round from each member in proportion to the weight the individual assigns to himself."

The assignment of votes to others is anonymously performed through an influence allocation computer program. The member passing votes may do so because 1) the expertise of another who is more qualified to choose or 2) passing votes to one who is more familiar with the expertise of the others will better allocate the votes throughout the group. The passing process could iterate through a number of cycles. But, Ferrell (1992) notes there is little to be gained from proceeding beyond two iterations.

Extended RCON, XRCON does employ several judgments of others qualifications at different levels of technical expertise. The simple matrix P is replaced by the limiting matrix from successive multiplications. But, again Ferrell notes that probably only two levels can be articulated effectively by the members.

The RCON model will be elaborated upon with a synthetic example in the section entitled Assessment Methodology and Subjective Probability.

STRUCTURED GROUP CONSENSUS

Delphi

Although not commonly practiced today the Nominal Group Technique and its forerunner Delphi warrant some discussion here.

"Delphi is characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff, 1975). The Delphi process today exists in two distinct forms (Linstone and Turoff, 1975). The most common is the paper-and-pencil version often referred to as a Delphi exercise. In this version a small monitor team designs a questionnaire for a larger survey group. The monitor team also summarize the results for the survey group and design follow-up questions. This form is thus a combination of polling and conference where there is a need for effective communication between the larger survey group and monitor team. This paper-and-pencil version is the conventional Delphi.

The literature on Delphi is full of controversy as to the effectiveness of the technique. Linstone and Turoff (1975) note the following common reasons for failure of the method:

- Imposition of monitor views and over specification of the structure of the Delphi do not allow for the contribution of other perspectives related to the problem. This is commonly manifested in using the Delphi as a surrogate for all other personal interaction in the group.

- Poor techniques of summarizing and presenting the group response, and ensuring common interpretations can lead to confusion. Ignoring and not exploring disagreements discourages dissenters, whereby they drop out resulting in an artificial consensus.

Users of the method note "virtual" problems in selecting a productive panel of experts. This problem is common to any industry and requires striking a balance between personalities and professional credentials. Like the Delphi that is too restrictive and explicit in form, borrowing the Delphi structure from a previous study will not lead to success with a new problem. The following pitfalls should be considered in the implementation of a Delphi study (Linstone, 1975). The prediction-urge typifies a person's dislike of uncertainty. Thus, results that have a high degree of convergence are often accepted whereas those that display wide differences after the final iteration are considered unusable. The simplification-urge states that simplicity is preferred to complexity. People are drawn to mathematical models that elegantly simplify, but caution must be exercised not to develop superficial caricatures. Illusory expertise suggests a reliance on a panel of experts, but they may not be the best forecasters. Sloppy execution of panel selection can result in a group of like-thinkers, excluding the mavericks.

Delphi Conference

A newer form of Delphi is sometimes referred to as a "Delphi conference". Here the monitor team is replaced by an expert computer system, thereby turning the process into a real-time communication system.

The stages of Delphi, as described by O'Keefe (1982) are:

1. The group can meet collectively or participate via telephone or mail service. The moderator will begin by leading the panel through an orientation of the subject material followed by a definition of the goals to be achieved;

2. the moderator then leads the experts through a series of initial questions. These questions are loosely defined in content so that significant issues not previously identified might surface;

3. the panel respond to the questions giving reason for each response;

4. it is the job of the moderator to receive the answers and to compile the results for presentation to the group;

5. in a second round, the group is asked to provide new answers in light of the initial responses addressing some of the differences observed;

6. these answers are again collated by the moderator who provides a summary to the group;

7. in the third round, the group begins to address specifically the differences remaining in the responses, with the moderator exploring these issues while preserving the anonymity of the respondents;

8. in the fourth round, the panel strives for convergence of opinion in light of information/opinions expressed in the previous round. If convergence cannot be attained, then the moderator may try to obtain justifications for differences of opinion. If convergence still seems to be unlikely, then the moderator may stop the process. If a convergence of opinion is obtained, then the moderator summarizes these results and presents them to the panel;

9. group feedback continues until a consensus is reached.

Throughout the process the moderator must be careful to ensure that his role remains neutral, providing the panel with only summarized results. It is the job of the moderator to clear up any ambiguities and to explore maverick responses.

Nominal Group Technique (NGT)

Nominal group technique NGT has been developed to retain some aspects of the group dynamics thought to be lost in the Delphi structure. NGT begins by eliciting from each group member judgments to be evaluated by the others. After discussion and resolution of controversies a group judgement is obtained by mathematical aggregation as discussed above (Delbecq, van de Ven, and Gustafson, 1975).

Evaluation and Comparisons

In an evaluation of both NGT and Delphi, Ferrell (1985) reports that NGT has generally performed better but by a non-statistically significant margin. Neither method is found to be better than free discussion to consensus. In a comparison of interactive methods like NGT and mathematical combination the interactive methods are again marginally better (Ferrell, 1990). No method will yield an aggregated result lower than that obtained from the worst individual response of the group. Like-wise the best response shifts to different members of the group for different tasks, suggesting that there may be little improvement over equal weights, but Ferrell (1990) notes: "... when the conditions were specifically designed to be such that a) questions on a variety of topics were asked, b) individuals in the group had different specialized knowledge and c) individuals were well acquainted with each other, the SPAN technique was superior (Aguilar, 1980). The failure of NGT and Delphi is generally information limited rather than expertise limited. Likewise there is a general insensitivity of linear models to weighting (Ferrell, 1990). In a comparison of Delphi, NGT, discussion to consensus, and mathematical models for combining the opinions of individual judges, Fischer (1981, p.97 as cited by Ferrell, 1990 p. 208) states: "from a practical standpoint it makes little or no difference how one aggregates the conflicting opinions of experts. Any reasonable approach is likely to be as good as any other." This has since been refuted by Ferrell (1990) who demonstrates that "specific knowledge about the judgement situation is needed, and it must be combined at its own level before rather than after it has been summarized into a final estimate by each individual. This is consistent with the structure of the SPAN and RCON models.

CHAPTER IX--ASSESSMENT METHODOLOGY AND SUBJECTIVE PROBABILITY

ASSESSMENT METHODOLOGY AND SUBJECTIVE PROBABILITY

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GROUP ASSESSMENT

- PERSPECTIVE
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ASSESSMENT METHODOLOGY AND SUBJECTIVE PROBABILITY

PERSPECTIVE

The discussion in this section of assessment methodology is presented under three major headings, direct elicitation, indirect elicitation, and group assessment. The first of these, direct elicitation, considers preferred methods when probabilities are elicited directly, meaning that questions about the event, e.g. number of deposits, are posed directly to the expert and that he either responds with a probability or for a stated probability responds with a quantile. The second heading considers methods that obtain the desired probabilities indirectly, or alternatively, the quantiles indirectly. The idea here is that questions posed to the expert do not require him to think in terms of probability but the answers that he provides can be analyzed for the desired probabilities. Finally, assessment by a group is considered, with special attention to the composition of the group in terms of expertise and the structure of the group processes that maximize the value of group assessment.

DIRECT ELICITATION

PROBABILITIES VERSUS CUMULATIVE PROBABILITIES

The research discussed in previous sections indicates clearly that probabilities should be elicited for the pdf, not for the cdf. Moreover, this elicitation should be aided by visual support, such as the display of the distribution of the elicited subjective probabilities. The particulars of estimating number of deposits give no reason a priori that this clear preference for elicitation of probabilities in the pdf format should not also apply to that task.

One feature mentioned in the conference as leading to preference for the cdf was that a large number of probabilities would be needed for rich areas, as the relevant range of the random variable might be quite large. When this is the case, the pdf format will require elicitation of probabilities for intervals of number of deposits. Quite naturally, this raises questions of identifying the intervals and the effect of interval specification on probability estimation. Clearly, to use the pdf format and not lead the geologist will require that the geologist himself specify the relevant numbers of deposits or the relevant intervals of number for which probabilities are to be elicited.

The role of the elicitor for the pdf format is to skillfully extract from the expert the range of possible events (number of deposits) that are relevant by review of useful analogues (control areas) and by insightful questions that relate to the geology, to spatial issues, and to density of mineralization. Allowing the expert to establish the events for which he will provide probabilities requires that the computer program for step three (a replacement for

MARK3) be designed to accept variable inputs, meaning numbers of classes and limits of classes, as well as the elicited probabilities. While the resulting program is more complex than MARK3, the design and construction of such a computer program is still a routine task.

Once the relevant numbers have been established, the elicitor is ready to turn to the elicitation of probabilities in the pdf format. Although various approaches have been used to elicit and encode subjective probabilities, e.g. bets, odds, log odds, probability wheel, etc., in general, direct elicitation has been shown to be as good as most and better than some. If direct elicitation is employed for the distribution of probabilities, it should stress the tails first so as to avoid heuristic bias due to excessive anchoring. However, since the subjective probabilities for number of deposits are for the assessment of mineral resources, there is an alternative indirect approach that should be considered instead of direct elicitation. This will be described in a later section.

ELICIT PROBABILITIES FOR SIMPLE BINARY EVENTS WHEN POSSIBLE

The excellent calibration of weather forecasters is attributed primarily to the availability of feedback and the use of this feedback by the expert to maintain a calibration of his subjective estimates of the probability for precipitation. Although the literature does not comment specifically upon the role of event simplicity i.e. binary, it is undoubtedly an important reason for the excellent calibration of weather forecasters. As noted elsewhere in this report, weather forecasters were quite well calibrated for the simple events : 1) one or more tornadoes during the coming day, and 2) one or more tornadoes within a given tornado watch. They were less well calibrated for the compound events: 1) ten or more tornadoes anywhere in the U.S. on that day, and 2) three or more tornadoes during the watch.

There is an important lesson here for mineral resource assessment methodology: Structure assessment so that subjective probabilities are for the simplest possible event. This means that to the extent that geology and geologic environment permit, smaller areas are preferred to larger ones. The smaller the area, the more important the probability for zero deposits. In the limit, the relevant events are zero and one. Drawing upon weather forecasting, subjective probabilities for one or more deposits, or equivalently, for zero deposits, should, ceteris paribus, be better calibrated than subjective probabilities for larger numbers of deposits.

A second reason for this simplification is that the geologist is more likely to be able to simulate feedback. Feedback in the same sense as that available to the weather forecaster is impossible for the mineral resource assessor. However, to the extent that control areas can be used to simulate training and feedback in some sense, it is more likely to be successful for the simple event of 0 and 1.

The third reason for simplification is that some calibration experiments and methods are based upon simple binary events. Moreover, other experimental means for calibration, are more likely to be effective for simple events. The recent work by Sponsler and Albert (1989) and Albert and Sponsler (1989), for example, provides a model for estimating the expected subjective probability for a simple binary event from the estimated subjective probability and an accuracy parameter. The idea here being that if for a simple event an expert's accuracy parameter can be estimated in an experimental setting, an unbiased expected subjective probability can be computed from the estimate that he provides.

WHAT ABOUT PROBABILITIES FOR NUMBERS GREATER THAN ONE?

It is for the estimation of the objective distribution of probabilities for a range of possible states of nature, such as number of deposits, that man's cognitive processes appear to be most limited and that heuristic biases are greatest. Consequently, preferred procedure may be to not elicit these probabilities directly, at least not initially, but indirectly.

INDIRECT ELICITATION

THE USE OF PROBABILITY MODELS FOR INITIAL ESTIMATES OF THE DISTRIBUTION OF PROBABILITIES

Basically, the idea advanced here is that a few selected judgements should be elicited from the expert that permit the estimation by a computer algorithm of the parameters of one or more formal probability models. For example, for number of deposits or the number of districts, the Poisson and negative binomial are obvious models. The idea here is not that the ultimate probability distribution be described by one of these models, but that one or both of these models be estimated from especially constructed judgements made by the geologist as an initial step, so that the geologist can see visually a distribution of probabilities by one or more possible theoretical models, the parameters of which are consistent with his judgements. If such an approach is carefully designed to represent well his strongest judgements about numbers of deposits, it has the advantage of exposing him to the range of possible events and their probabilities when such are defined by theoretical probability models. This should help considerably to mitigate the conservatism that results from unbridled exercise of heuristics, namely the underestimation of probabilities for events in both tails of the pdf by 20 to 50%.

Clearly, this proposed methodology is contradicted by the personalistic school of subjective probability, which is quite unanimous and definite in its counsel to avoid formal probability models in elicitation and encoding. Of course, this is expected, as it is consistent with the objective of the personalistic school, which is simply to elicit opinion, irrespective of whether it is coherent[1] or related to objective probability. However, if the goal is to have the best possible estimates of objective probabilities, as should be the case for mineral resource

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[1] Obeys the Additive Axioms of probability

assessment for societal decisions, disregarding formal probability models as an aid to subjective assessment seems ill-advised.

Inasmuch as directly elicited subjective probability distributions tend to be much too narrow and to the extent that one or more formal probability models are known on *a priori* or experimental grounds to be useful distributions, there is a strong case to be made for using them to mitigate the natural heuristic biases present in unconstrained subjective probability distributions, i.e the excessive narrowness (overconfidence). At least in the early stages of elicitation and encoding, presenting the geologist with a visual display of what his strongest judgements about number of deposits imply as to the distribution of probabilities by one or more relevant formal probability models seems to offer more benefits than liabilities when the goal is a subjective probability distribution that approximates the distribution of objective probabilities.

One appealing aspect of the nonparametric approach , like that currently employed, is that no one can be criticized for the mathematical model selected. Everything else being equal, this safe approach is appealing, but everything else clearly is not equal! The evidence for heuristic bias in unstructured subjective probabilities for compound events, such as number of deposits is overwhelming. This being the case, it is doubtful that the 'safe', nonparametric approach can be optimal. Is it not far better to support the expert, at least initially, in the estimation of the distribution of probabilities with one or more relevant probability models so that he is reminded what the range of events and their probabilities might be when they are distributed according to formal probability models, models that are conformable with his strongest judgements about number of deposits?

Clearly, if formal probability models are to be used for initial support for the expert, the parameters of these models must be estimated from judgements by the expert that do not themselves carry a strong heuristic bias. Accordingly, to the degree possible, these judgements should be about events, not their probabilities. It would be contradictory to estimate the parameters of the formal probability models from subjective probabilities when the motivation for the models is that the subjective probabilities are biased. The following section explores this notion further.

USE JUDGEMENTS OF FAMILIAR EVENTS AND THE PROBABILITY FOR AT LEAST ONE DEPOSIT TO ESTIMATE PARAMETERS OF THE PROBABILITY MODEL

GENERAL

The utility of using a probability model in the initial stages of elicitation of the subjective probability distribution is especially high when required parameters can be estimated from the probability for 0 or for one or more deposits supplemented by one or two judgements about number of deposits, or about relative likelihood of two different events (number of deposits). In other words, the elicitor would have access to an algorithm that estimates the parameter(s) of the probability model from judgements that are primarily about number of deposits, not about their probabilities, except for the probability for at least one deposit.

In concept, elicited judgements should be about events with which the geologist is most familiar by virtue of his experience. For example, one judgement that is indicated on a priori grounds is about that number of deposits believed by the geologist to be most likely. This may appear to contradict the counsel of the experts on subjective probability, which is to avoid elicitation of the most likely or median quantities when eliciting the entire distribution by direct means. That counsel is based upon the premise that estimation of modes or medians encourages the expert to anchor on these quantities and to underestimate the probability for events in the tails of the distribution. While this is good counsel in general, it is not relevant to the procedure here described. Here, anchoring is not an important issue, because the initial probabilities are to be generated by the formal probability model that is to be estimated from judgements elicited from the geologist. That being the case, it is logical as well as good procedure to elicit judgements about those events that the geologist is most familiar with, or equivalently, best informed about.

Knowing *a priori* that subjective estimates of probabilities for extreme events are underestimated, we should avoid the use of such probabilities in the initial estimation of the probability model. To the degree possible, parameters of the probability model should be estimated from judgements about familiar events. The essence of the approach is to use the formal probability model to reveal to the geologist what a full distribution of probabilities may look like as implied by his judgments about familiar events as structured by the formal probability model. The estimates based on the familiar events are not the final probabilities but rather are starting points from which the expert estimates the final distribution. In the case of number of deposits, a familiar event might be the number of deposits that occurs most frequently in areas of the specified size.

MEAN, MEDIAN OR MODE?

Alternatives to the modal event are the median and the mean.
Although psychometric and decision analysis literature shows that experts can estimate these quite well, the use of the mean should be questioned when the distribution can be highly skewed, as is often the case for probability distributions for number of deposits, especially for small or poorly endowed large regions. As the mean is the probability-weighted average of number of deposits, its calculation requires the mind to simulate the calculation of a mathematical expectation. As this would be done informally by one or more heuristics, it is not likely on a priori grounds that subjective estimates of means for highly skewed distributions are good. It must be emphasized here, however, that this is conjecture and has not been demonstrated directly. However, the results of the experiment with expert estimation of probability distributions for uranium endowment for the San Juan Basin of New

Mexico by Harris and Carrigan (1980) support this conjecture indirectly: The system generated distributions were skewed and nearly twice as broad as those estimated by unconstrained subjective processes, and the means of the two distributions differed greatly.

What about the median? As the median requires a partitioning of the probability distribution into equal parts, it appears a priori that individuals would be able to provide better estimates of medians on skewed distributions than they would means. This reasoning here is that partitioning of the probability distribution into equal parts is a much simpler task than estimating a probability weighted average of events. But, both require some knowledge of the distribution of probabilities, although the requirement for the estimation of medians is less demanding than that for the estimation of means. The more difficult question to answer is whether subjects can estimate medians as well or better than modal values. The literature on psychometrics and decision analysis deals more frequently with the estimation of medians than any other measure of central tendency. Moreover, empirical studies, such as those for weather forecasting, conclude that estimates of medians by weather forecasters are overall quite well calibrated. As there is no evaluation of the calibration of these same experts on modes, the literature is not helpful in resolving this question. Of course, if the event being estimated in symmetrically distributed and possesses only one mode, there is likely to be little difference in the calibration of experts on estimates of modes or medians.

What about the estimate of a measure of central tendency on skewed distributions? While this cannot be answered from experimental studies or empirical results, it seems indicated a priori that for unimodal skewed distributions, the subjective estimate of the mode should be more reliably made than that of the median, for, at least in concept, it requires the expert to search his experience for the most commonly occurring event. This should be, ceteris paribus, a more natural and easier task than partitioning a mentally constructed relatively frequency distribution.

FORMAL USE OF THE TONNAGE AND GRADE DISTRIBUTIONS TO ESTIMATE THE NUMBER OF DEPOSITS DISTRIBUTION

CURRENT APPROACH EXCELLENT IN CONCEPT, BUT DIFFICULT TO IMPLEMENT

Consider an unexplored region: If deposits of the type under consideration do occur, their sizes and grades are expected to be a sample from the parent population. Thus, to the extent that the data used to construct size and grade distributions are representative, the size and grade distributions for a deposit type serve as models of the parent populations. Assume for this discussion that these distributions are good models. Given that assumption, the motivation for constraining the geologist's estimate of number of deposits to be consistent with tonnage and grade distributions is basically a very good idea. Otherwise, each geologist might preferentially be estimating number of deposits for different populations of deposit tonnage and grade, sizes and grades with which he is familiar but which are not necessarily representative of the deposit type in general. Naturally, such estimates for number of deposits would differ by virtue of different perceptions of the population being estimated, even when the geologists might be in agreement otherwise. Clearly, in concept, the use of the tonnage and grade distributions is an important feature of methodology, because it establishes a common reference for all geologists and removes what could be a significant source of variation in number of deposit estimates.

The idea developed here is that the use of tonnage and grade distributions to support and constrain the geologist's estimation of number of deposits is excellent in principle, but difficult to apply. This is especially so when that constraint is simply informal reference to the distributions, as is the case with the current USGS methodology. There is concern about how well the mind truly factors into the estimation of the number of deposits distribution the full tonnage and grade distributions. Anyone who has attempted to do this knows first hand that it is far more difficult to put into practice than the idea itself suggests. When the individual's experience is mainly with a subset of the deposits that make up the tonnage and grade distributions this is particularly the case.

Suppose, for argument, that the experience of the individual who is estimating number of deposits includes deposits that fall on the central part of the tonnage distribution but on the upper half of the grade distribution. How does he generalize from this experience to number of deposits in the full bivariate population? Does he focus only on tonnage or on both tonnage and grade? And, what are the heuristics that he employs? How good are the resulting generalizations? When experience of each assessor is different and this process is informal, variation among assessors on the effective integration of these distributions to the estimation of number of deposits could be a significant source of variation in estimates of number of deposits and their associated probabilities. What is the magnitude of this variation?

As an aside, difficulty in considering number of deposits as relevant to the full tonnage and grade population was observed during the Tucson conference: specifically, some criticisms of the number of deposit estimates by one or more panel members were modified when they were reminded that the numbers referred to a size and grade population described by the tonnage and grade distributions. The important point here is that panel members had to be reminded several times because their experience was not with the full distributions.

Even though the answers to the above questions are not known at this time, the questions themselves are sufficient to indicate the need for a more formal structure for integrating tonnage and grade distributions into the estimation of number of deposits. When the area to be assessed has received little exploration, this formalization can employ the original size and grade distributions. Otherwise, it should be based upon distributions that have been modified to account for the size and grade bias of exploration, provided that such influences are significant for that deposit type.

FORMALIZING THE USE OF TONNAGE AND GRADE DISTRIBUTIONS

The concepts examined in this section assume that the geologist does not possess sufficient information to estimate number of deposits directly from process-based analysis. Usually, this assumption represents reality. When such circumstances exist, the geologist must infer number of deposits from experience, analogue regions, and statistically related features. It is for such inference that the formalization of tonnage and grade distributions is potentially useful.

There are different ways that the use of the tonnage and grade distributions to estimate number of deposits could be formalized. The perspective for the procedure described in this section is that such formalization should be early in the process of estimating the number of deposits distribution. Accordingly, the procedure described here uses this formalization to obtain consistent initial judgements about number of deposits.

Consider the proposition that when number of deposits is estimated, the geologist associates this number with a mental population that is easily retrieved from his experience and that in general this mental population is not representative of the population implied by the tonnage and grade distributions. This does not imply purposeful bias; it implies only that the subset that is recalled reflects experience, preferential interest, and psychological influences that in general do not conform with the full tonnage and grade distributions or the populations that they imply.

This notion of mentally retrieving a subset of the actual population is a specific case of the general model for subjective probability estimation described by Albert and Sponsler (1989), which proposes that when estimating probability for a binary event, the mind recalls a subset of the entire event space and takes the proportion of that subset for which the event occurs as the estimate of the proportion of the full population. The work of Albert and Sponsler is especially relevant because it is the first to propose a model of how the mind estimates subjective probability for a simple binary event.

To assure consistency between number of deposits and the tonnage and grade distributions, a better procedure may be to elicit a judgement about number of deposits for the ranges of tonnages and grades about which the geologist is most familiar and then to use the tonnage and grade distributions to infer the number of deposits in the full population. The familiar range is analogous to Albert and Sponsler's (1989) 'recalled subset'.

SPECIFIC CONCEPTS IN FORMALIZATION

Consistent with the foregoing notions, estimation of the number of deposits begins with the specification by the geologist of the ranges of deposit tonnages and grades with which he is most familiar, i.e.. the shaded in Figure 9.1. Then, after careful consideration of the geology of the area, the geologist makes a judgement about the number of deposits, having tonnages and grades within these ranges, that is most likely to occur within the assessment area, N_m^{**}. From this number, the elicitor (not the geologist) computes an initial estimate of the most likely number of deposits of all tonnages and grades (full tonnage and grade distribution), N_m, by dividing N_m^{**} by the probability for deposits in the full population having tonnages and grades within these ranges:

$$[P(t_L^* < T < t_H^* \ , \ q_L^* < Q < q_H^*)]$$

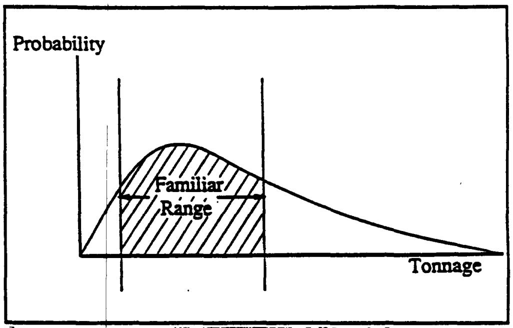

Figure 9.1: The shaded area represents the familiar range in a probability distribution.

$$N_m = \frac{N_m^{**}}{P(t_L^* < T < t_H^* \ , \ q_L^* < Q < q_H^*)}$$

as inferred by relative frequencies from the tonnage and grade distribution:

Where:

N_m^{**} is the most likely number of deposits of the familiar tonnage and grade ranges,

and $$[P(t_L^* < T < t_H^* \ , \ q_L^* < Q < q_H^*)]$$

is the probability (relative frequency) for deposits of the familiar tonnage and grade ranges.

Note that the probabilities that are used to infer N_m from N_m^{**} can be computed from formal probability models, e.g. lognormal, fitted to the data on deposit tonnage and average grade, or they can be replaced by relative frequencies taken from the tonnage and grade curves that currently accompany the USGS deposit models. Of course, to be a more direct support of this analysis, the same data that are used to create the tonnage and grade curves should be recast as relative frequency histograms, or as some smoothed version of the histograms. For the special case of independence of deposit tonnage and grade,the relative frequency approximation to the probability described above would be obtained simply by 1) reading from the histogram for deposit tonnage that relative frequency of tonnages within the familiar tonnage range, 2) reading from the grade histogram, the relative frequency of grades within the familiar grade range, and 3) multiplying the two relative frequencies.

Consider two other tonnage and two other grade classes:

$$T < t^{*L} \quad \text{and} \quad T > t^{*H}$$
$$Q < q^{*L} \quad \text{and} \quad Q > q^{*H}$$

Using N_m and the tonnage and grade distributions, numbers of deposits for combinations of these grade and tonnage classes can be computed by rearranging the above relation. For example, the number of deposits having sizes less than t^{*L} and grades less than q^{*L} is computed as follows:

$$N_M^{LL} = N_M \cdot P(\ T < t_L^*\ ,\ Q < q_L^*)$$

As explained above, the probabilities involved in these calculations could be approximated by relative frequencies from histograms generated with data that comprise the current tonnage and grade curves that accompany the deposit models.

Construct a table and enter these numbers appropriately (Table 9.1).

Table 9.1: Numbers of deposits for selected combinations of tonnage and grade classes based on the initial number estimates for familiar ranges.

	Deposit Tonnage		
Deposit Grade	$T < t^{*L}$	$t^{*L} < T < t^{*H}$	$T > t^{*H}$
$Q < q^{*L}$	N_m^{LL}	N_m^{L*}	N_m^{LH}
$q^{*L} < Q < q^{*H}$	N_m^{*L}	N_m^{**}	N_m^{H*}
$Q > q^{*H}$	N_m^{HL}	N_m^{H*}	N_m^{HH}

Clearly, N_m is the sum of all table entries and constitutes the initial estimate of the most likely number of deposits over all tonnage and grade classes.

The purpose of the foregoing analysis is to provide the geologist with the above table so that he can see what his judgement about number of deposits for the familiar tonnage and grade ranges means as to the total number of deposits over all tonnage and grade classes. He may decide that even though he still likes his estimate of number (N_m^{**}) for the familiar tonnage and grade classes, the total number of deposits (N_m) implied by that initial estimate (N_m^{**}) is too large, or perhaps too small.

This formal use of the tonnage and grade distributions forces the geologist to relate knowledge of familiar events to the population of deposit sizes and grades as they occur in nature. This may require a sequence of adjustments, seeking that total number of deposits that is conformable with features of the population represented by the tonnage and grade distributions and at the same implies a number of deposits within the familiar tonnage and grade classes that is a acceptable to the geologist, given his experience and interpretation of the geology of the area.

A SIMPLIFIED AND CONTRIVED EXAMPLE OF FORMALIZATION

The following simplified and contrived numerical demonstration may be useful in clarifying concepts and procedure, as well as calculations: Suppose that the number of deposits for the familiar tonnage and grade classes is estimated to be 20. Suppose also that from the tonnage and grade distributions, the joint probability (relative frequency) for deposits having tonnages and grades within these ranges is estimated to be 0.5 , meaning that

Table 9.2: Probabilities for combinations of tonnage and grade classes estimated from the tonnage and grade distributions.

	Deposit Tonnage Classes		
Deposit Grade Classes	$(T < t_L^*)$	$(t_L^* < T < t_H^*)$	$(T > t_H^*)$
$Q < q_L^*$	0.05	0.12	0.03
$q_L^* < Q < q_H^*$	0.10	0.50	0.05
$Q > q_H^*$	0.05	0.08	0.02

one-half of the deposits used to construct these distributions have tonnages and grades that fall within the familiar ranges. Thus, the total number of deposits inferred from this initial judgement is 40 = 20/ 0.5. Suppose further that the probabilities for the combinations of tonnage and grade identified in Table 9.1 are all calculated, as shown in Table 9.2.

Multiplying these probabilities by 40 gives the number of deposits implied by his initial estimate and the tonnage and grade distributions for each combination of tonnage and grade classes (refer to Table 9.3).

Table 9.3: Number of deposits for combinations of tonnage and grade classes based on the familiar ranges when evaluated by the full tonnage and grade distributions.

		Deposit Tonnage Classes		
Deposit Grade Classes	($T < t_L^*$)	($t_L^* < T < t_H^*$)	($T > t_H^*$)	Row Totals
$Q < q_L^*$	2	4.8	1.2	8
$q_L^* < Q < q_H^*$	4	20	2	26
$Q > q_H^*$	2	3.2	0.8	6
Column Totals	8	28	4	40

This is the table that the geologist should examine carefully, for it contains his initial estimate of 20 for the familiar tonnage and grade class combination as well as the number of deposits implied by that number and the tonnage and grade distributions. He might not like some of these numbers even though he likes the initial estimate of 20 for the combination of familiar tonnage and grade classes. Suppose, for example, that he believes that a total of 40 is a bit high and that 4 deposits in the high tonnage class is too optimistic. His intuition tells him that there could be no more than 2 large deposits in the area, and that a total of 30 seems more reasonable. Here, the elicitor points out that to reduce the number of deposits in the high tonnage class to 2 requires reducing the total to 20 and the number in the familiar tonnage and grade class to 10. On the basis of the geology, is this acceptable? Upon reflection, the geologist may compromise, suggesting that perhaps the number in the combination of familiar tonnage and grade classes should be reduced, but only to 15, not 10. So the elicitor generates the revised table for his review as shown in Table 9.4.

Table 9.4: Revised estimates for number of deposits.

	Deposit Tonnage Classes			
Deposit Grade Classes	$(T < t_L^*)$	$(t_L^* < T < t_H^*)$	$(T > t_H^*)$	Row Totals
$Q < q_L^*$	1.8	4.3	1.1	7.2
$q_L^* < Q < q_H^*$	3.6	18	1.8	23.4
$Q > q_H^*$	1.8	2.9	0.7	5.4
Column Totals	7.2	25.2	3.6	36

Although the geologist still believes the number of deposits in the high tonnage class is a bit too high, he does not want to reduce any further the number of deposits in the familiar tonnage and grade class(18), nor the total (36). Thus, he has arrived at a modified judgement about number of deposits, 36, one that he can accept in view of the number of deposits in all combinations of tonnage and grade classes implied by the tonnage and grade distributions. While such a procedure does not ensure that the resulting estimate of number of deposits is a good estimate, it does ensure that the geologist has considered what the estimated number of deposit means in terms of a population of undiscovered deposits in that area, as implied by the tonnage and grade distributions.

Notice that the above procedure has not posed any question to the geologist about the probability for number of deposits. All numbers of deposit are related to the judgement (most likely number) for the familiar tonnage and grade class and subsequent modifications as dictated by the distribution of deposits among the combinations of classes.

The above example used only three tonnage classes and three grade classes for simplicity. Obviously, more classes could easily be used if such an approach were supported by appropriate computer software. Of course, the larger the number of classes, the more information provided about numbers in specific tonnage and grade classes. However, too many classes may tax the tolerance of the geologist; moreover, except for areas with very large numbers of deposits, as number of classes increases, the more frequent are those classes having fractional numbers less than 1.

Having examined carefully the interaction of number of deposits with the tonnage and grade distributions and having arrived at a stable judgement of the most likely number of deposits for the area, elicitation now seeks additional information that permits the estimation of the parameters of a formal probability model for number of deposits. The specific questions posed by the elicitor will vary depending upon which of the formal probability models is selected. But, the overall procedure is the same: Specifically, to elicit those judgements about number of deposits that permit a computer algorithm to estimate the parameter(s) of the probability model.

COMBINING FORMAL USE OF TONNAGE AND GRADE DISTRIBUTIONS WITH A PROBABILITY MODEL FOR NUMBER OF DEPOSITS--A SIMPLIFIED NUMERICAL DEMONSTRATION OF CONCEPTS.

ESTIMATING PARAMETERS OF THE PROBABILITY MODEL

Suppose that the foregoing procedure has produced an adjusted initial judgement that there is a total of 36 deposits in the area; suppose also that there is evidence that the Poisson distribution might be an appropriate probability model. Finally, suppose that upon elicitation of the probability for one or more deposits, the geologist responds that he is very confident that there is at least one deposit present, that the probability must be approximately 1. The elicitor then asks the geologist to select a number of deposits that is close to his most likely number, 36, but a little less, a number that he believes is quite possible as the actual number. The geologist responds with 30 deposits, whereupon the elicitor now questions the geologist about how much more likely his most likely number of deposits is than this lower but highly possible number. The geologist responds with about 55 % more likely. Given these responses, the elicitor conveys them to a computer program, which for the stated circumstances computes lambda, the parameter of the implied Poisson distribution. For this simple contrived situation, the geologists' responses are consistent with the Poisson probability model; consequently, lambda can be computed directly from the following relationship:

$$\ln(\lambda) = \ln P(N=N^m)/P(N=n)x(N^m!/n!)/(N^m-n)$$

where n is the smaller but highly likely number.

This relation is derived directly from the Poisson probability function. For this numerical demonstration,

$$\ln(\lambda) = \ln[(1.55)\cdot(36!/30!)]/6$$

giving $\lambda = 35.99$, or approximately 36, which is the geologist's most likely number of deposits.

REVIEW AND MODIFICATION OF INITIAL PROBABILITIES

Given the estimated lambda, the Poisson is used to generate the probability distribution for number of deposits, as shown in Table 9.5. Preferably, these data would also be displayed visually to facilitate inspection by the geologist of the distribution of probabilities, as in Figure 9.2. In this figure, the line with the circular markers depicts part of a Poisson distribution with λ=36. The important point here is that this distribution of probabilities provides the geologist with probabilities for extreme events by a probability model that is consistent with his stated judgements about number of deposits. Having been given this information, the geologist is then instructed that his probabilities need not be the same as those of the probability model if he has experience or

Table 9.5: Initial Poisson distribution (λ=36).

Number of Deposits	Poisson Probability
20	0.0013
25	0.0121
30	0.0427
35	0.0663
40	0.0508
45	0.0210
50	0.0069
55	0.0007

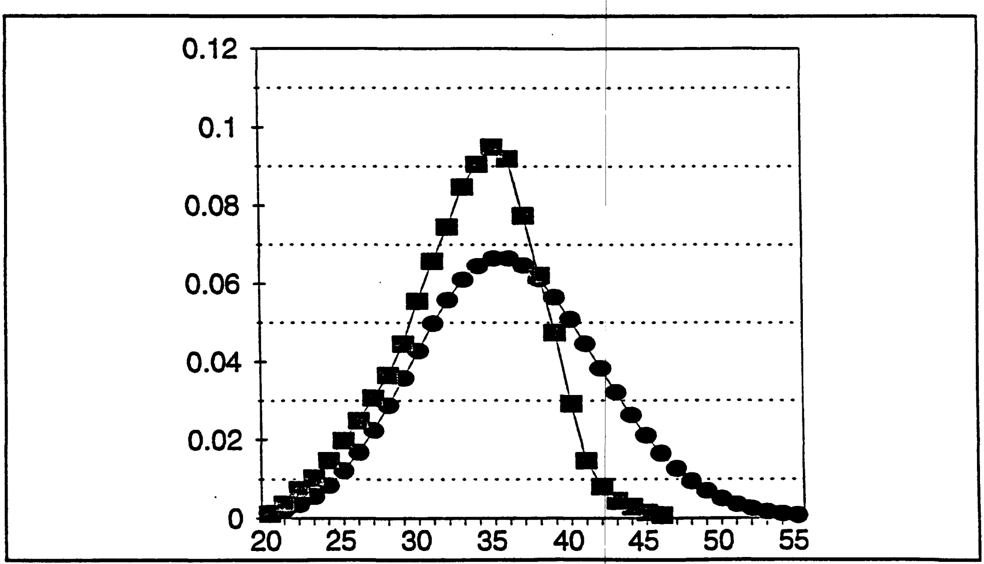

Figure 9.2: A plot of the Poisson distribution (λ=36, circular markers) with the revised distribution for the number of undiscovered deposits.

geological evidence that indicate that a different distribution is appropriate. Consequently, he is asked to modify the displayed probabilities to reflect the additional information, taking special care to reflect upon the possibilities for extreme events, i.e. those in the tails of his distribution.

As an example of this consider Figure 9.2. As noted above, the circular markers depict the Poisson probability distribution implied by the geologist's estimates. Upon examination of the plot, the geologist may decide that the probabilities for the higher numbers of deposits (>38) are lower than those shown by the Poiss and that there is a greater probability for numbers in the middle of the distribution (30 to 37). He then modifies the tabulated probabilities to reflect this and the new values are normalized to sum to 1. The revised distribution for number of deposits is shown in Table 9.6 and by the square markers in Figure 9.2, reflecting the modifications made by the geologist.

Table 9.6: The revised probabilities for number of deposits.

Number of Deposits	Revised Probability
20	0.0011
25	0.0197
30	0.0555
35	0.0949
40	0.0292
45	0.0015
50	0.0000

THE NEED FOR AN ESTIMATION ALGORITHM AND COMPUTER SUPPORT FOR REAL WORLD ASSESSMENTS

The point of the above demonstration is not that the Poisson is the appropriate model, nor is it that the relationship for estimating lambda is the one to use in a real world assessment. Given 1) a most likely number that is greater than 0, 2) a probability for zero deposits that is near zero, and 3) responses of the geologist that are consistent with a Poisson model, the above relation provides an algebraic solution. Parameter estimation in real world assessment, however, must deal with responses that may be inconsistent in that a Poisson model cannot honor exactly all judgements. Thus, this approach in real world assessment would require development of a useful estimation algorithm and a computer program for its implementation such that it would provide estimates of the Poisson parameter when all responses are not consistent.

CLUSTERING AND THE NEGATIVE BINOMIAL

The Poisson model implies independence of events; consequently, it is not appropriate when deposits exhibit a natural clustering. A commonly employed model for clustered mineral occurrences is the negative binomial. A comprehensive implementation of the approach described above would develop the algorithm and computer program to estimate parameters for both the Poisson and negative binomial distributions from the judgements given by the geologist. This program should also be designed to compute the usual statistics, e.g. mean, mode, and median, and selected probabilities, e.g. the probability for at least one deposit, so that these also could be displayed along with the distributions of probabilities. Both distributions could be examined by the geologist in terms of how well they fit his responses and in terms of how well they reflect his experience regarding the number of deposits and deposit clustering. Accordingly, the geologist could select one of them to consider and modify for his final probability distribution, or he could consider both of them, weighing them appropriately as he provides his subjective probability distribution.

DO THE INADEQUACIES OF THE TONNAGE AND GRADE DISTRIBUTIONS DICTATE A MODIFICATION OF FORMALIZATION?

The above formalization is clearly most useful when the tonnage and grade distributions are unequivocal. As indicated in another section, the tonnage and grade distributions can be criticized as representations of natural populations because of the influence of incomplete sampling by exploration and the effects of economics of exploration and exploitation. The presence of these effects does not alter the above recommended procedure. Adopting an informal procedure, like that currently used, does not remove or cure the inadequacies of the tonnage and grade data: They are still there! Informal analysis also is predicated in some undefined way upon existing data on tonnage and grade; this must be so, for there are no other data! An informal approach does not change this fundamental constraint; however, it does leave open the possibility for the assessor to consider some subset of the existing data, which introduces an additional source of variation among assessors. The above procedure is still strongly indicated in spite of data inadequacies, because it 1) assures that assessors are using a common methodology 2) supports the complex mental imaging necessary to relate experience and geoscience to number of deposits, and 3) employs our best current perception of the distribution of sizes and grades. Obviously, formalization stresses the need for a continuing program for the acquisition and analysis of deposit tonnage and grade data. As these data improve, the power of the formalized approach also increases.

GROUP ASSESSMENT

PERSPECTIVE

There are different motivations for assessment by a group, ranging from 1) obtaining a consensus position on a social issue , 2) offsetting errors or bias in scientific judgement, and 3) increasing the level of relevant science and technical information brought to bear upon estimation. In the first case it is the trade-off of values that is important. In the latter two cases it is bias in judgment and the level of science and technological information the are improved by group assessment. Of these two, however, the most important one is to increase the level of science and the amount of relevant technical information that is brought to bear upon assessment. This must be so, because group assessment per se is not necessary to offset biases or errors, for such can be diminished simply by averaging multiple individual assessments, without group interaction. Moreover, as group assessment can bring liabilities as well as benefits there is only one important motivation for some form of group assessment, which is to increase the level of science and technical information.

Since the estimation of undiscovered mineral deposits is a very complex and difficult task, requiring various kinds of geo-expertise and the integration of a wide range of diverse geodata, there is a priori a strong justification for some form of group assessment. Taking that as given, there remain a number of important specific issues regarding the use of a group:

- The science (specialty) composition of the group
- The format for exchange of science and information
- The procedure for estimation
- The procedure for resolution of multiple estimates

The above issues are not independent in a real world assessment.

COMPOSITION OF GROUP AND FORMAT FOR SCIENCE EXCHANGE

EXPERTISE

A group or team for the assessment of the undiscovered mineral resources of a region should , at the minimum, be comprised of the following expertise:

- economic geologist
- regional geologist
- geophysicist
- assessment methodology specialist
- remote sensing/GIS geoscientist
- assessors

Of course, assessment by a group requires a group leader, or facilitator. This could be an additional member of the group, or that function might be assumed by one of the above group members. Important expertise not explicitly mentioned in the above list includes geochemistry, metallogeny, and integration and synthesis of diverse data, including the processing and integration (filtering, image analysis, pattern recognition, etc.) of thematic data from satellite with other traditional data, e.g. lithologic, geophysical , structural, etc. To some degree, such expertise may exist in the above specialties. For example, the economic geologist and the regional geologist may bring useful expertise in geochemistry and metallogeny. If that is not the case and resources permit, the above nominal expertise should be augmented appropriately.

TWO KINDS OF GROUP DYNAMICS

Much less clear than the constitution of the group by expertise is how the expertise should be applied to assessment. There are two polar positions on this subject, each offering advantages and disadvantages:

- Every member of the group makes quantitative assessments of undiscovered resources;

- Quantitative assessments per se are made only by trained, experienced assessors, but only after consideration of the scientific information offered by all members of the group.

EVERYONE MAKES ASSESSMENTS - JUSTIFICATIONS

The argument for this approach is that it assures that the various geoscience and information specialties are explicitly considered in the assessment. When there are several highly informed regional geologists, a format that includes their explicit participation is appealing. A similar statement can be made about the exploration geophysicist. As geophysical information often is the only information available about the subsurface, it is very important that such information be carefully and thoroughly considered in the estimation of undiscovered mineral resources. Clearly, if the geophysicist is also one of the assessors, there is some assurance that the assessment reflects his expertise, as well as the geophysical information about the region. Everything else being equal, these are compelling arguments, especially when assessment is to be performed by an institution possessing a wide spectrum of expertise in geoscience, as does the U.S. Geological Survey.

A FORMAT FOR SCIENCE AND INFORMATION EXCHANGE WITHIN A GROUP WHEN QUANTITATIVE ASSESSMENTS ARE MADE BY ALL MEMBERS OF THE TEAM OF ASSESSORS

GENERAL

If the assessment team is composed of individuals from various geoscience disciplines then obtaining group consensus on the number of undiscovered deposits is difficult. The situation recalls the adage that from heterogeneity does not flow homogeneity. What is required is a methodology that honors the diversity of expertise while unobtrusively working towards a group response. This section describes the use of a computerized methodology, referred to as RCON, that holds great promise for obtaining a group response when the group is made up of experts of different specialities.

THE CONCEPT OF INFLUENCE ALLOCATION

Consider an influence allocation process where each member of the group is asked to explore subsets of the information available for the assessment. In this review the group identifies geological factors deemed important in aiding the geologist in the estimation of the number of undiscovered deposits. From this set of important geological factors the group then identifies the most important relating to the deposit model and the corresponding estimation of undiscovered deposits in that area. This sub-set of 'sensitive' geological factors may be interpreted as recognition criteria in the delineation of favorable areas for the deposit model in the study tract. Suppose that each team member is then asked to judge the relative expertise of all participants in estimating the number of undiscovered deposits. If the group has identified and discussed the sensitive geological factors then the evaluation of expertise may be conditioned upon this list. When the group has explored many of the information types available for study, for example different geophysical surveys, then they have also explored the expertise of each member on a variety of subjects within the science. Decomposition of the assessment methodology into information subsets allows the intrinsic heterogeneity of group expertise to be explored. Given group heterogeneity it seems unreasonable to expect a consensus on the number of undiscovered deposits without sacrificing some individualism. By combining estimates from each assessor using a modified RCON methodology an algebraic group response can be achieved without the traditional conflicts.

STEPS IN THE ASSESSMENT: AN OVERVIEW

Some desirable features when all members of the group estimate are:

A thorough presentation and discussion of all relevant science, data, and analogue regions prior to the estimation of the number of undiscovered deposits;

Exchange of scientific models and concepts as they relate to the estimation of the number of undiscovered deposits;

Discussion and resolution of conflicts arising from scientific interpretation of data and models to be employed in the estimation process;

An electronic bulletin board allowing for the anonymous (or known) contribution of ideas from members for discussion and evaluation by the group;

An electronic RCON voting system allowing for anonymous allocation of votes amongst alternatives and members of the group.

Identification by the group of geological factors that are deemed to be important in the formation and recognition of mineral deposits;

Identification of a subset of geological factors, the 'sensitive' geological factors, the are deemed by the group to be recognition criteria in the delineation of favorable tracts for mineral deposits;

Familiarity of each group member with all others members so that subjective judgments of the relative expertise of individuals may be made: conditional on the geological factors under consideration;

Assessment privately by all group members, following preferred procedures. Combination of individual estimates using weights reflecting the expertise of each assessor, as determined indirectly from the RCON voting algorithm.

FORMAT OF THE ASSESSMENT

A system in which all members of the team make assessments requires that the formal training for the task is completed in advance of the assessment program. The introduction of relevant science, data, and analogue regions proceeds as is currently done for assessments. Each expert contributes information for discussion and evaluation of its relevance to the estimation procedure. Exploring within the group conflicts and new, or unfamiliar, concepts establishes a level of familiarity between participants as required in an RCON allocation process. Recall that the RCON voting process proceeds in two stages: 1) the group members pass judgment on a series of alternatives by casting votes, and 2) members pass judgment on the relative expertise of individuals within the group by passing votes.

With the relevant data and concepts as a framework the group is now ready to begin the RCON process. All contributions for discussion can be made via key boards in front of each member to an electronic note pad viewed by the group. Contributions can be submitted anonymously if the situation warrants. Using the formal definitions of RCON, in this methodology the sensitive geological factors are the 'attributes' and the other members of the team the 'levels of expertise'.

BUILDING DATA-CLASSES

General discussion should begin by defining the geological factors important in the formation and recognition of mineral deposits. The geological factors are classified according to the data-class from which they are derived. As an example suppose a panel of assessors have identified two seemingly similar data types important to a deposit model: 1) the downward continuation of magnetic data, and 2) Fraser filtered VLF data. The group may then construct the general data-classes of Magnetics and Electro-magnetics to accommodate these factors. Various methods of downward/upward continuation form entries within the Geophysical/Magnetic data-class. Likewise, the data-class Geological/Rock-type may contain entries such as intrusive stock present, calc-silicate alteration mineralogy observed, etc. The various data-classes are decided upon by the group in a 'brainstorming' session taking care to incorporate all valid data types useful in the estimation. No group consensus is required for the inclusion of any one data-class and care must be taken not to omit the contribution of a group member. The larger the number of classes the more disaggregated the level of information. The more the disaggregated the level of information the more robust is the RCON methodology.

ROUND ONE

Having defined all possible data-classes the panel is now ready to proceed with the RCON. If all group members are satisfied that no important geological factors have been omitted from the data-classes then discussion should begin on the relevant importance of each factor in the estimation of the number of undiscovered deposits. Salient points can be contributed to the electronic note pad, entered beside the factor to which they pertain. If a contributor wishes to remain anonymous for a particular contribution, they may do so. It is not necessary that the important geological factor be observed in the map area of study, only that the panel believe it to be important in the formation and recognition of the mineral deposit being modelled. When discussion and conflict resolution of the list is complete the group votes, anonymously, on the relative importance of each of the entries. The electronic voting utility then rank orders the results for presentation to the group. The top five to ten entries become sensitive geological factors, stored internally in RCON. The group may wish to discuss the results and vote again if conflict leads to a re-interpretation of the factors.

The second stage of round one is the group evaluation of the relative levels of expertise regarding the data-classes under consideration. Each member is asked to reflect upon the experience, contributions, and discussions of all others. Each member holds a unit of votes within the RCON allocation system. Each member then anonymously passes a percentage of votes to other members in proportion to their perceived expertise of that person.

The perceived level of expertise is conditional on the data-class under consideration and their ability to estimate the number of undiscovered deposits. As described in the Summary of Relevant Research Results each person may withhold a percentage of votes for themselves reflecting a perception of their self-expertise. No group member is aware of the results of vote passing as the results are stored internally in the RCON system.

ROUND TWO AND ONWARDS

For each round a new data-class is evaluated. The panel first examines the list of important geological factors ensuring no errors or omissions have been made. They then vote through the RCON vote utility on the factors they perceive to be most important in the formation and recognition of the mineral deposit. The RCON system then rank orders the results presenting them to the group for further discussion. If the group is satisfied with the results they proceed to the second stage of evaluation of individual expertise. Again, this vote passing reflects relative levels of expertise in the group conditional on the data-class and their ability to estimate the number of undiscovered deposits. Each subsequent round then proceeds with a new data-class as described above.

After all data-classes have been exhausted there is one final vote to be taken. The sensitive geological factors determined in each round are now combined into one comprehensive list. Each member of the group is then asked to cast votes reflecting the relative importance of factors of the data-classes. The results are rank ordered and presented to the group. They reflect the anonymous, group consensus of the importance of data-types (the data-class) and geological factors in the recognition of the mineral deposit. This rank ordered list of sensitive geological factors across data-classes should form the criteria the experts to use when estimating the number of undiscovered mineral deposits. Thus, if one of the sensitive geological factors identified by the group is missing or is not observed, then the estimated number of deposits should reflect this fact.

ESTIMATION OF THE NUMBER OF UNDISCOVERED DEPOSITS

Assessment of the number of undiscovered deposits proceeds privately for each group member, following preferred procedures, for example the formal use of tonnage and grade distributions and a probability model described in an earlier section. The vote aggregation methodology used when all members of the team estimate has no influence on the estimation technique. Thus the selection of a preferred estimation method is independent of the number of estimators within the group.

AGGREGATION OF THE RCON RESULTS

At this point the group has 1) individual distributions for the number of undiscovered deposits, and 2) a matrix of votes reflecting the groups judgment of each individual's capability to estimate this number by data-class (geologic factor). Aggregation of these distributions proceeds as follows:

1) combine the votes each individual received across the data-classes into a score for that person overall. A simple sum of votes will do for demonstration purposes;

2) build class intervals for the number of undiscovered deposits. e.g.

class
1-2
3-4
5-6
7-8
:
:

3) determine the area under the individuals probability curve for the number of deposits by the classes above. e.g.

class	prob.
1-2	0.01
3-4	0.07
5-6	0.11
7-8	0.23
:	
:	

4) allocate each individuals votes across the classes for number of undiscovered deposits in proportion to the associated probability. e.g. for 5108 total votes across 12 rounds for estimator #1:

class	prob.	votes
1-2	0.01	51.1
3-4	0.07	357.6
5-6	0.11	561.9
7-8	0.23	1174.8
:	:	:

5) for each estimator, multiply by vote probability:

	Estimator #1			Estimator #2		
Number Class	Prob.	Votes	Prob. x Vote	Prob.	Votes	Prob. x Vote
1-2	0.01	51.1	0.511	0.06	436	26.16
3-4	0.07	357.6	25.03	0.12	872	104.64
5-6	0.11	561.9	58.51	0.28	2034	569.52
7-8	0.23	1174.8	272.6	0.46	3342.9	1537.7
:	:	:	:	:	:	:

6) sum separately the products(probability x vote) and total votes across the estimators:

	Estimator # 1		Estimator #2			
Number Class	Product	Votes	Product	Votes	Sum of Products	Sum of Votes
1-2	0.551	51.1	26.16	436	26.6	487.1
3-4	25.03	357.6	104.6	872	129.7	229.6
5-6	58.5	561.9	569.5	2034	628	2595.9
7-8	272.6	1174.8	1537.7	3342.9	1810.3	4517.7
:	:	:	:	:	:	:

7) divide the column Sum by the total number of votes in the system. e.g. in this two person model the total votes cast were 12,375.

class	relative frequency
1-2	0.039
3-4	0.099
5-6	0.21
7-8	0.364
:	:

The right hand column, relative proportion, now represents the group response (weighted average) for the number of undiscovered deposits, by class interval.

POTENTIAL MODIFICATIONS

There are two issues that warrant further consideration in light of our objective - to have the entire panel estimate the number of undiscovered mineral deposits free from group biases. The first is the weight given to the various data-classes: Are these optimum with regards to number of deposits? Weights may be assigned to the data-classes indicating relative importance to the estimation task. Relative weights can be expected to vary across different assessment regions in response to varying levels of information. Thus, assigning the weights can be a task of the assessment team prior to the RCON process. As a simple example an assessment group may decide that exploration of the area has been low and restricted to grass roots programs. Therefore, the data-class Known Occurrences may be weighted less than other data-classes to reflect this level of information. Determination of weights may be through group discussion followed by concensus or RCON voting. Where the information level of an area is high statistical models might also determine varying levels of information by data-class.

The group can define data-classes that are not solely physical attributes. As an example, if previous exploration in the area has important bearing on the estimated number of undiscovered deposits then they may construct an Exploration data-class. Within this class the entries of: known occurrences, type of exploration program/intensity, exploration permit history, age of the program, principle commodity being explored for, and historic and current land status are all viable. This is a formal incorporation of aspects that have been subject to criticism in the current methodology.

The second issue pertains to the weights assigned to each expert of the group. The RCON system dynamically determines the levels of expertise of each member of the group relative to all others present. But in the voting process how many votes should each individual have? Are all estimators equally familiar with the strengths and weaknesses of all others or do long standing working relationships exist? Furthermore, are those who regularly assess the number of undiscovered deposits justified in starting with a greater number of votes to distribute amongst the group? The reader will recall that the RCON system requires only that the participants pass a percentage of their vote allotment. There is no requirement that the participant be aware of the number of votes they posses relative to others at the table. The *a priori* distribution of weights is a Survey management decision beyond the scope of this proposed methodology.

Three very important circumstances are required for assessment by all members of the group:

1) Geoscientists other than those within BORA, e.g. those in regional offices and other branches, having relevant expertise desire to be participate in the quantitative assessment task;

2) All geoscientists so involved are willing to receive training in assessment which is relevant and necessary for them to become credible quantitative assessors;

3) The USGS has the resources to provide such training for the regional specialists as needed to respond to Congressional and other institutional needs for land-use decisions.

The first of the circumstances required for the direct involvement of all members of the group in actual quantitative assessment has not existed in the past, and probably does not now exist. Perhaps, this will change in the future, but if it does so, it probably will be only after some significant institutional changes.

REQUIRED CHANGES AND INSTITUTIONAL SUPPORT

REDIRECTION

Probably, a circumstance in which non-BORA USGS geoscientists desire to participate in quantitative assessment will come to exist only through institutional redirection. This redirection could take the form of 1) administrative mandating of selected current personnel to become resource assessors, or 2) through personnel turnover, with hiring directed to geoscientists who are willing to develop a career in resource assessment. Redirection by either means must be accompanied with an equitable merit structure as well as administrative support of resource assessment as an important activity of the U.S. Geological Survey. The latter is extremely important to the future development of improved response capability in resource assessment. The impression that resource assessment is a second class activity for a geoscientist within the U.S.G.S. must be eliminated. Strong, unwavering support by USGS administration would go a long way towards achieving this. Particularly, since some resulting land-use decisions may be contested in the courts, the USGS must function as a team committed to the assessment activity.

REAL COMMITMENT

Past experience is not always a good basis for judging the present or future, but to the extent that such experience is a useful commentary on required circumstances, it would indicate strongly that the willingness of geologists outside of BORA to become involved in the actual assessment task is minimal. This statement may need explanation considering the current allegation that some non-BORA USGS geologists, particularly from Denver, would have liked to have been involved, say in the Handies Peak assessment, but BORA did not invite them to do so. Certainly, this is a possibility, however, it is important to differentiate between 1) willingness of individuals or groups of the USGS to be involved in the geological studies leading to and supporting assessment, and 2) willingness to actually participate in quantitative assessment.

As long as involvement means only that the geologists have a budget to pursue their professional specialty on the region that is to be assessed, many will be willing, if not eager, to become involved. Usually, however, those same individuals have neither the desire for, nor intentions of, participating in the quantitative assessment task itself. Such behavior in the past has been the rule, not the exception. For example, in the NURE program, some USGS geologists devoted years of excellent work to the quadrangle studies with full knowledge that the major purpose of those studies was to prepare for the assessment of that quadrangle's uranium resources. Incredibly, however, some USGS geologists attended the elicitation sessions with absolutely zero knowledge of the assessment format and without having given any thought whatsoever to the resource questions to which they were to respond (Harris, 1984)! Naturally, their responses to the elicitors were often useless, even though they had completed excellent geological studies! Some, but not all, of those same geologists had refused earlier efforts made by DOE to educate them on the assessment methodology and to prepare them for the elicitation process and assessment experience. The conclusion is inescapable that these geologists had never intended to make quantitative assessments. Basically, the geologists were more than willing to be involved in NURE to the extent that they "could do their thing", but they had no intention of performing a conscientious quantitative resource assessment. Probably, some of the recently professed desire to participate in assessment reflects the same conflicts and contradictions as prevailed in NURE. Given this previous experience, recent criticisms of BORA by non-BORA USGS geologists for not involving them in assessment should be examined carefully to determine whether the resentment for having not been involved is totally forthright or a veiled attempt to obtain program support without commitment to the assessment task.

The distinction referred to in the foregoing is vital if the objective for group assessment is that all members of the group participate in quantitative assessment. As indicated earlier that is not the only alternative, the other being that actual quantitative assessment is made by only experienced assessors, after taking into consideration the expertise and knowledge of the other members of the group. Clearly, the alternative permits geoscientists to pursue their own specialties in a more traditional way and still be of great value in assessment. A format for this approach is described later, after the discussion of the first approach has been completed.

TRAINING AND EXPERIENCE

The foregoing discussion has already commented on the second circumstance for successful implementation of the "everyone assesses" approach, namely, the willingness of every group member to receive the training that is necessary to become good assessors. Undoubtedly, there are some geologists for whom this circumstance reflects reality. Probably there are many more for whom this circumstance is fictitious. Those geologists using assessment as a cover for the funding of their own geological programs will not submit willingly to the training to acquire experience necessary to become good assessors. Here, it is important that the training and experience not be trivialized. Contrary to the perceptions of many, the estimation of the magnitude of undiscovered endowment within a region is a very difficult task and being a qualified economic geologist is not, of itself, sufficient preparation for quantitative assessment; neither is being an experienced explorationist. Like anything else, good assessment requires practice and experience.

The value of assessment experience was revealed most vividly in the experiment by Harris and Carrigan (1980) with expert uranium resource and exploration geologists. Of the six experts who participated in the study, two were either current or previous exploration managers and one was a senior DOE geologist with extensive first hand knowledge of uranium deposits and with much experience with making resource assessments. Although the senior DOE geologist had much more difficulty than the others in constructing his computerized expert system, once it was constructed and calibrated, the estimates made by his expert system differed very little from his unstructured subjective probability distribution. Agreement between his subjective probability distribution, elicited directly, and the distribution estimated by his expert system was noticeably greater than for any of the other geologists. It is doubtfully just coincidence that he had a great deal of first-hand field experience with uranium deposits and that he had extensive experience in making assessments. The point to be made here is that making good assessments requires training and experience, and the requisite training and experience can not be achieved with a few sessions on the mechanics of the assessment procedure.

RESOURCES FOR TRAINING

The third circumstance, that the USGS has the resources to provide the requisite training, is less likely to be reality when such training and experience must be developed for all members of the group (team) and when members of the team change with each assessment, as would be the case when members of the team include one or more regional geologists. As a long-term goal, with sufficient lead time, requisite expertise, training, and experience could be developed for a priori designated regions and their teams (groups). But, for ad hoc assessments, as in response to Congressional mandates for specific land-use decisions, it may not be realistic to expect that the requisite training and experience could be developed for each assessment when assessment teams (groups) are especially constituted for each assessment and all members of the group are to make quantitative assessments.

ASSESSMENT BY BORA ASSESSORS, GIVEN GROUP INPUT

GROUP EFFORT

If the requisite level of training cannot be immediately provided to the non-BORA participants to support their estimations, then an alternative methodology is needed. The idea here is that assessment is to be a group effort, but that a BORA team of experienced assessors make the actual quantitative assessments. Critical to the success of this plan for group assessment is a format that assures that the expertise of all group members is given appropriate consideration in the quantitative assessment by the BORA team. Achieving this is not a trivial task. This approach is quite similar in concept to that currently employed; however, the format for group assessment needs to be more highly structured and more consistently applied than it has in the past.

CONSISTENCY IS VITAL

It is very important that institutions using the assessments, and society in general, have some assurance that the assessments do not represent just one person's opinion. Equally important is that relevant expertise and knowledge be utilized, and that a consistent methodology be applied. While BORA deserves commendation for the structure that it has developed on its own initiatives, as assessments become more routinely used in land-use decisions, it becomes much more important that the methodology as well as its implementation be consistent, at least in its major elements. Otherwise, the USGS will be a frequent target of legal suits initiated by special interest groups, and the credibility of its assessments may be challenged because of inconsistent methodology or implementation of methodology. As more and more land-use decisions are made with consideration of assessed mineral resources, the more likely it is that legal suits will be implemented. That being the case, the USGS should strive to avoid the variation in implementation that has characterized past assessments. Contrast, for example, the quasi-formal team approach used in Bolivia and in 18 Wilderness Areas with the assessment of the Tongass National Forest, which was not only informal but somewhat ad hoc and seems to represent primarily the team leader's judgements about number of deposits. Even though these may be excellent judgements, to avoid future litigation and harsh criticisms, assessments should explicitly document the use of multiple judgements and the use of a common format.

THE NEED FOR MULTIPLE ASSESSORS

The USGS cannot afford in the future the variation in implementation of its methodology that exists in previous assessments. Moreover, both the users and the public deserve some assurance of not only consistency but that the assessments represent more than one person's judgement. To this end, not only should group composition be consistent from one assessment to the next, but every group should consist of at least three individuals who will make quantitative assessments. Clearly, three should be the minimum number of assessors, and preferably, there would be several assessors in each group. As a long-term goal, BORA should build and maintain a reasonably large group of experienced assessors, say 15, and some subset of this large group could be selected for a given assessment. Moreover, the format for group assessment should be one which assures the consideration of expertise of other specialists in the assessment.

The following section examines a possible format for exchange of science and information within a group composed to support assessment but for which quantitative assessment is made by a team of specialists. The format described also includes previously described preferred procedures for subjective probability elicitation.

A FORMAT FOR SCIENCE AND INFORMATION EXCHANGE WITHIN A GROUP WHEN QUANTITATIVE ASSESSMENTS ARE MADE BY A TEAM OF ASSESSORS

STEPS IN ASSESSMENT

Consideration of decision-analysis literature as well as the specifics of mineral resource assessment dictate some general desirable features for group assessment:

- A thorough discussion by members of the constituted group of relevant science, data, and analogue areas prior to assessment;
- Assessment privately by each assessor, following preferred procedures;
- Identification privately by each assessor of those geological or informational issues to which his assessment is most sensitive;
- Group discussion of sensitive geological and informational issues identified collectively by the assessors;
- Private reassessment by each assessor, following preferred procedures and striving to integrate additional science and information generated in the previous step.

EXCHANGE OF SCIENCE AND INFORMATION--VITAL

In that the primary motivation, and justification, for some form of group assessment is to increase the level of geoscience and technical information, the first function of an appropriately constituted group should be a thorough discussion by members of the group of relevant science, data, and technical information (relevant geoscience, metallogeny, intensity of exploration, evidence of size bias, known mineral occurrences of the region, relevant analogue areas and their deposit densities). Each member of the group would review thoroughly his knowledge domain as it relates to the assessment task, data, and the region. Because of the difficulty of estimating unseen deposits, considerable effort should be made to review in Group sessions the geology and the deposit densities of relevant analogue areas. This is very important support for the assessment task. In fact, from the assessment point of view, thorough study and review prior to assessment of relevant analogues is as important as is the study of the area to be assessed. If good analogue areas exist and are appropriately selected, their thorough review prior to assessment may considerably decrease variation among assessments, especially if that review includes good information on exploration and deposit densities for several areas that are geologically quite similar to the area to be assessed.

INDIVIDUAL ASSESSMENTS

Following this general discussion of science and information, each assessor would make individual estimates, following the preferred procedure described in a preceding section, i.e. formalization of tonnage and grade distributions and the use of probability models as supports and aids to estimation of the subjective probability distribution.

IDENTIFICATION OF SENSITIVE GEOLOGICAL FACTORS

Upon completion of his individual estimation, each assessor would be requested to identify a few geological factors or considerations that he believes are most relevant to his assessed distribution, meaning that his distribution is sensitive to the interpretation of information regarding these factors. Having just completed the assessment, these should be more apparent to the assessor than they were prior to assessment, and the assessment might well have raised technical questions in the knowledge domain of others within the group. For example, an assessor might decide that his assessment is very sensitive to the number of shallow intrusives believed to occur within the area, for which the only evidence comes from geophysical maps. Accordingly, an assessor may desire a group discussion about the discriminating power of the geophysical surveys, and the resulting maps, for shallow intrusives, given what is known of the geology of the area. Clearly, the expertise of an exploration geophysicist as well an experienced regional geologist may be a source of valuable information for the assessor.

GROUP DISCUSSION OF SENSITIVE GEOLOGICAL FACTORS

Following the private identification of sensitive factors, the group is reconvened to discuss the collective set of factors. Here the discussion should be solely about relevant geology and geo-information by the pooled science of the group. So as to avoid modification of estimates for nonscientific reasons, e.g. the herding instinct or dominant personalities, there should be absolutely no discussion about anyone's estimate of number of deposits! The sole function of this reconvening is to explore those science or information related issues to which assessment is most sensitive, with the objective being to increase the level of scientific understanding and information available to all assessors about those sensitive issues, not about number of deposits. While number of deposits within the area being assessed should not be a subject of group discussion, such discussion about analogue areas and how similar or dissimilar they are geologically to the assessment area(s) is relevant and an important subject to be discussed by the group. Care should be taken to avoid discussion of number of deposits within the area being assessed. Instead, discussion should be restricted to those science and geo-information issues that relate to the assessment of number of deposits.

INDIVIDUAL REASSESSMENT

Subsequent to the second round discussion of selected geologic factors and information, each assessor reconsiders his initial subjective probability distribution for number of deposits and makes appropriate adjustments such that he is satisfied with this as his final assessment in view of all relevant geoscience and information as considered individually and collectively by the group.

RESOLUTION OF MULTIPLE OPINION TO A GROUP RESPONSE

There should be no attempt to represent the individual assessments by a group consensus prior to the completion of step three, meaning prior to the integration of number of deposits with deposit tonnage and grade distributions by a computer program like MARK3. The reasons for this are two fold: First, the users of resource assessments, as well as the public in general, deserve to know the variation among the experts as to the assessed resources. For this to be most useful, the assessment should produce the probability distribution of the final resource measure, e.g. GIPV, for each assessor, and these should be depicted graphically in the final report, as well as by selected measures, such as 95 % confidence intervals. Second, so that the decision-makers can have a single distribution to consider, the individual distributions should be averaged, and this average distribution should be depicted graphically, as are each expert's distribution, as well as by selected statistical measures of the average distribution. In this way, the decision-makers and the public are given full information about the variation in jüdgement by the individual assessors and they are given a single distribution that they can use to represent the collective judgements of the group, i.e. the average distribution.

CHAPTER X -- SUMMARY AND RECOMMENDATIONS

SUMMARY AND RECOMMENDATIONS

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SUMMARY AND RECOMMENDATIONS

PERSPECTIVE

Comments and recommendations provided here are primarily about methodology, although some are made about the assessment program as it has been managed and administered by the United States Geological Survey. Although this research effort did include a conference in which some presentations were invited that dealt with recent assessment controversies, the purpose of that conference was primarily to inform the Panel about possible deficiencies in assessment methodology and in selected assessments and to identify relevant scientific, informational, and methodological issues.

That an evaluation of assessment methodology would some day be called for should not have been a surprise, given the rapid and at times ad hoc evolution of needs for assessment and of assessment methodologies. It is unfortunate, however, that such an evaluation had to be complicated by accusations of conspiracy. In order for the principals to complete the study requested, they have had to set aside the issue of conspiracy as the business of some other group properly constituted to deal with professional ethics and with relevant testimony. To the extent possible, the principals of this study have gleaned from memoranda and presentations, whether pro- or anti- the current assessment methodology and program, relevant scientific or methodological issues.

The controversies referred to in the foregoing resulted in a serious erosion of morale and loss of confidence within the USGS. Undoubtedly, this was one motivation for an evaluation of assessment methodology. Some of the issues cited in various memoranda were inaccurately perceived and described, and the level of rhetoric and emotion regarding them far exceeded their scientific or methodological merit. In part, this was due to the widespread publicity given an alleged conspiracy to "keep the words that mining is prohibited " out of legislation.

There are other long-standing problems that contributed to the severity of the crisis. The rhetoric at that time served as a lightning rod, drawing out and exposing other problems, which are neither conspiratorial nor methodological but programmatic and institutional. Assessment as an applied field of geology is young, having evolved from a mere scientific curiosity to a few scientists in the 1960's to national importance a decade later as a means to analyzing resource adequacy and potential supply of energy. Moreover, assessment is applied multidisciplinary predictive science. Accordingly, the evolution of methodologies is reflective of efforts to wed science with predictive (probabilistic) theory and methods and economics. Naturally, such a wedding is difficult. Moreover, as assessments become more important, methodologies are, and should be, subject to greater scrutiny. Only in this way will assessments meet the evolving needs of society for resource information.

STRUCTURE OF THIS SECTION

This section is organized into two major parts. The first one deals with the assessment program and recommended changes. The second part deals with methodology, which is subdivided into three subsections: Positive aspects of the USGS assessment methodology, short-run modifications, and long-run modifications in methodology.

PROGRAMMATIC AND INSTITUTIONAL CONSIDERATIONS

INCREASING IMPORTANCE OF PROGRAM

Mineral resource assessment is a program of growing importance to society and should, therefore, be continued; however, this growing importance does of itself call for improvements in both assessment program and methodology. Although the focus of this research effort is on methodology, the need for changes in the assessment program as it is currently managed is apparent and important. Some of these changes are described below.

A TURNING POINT (WATERSHED)

In view of recent events, as well as future needs for support of land-use decisions, the year 1992 should witness a "watershed" in both methodology and institutional support for mineral resource assessment. If this were to come to pass, primary among the conditions responsible would be the following: 1) the growing importance of land-use decisions, 2) insufficient institutional support of the assessment activity, and 3) reluctance of USGS geologists to accept assessment as a desirable and important professional activity. These conflicts cannot continue if the USGS is to meet future needs for resource information: the latter two factors must be resolved in some manner.

Other important changes must be made as well. Among these are increased formalization of assessment procedure and methodology, consistency in application of assessment methodology, and an assessment product that is consistent and relevant to land-use decisions. When critical remarks were encountered in the survey of users, they usually were that the assessed quantities (metal or GIPV) are too low; the USGS is too conservative; or that the USGS is too risk-averse, i.e., "afraid to stick its neck out". Other criticisms are that the USGS is too academic, that it is too slow in responding to user's needs, and that it should do more to describe and interpret assessed quantities so that they are more useful. Changes to improve assessments and to make them relevant to societal needs are in the interest of both society and the USGS as an agency of the US government. As our society and economy continue to grow in both size and complexity, issues of optimum land-use become more numerous as well as more complex. Society needs assurance that assessments are well done, and the USGS needs the security that comes from assessments that are scientifically and methodologically defensible, particularly in view of possible litigations of land-use decisions.

DISPARITY OF ASSESSMENT IMPORTANCE AND INSTITUTIONAL COMMITMENT

There seems to be a disparity between 1) the internal acceptance by USGS geologists of assessment as a legitimate branch of geoscience and as a desirable professional activity and 2) the importance of assessments. As an institution, the USGS must now decide to either support wholeheartedly the assessment activity as well as research and development of methodologies, or turn the responsibility over to some other agency that will. One or the other of these actions is mandatory if the future requirements for resource information for societal decisions about land-use are to be met.

USGS MANAGEMENT STRUCTURE AND PHILOSOPHY ARE PROBLEMATIC

Testimony of some USGS personnel suggests a weak capability of management to direct the activities of USGS geologists. The impression obtained is that individual scientists do pretty much what they wish and can not be directed to participate in any given project. If this impression is accurate, there is some question that the USGS, as currently organized and managed, can be responsive to future societal needs for mineral resource information.

Undoubtedly, the weak management capability reflects the the "academic-like" research tradition of the USGS. Certainly, some of this should be preserved, but times are and have been changing. And, one sign of the times is that scientists of all kinds are being pressed to make their work relevant to societal decisions. In general, this is forcing scientists to become predictive as well as descriptive. Resource assessment is just one thread of this broader fabric. But, to keep this thread strong requires that management be able to direct activities of its scientists.

ASSESSMENT METHODOLOGY

IMPORTANT CONSIDERATIONS

When previous USGS assessments are examined against the current assessment requirements, it is easy to find fault in some regard. But, as assessments by their very nature are predictions based upon meager information, every assessment will receive criticism of some kind from someone. While it is important that assessments and assessment methodologies receive criticism, it is also important that these criticisms be made with full understanding of the difficulties in assessment and of the following three facts:

1) assessment is a young field in applied geoscience, and methodology has been and is now evolving,

2) that evolution has been through the influence of only a few geoscientists because they were the only ones within the USGS who were sufficiently interested, and

3) institutional support of research and development of assessment as a branch of geoscience has been meager, at best.

POSITIVE ASPECTS OF USGS ASSESSMENT METHODOLOGY

GENERAL

The importance of contributions made to assessment methodology by some USGS scientists should be acknowledged prior to examining criticisms and suggested changes. Both the demands for assessments and the current assessment capability of the USGS are a tribute to the creative ideas and careful scientific work of USGS geologists. Assessing resources of undiscovered, unseen mineral deposits by the analysis of indirect (geological) information is, by any conceivable measure, a very difficult task. The efforts of the USGS to respond to mandates and institutional requests for assessments, often under very taxing circumstances of time and information, and at the same time, base the assessment upon the use of science and a structured methodology is commendable. That other institutions or other nations have, or are, adopting many features of the USGS methodology is a certification of the basically sound work of the USGS.

A telephone survey of thirty-five users of USGS assessments revealed that the work of the USGS and the USBOM generally is well regarded, although there are a few detractors. The USGS is not viewed as an advocate of mining or anything else, and it is generally perceived as unbiased. Moreover, contrary to some recent widely circulated claims, e.g. those of Hamilton and Bultman et al, when critical judgements were offered by the users, they often were that the assessments are too low, that the USGS is too conservative.

The recommended changes in methodology made later in this section do not denigrate the contributions of the USGS. Rather, they are reflective of the increasing importance of assessment to societal decisions, the fact that assessment is predictive science, and that methodology is still evolving. Assessment methodologies must involve multiple disciplines (geoscience, economics, probability theory and methods, technology, etc.) and must deal with highly variable information quality as well as quantity. Accordingly, we must continue to strive for improved science, methods, and information.

SOUND PRINCIPLES OVERALL

Deposit Model and Geological Environment--The Foundation

When viewed against the fabric of techniques and methods that have been developed and employed in some aspect of assessment, the USGS methodology stands out as being based upon sound geological principles overall. Moreover, it has been designed to support the geologist in the use of his science and geological information to assess undiscovered resources. As the foundation for the methodology is deposit type and geologic environment, it is conformable with geoscience and presents a useful structure for the organization of relevant geological information.

Geological Analogy Is Appropriate

An assessment based upon the analysis by a geologist of geological information must rely upon process analysis and materials accounting or upon the use of analogy. The current USGS methodology permits both but relies heavily upon analogy, as it employs the experience of the geologist as well as information from specific control areas.

The use by the USGS of geological analogy and subjective probability has been criticized, recommending instead that assessment be process-based and deterministic. To some degree, geologists naturally think in terms of processes, but usually, either limited information or understanding prevents the basing of an assessment solely upon process analysis. Although analogy has its problems, when properly used and supported it also can be a powerful basis for assessment. Moreover analogy currently is the only practical approach to assessment in most cases. Accordingly, greater efforts should be devoted to the study and preparation of analogue areas and to informational supports to the geologist's assessment.

Basing assessments upon judgement is both a strength and a weakness. The strength lies in flexibility and in the opportunity for geologists to integrate knowledge from outside the area as well as knowledge based upon exploration or assessment experience. The weakness is simply that of all subjective analyses, namely the difficulty of rationalizing judgement, documenting judgement, and consistency in weighting of information.

Subjective Probability--Difficult and Complex, but Mandatory

Given that assessment is to be based upon geological analysis and expert judgement, the use of subjective probability is not only appropriate, it is mandatory. First of all, given the circumstances for which assessments are made, a geologist can not know with certainty the number of deposits that are present. Consequently, society should know his uncertainty about number of deposits. The most useful way that such can be expressed when number of deposits is estimated subjectively is through subjective probability. Thus, at least in principle, the use of subjective probability in the USGS assessment methodology is appropriate.

There are two philosophies of subjective probability: The frequentists and the "degree of belief". Of these, the frequentist philosophy is most relevant for assessment. When assessment is performed to support societal decisions, the desired subjective probability is the subjective estimates of the "objective probabilities". These are equivalent to probabilities of the frequentists. The use of deposit densities from analogue areas to support assessment is consistent with estimating objective probabilities.

Although appropriate in principle, subjective probability is a complex measure and presents challenging problems. Accordingly, both short-term and long-term modifications in methodology are recommended to improve the subjective probabilities for number of deposits.

ROLE OF DEPOSIT MODELS AND TONNAGE AND GRADE DISTRIBUTIONS

Overall

Deposit models and their associated tonnage and grade distributions are extremely important elements of the USGS assessment methodology. The idea of using tonnage and grade distributions to support the estimation of number of deposits originated with scientists of the USGS. This feature is a strength of the USGS assessment methodology and should be continued and enhanced. Accordingly, USGS Bulletin 1693 is a very important, and perhaps courageous, contribution, since any such attempt invites scientific discussion and disagreement.

The foregoing comments are about the role of deposit models and tonnage and grade distributions in the USGS assessment methodology. The fact that the deposit models themselves are frequently criticized does not negate the importance of this contribution in the evolution of improved assessment methodology. Comments and recommendations regarding the construction of and improvement of the deposit models and tonnage and grade distributions are made in a later section.

Discovery Distribution of Tonnages and Grades Is Appropriate

Much of the criticism made of the use of tonnage and grade distributions of discoveries is confused and misleading. Contrary to such criticisms, given that the assessment objective is to support land-use decisions for current economic circumstances, the USGS is correct in using distributions of tonnage and grade of discoveries as contrasted with endowment distributions of tonnage and grade. The latter refer to the distributions of tonnage and grade of deposits as they occur in nature. The discovery distribution would not be appropriate if the assessment objective were to estimate the potential supply curve for prices that range up to many times current prices, as was the case in the NURE program.

As pointed out in the body of this report, when the assessment objective is to support land-use decisions for current or recent economic circumstances, endowment tonnage and grade distributions greatly complicate the assessment task. Even if such were available, the geologist would have to estimate the number of deposits in the endowment, a task for which he has no experience. Moreover, since we don't have endowment tonnage and grade distributions, they would have to be estimated from distributions of discoveries. Finally, such a methodology would require the simulation of exploration to determine which of these deposits will be discovered.

There are difficulties and problems with the tonnage and grade distributions and in how they are used in assessment, and these are discussed further in modifications of methodology. But, the difficulties do not change the basic fact that the discovery distributions of tonnage and grade, not the endowment distributions, are appropriate for the land-use decision.

THE DISTRIBUTION FOR NUMBER OF DEPOSITS

The USGS elicits number of deposit quantiles for the at least form of cumulative probabilities. This nonparametric approach has been criticized because it does not result in exponential-like probability distributions for number of deposits. These criticism are misguided and based upon some misconceptions. One of those is that the largest probability for number of deposits is, *a priori*, for zero deposits, with probabilities declining progressively for larger numbers. Although an exponential-like distribution can be appropriate for certain circumstances, it is fundamentally incorrect as a generalization, for it ignores the fact that the probability distribution for number of deposits is conditioned upon the size of the permissive area and its observed geology. Clearly, when the area is large and the geology is highly favorable, the probability for zero deposits may itself be zero, and the distribution of probabilities for numbers larger than zero may increase with number before declining, giving a distinctly non-exponential form.

Although recommendations are made in a later section for a change in the elicitation format, those changes have nothing to do with the fact that the current methodology is nonparametric and that it does not always yield exponential-like distributions. In these regards, the USGS methodology is appropriate; however, implementation of the current methodology would be improved by eliciting several quantiles, instead of the usual three.

MARK3

A computer program like MARK3 is a necessary component of an assessment methodology, for it combines the number distribution with the deposit tonnage and grade distributions to give either distributions for metal or GIPV. Moreover, using Monte Carlo methods to combine probability distributions, which did not originate with MARK3, has been generally accepted as a basically sound procedure for many years (about twenty). Accordingly, most of the very harsh criticisms made of MARK3 are blatantly incorrect and misleading.

Contrary to some of the early claims by those promoting the notion of a conspiracy, inappropriate operations within MARK3 are not the source of large GIPV's! In retrospect, these erroneous claims are extremely useful, since they are so easily proven to be false. Speaking very plainly, many of the highly critical statements reflect primarily the naivete of the person making them. In fact, the claimed distortions about MARK3 are a most vivid demonstration of scientists, who may be excellent in their own right, taking inappropriate liberties to criticize something about which their knowledge is highly deficient, if not totally lacking.

The foregoing comments do not mean that all assumptions and numerical modeling procedures employed in MARK3 are the most appropriate or that there are no better ways. But, they do mean that, MARK3 fulfills an important role in the methodology, that it is technically acceptable, that it does not create any major distortions, and that an independently designed Monte Carlo program, if well constructed, would give similar results.
Quite the contrary to some claims, those who designed MARK3 took special care to make sure that the program did not create distortions by constraining it so that simulated results are highly conformable with statistical data. This constraint has not usually been imposed in other similar programs.

Recommendations are made in a subsequent section to replace MARK3 with a new version. Those recommendations have nothing to do with the criticisms made of MARK3 or technical deficiencies. The replacement is recommended to accommodate additional information and to perform additional analyses.

EXPERT/AI SYSTEMS

The USGS was one of the earliest supporters of the use of expert systems. Although the early efforts to develop PROSPECTOR did not achieve initial expectations as an assessment tool, the experience gained therefrom has been important in the development of PROSPECTOR II and PROSPECTOR III. The Panel was particularly impressed with the development of PROSPECTOR II and its potential use in assessment. The capability to easily modify and update the models of PROSPECTOR II will be important when the deposit models of Bulletin 1693 are redone.

FORMAT FOR RECOMMENDATIONS

This section describes two major classes of comments or recommendations:

1) Short-run modifications, some of them urgent, that can be implemented immediately within the current assessment program and without major efforts;

2) Long-run, major modifications in methodology, informational support, or assessment program that require considerable time and institutional commitment.

Needless to say, some of the methodological changes recommended for the short run require further modification once the long-run, major modifications have been made. Thus, a single feature of methodology may receive very different recommendations for the short-run and long-run time frames.

SHORT-RUN (IMMEDIATE) MODIFICATIONS

ESTABLISH AND PUBLICIZE GUIDELINES

The recommendation most strongly and unanimously supported by the Panel is to develop comprehensive guidelines and to make them easily available to all interested scientists. No matter what the methodology is, whether it is the current one or a modified one, guidelines are mandatory for the following:

- construction of deposit models
- identification of deposit types
- delineation of permissive areas
- subjective probability

The availability of these guidelines to all interested individuals serves at least three major purposes: First, it removes some of the mystery (suspicion) about assessment; second, it informs and educates scientists who may wish to become involved; and third, it fosters uniformity of methods and assessments.

This recommendation is not a certification of the claims that interested USGS scientists could not obtain documentation of the three-part methodology. These claims appear to be unfounded. Even so, as assessments are made to serve society, a comprehensive description of methodology replete with guidelines should be easily available to any interested party.

REPLACE GIPV WITH A USEFUL MEASURE OF VALUE

Discontinue GIPV Immediately

The USGS should discontinue the practice of providing GIPV to those making land-use decisions. GIPV, as currently computed, is not a useful measure of the social value of mineral resources.

There are two major reasons for this:

1) GIPV is computed on all deposits of the tonnage and grade distributions irrespective of capital and operating costs for mine, mill and infrastructure;

2) The tonnage and grade distributions for some deposit types contain many sizes and grades that can not contribute to social value because of high costs of their development and production..

The fact that other agencies, e.g. Forestry, use GIPV does not justify the use of GIPV for mineral resources or for any national resource.

Cooperate with the USBOM for a Comprehensive Value Measure

When time, resources, and logistics permit, the assessment of number of deposits should be followed by a comprehensive economic analysis by the USBOM. This would provide the decision-makers with measures of the mineral-use value of subject lands that approximates true social value.

Modify MARK3 (Or its Replacement) to Compute RGIPV

As a fall-back position when efforts can not be coordinated with the USBOM, the USGS should modify MARK3, or its replacement, to filter simulated deposits so that GIPV is computed only on those deposits having tonnages and grades such that they may be economically developed and produced. This restricted value, RGIPV, is not a comprehensive measure of social value, but it is a much more acceptable proxy than GIPV. Moreover, the presence of uneconomic tonnages and grades in tonnage and grade distributions is of no consequence, at least as they pertain to value, when RGIPV is computed, because they are excluded from subsequent computations that lead to RGIPV.

Filtering could be performed by augmenting MARK3 with either 1) an evaluation subroutine replete with simplified capital, operating, and infrastructure cost relations by deposit type, or 2) mathematical filter equations derived (estimated) externally.
Very useful in either of these approaches would be the simplified cost models developed by the USBOM.

REPORTING OF ASSESSMENTS

A criticism commonly made by users of USGS assessments is that the assessments are described in terms that are either unfamiliar or too technical. Accordingly, the following recommendations are made for the reporting of assessments:

- assessments should be depicted graphically by the histogram, or a smoothed version, of simulated results;

- in addition to the graph of the simulated results, selected statistical measures should be consistently described in the body of the report;

- among these statistical measures should be the mean, the mode (most likely), and the 95% confidence limits;

- these statistical measures should also be noted on the graphical depiction of the histogram;

- all reports should contain "boiler-plate" which describes the statistical measures technically and in layman's terms.

DOCUMENT IMPORTANT GEOLOGICAL RATIONALE

The formal documentation for each assessment of important geological rationale for the selection of deposit types, the delineation of permissive areas, and the assessment of number of deposits is strongly recommended. Moreover, this documentation should be computerized so that it could be easily made and easily accessed at a later date. This formal documentation is not only important to those who use the assessment, it is important to the US Geological Survey. If an assessment should be challenged, this record could be presented as the basis for the assessment. Moreover, as new geological information becomes available, it may be desirable to reassess some areas. The electronic record of the earlier assessment is valuable information to be considered in the new assessment. Finally, this record, along with the geological data that were available, could be very useful in the training of assessors.

USE TAILORED TONNAGE AND GRADE DISTRIBUTIONS FOR ASSESSMENTS

Whenever data and knowledge permit and conditions require it, the global tonnage and grade distributions should be tailored for specific assessments. Such tailoring should consider two factors: 1) regional gradients (or terrane specific features) in deposit tonnage and grade and 2) the economic circumstances of the assessment area with respect to the deposits that comprise the global distributions of discoveries. The objective is to select a subset of discoveries that are not only geologically similar but also were made under economic circumstances similar to those that prevail in the assessment area. This helps to assure that RGIPV is a consistent and useful measure.

The "local" tonnage and grade distributions used on occasion by USGS assessors is an example of tailoring global distributions for geologic considerations. That tailoring should be expanded to include those factors that have a major impact on development and production costs, e.g. infrastructure, that vary geographically.

This recommendation is not a certification of the preferential use of highly selective data or of data only from the region itself, for these perpetuate errors due to small samples and bias due to the specificity heuristic. Great care must be exercised to mitigate the inclination of many geologists to over-differentiate deposits. Everything else being equal, distributions based upon large samples are preferred to those based on small samples. Moreover, generalized models lead to more robust estimates of uncertain events than do highly specific models.

DISCONTINUE ELICITATION OF QUANTILES (NUMBERS FOR CUMULATIVE PROBABILITY---AT LEAST FORM)

PDF is Preferred

Although relevant research is meager, it is unanimous in the conclusion that elicitation of probabilities for events or classes of events (PDF) is better procedure than elicitation of cumulative probability (CDF). Accordingly, it is recommended that the USGS eliminate the elicitation of quantiles.

Preferred methodology would elicit probabilities for specified numbers or, when the range of numbers is large, intervals of numbers. Moreover, the number of intervals and the breadth of intervals should be large enough to express the expert's uncertainty about number of deposits. Since different experts may view the range of possible events quite differently, each expert should be permitted to specify the relevant range and the events or intervals for which he provides subjective probabilities.

Separate Elicitation of PDF's

It is recommended that subjective probabilities be elicited separately from each expert instead of collectively from the assessment group. The primary, and very important, function of assessment by a group is the exchange of group expertise and information. More is said about group assessment in another section. Here, it is assumed that assessment is performed by a well constructed group and that group activities are structured to facilitate the exchange of science and information. Given such a group and given completion of science and information exchange, it is recommended that the quantitative assessment itself be made individually, using appropriate grade and tonnage models and the pdf elicitation and encoding format described above.

Contrary to some recent criticisms, when elicitation is direct (meaning probabilities for specified events), as is assumed for short-run changes in methodology, elicitation of event or interval probabilities for number of deposits should concentrate first on the tails of the distribution, pushing the geologist to consider probabilities for extreme events. The notions of accuracy and error suggested during the conference are irrelevant to this elicitation.

In the long-run, elicitation should be highly structured and about numbers of deposits to the extent possible, using the tonnage and grade models and probability models to assist the geologist in the estimation of probabilities. A methodology with these features is described in a subsequent section on long-run modifications.

Use of Deposit Densities of Analogue Areas

Quantitative assessment is now, and will continue for quite some time, to be made by analogic reasoning. We are not capable at this time to perform assessments by purely process-based analysis, although processes of genetic models constitute an important paradigm for geological analysis. Consequently, assessment programs and methodologies should be designed to support and enhance the use of analogue information. This information includes both experience of the geologist as well as explicit analogue areas. Future assessments should take even greater care to present useful analogue information to the geologists performing the assessment. Well selected and prepared analogue areas constitute a very valuable foundation for assessment. Particularly useful are measures of the densities of discovered deposits. This information should be reviewed by the assessment group so that the group can collectively discuss geological differences among analogues and with the assessment area.

Companion Changes in MARK3

The changes described above would require appropriate modifications in MARK3, or its replacement. MARK3 would have to be designed to accept as input each geologist's number of intervals, limits of each interval, and the probability for each interval. MARK3 would be designed to accumulate these probabilities and to sample them by Monte Carlo methods. Moreover, MARK3 should be designed to process the responses of each geologist separately for his probability distribution for RGIPV, as well as to compute an average RGIPV distribution. This assures that the users of assessments are provided full information about uncertainty and variation in judgement, while at the same time the user also receives a single distribution that represents assessment by the group. Although incorporating these changes in MARK3 would require some reprogramming, these modifications are technically trivial.

UNCERTAINTIES ABOUT DEPOSIT TYPE FOR DELINEATED PERMISSIVE AREAS

Recommended Modification

The USGS assessment methodology should be extended to include uncertainty about deposit type when multiple types could occur within a single permissive area, or when each subclass of a deposit type could occur but the geology indicates uncertain preferences among the subclasses. This change would, of course, require the geologist to express a new dimension of probability, that for deposit type. Moreover, MARK3 or its replacement, would have to be designed to accommodate probabilities by deposit type and the associated distributions of number of deposits and of deposit tonnage and grade. Of course dependencies, if present, would have to be explicitly considered.

Consider the hypothetical case in which areas that are permissive for a broad class of deposits, e.g. epithermal, have been delineated. Geological information does not permit the exclusion of subtypes of this broad class with certainty, but known occurrences and geologic interpretation does lead to preferences among the subtypes. As currently designed, Step Three ignores this important dimension of uncertainty. With respect to these hypothetical circumstances, the USGS assessment methodology as currently implemented would require the geologist to either select that subtype for which he has greatest preference, or to build a tonnage-grade model that is some composite of the subtypes.

The consequences of ignoring this dimension of uncertainty are quite complex and could impact both geologic analysis as well as the estimated resource value. At the very least, ignoring this dimension of uncertainty can lead to understating the varieties of metals that could occur and understating the variance in value of mineral resources.

Discussion--Niobium in the East Mojave National Scenic Area

Consider, the assessment of niobium resources in the East Mojave National Scenic Area. This assessment has been harshly criticized by some because of the assessed value of niobium resources. Since no niobium resources currently are known where the carbonatite outcrops, an assessed value for undiscovered niobium resources appears anomalous to those who believe that any unknown (covered) carbonatites that might be present at depth will be just like the one that currently is known.

Rationalization of the assessment included a geologic model of the relationship of depth-to-intrusion to niobium content and the fact that much of the resource area for niobium is at greater depth. Accepting this rationalization, which geologically is possible, there still remains at issue the way that the uncertainty about niobium content of possible intrusives entered the analysis. In that assessment, the assumption was made that every unknown carbonatite that occurred at depth contained niobium, even though the assessor expressed some uncertainty about the presence of niobium. As MARK3 is currently designed, it does not accommodate uncertainty about deposit type. Consequently, the assessor must decide whether he believes the evidence for a deposit type outweighs the evidence against it. This is a restrictive format and may lead to understating possible deposit types.

A preferred alternative in the niobium case would have been a computer program that includes a front-end that accounts for uncertainties about deposit type. Such a program would permit, or require, the geologist to state his uncertainties as probabilities that each deposit type is the type that occurs as well as probabilities for the joint occurrence of multiple deposit types. This would have resulted in the simulation of both barren and niobium-containing deposits in accordance with the specified probabilities. It is acknowledged that MARK3, as currently constructed, has the capability to deal with different suites of metals for a given deposit type, but this generally is not equivalent to uncertainty about deposit type. The probability for a specific metal suite is derived from its frequency of occurrence in the data for the deposit type.

SUMMARY OF RECOMMENDED FEATURES OF THE MARK3 REPLACEMENT

Step three, which currently is comprised of the MARK3 simulation program should be replaced as soon as possible with a new computer program having the following features:

- A front-end that accounts for uncertainties regarding deposit types for a delineated favorable area;
- Provisions for the input of event or interval probabilities by geologists, allowing for variable number of intervals and bounds of intervals;
- Filters to remove from value calculation those simulated deposits having sizes and grades too small or depth too great to be contribute to economically recoverable resources.
- A structure that computes probability distributions for metal and RGIPV separately for each geologist and collectively for all geologists;

CONSISTENT DESCRIPTION AND APPLICATION OF METHODOLOGY

Evidence

Examination of documents and assessments reveals a lack of consistency in 1) the implementation of methodology, e.g. one assessor, a panel of assessors, composition of team, etc., 2)description of methodology (three-step (stage), four-stage, order of stages, etc., 3) assessment product (metal, GIPV), and 4) written descriptions of assessments and methodology (especially probabilistic descriptions).

Importance

Consistency of description and application is a very important goal for the USGS assessment program for two very different reasons: The first is that it is through these descriptions that others have an understanding of how assessments are made and an appreciation of how well made the assessments are. The second reason is that in the event of litigation of a land-use decision, consistency of application and of description may be more important than the geological analysis and assessment per se. For both reasons, a recommendation of this study is that the USGS be much more consistent in its application of methodology and in the description of both methodology and assessed value.

Consistent Description and Consistent Product, RGIPV

Some of the past inconsistencies can be remedied very easily, such as consistent description. Requiring that all reports on assessments pass a review by an individual who is a specialist in methodology would take care of most of the inconsistencies in description. Of course, consistent description of a methodology that is applied inconsistently is still a problem. Therefore, there also must be consistent application of methodology and a consistent product. As recommendations have already been made above for filtering simulated deposits and computing restricted gross in place value (RGIPV), no further comment on these is necessary.

Consistency of Methodology and Variation in Information

It is recognized that the assessment task varies, sometimes greatly, with deposit type, e.g. bedded evaporites versus epithermal veins, and with level of and kind of information. Thus, every assessment in the detail may differ in some regards. Certainly, to the extent that variation is necessary to optimize the available information and expertise, society benefits from such variation, everything else being equal. Moreover, as methodologies and information evolve over time, consistency of methodology is not a useful long-term goal. Even so, a given methodology should be consistently applied and described. At least, some major elements should be consistent, even though informational support and information processing may vary considerably.

Centralized Responsibility with Oversight and Rotation of USGS Scientists

The importance of consistency indicates that the responsibilities for research and development of methodology, the training of assessors, the monitoring of the assessment process, and the review of reported assessments should be institutionally centralized, with provision made for oversight of the central unit. This oversight group should include some well-informed impartial individuals from outside of the USGS.

To ensure that this "central" unit remains dynamic and that the ideas of USGS scientists not in the unit but having interests in methodology are considered, it is recommended that a provision be made institutionally for the rotation of interested scientists into the unit for a limited, but appropriate, period of time. Such a structure may also yield side benefits of improving the acceptance of assessment by USGS scientists and of fostering a better "team spirit" within the USGS regarding assessment.

Specific Elements and Consistency

Specifically, it is recommended that consistency be sought for the following:

- Delineation of permissive areas
- Number of assessors
- Composition of assessment team (group)
- Elicitation and assessment procedure

Delineation of Permissive Areas by Deposit Type

Judging from USGS Bulletin 1693 , open-file reports, and presentations at the Arizona Conference, there is considerable variation in the criteria used to identify deposit types and to delineate assessment areas. In some cases, such as Costa Rica, deposit types appear to have been selected, at least to some degree, by known occurrences, while in other assessments the broad guidelines in Bulletin 1693 for permissivity seem to have been used. Some variation represents, at least in part, different assessment objectives, for example the stimulation of exploration and development in Costa Rica and Bolivia, as contrasted with land-use decisions in California. Greater care should be given to explaining changes in criteria for the identification of assessment areas; without such explanation, this variation appears to be due to either deficiencies in methodology or inconsistent application.

Even when variation of objective is taken into account, the delineation of permissive areas seems to be somewhat vague, sometimes being based upon tectonic setting, while at other times being based upon age and host rock assemblages. Moreover, for some unexplored areas, the geologic information available seems to admit more deposit types than are used. When this is the case, the selection should be rationalized, as well as those that were ignored.

It is recommended that the identification of deposit types and the delineation of assessment areas be more formally described and more consistently executed. Guidelines on criteria and procedure should be promulgated and made easily accessible.

A Minimum Number of Assessors

It is recommended that no assessment be made by less than three experienced assessors, meaning those who make quantitative estimates. Naturally, five or seven would be even better, provided that they all are experienced assessors. Here, it is assumed that the team does have other members, but they do not assess.

No assessment for societal use should be based upon just one assessor's judgement.

Composition of Team (Group) When only Assessors Estimate Number

The assessment team (group) should, at the very least, include the following:

- regional geologist who is very familiar with the geology of the assessment area;
- economic geologist who is very knowledgeable about deposit types;
- geophysicist with some exploration experience;
- geoscientist with expertise in remote sensing, GIS, data integration, and pattern analysis;
- assessment methodology specialist.

This minimum group is based upon the assumption that geochemical expertise is provided by the regional or economic geologists. Typically, the remote sensing geoscientist has not been a member of assessment teams, and often neither has the geophysicist. Future assessments should give greater consideration to the use of both geophysical (especially aeromagnetic, gravity, and electromagnetic) information and other remote sensing data (e.g. Landsat TM, Spot, airborne imaging spectrometer, radar), with appropriate processing and enhancement.

The experts other than the assessment methodology specialist may or may not be assessors. Whether or not they are depends upon choices that the USGS must make on assessment program, especially time and resources for training in assessment. One short-run strategy is that they are not assessors, in which case at least two well trained and experienced assessors should be added to the group, making a total of seven as the minimum sized group.

A more complex strategy in which every member of the group can participate in assessment is described in a following section on long-run changes in methodology.

ASSESSMENT BY A GROUP (TEAM)

Even when the combined scientific expertise and information provided by a group is very great, that of itself does not guarantee appropriate weighting of this information in the assessment of number of deposits when assessment is made only by experienced assessors. As explained above such a group is a short-run strategy for including both scientific and assessment expertise. Even when well constituted, however, there remains the very important question: Does the knowledge of the specialist, e.g. the geophysicist, receive proper consideration and weighting by the assessors ?

A recommended short-run strategy for group assessment is that the USGS modify its group assessment strategy in the following ways:

- Maintain at least the established minimum composition (explained above);
- Provide a forum for a thorough discussion by all group members prior to assessment of relevant science, data, and analogue areas;
- Subsequent to discussion of science and the delineation of permissive areas, obtain separately and privately an initial assessment of the probability distribution for number of deposits by permissive area and deposit type;
- Prior to reconvening the group, each assessor identifies those geological or informational issues to which his assessment is most sensitive by permissive area and deposit type;
- In group session, each of the geological and informational issues on the collective list is thoroughly discussed, and relevant geoinformation is introduced;
- There is no discussion of number of deposits by the reconvened group;
- Subsequent to the thorough discussion of science and information that relate to the sensitive issues, each assessor privately makes a final assessment of the probability distribution for number of deposits following preferred procedures, explained earlier in this report.

There is no attempt to reach a group consensus. The subjective probability distributions for number of deposits, along with the tonnage and grade distributions, are submitted to a simulation program (revised MARK3) which produces a probability distribution for RGIPV for each assessor and an average probability distribution for RGIPV over all assessors. Thus, the user of assessments can see the variation among assessors by examining the individual distributions of RGIPV , and at the same time he has the average distribution as a group assessment.

LONG-RUN, MAJOR MODIFICATIONS

REDO DEPOSIT MODELS --BULLETIN 1693

Although widely acknowledged as a very important contribution, the Panel is unanimous in its judgement that Bulletin 1693 needs to be redone and that this task should be given high priority. As deposit models are the foundation or key to the USGS assessment methodology, these models need to be updated to include recently published information. Some models need to be split, but others need to be grouped, and some deposits that comprise the associated tonnage and grade distributions need to be reclassified.

Since deposit models and their associated tonnage and grade distributions are so vital to the successful application of the USGS assessment methodology, the following suggestions merit consideration. First, the new compendium should be computerized to facilitate its use as well as future updating. Second, to increase the acceptance of the deposit models and assessments involve a broader intellectual guidance or review by including scientists from outside of the USGS. Perhaps, a committee appointed by the Society of Economic Geology could be useful in that regard or in identifying experts for this task. For each panel, a small team should be selected and charged with the task of refining and updating the model. Insofar as possible and practical, members of surveys from other countries should be involved. Third, develop and present one or more hierarchies of features or characteristics, based upon their importance in identifying the deposit type and in delineating permissive areas. Fourth, broaden the scale of the characteristics looked at to at least the scale of the terrane.

Potentially useful in developing the hierarchies referred to in the foregoing is the RCON (rational consensus) system. Experts working within the RCON system would identify important features, their rankings, and relative weights that each should be given for the identification of deposit type or for the delineation of permissive area. Both the hierarchy and the weights would represent a resolution of the group of experts, and these could be presented as elements of the deposit model.

A logical extension of this work would be to use the output from the RCON system to construct a PROSPECTOR II-type model for each deposit type. When coordinated within an expert-like system, these models could be of considerable value in future assessments.

DEVELOP EXPLORATION INFORMATION FOR ASSESSMENT

When the area to be assessed has already received some exploration, the intensity of exploration across the area is very important information to be considered in assessment. This theme was repeatedly raised in the conference by Panel members. Of course, that such information is important has long been acknowledged by those making assessments. The basic problem, however, is that as long as consideration of exploration is totally implicit to the judgment of the assessors, there will remain concern whether exploration had been given proper consideration.

An obvious recommendation for long-term improvement is for the USGS to compile information on exploration intensity and to make that a formal part of the data base for assessment (both analogue and assessment areas). Unfortunately, it is known *a priori* that the desired data are very difficult, and in many instances impossible, to obtain. Accordingly, when that is the case, which may be most of the time, a different strategy must be used.

When useful exploration data are not available, it is recommended that a methodology be constructed to simulate such data by the use of judgements of highly experienced explorationists. This should be viewed as a separate effort, independent of the assessment. A group properly constituted and supported by a system such as RCON could produce a map of exploration intensity. This map would constitute an input to the assessment team, and it could be presented as part of the data support for the assessment.

DEVELOP A MORE FORMAL AND STRUCTURED PROCEDURE FOR ELICITATION OF JUDGEMENT AND ENCODING OF PROBABILITIES FOR NUMBER OF DEPOSITS

General

Recommended short-run changes included replacing elicitation of quantiles for specified "at least" probabilities by probabilities for specified numbers or intervals of numbers of deposits. That same recommendation applies for the long-run. However, apart from the pdf elicitation format, recommendations for the long-run differ markedly from those for the short-run. Whereas in the short run, recommended procedures emphasize the elicitation of probabilities for extreme events as a means to mitigating heuristic biases, recommendations for the long-run replace direct with indirect elicitation. Central to these recommendations is the objective of approximating "objective probabilities" and minimizing heuristic biases by increased formalization and support of the elicitation process.

Recommended long-run changes in methodology impose much greater structure on the elicitation of probabilities for number of deposits, the objective being to support the mental processes of the geologist and to mitigate cognitive biases. Principal elements in recommended procedures are 1) formalization of the use of tonnage and grade models as supports and constraints, 2) the use of formal probability models, estimated from the geologist's judgements, for initial probabilities, i.e to demonstrate the range of possible outcomes and their probabilities by mathematical models that are consistent with his judgements, 3) development of mathematical algorithms and computer software to implement the estimation of the formal models with a minimum of subjective probabilities, and 4) appropriate support by computer displays and processing software. Additional comment is presented below on some recommended procedures.

Elicit Number of Deposits for Familiar Deposit Tonnage and Grade Classes

Here, it is assumed that the deposit model and associated tonnage and grade distributions are appropriate supports for the specific assessment. In other words, if geological and economic circumstances require the use of tailored distributions, these have been constructed. Given these conditions, it is recommended that the elicitation of number of deposits begin by eliciting from the geologist ranges of deposit tonnage and grades with which he is highly familiar. Having established these ranges, elicit the most likely number of discoveries for the assessment area having tonnages and grades that fall within the familiar ranges.

Rationalization of this approach is that the geologist's estimate of number of deposits must reflect primarily his experience; consequently, if his experience regarding deposit density is mainly for limited ranges of deposit tonnages and grades, a subjective estimate of number of deposits within the assessment area must begin with that with which he is most familiar.

Use the Tonnage and Grade Distributions of Discoveries to Transform the Number of Deposits for Familiar Ranges to Number of Deposits for the Full Discovery Population of Tonnages and Grades

Since tonnage and grade distributions are specified as the window through which the geologist is to estimate number of deposits, it makes good sense to use those distributions to transform the most likely number of deposits for the familiar tonnage and grade ranges to the most likely number for all tonnage and grade classes for the assessment area.

Having computed the inferred total number of deposits of all tonnages and grades on the discovery distributions, this number should be distributed among selected combinations of tonnage and grade classes using the tonnage and grade models. This distribution presents the geologist with the implications of his initial estimate of number when it is expanded to represent the population of discoveries. The geologist then modifies these numbers as geology, experience, and analogue information dictate. The sum of these modified numbers over all tonnage and grade combinations is his estimate of number of deposits for the assessment area.

The foregoing analyses produce a single estimate of number of deposits, given his familiar ranges of tonnage and grade and given the tonnage and grade models. The next step is to obtain an initial distribution of possible other states of nature and associated probabilities. The following section describes briefly the use of formal probability models to obtain that initial distribution.

Develop an Inference Algorithm for the Estimation of Parameters of Selected Probability Models, Based Upon the Most Likely Number Augmented with Additional Judgements

The most likely estimate of number of deposits for the assessment area, as described in the foregoing, should be the primary input, along with additional selected judgements about other possible states, to a computerized algorithm for the estimation of the parameters of selected probability models. The purpose of this step is only to demonstrate to the geologist the distribution of probabilities by mathematical models that are consistent with his judgements. None of them is intended to be the assessment distribution for number of deposits. Having viewed these distributions, the geologist is then asked to either modify one of them to conform with his knowledge and experience or to specify directly a histogram of his subjective probabilities for selected numbers or intervals of numbers. It is this distribution that is his probabilistic assessment of the number of deposits.

Implementation of the above procedure will require the USGS to develop suitable mathematical algorithms and computer software to estimate the parameters of the probability models from judgements provided by the geologist and to display them for inspection by the geologist. These algorithms should minimize the use of elicited probabilities for number of deposits, except for the probability for at least one deposit, in the estimation of parameters. To the extent possible, parameters should be estimated from judgements about number of deposits, such as the most likely number.

Successful implementation of this element of a long-run methodology will require some research, development, and testing of the algorithms and the construction of user-friendly software for real time implementation.

GROUP ASSESSMENT USING RCON

The section on short-run changes in methodology describes assessment by a group in which only assessors make estimates, given extensive discussion of scientific and informational issues to which assessment is sensitive. Even when carefully done, such an approach does not guarantee that the scientific knowledge of the non-assessing scientists in the group is incorporated into the assessment. Concern about this integration leads naturally to a methodology for group assessment in which all scientists participate in assessment. Naturally, such an approach raises other issues, such as the capability of specialists to assess resources and the required training. These are legitimate concerns; certainly, group members would have to receive some training in probability and assessment methodology. But, even with training, there is the need to weight multiple responses to arrive at a distribution for the group. Here, a new and developing system referred to as RCON is designed explicitly for the integration of various expertise to a group response.

The recommendation is made that the USGS begin investigating the use of RCON, or some similar system, for assessment when everyone assesses. Basically, RCON is an influence allocation scheme which determines weights to use in aggregating individual assessments made by each member of the team. These weights are determined by an electronic voting system which allocates votes to alternatives and to members of the group according to perceived expertise and relevance to assessment.

The front-end of RCON calls for extensive exchange of science and information in which each expert would share his knowledge domain as well as relevant information. Other features include the following:

- Identification by the group of geological factors that are deemed to be important in the formation and recognition of mineral deposits;

- Identification of a subset of geological factors, the 'sensitive' geological factors, that are deemed by the group to be recognition criteria for the delineation of tracts for mineral deposits;

- Familiarity of each group member with all other members so that subjective judgments of the relative expertise of individuals may be made with regard to the geological factors under consideration;

- Assessment privately by each group member, following preferred procedures.

- Combination of individual assessments using weights reflecting the expertise of each assessor, as determined from the RCON voting algorithm.

RCON is based upon a weighting method proposed by DeGroot (1974) with continuing research by Balthazard et al (1992). A specially designed conference room, replete with terminals connected to RCON on a central computer is available at the University of Arizona. Commercial use of this system is $2000 per day. However, an initial examination of the system for assessment may be possible through a cooperative research effort in which an actual assessment is used as part of current research on applications of RCON. Such an arrangement would also provide the USGS with some experience with the system and a basis for evaluating its potential as part of an assessment methodology.

A METRIC FOR OCCURRENCE PROBABILITIES

A recent manuscript prepared by Lawrence J. Drew and David Menzie (1992) indicates potentially valuable directions of research and development for resource assessment: 1) the relationship between deposit density and important geological determinants, and 2) the geologic and spatial relationships of deposit types. They found, for example, that preliminary data suggest that probabilities of occurrence of porphyry copper deposits within the intrusive parts of volcano-plutonic complexes lies between 0.00X and 0.000X.

This work is very important because it serves as an example of the geological perspective and the organization of information that is vital to improvement of assessments. Geologists by nature of their training think qualitatively about processes and their geologic expressions, but assessment requires three-dimensional qualitative and quantitative analysis. Clearly, the description of deposit occurrences in terms of geologic determinants in three-dimensional space would be of great assistance to the geological component of assessment.

The second part of their study developed the notion of "kin" deposits, meaning that a basic determinant, such as a porphyry system, can generate several deposit types that have a typical spatial distribution. Naturally, the documentation of a consistent pattern in the spatial distribution of deposits as they relate to each other and to a fundamental geological determinant would require changes in the way that assessments are performed. Assessment methodology would become more complicated to take into account relevant dependencies, and the credibility of assessments would be increased significantly.

As both directions of study are very important to future improvements in methodology and to assessments themselves, it is recommended that this effort receive continuing long-term support. Although the payoff for such research may be a few years away, it could be a very important contribution to improved future assessments.

PATTERN ANALYSIS FOR ANOMALIES

PURPOSE

The current methodology identifies geologic environments and deposit types and delineates areas that are permissive, based upon observed geology and recognition criteria for the deposit type and its environment. There is some concern that some deposit types may not be recognized or that assessment areas might be missed. And, given an initial selection of deposit types, a generally geologically anomalous area may not be delineated. Finally, for a given deposit type and permissive area, existing geodata may not be optimally used to estimate number of deposits when data integration is done subjectively. The delineation of anomalous zones within a permissive area may be of considerable assisstance in the assessment of probabilities for number of deposits. Accordingly, there is a strong argument for augmenting current procedures with a strictly empirical (statistical) approach designed to identify general geologic anomalies.

In accordance with the foregoing, an important future extension is to augment the traditional maps or images with images of variables especially constructed to delineate anomalous areas by strictly empirical data analysis designed to identify patterns and anomalies. Once delineated, these are carefully examined for deposit type classification. At the very least, this approach may add permissive areas of identified deposit types. Or, at its best, it may result in the identification of an additional deposit type and its permissive areas.

Finally, the delineated patterns and anomalies may be useful in the assessment of probabilities for number of deposits.

METHODS

Soviet resource prognosticators have been developing techniques to implement this notion for many years, for example, the "exceptional" zones of Gorelov (1982). Other similar work includes the complexity variable of Sinding-Larsen, et al (1988) and the multivariate relative exceptionalness zones of Harris and Pan (1991), the favorability maps of Liu (1991) and of Pan and Harris (1992), the typification areas of Harf and Davis (1990), and the "weights of evidence" probability maps of Agterberg et al (1990).

The idea here is that one or more of these methods would be employed, as is appropriate, and an image of the constructed variable, e.g. exceptionalness, complexity, favorability, etc. would be created and examined for anomalies that had not been identified, or for extensions or subdivisions of already-delineated permissive zones. At the very least, maps of these variables could be very useful as information for the geologist to consider in his subjective delineation of assessment areas, checks on his permissive areas, and possibilities for additional deposit types or permissive areas.

This analysis may be especially useful when remote sensing data and geophysical data are included along with the usual geological data and when multivariate pattern integration is performed. Naturally, GIS software would facilitate the implementation of these techniques.

INTEGRATION OF OBJECTIVE METHODS INTO THE USGS ASSESSMENT METHODOLOGY

It is recommended that continuing research be directed to the development, testing, and integration of objective quantitative methods, such as information synthesis and intrinsic sample concepts and methods, into the USGS assessment methodology.

When geodata are abundant and good analogue areas can be identified, the potential exists for the probabilistic estimation of number of deposits by well-designed objective quantitative analyses. A less intrusive way of integrating such methods into the USGS assessment methodology is to employ them to generate additional images for the geologist to consider in his delineation of assessment areas or in the assessment of the areas.

Appropriately designed methods could be useful in 1) the integration of diverse geodata, 2) the generation of enriched information for consideration by the geologist, 3) the delineation of assessment areas, 4) the delineation of anomalies, and 5) the delineation of district-size deposits.

At the very least, well-designed objective quantitative methods could provide useful additional information to be considered by the assessing geologists. If such analyses do no more than provoke the geologists to rationalize their own analyses, they may be very worthwhile.

EXPERT/AI SYSTEMS

It is clear that the USGS has many of the necessary conditions to embark on an expert system for mineral resource appraisal. During McCammon's presentation, the panel remarked on the utility and applicability of PROSPECTOR to mineral resource appraisal and, at the same time, the apparent lack of interest exhibited by the Survey towards the system. Clearly, there needs to be a continuing long-term commitment to research and development of Expert/AI systems for assessment; however, such research should be conducted explicitly through the assessment window.

What should be the principal features of the mineral resource assessment expert/AI system? The following outline is not comprehensive, but denotes the overall framework for an expert/AI/GIS system for assessment:

- The selection of deposit models must be based upon a defensible algorithm as offered by numerical deposit modelling and PROSPECTOR.

- Delineation of favorable tracts should be performed, where possible, through a statistical process, such as is offered by the intrinsic sample methodology (Pan and Harris, 1991). Or where information is unevenly distributed across the study area, tract delineation should be supplemented with a weights of evidence analysis (Agterberg and Bonham-Carter, 1988). Note that both of these approaches require that all information be digitized and referenced geographically. This requires the implementation of a geographic information system. Again, the general framework for tract delineation through a GIS/expert system is contained in PROSPECTOR.

- Given the GIS/expert system interface the RCON methodology should be introduced into the program to permit the group to determine the relative weights assigned to various geological attributes in numerical deposit modelling. These weights are discussed in the section of Assessment Methodology and Subjective Probability. There, reference to a data-class is synonymous with airegions in PROSPECTOR whereas recognition criteria of the data-class correspond to geological attributes.

- The introduction of RCON into an expert system formalizes the use of subjective probability in group opinion and offers the potential for mitigating biases.

- Finally, an expert system used in the assessment methodology would ensure greater consistency across assessment areas.

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APPENDIX I -- EVOLUTION OF CONTROVERSIES

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APPENDIX I - EVOLUTION OF CONTROVERSIES

INTRODUCTION

> "The difficulty of estimating the unknown (undiscovered deposits) from indirect evidence (geology) makes assessments easy to criticize. But, this study is not a result of the usual general criticisms. What led to this study are 1) recent criticisms that originated with some USGS geologists and 2) the use of these criticisms by factions desiring to challenge some land-use decisions. Adding to the pressure from special interest groups were those USGS geologists who had 1) resisted quantitative assessment and wished to return to the traditional subjective assessment of a region as favorable or unfavorable for the deposit occurrence, or 2) believe that the USGS should use different methods for quantitative assessment."
>
> DeVerle Harris (1992): Instructions to the review panel
> prior to the Arizona Conference

The following description of the evolution of the controversies surrounding the OMR three-step methodology has been compiled from documentation provided by the U.S. Geological Survey and presentations at the Arizona Conference in August, 1992. As such, it may be incomplete in some respects. If so, this is unintentional.

AN EVALUATION OF THE USGS METHOD BY WARREN HAMILTON

The controversy surrounding the current mineral resource assessment methodology began, in part, as reaction to GIPV estimates for the East Mojave National Scenic Area, California and Red Cloud/Handies Peak, Colorado. Subsequent review of the studies by members of the Office of Western Regional Geology, and The Branch of Geophysics lead to a dissenting opinion as to the validity of the methodology in representing an unbiased estimation of the undiscovered mineral resource. The ensuing controversy was articulated through a series of inter-office memos having wide distribution within the rank and file of the US Geological Survey. In particular, a paper entitled "An Evaluation of the USGS Method of Quantitative Assessment of Mineral Resources" incomplete draft - dated October 6, 1991 by Warren Hamilton gained wide circulation. The accompanying cover letter addressed to 'Survey mineral-resource assessors' began with the following statement:

> "Congress and DOI are now being given the grossly inflated dollar-value estimates of undiscovered resources on public lands that are deemed necessary to persuade politicians and administrators to "Keep the words 'mining is prohibited' out of all legislation." Not close-enough-for-government-work factor-of-ten inflation, but heavy duty stretching, factor of a hundred or a thousand."

The document goes on to state (p.1), "The large biases in these successive stages [the three-step methodology] operate in the same direction and cumulatively they grossly overstate the economic resources likely present. Overstatements by factors of 1000 appear to be common." Hamilton has stated that his charge of conspiracy by BORA mineral resource assessors to inflate dollar value estimates of undiscovered resources on public lands stems from a June 4, 1991 meeting of NAMRAP Projects Coordinators Meeting in which Chief of OMR Glenn Allcott is quoted as saying "Keep the words 'mining is prohibited' out of all legislation" (edited version of notes taken by David John). The reputed quote has since become a lightening rod for dissenters to challenge the current assessment methodology and, in turn, BORA.

Some of the statements with respect to the data used and the results, as perceived by Hamilton are:

1) "The computer program is tremendously biased toward calculating high values by the inclusion of giant deposits when there is only the remotest chance that similar deposits will be found in random areas elsewhere." (p.4);

2) that the estimates of the number of undiscovered deposits are "guesses" (p.5) and that "The calculations start with the geologists initial guesses, which commonly are vastly too high, of the number of deposits (p.6);

3) with respect to the MARK3 "access to the program is restricted and only general and confusing descriptions of its workings have been released" (p.5);

4) furthermore, MARK3 "increases all guesses, even the forced default-probability guesses to a higher probability than that stated" (p.6);

5) That "The presentations of the end results of the optimistic guesses and biased calculations are dominated by statements in text and tables of astounding dollar values of undiscovered resources." (p.6)

The text is accompanied by a case study for the Redcloud Peak and Handies Peak area, in the San Juan Mountains in which Hamilton cites an internationally known mining-industry porphyry-molybdenum geologist [not referenced] as finding " absurd both the assertion of near certainty that a Climax-type deposit was present and the calculation of great value for that imaginary deposit"(p.9). From this Hamilton concluded that "the multiplication of the successive biases in guesswork, calculations, and presentation cumulatively overstate realistic possible values by a factor of probably much more than 1000" (p.9).

RESPONSES TO THE HAMILTON DOCUMENT

A response to Hamilton came from David Campbell, Chief, USGS Branch of Geophysics on October 15, 1991 in which he writes:

> "I was alarmed by your recent diatribe against OMR's mineral resource appraisal efforts, which you chose to masquerade as a scientific review. My problem is not that you chose to review this work, but with the rhetoric with which you lambasted it. I always welcome thoughtful, scientific reviews (solicited or not) of USGS work. If you can make the case that the work is poor, so be it. I expect to judge the arguments in such a review by the same scientific standards that the reviewer himself is supposed to use. These standards include careful statements of conclusions reached, made fairly, clearly, and without hyperbole. I think that you have failed these standards."

Then, on October 16 a reply sent to Hamilton from Singer, Menzie, and McCammon responds with:

> "You have questioned the integrity of our work, and therefore, our reputation, by your actions.-You have disseminated your charges widely in a manner that leaves us few ways to defend our reputations. We ask that you publish these charges, as circulated, in a scientific journal and that you provide to us an address list of all those who have received your paper so that we can reply."

And a second memo to The Director (through Chief, Geologic Division; through Chief, Office of Mineral Resources) from Menzie, McCammon, Root, and Singer complaining of unprofessional and unethical behavior. They state:

> "These charges were made by Hamilton in the attached October 6, 1991 memo and paper that were widely distributed, at government expense, in Reston, Denver, Menlo Park, Anchorage, Spokane, and Tucson. Hamilton has in effect accused us of fraud, in an inflammatory and irresponsible manner. Such charges are extremely serious, and should have been presented in a manner that would allow us to address them."

Rick Sanford delivered a protest to Glenn Allcott on October 17, 1991. This is a nine page examination of the mineral resource potential in general and Redcloud Handies Peak in particular. The main points of the text are supplemented with conceptual scenarios under which assessments are performed. The general issues raised by Sanford are that 1) differences of opinion on the mineral potential depend primarily on the individual's criteria or assumptions, not on details of calculations, 2) that Hamilton's criticism of the method of calculating a particular mineral resource potential (MRP) misses the basic point that all estimates are gross underestimates in the long run given technological change, and 3) the different MRP estimates in Bulletin 1715B and OF91-384 for Mo in this area are due to the use of a better assessment methodology by BORA. Sanford argues that Hamilton's claims of exaggerated MRP are without substance:

> "If professional experience is any guide to objectivity, then OF91-384 is clearly the better assessment. The assessment of OF91-383 relies on far more professional expertise than that of Bull. 1715B. The Mo section in Bull. 1715B was written by an individual with about 5 years of experience with the USGS at that time. The Menlo Park meeting, which led to the assessment of OF91-384, consisted of 9 individuals who cumulatively have some 150 years of experience in mineral resources, both with the Survey and private industry."

In a second memo to Dallas Peck, Ben Morgan, and Glenn Allcott, Sanford (December 4, 1991) claims to have been the target of a smear campaign led by Hamilton to discredit those who participated in the Redcloud-Handies WSA. He writes:

> "I welcome objective criticism, but Hamilton's assertions are not that. Because of my views, I have now become the target of a character assassination squad, as have others who have had the courage to speak out on this issue. It is time the campaign stopped."

The most lengthy rebuttal to Hamilton's memo came from Don Singer on October 28, 1991 in which he starts his reply with:

> " A key assumption made by Hamilton is that the target population we are interested in is the distribution of metal in the earth's crust. This is simply wrong. On page 1 of USGS Bulletin 1693, a mineral deposit is defined by Cox, Barton, and Singer (1986) as "...a mineral occurrence of sufficient size and grade that it might, under the most favorable circumstances, be considered to have economic potential." This is our target population."

And, the following text refutes Hamilton's basic premise that the estimated number of deposits reflects mineral endowment:

> "A second key assumption made by Hamilton is that the estimated number of undiscovered deposits represents the number of occurrences and deposits is the earth's crust and is therefore biased with respect to the grade and tonnage models."

Singer clarifies the estimated number of deposits population as:

> "...it clearly states that the estimated number of deposits must be consistent with the appropriate grade and tonnage model."

These passages are followed by five pages of line-by-line analysis of Hamilton's assertions and a two page tableau of significance tests of lognormal tonnages and grade-tonnage correlations. This in-depth analysis focuses on the grade/tonnage models, the testing of distributional forms and the resulting implications to Monte Carlo sampling by MARK3. Singer protests:

> "Hamilton is confused. His untested speculation is treated as certainty whereas a through [sic] analysis of 67 types of deposits represented by over 4,000 mineral deposits is treated as assumption."

THE CONTROVERSY APPEARS IN THE DENVER POST

After release of Hamilton's document the controversy became public, with three articles in the Denver Post about the high gross-in-place-dollar-values for the proposed Redcloud and Handies Peak wilderness area of Colorado. On October 12, Mark Obmascik, author of the ENVIRONMENT column reported that Interior Secretary Manuel Lujan had rejected BLM plans to protect the 35,000 acre area as wilderness based on a GIPV estimate of $4.9 billion, a value that the article claimed was in error because of "...some fishy number crunching by the US Geological Survey". The more important passages from that article are:

> "Let's put that $4.9 billion number in perspective. One full century of full-bore excavation in the San Juan Mountain range, one of Americas biggest mining areas with towns like Silverton, Ouray and Telluride, produced minerals worth $8.5 billion at today's prices, USGS says.
>
> YET THE SAME agency now says one little 35,000-acre corner of the whole San Juan range contains $4.9 billion of undiscovered minerals. If the Handies and Redcloud really offered such rich rock, why weren't they mined years ago?
>
> Here's one answer:USGS only calculated the value of minerals in the ground at Handies and Redcloud. But USGS never figured out how much it would cost to get the minerals out.
>
> Even if you believe the areas contain $4.9 billion of minerals, it might cost twice that much to extract and transport them to market because they're buried in such rugged country.
>
> What's more curious is the USGS claim that the most valuable mineral at Handies and Redcloud is molybdenum, a hardening agent used to make steel.
>
> USGS claims that the tracts contain $4 billion of moly. By contrast, the worlds biggest single source of moly, the Climax mine near Leadville, has produced just $4.5 billion of the mineral, based on current prices, after 80 years of mining, a Climax spokesman said."

The article ends with the passage "...there are lies, damn lies, and then there are statistics. Lujan should ask which one he got", leaving little doubt that the controversy about the current USGS mineral resource assessment methodology had a significant public impact.

FURTHER CRITICISMS OF THE THREE-STEP METHOD

There was a second memo that began to circulate within the USGS two days before the Denver article above. On October 10, 1991 (as cited by Singer in a Memo to Menzie, October 17, 1991), Howard Wilshire, David Miller, and Jane Nielsen of the Branch of Western Regional Geology sent a memorandum to Ben Morgan, Chief Geologist entitled Misrepresentation of geologic information with regard to assessment of undiscovered metallic mineral resources, East Mojave National Scenic Area (EMNSA). In this document they note the following problems with the assessment of undiscovered metallic mineral resources in the East Mojave National Scenic Area:

- Dollar values of in-place minerals are grossly inflated by systematic bias: Examples are $1.3 billion assigned to iron and $2.1 billion assigned to carbonatite.

- Biases occur in the MARK3 treatment of data because the grade/tonnage models over represent large deposits and under represent small ones; use of arithmetic means of statistical data feeds on that bias.

- The MARK3 program documentation has never been published, subjected to independent critical review, or tested in the field. Therefore, the credibility of the products of the program has not been scientifically demonstrated.

- No consideration is given to boundary adjustments to eliminate favorable areas at the edge of the Scenic Area.

The authors protested "misuse of our information" in an assessment methodology they felt to be "..a black art at best, and is essentially untested" (p.1). More informative with respect to the protest is the following passage (p.2):

> "In addition to the problems with MARK3, a matter that is simply ignored in the case of EMNSA, as well as other WSA and NF areas subjected to MARK3 analysis, is the common possibility that minor adjustments in boundaries can be made to exclude what are considered to be hot areas. For example, only a small part of the terrane favorable for REE in EMNSA actually lies in EMNSA, and is on the boundary. This could be excluded from the area to be considered for withdrawal. We believe that the USGS should be making observations about regions of high potential for resources when they are near boundaries, so that decision makers can quickly understand the several options available to them."

In a follow-on memo dated 10/7/91 from Howard Wilshire to Ben Morgan it was stated that the kind of information that entered into discussions leading to consensus included "rumor, hearsay, assessments of the mind-set of mining companies, locations of drilling activities etc." Wilshire summarizes:

> "In the midst of this, I remarked that I was astonished at the nature of the input into this process, seemingly including hearsay, sidewalk psychology, mind-reading, and the like. I was asked how I would do it, and responded that I would be very conservative. This was attacked as bias."

He concluded this section with:

> "I think that when we bend over to factor in rumors, activities, and unsubstantiated statements involving those with vested interests, including other government agencies, we have ceased to be objective."

MINERAL RESOURCE ASSESSMENT OF THE CORONADO NATIONAL FOREST: CHAPTER J

Concurrent with the circulation of Hamilton's memo was the release of the document Mineral Resource Potential and Geology of Coronado National Forrest, Arizona and New Mexico by Bultman, Drewes, du Bray, Fisher, Gettings, Klein, and Nowlan (1991). In the Abstract of Chapter J: Quantitative Mineral Resource Assessment of Coronado National Forest, Arizona and New Mexico the authors stated "A number of assumptions used in this methodology caused MARK3 to generate greatly exaggerated estimates of metal contained in inferred, undiscovered deposits. An additional series of simulations was run in order to redefine the mineral resource assessment of Coronado National Forest" (p. J1). The following excerpt from this chapter summarizes the position of the authors with respect to the mineral resource assessment methodology (p.J7):

> "The standard procedure in step three of quantitative mineral resource assessments made by the USGS involves in putting undiscovered deposit estimates generated by the assessment team into MARK3, a simulation program designed to build hypothetical distributions of metal from information on deposit grade and tonnage and the expected numbers of undiscovered deposits (Drew, 1991). Although this procedure was followed, three factors which cause MARK3 to generate exaggerated estimates of metal contained in inferred undiscovered deposits in Coronado National Forest caused an additional series of simulations to be run in order to refine the mineral resource assessment. These factors are: 1) MARK3 cannot easily accommodate local tonnage models; 2) MARK3 inappropriately (in the authors opinion) uses piecewise log-linear (or lognormal) models to approximate grade and tonnage data contained in Cox and Singer (1986); and 3) the method used by MARK3 to build probability mass functions (PMFs) used in simulations is counter-intuitive and did not represent the information that the assessors were trying to convey."

COMMENTS ON THE THREE-STEP METHOD: BULTMAN ET AL.

The ideas put forward by the authors in Chapter J were formalized in a paper entitled Comments on the "three-step" method for quantification of undiscovered mineral resources by Bultman, Force, Gettings, and Fisher (draft versions 1/21/92; 2/7/92; and 3/17/92). This document is hereafter referred to, and is cited throughout the report as the 'Bultman et al. paper'. During the Tucson Conference, Menzie and Force reported that there existed an earlier version of the paper submitted to the Branch Chief in November of 1991 (possibly written August 1991) as an internal manuscript. No copies of this document were provided but Force stated to the panel that it was similar in content to Version 1 (dated 1/21/92) but with some of the "phrases that seemed personal" removed. Under questioning by the panel, Force stated that all three versions are marked Open-File Report 92-xxx to indicate that they are considered to be official reviews.

The Bultman et al. paper challenged the methodology beyond the earlier criticisms of MARK3. With regards to presentation of the method the authors note (p.2, version 1/21/92):

> "At present, only a few components of the proposed method are adequately published. The overall method has been published mostly as undocumented claims of success, in which the logic is poorly presented (for example, Drew and Others, 1986). The work actually proceeds on the basis of some in-house manuals that have not been widely circulated to all members of the mineral-resource assessment teams and that have not been subject to public scrutiny, internal USGS review, or external review. In fact, some of the pertinent documents are in Spanish or Japanese. The most recent comprehensive description of the method is an extended abstract by Menzie and Singer (1990); however this document lacks clarity and is too brief to serve as the required presentation of the overall method of assessment."

With respect to testing of the method they state (p.3 version 1/21/92):

> "Testing of the geological hypothesis embodied in the method apparently has been limited to a single, unpublished, test utilizing porphyry copper deposits that may or may not be present in 13 selected areas (J.A. Briskey, Jr., U.S. Geological Survey, written commun., 1991). Even though this test has been repeated frequently, it still constitutes a single test. Clearly, several blind tests are required to validate the hypothesis for each deposit type. For the claimed general applicability to all deposit types, such tests are required for each deposit type. In addition, the test themselves must be subject to peer review and public scrutiny before their validity can be established."

And the selection of porphyry copper as the test deposit type draws further criticism (p.3 version 1/21/92):

> "We maintain that the choice of porphyry copper deposits for a test enhanced the chances of a favorable result. No other type of deposit model is more highly correlated to geologic and geophysical data as expressed on regional scale maps than are porphyry copper deposits. Also, the necessary condition of the presence of an associated intrusion and the large size of these deposits puts strict bounds on the lower and upper limits of their numbers in a region. Even given these facts, only one half of the geologists tested were "right" (J.A. Briskey, Jr., U.S. Geological Survey, written commun., 1991). Since the actual number of geologic deposits that can be described

> by the porphyry copper model is, of course, not known, the results of the test are, in fact, unknown."

Bultman et al., (p.4 version 1/21/92) cite the ERDA subjective probability assessment of the uranium endowment of New Mexico as evidence of the great difficulty geologists encounter in assessment:

> "The results of this assessment indicate that subjectively created expert estimates of number of undiscovered deposits can vary tremendously. Figure 2 [not included in this report] indicates that a mean or median value of these estimates is meaningless because there is no clustering of tonnage estimates, that is, there is no tonnage estimate that many of the estimators agree on. The choice of median or mean value for an estimator, in this case, simply the indicates the belief that more confidence should be given to an estimator whose result happens to fall in the middle of the range of estimates."

The authors suggest that an analysis of the errors in the method is warranted. They state (p.4 version 1/21/92):.

> "There has to date been no analysis of the effects of the uncertainties in the various parameters in the method upon the final predicted mineral endowment. We show in the section below on analysis of errors that the uncertainties in the statistical techniques alone are of the same order or larger than the estimated values, and that even conservative estimates of the errors inherent in the subjective estimate of the number of undiscovered deposits is at least as large as the statistical uncertainties. These two error sources multiply, yielding an endowment estimate which is in no sense robust. In most cases tested, endowment estimates were not accurate to an order of magnitude, although they may be presented as precise to one or two significant digits. The publication of estimates with no consideration of their reliability renders those estimates as mere guesses."

REVIEWS OF THE BULTMAN ET AL., DOCUMENT AND REPLIES

INTRODUCTION

The Bultman et al. document (Version 1) was submitted for comments to Steve Ludington (BORA), Charles Thorman (Branch of Mineral Resources), and an independent review by DeVerle Harris (The University of Arizona). The review process became lengthy with Bultman et al. re-submitting two revised editions of Version 1. During the Arizona Conference, Force and Menzie discussed an initial version of the document (Version 0) but did not comment on who, if anyone, performed a formal review. The following historical outline is meant to summarize the evolution of the document through critical reviews. The comments provided by the reviewers reflect a great effort to make the document more scientifically valid in its criticisms of the three-step method. Charles Thorman writes " This has been the most time consuming review I have undertaken in my 21 years with the USGS. To put it mildly, such a challenge should come along only once in a career." The review process greatly modified the original document's challenges to the methodology and the content of the argument. Thus, in the review of Bultman et al. above it is intentional that, wherever possible, quotations are taken from the original document (Version 1). This ensures that quotations are attributable to the authors prior to revision and are not inclusions of reviewer's comments and criticisms.

STEVE LUDINGTON'S REVIEW OF BULTMAN ET AL. VERSION 1

Ludington's comments begin with a discussion of the intent of the paper. He notes that the BORA policy of performing mineral resource assessments is quite different than the methodology employed in the process. Ludington faults Bultman et al. for "intermixing" policy and methodology throughout the document. Ludington states:

> "If we are to do quantitative assessments, deposits must have a quantitative definition. The method makes no assumptions about what the grade and tonnage characteristics of actual undiscovered deposits (whatever that may mean -- I mean those physical deposits that will be found in the future) are."

Interestingly, it is during the first review of the document that Bultman et al. are challenged on the statement that pertinent information on the three-step methodology is published in Spanish and Japanese. Ludington states:

> " There are absolutely no documents that are published in only Spanish, or Japanese. The Columbian and Costa Rican assessments have been translated into Spanish, bulletin 1693 has been translated into Spanish, and Singer's 1984 paper for the U.S.-Japan joint seminar has been translated into Japanese. Your sentence implies an effort to conceal technology in non-English publications, an effort that simply does not exist. For an exposition that is really clear, I refer you to chapter 8, **Methods of Resource Assessment**, in bulletin 1975 (Bolivia)."

Ludington included eight pages of annotated summaries of mineral resource assessment methodology and controversial points within the Bultman et al. text. Much of this memo reflects Ludington's efforts to draw from the published literature and cite sections and passages to dispute statements he believes to be erroneous. The most significant of these challenges is the notion that the estimates are invalid as they are adjusted to fit the given tonnage and grade model. Ludington quotes text from Singer and Ovenshine, 1980:"...estimates referred only to deposits with tonnages and grades comparable to those used in the grade-tonnage models", along with passages from Cox and Singer (1986), the Costa Rica assessment (I-1865, 1987), and Menzie and Singer (1990, SAME short course abstract). That estimates of the number of undiscovered deposits must consistent with the grade/tonnage models constitutes a large part of the critique.

Ludington's review concludes with the following statement:

> "There is some good work reflected in this paper, but I cannot recommend that it be published in it's present form, for two reasons. First, there is an underlying misunderstanding of the basic premise of the method you are criticizing, and second, you bring up numerous issues which have to do with policy, and not with science. Publication of these matters, should at least be separated; our open-file report system is no place for dissent from policy directions."

REPLY TO LUDINGTON'S REVIEW (VERSION 1) BY BULTMAN ET AL.

In reply to Ludington's comments, Bultman et al. reply to the above quotation:

"...the authors would like to point out that the reviewer has erroneously reached the wrong conclusion that the authors misunderstand the basic premise of the three-step method of mineral resource assessment (henceforth "the OMR method"). The authors believe that the reviewer's conclusion is based on the reviewer's own misconceptions about the OMR method."

They contend that:

- "... grade and tonnage models used by the OMR method must be assumed to represent the characteristics of the undiscovered deposits in a region or the results generated by the OMR method will be trivial." This premise is supported with a quote from Menzie and Singer (1990): ...they (*grade and tonnage models*) serve as models of the tonnages and average grades of undiscovered deposits in the area being assessed (italics added)."

- "... grade and tonnage estimates are not used to guide and constrain the OMR method but are used to make the quantitative estimates of contained metal." This is in comparison to a comment by Ludington that the OMR method "uses the existing grade and tonnage models, worldwide or regional, to define the sorts of deposits that are to be estimated, to define their size characteristics in order to guide and constrain the estimate."

- Ludington's conclusions that Bultman et al. misunderstand the basic premise of the OMR method because of the large portion of the manuscript dedicated to selection of local deposit models. They state "..the linkage of the actual grades and tonnages to the grades and tonnage models used as a basis for estimation is a paramount issue here."

- that the OMR method presents no analysis of error for any of the assumptions or procedures. Furthermore, unlike geological mapping which can be subjected to verification, mineral resource assessment is not verifiable, or repeatable. Thus it is impossible to establish the accuracy of the results of the OMR method.

- the purpose of the document is to address: 1) lack of a published document on the methodology; 2) known problems on the OMR methodology; 3) inflated GIPV estimates from the current methodology; 4) a lack of inputs from most OMR geoscientists into the method; and 5) a lack of discussion on the method in general.

DEVERLE HARRIS' REVIEW OF BULTMAN ET AL., VERSION 1[**1]

Harris, like Thorman, begins his critique of the document with the following statement as to the magnitude of the task:

> "First of all, I do not present this memo as a thorough review of the subject manuscript. Because of the wide range of criticisms and claims made in the manuscript, an in-depth review would itself be a research project, a project that the survey should give some consideration to sponsoring. Due to prior commitments and the short time allowed for the review (approximately one week), I have had to limit my critique to the major issues."

Harris notes that with time any methodology will be subject to review, and improvements. "Certainly, improvements of deposit models, tonnage-grade models, and methodology should constitute on-going research by the U.S. Geological Survey". But the Bultman et al. document does not solely address methodological review:

> "...besides useful criticisms, it contains some major problems: 1) errors in terminology and concepts, 2) exaggerated or substantiated claims, 3) impossible, unrealistic, or useless standards, 4) obvious bias. Consequently, while the document makes some useful criticisms and would be useful as an internal Survey document to stimulate discussion and research on resource assessment, I am surprised that it is being considered as an open file document."

Harris agreed with the document that it would be better to elicit probabilities for specified numbers of deposits then to elicit quantiles for cumulative probability. As many of the inaccurate, misleading or incorrect statements originate in what Harris calls an "intent to

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[1**] Note: The reader is cautioned that this section may contain personal bias, because it is an editorializing by Harris of documents previously written by Harris and by Bultman et al. and about their criticisms. Accordingly, this section does not necessarily represent the views of the panel. The purpose of this section is primarily to pull together for the reader's convenience those statements that highlight controversies so that the reader does not have to read the complete documents.

discredit the three-step method", rather than to attempt to correct specific passages he begins the critique with a review of literature that should be cited. First, to cite the New Mexico uranium study as "an assessment technique similar to the method [three-step]" is, in his opinion, "a serious misrepresentation, for the only similarities of that study with the three-step methods is that estimates were made by geologists as subjective probabilities" (p. 2). In the uranium study: 1) most geologists had never made a resource assessment; 2) there was no training; 3) forms for probabilities were sent to each geologist with no supervision; and 4) the geologists were asked to give probabilities for deposit tonnage and grade, a task for which they were not prepared by experience. It was misleading and careless not to also cite the mineral resource assessment of British Columbia and Yukon as reported in the same text from which Bultman et al. selected the uranium study. In this latter study cells were also employed but: 1) the Canadian study was for several mineral commodities; 2) the geologists were carefully selected; and 3) geologists were provided with training and support in the completion of the assessment. That study is noteworthy because it has withstood a partial test by time as indicated by the remarks of R.J.Cathro (July, 1983):

> "The results were synthesized and appear to have been remarkably perceptive. I am sure none of us who took part in that project 15 years ago would have guessed that it would turn out so well."

Furthermore, Harris faults Bultman et al. for failing to cite significant discoveries in areas delineated by previous resource assessments as having high mineral potential. This failure on the part of the authors suggests to Harris a "bias" inherent in the document. As Harris reports:

> "The over thrust of this manuscript seems to be to either get the U.S. Geol. Survey out of the assessment activity or retrogress to practice and philosophy of two decades ago, namely that the area is favorable or unfavorable for mineralization, whatever that means."

With respect to the call by the authors for the accurate prediction of undiscovered and unseen deposits, Harris dismisses this request as "useless". He notes:

> "...there is for every use of resource information, an optimum level of information, one for which the marginal cost of information equals its marginal benefits. For any use of resource information that I know of, e.g. support of policy analysis and land management decisions, that optimum level of information is far less than that required for accurate predictions."

Bultman et al. charge that there is "... confusion over what is being estimated" and that it "has a large effect on the contained metal quantities that are derived from a simulation procedure based on the estimate of number of undiscovered deposits". They note that the sum of probabilities for the 90, 50, and 10th percentiles is 150, a violation of the probability space for specific numbers. Harris replies ""Even the most rudimentary understanding of probability would appreciate that the three probabilities are for the at least case, not for specific numbers". Furthermore, the characterization by Bultman et al. that the 1 and 5 percentile estimates imply that the number of deposits can be estimated to the 1 and 5 percent accuracy is, in Harris' words "blatantly wrong". Harris notes "these probabilities imply just the opposite, namely that there is 1 and 5 percent probability that the numbers of deposits are as great as the numbers specified for these percentiles."

Controversy over probability theory in the interpretation of MARK3 persists. Bultman et al. suggest that the "at least" mode of elicitation produces a distribution that is skewed to large numbers, creating a distribution for which the highest probability is for the highest number. Harris suggests:

> "this strange shape results from the truncation of the PDF at the 10% number and the ascribing of all events larger than the 10% number to that number. Probably, the OMR team chose to be conservative and not to risk bizarre outcomes (very large numbers) by simulating numbers larger than 10% value, choosing instead to represent larger values by the 10% value."

Furthermore, the use of the term continuous PDF by the authors is, in Harris' words "incorrect and a violation of accepted usage." He notes that a continuous random variable refers to one that has no physical bounds, as in the boundaries of a mining district and suggests that the authors are referring to a random spatial distribution which, when applied here, is still incorrect.

Lastly, Bultman et al. argue strongly for local grade/tonnage models that have the upper tails truncated to account for size-biased sampling through exploration discoveries. Since size-biased sampling is in the section on Grade and Tonnage Models, only the following quote from Harris' critique is presented here:

> "Just how serious these features are depends greatly upon their use; moreover, these effects differ with deposit types."

REPLY TO HARRIS' REVIEW BY BULTMAN ET AL. (VERSION 1)

Bultman et al. begin their reply to the Harris critique:

> "The reviewer does seem to agree with about one-third of the points brought forward in the manuscript. The reviewer also seems to disagree with about one third of the points in the manuscript, but little is offered in the way of scientific proof supporting criticisms of the manuscript." They go on to clarify this statement with: "This part of the review seemed to focus on the use of probabilistic estimates of number of deposits and on the generation of probability mass functions (PMFs) in the three-step method..."

The authors state that the review did not comment on the one-third of manuscript containing the "most important points". They thus assume that "the reviewer does not object to these points since he did not address them". These comments were self serving since Harris stated that this review was not complete. These points listed by the authors are:

1) Problems in the OMR method due to the lack of statistical stationarity of grade and tonnage models.

2) Problems in the OMR method due to grade and tonnage model mis-specification (although the reviewer did address grade and tonnage models in a general sense, this problem was not addressed specifically).

3) Problems in the OMR method due to the inability of a geologist to accurately determine the number of undiscovered deposits in a region (although the reviewer did say accuracy is an unattainable objective).

4) Problems in the OMR method due to its use in small areas, areas that can not contain the diversity of deposits that are contained in grade and tonnage models.

5) Problems in the OMR method due to the propagation of errors through the assumptions and procedures in the OMR method.

This is followed by the authors' interpretation of the critique overall:

> "The basic conclusion of the review seems to be that the OMR method has some problems but that we need to continue using it in order to include quantitative mineral resource information in land-use decision making and to bring money into the Office of Mineral Resources. In other words, the OMR method seems good enough for government work. While expressing concern about the need for mineral resource information in land-use decision making, the reviewer has not discussed the need for demonstrating the quality of that information."
>
> Interestingly, the following paragraph was removed from the document sent to Harris:
>
> "The authors must point out that the reviewer has received research monies, in the form of U.S. Geological Survey Grants, from the Branch of Resource Assessment. The reviewer is also hoping for future financial support from the U.S. Geological Survey. The reviewer, therefore, is not impartial and presents an opinion biased towards the continuation of use of the three-step method. This bias is driven by the fact that the same individuals who supported him are the individuals supporting the OMR method. The authors will attempt to separate opinions expressed by the reviewer from his points of scientific concern."

As discussed, in a memo submitted to Dallas Peck and Benjamin Morgan is on October 5, 1992, the research referred to on the Intrinsic Sample Methodology, which is an objective alternative to delineation of favorable tract delineation. If anything, the Intrinsic Sample Methodology addresses what Bultman et al. have been requesting, an objective methodology to replace a portion of the current process.

HARRIS REVIEW OF BULTMAN ET AL. (VERSION 2)

The second review, that of Version 2, begins with the following:

> "..the manuscript contains too many erroneous statements or inferences to be released in its current form. Moreover, as I have stated in my review, I believe the authors could serve themselves as well as the U.S. Geological Survey by rewriting at least parts of the manuscript in a more objective and less opinionated style."

Specifically, that the probabilities for the number of deposits must decline monotonically with increasing number of deposits defies logic. Harris states that the probability for zero deposits for large areas or for small but rich areas will be zero or some small value. This probability will increase to a maximum for the most likely number and thereafter will decline monotonically. This decrease can of course be interrupted should the deposits exhibit clustering. Depending on the size of the area and the favorability of its geology, the hypothetical population to which the area belongs may, or may not, have a large relative frequency for zero deposits.

Harris identifies in the review what he believes to be excessive comment on MARK3 predicated on the assumption that the geologists misunderstand the elicitation and actually give the number of deposits for specific probabilities. Harris states: "..even if the authors' personal experience has been confusion, that is not proof that geologists in general have been confused. Unless that can be demonstrated, there is simply too much of the manuscript devoted to anomalies from MARK3 based upon <u>presumed</u> confusion".

The charge that MARK3 is insensitive to clustering of deposits is discounted:

> "As the distribution applies to the entire favorable area as a member of an implied population of geologically and spatially similar favorable areas, nothing is implied about clustering, neither to its presence or absence."

The claim by the authors that some of the confusion results from a lack of published information on MARK3 is addressed with a reference to Root et al. (1992) in which the procedure is described in a journal article.

The use of process analysis in a deterministic assessment methodology has been proposed by the authors as a viable alternative to the three-step methodology. Furthermore they are critical of the deposit models and associated grade and tonnage distributions as being inadequate for assessment methodology. These controversies received more consideration in the section on controversies below, and a comprehensive analysis in the Chapters on Deposit Models and Tonnage and Grade Distributions.

REPLY TO HARRIS REVIEW BY BULTMAN ET AL. (VERSION 2)

The authors state that although the methodology is transparent to the end-user, there is no accompanying estimate of error to suggest the subjective nature of the process and the "huge uncertainties that are associated with the OMR method". Many of these errors are reported to result from a lack of consideration of the size of the assessment area and the level of exploration in the region.

The authors suggest that an assessor needs to be able to control the location of the mode of the PMF but generally geologists using the methodology lack the knowledge to do so.

Bultman et al. persist with the notion that a monotonically decreasing function for increasing number of deposits is appropriate and should be dealt with quantitatively in the OMR method.

The reply continues the discussion of process and analysis and materials balance. The authors state that a shift away from geologic analogy is necessary, as many assessors have problems with its use. They contend that if analogues are to be used then the quantification of errors is necessary and should be combined with the other errors in the OMR method.

The authors contend that the use of deposit models is not simply to constrain what a deposit is, as suggested by Harris. They argue instead, that in many cases the information supplied by a model is wrong for a given terrane. The authors state:

> "The result of the use of given grade and tonnage models is that assessors must now change their estimates of numbers of deposits in order to force the final results to fit a region."

They question why geologists, who were found to be poor at estimating grades and tonnages in the NURE assessment, should be any better at estimating the number of undiscovered deposits.

The authors continue to make confused statements about probability and its use in assessment:

> "In the authors opinion the 5- and 1-percent probabilities were added for the purpose of assessing small, well explored tracts. The 5- and 1-percent estimates allow assessors

to estimate at least zero deposits at the 90-, 50-, and 10-percent estimates and still have a non-zero contained metal estimate. The effect of making estimates of zero deposits at the 90-, 50-, and 10-percent levels is to allocate the sum of, respectively, 10-, 40-, and approximately 40-percent [authors' error] of the total probability on zero deposits in the PMF. The remaining approximately 10-percent of the probability (approximate because MARK3 allocates part of one interval to the adjacent interval) is allocated in accordance with the 5- and 1-percent estimates. Thus, the addition of the 5- and 1-percent estimates aid in building a PMF that can be described as monotonically decreasing probability for increasing deposit number by "stacking" or allocating a great deal of probability on the zero deposits estimate of the PMF."

UNRESOLVED QUESTIONS OR ISSUES

PERSPECTIVE

Methodology is only one of the topics at issue in presentations at the conference and in pre- and- post conference events and memoranda. Foremost among these is conspiracy by BORA scientists to inflate resource values to "keep the words mining is prohibited" from legislation. Others may include 1) professional ambition and internal politics, and 2) "geology as usual" meaning return to qualitative assessment. To some degree, methodology may have been used as the proverbial "smoke screen" for promoting these other issues. If that is so, those so involved have rendered a disservice to their profession and to society. The relevant question is, of course, to what extent is that the case?

QUESTIONS

Specifically, is Hamilton's conviction of a conspiracy based upon professional objectivity, or is he motivated by other personal matters? Is the statement attributed to Glen Allcott merely an unfortunate, off-the-cuff quip, possibly representing only personal views? Or does it represent, as Hamilton implies, a desire to use his position to influence land-use decisions? What responsibility do the geologists working under Allcott have for this statement? Is it proper for Hamilton to attempt to impugn their characters and scientific credibility solely by the statement attributed to Allcott?

Are the broadly-based, strongly stated criticisms by Bultman et al. a courageous crusade to expose bad science and social injustice, and to improve quantitative assessment? Or, are they a veiled attempt to return to "geology as usual" and qualitative assessment? And, what about the claims that 1) they were unable to obtain the documentation that they required to clarify the three-step methodology and 2) their document was simply to invite scientific discussion about assessment methodology? Are these totally forthright? Is one to really believe that over the span of year that scientists within the USGS could not get documentation of a USGS methodology ? Does one invite scientific discussion with a document that is highly accusatory, promotes unrealistic and scientifically naive standards, and is replete with elementary errors?

RELEVANT INFORMATION

As indicated by the title of this section, many of these questions remain unanswered. In part, that is because answering them is beyond the scope of this investigation. Clearly, some of these involve motives, professional ethics, and personnel and management issues that are internal to the USGS; consequently, they require a different forum and research agenda than that of this conference. Nevertheless, some information that bears on these unanswered questions or issues was acquired during the conference or while investigating methodology. The following sections present some of this information, with no attempt at resolution of the unresolved question or issue.

THE ALLEGED CONSPIRACY

On Thursday, August 6, 1992 Warren Hamilton presented his views on the BORA three-step methodology to the review panel. His talk began at 1:10 pm, concluded at 2:25 pm, and entertained questions from the panel and gallery until 3:15 that afternoon. This talk was followed by a rebuttal lead by Chief of Branch of Mineral Resource Assessment Dave Menzie and a short presentation by Richard Sanford, a geologist on the controversial Redcloud Handies Peak WSA. Hamilton suggested to the panel that they were players in what he termed a "BORA show". That the time allotted to challengers of the methodology, the materials distributed, and materials kept from distribution were controlled by BORA. Hamilton stated that his charge of conspiracy by BORA mineral resource assessors to inflate dollar value estimates of undiscovered resources on public lands stems from a June, 1991 meeting of NAMRAP Projects Coordinators in which Chief of OMR Glenn Allcott is paraphrased as saying "Keep the words 'mining is prohibited' out of all legislation". This is reported by Hamilton using a set of meeting notes (edited version of notes taken by David John), from a NAMRAP Projects Coordinators meeting of June 4-5, 1991. The relevant section reads:

> "(6) Glenn Allcott's goal is to "Keep the words 'mining is prohibited' out of all legislation". The office objective is, therefore, to develop mineral-resource information and technology in order to keep a long term non-fuel mineral supply available for the US."

Hamilton contends that Allcott has given maximized data to anti-environmentalists as seen in studies such as EMNSA which was a simulation of objectivity, chain multiplication of errors, and misleading presentation of results. Hamilton's technical presentation of the three-step methodology has been covered in the introduction to controversies at the start of this chapter and will not be repeated here. His greatest criticisms were the assumption of lognormality for the deposit tonnage and grade and the resulting over estimation of discoverable metal quantities by sampling off these distributions using the MARK3 monte carlo program. Hamilton used results from the East Mojave National Scenic Area, California and the Redcloud/Handies Peak WSA, Colorado to support his claims. This material can be found in his manuscripts.

From examination of these mineral assessments Hamilton concluded that:

- BORA has stonewalled challenges to the methodology;

- the programs are flawed, and that the panel disregards the rules so that the guesses (estimate of the number of undiscovered deposits) is related to Allcott's objective;

- the reporting of Gross In Place Value is of no value as cost models for these areas are not estimated and the presentation of these values is visually misleading, GIPV is a scam;

- panelists are selected by BORA to avoid public dissent. He notes that there has never been a minority report challenging the results of an assessment;

- this entire process is compounded by BORA personnel characterized as being one of: 1)idealogues - who don't belong in science; 2) go-along-to-get-along - implying that they produce results to appease management; and 3) enthusiasts - who think any methodology is better than nothing, thus exhibiting no scientific judgement. In his opinion these groups do not belong in mineral resource assessment;

- the result is a methodology that is hopelessly and fatally flawed with no way to be salvaged in its present form;

Hamilton then drew the following conclusions:

- that the method starts with untestable guesses;

- it is virtually unconstrained;

- the database is not used and all that has been presented is 'window dressing'. This is with the exception of the Coronado assessment which is not a part of this and is a 'geological assessment', science, as opposed to the guessing panel;

- the guesses are extremely optimistic and deliberate in many cases, although he admits that he has never participated in one of these assessments and has no 'moles' in BORA or central OMR;

- MARK3 plugs in its own biases, particularly the 'more-than scam' so that it will automatically enlarge the guesses, then applies a lognormal bias;

- the presenters than take contained metal, as calculated by MARK3, translate it into dollars, and misleadingly present it to influence the land-use decisions the way they want;

- the method is bad science, if not fraud in its guessing stage;

- the method is bad science in the calculation stage;

- it is fraud in the presentation stage;

- BORA have stonewalled all requests, all demands from the outside for testing, documenting and reforming;

- there has been no improvement of the methodology.

Hamilton thus recommends:

- That the program should be dumped and [OMR] should start over.

PANEL QUESTIONS TO HAMILTON

To Hamilton's knowledge has one of these assessments ever received a survey review? Hamilton replied if so it was in house and not by regional experts. In the EMNSA, some geologists in Menlo said the results were fraud and that the magnetic survey indicated that there was no more iron and the tonnage model was irrelevant. This was a view confirmed by some panel members but there maybe other low iron deposits around. It was also suggested by some that Hamilton was using an incorrect assumption requiring that the iron skarn deposit model have carbonate.

With respect to conspiracy Hamilton told the gallery that the numbers are being used to unidirectionally influence public policy and, so far as he knows, no one in the BORA core has ever protested this use. Of course Hamilton acknowledged that he is not privy to what goes on in BORA. Hamilton acknowledges that he is not quoting Allcott but paraphrasing what he said.

SOME PANEL COMMENTS ON HAMILTON

Some panel members have identified points made by Hamilton that warrant investigation: First, that estimates and calculated values should not be presented with excess significant figures. That reporting of the mean, and not the median, value of metal produces an overly large estimate of metal endowment and gross in place dollar value. That the panel should have been provided with copies from USGS personnel critical of the current resource assessment methodology. And that the panel could have been better balanced in terms of representing diverse viewpoints and expertise.

HAMILTON'S CONFERENCE DOCUMENT

During the Arizona Conference Warren Hamilton provided to the panel a document entitled - An Evaluation of the Quantitative Resource Assessment Program of the U.S. Geological Survey, *A personal statement for presentation to the Panel for Evaluation of the USGS Assessment Methodology, Tucson, Arizona, 6 August 1992.*

This document states that the current BORA method of quantitative assessment contains chain-multiplying positive biases that overstate resources by a factor of 2000. Hamilton claims that: 1) estimations are biased by BORA panel members where the group consensus does not reflect individual estimations, 2) the MARK3 program contains systematic positive biases, 3) MARK3 is constructed on a data set that over represents large deposits, 4) the use of lognormal functions to represent the data leads to high estimates of grade and tonnage, 5) that presentation of the assessment results to five significant figures is misleading to non-scientists, and 6) that the current methodology contains less information than its predecessor methodology of qualitatively rating areas as low, moderate and high mineral potential.

DOCUMENTATION OF THE METHODOLOGY AND ITS AVAILABILITY

Bultman et al., repeatedly state that they were unable to obtain the documentation that they required to clarify the three-step methodology. Furthermore, during the Arizona Conference Robert Kamilli (Tucson Field Office) stated to the panel that he would like to back-up a request for a published methodology. He stated that during his participation in the mineral resource assessment he would liked to have reviewed documents to see how others had delineated tracts in the past. Without these documents a number of mistakes were made and in his own mind he was forced to "re-invent the wheel" in his own mind.

Bultman et al., claim that pertinent information on the three-step methodology is published only in Spanish and Japanese. This claim was challenged by Ludington in his review of the manuscript (Version 1):

> " There are absolutely no documents that are published in only Spanish, or Japanese. The Columbian and Costa Rican assessments have been translated into Spanish, bulletin 1693 has been translated into Spanish, and Singer's 1984 paper for the U.S.-Japan joint seminar has been translated into Japanese. Your sentence implies an effort to conceal technology in non-english publications, an effort that simply does not exist. For an exposition that is really clear, I refer you to chapter 8, **Methods of Resource Assessment**, in bulletin 1975 (Bolivia)."

The statement by Bultman et al., in their reply to the Harris review is curious, given their claims of lack of documentation:

> "In fact, the sum of all manuscripts that describe the OMR method neglect to detail many of the important parts of the OMR method."

This statement implies that the authors had in their possession several documents that "describe the OMR method". Furthermore, "neglect to detail" implies that many of these documents fail to provide the authors with the level of information they seek.

Is it that documentation was unavailable, or that documentation was available but not in the detail desired by Bultman et al.? These are different issues.

Bultman et al., continue in Versions 2 and 3 that little, if any, documentation on the methodology is published.

In Version 2, p. 33:

> "To prepare for the desired debate on the OMR method, we present the following list of independent points we have questioned. A valid method must be valid for each of the following issues.
> 1. Public presentation of the OMR method."

And again in Version 3, p. 32

> "1. Public presentation of the OMR method."

Is it really the intent to state that documentation on the methodology does not exist, or was not available to them? In light of the fact that they acknowledged that they had such documents and that on February 7, 1992 Ludington wrote to them "For an exposition that is really clear, I refer you to Chapter 8, **Methods of Resource Assessment**, in Bulletin 1975 (Bolivia)".

It is instructive to consider this question with regard to the mineral resource assessment of the Coronado National Forest. During the Arizona Conference, the panel commented that the Coronado assessment was strengthened by a high level of field examination and advanced types of data processing (image analysis). Bultman responded that the assessment on Coronado was successful partly because they had a year to prepare. Does this mean that after one year the team was unable to obtain the documentation requisite to the assessment? Is it really possible that the authors were unable to attain the necessary documents and, where confusion existed or documentation is inadequate, to discuss issues with the principal authors of the respective papers and other survey personnel?

A statement is provided by Bultman et al. in response to the Harris critique of Version 1 as follows may be enlightening:

> "There is no published manuscript that examines strengths, weaknesses, and the assumptions and errors in the OMR method. If the manuscript [their document] has a negative tone, it is because the OMR method is being used without ever being scrutinized."

The meaning here is very different from claims that the "public presentation of the OMR method" is not available and that the public has not been presented with the OMR method. Is it appropriate to make the charge of no documentation when documentation exists but does not describe weaknesses, strengths, and errors? Why, if that is the issue were so many inflammatory statements about documentation made?

CHARGES OF COVER-UP

Warren Hamilton alleges that challenges to the three-step methodology have been suppressed by BORA. Likewise, Bultman and Force have expressed frustration at what they termed inaction on the part of BORA to release the manuscript as an open file.

As much of the alleged cover-up is centered on the Bultman et al. document it is fitting to begin with the intent of that manuscript. In the accompanying memo to Allcott and Bagby the authors state the purpose of the document:

> "The purpose of our manuscript is to elicit lively scientific debate of the topic."

And,

> "It is our opinion that before any methodology for quantification of resource estimates is adopted it must have undergone rigorous peer review and have been clearly elucidated in the public scientific press. We have, therefore, in the manuscript, discussed our concerns and have made suggestions as to what research and policy directions might be fruitful to pursue."

The authors do not state in this memo that their intent is to publish this manuscript as an open file report. This is provided to the reader on the title page of the document where the report is referred to as: Open-file Report 92-xxx. The following is stated to Allcott and Bagby:

> "We want scientific criticism of the manuscript and we believe this is best done by our peers both within and outside of the USGS. But we do not want to give the public impression that because there may be scientific debate between Survey scientists that this indicates some sort of rift within the Survey. Therefore with your approval we hereby request that the manuscript, for the time being, remain with the USGS and be given to three individuals from a group of proponents and developers of the existing "3-step" method such as Paul Barton, Dennis Cox, Larry Drew, Steve Ludington, Dave

> Menzie, or Don Singer for their review. We also request that three other reviewers be chosen from individuals in OMR familiar with ore-deposit geology, such as; Roger Ashley, Warren Day, Bruce Lipin, Tom Nash, Dan Shawe, Holly Stein, John Slack, Doug Stoeser, Ted Theodore, Allen Wallace, or Ron Worl. AS you know, six reviewers is unusual for the manuscript, however we believe because of the importance of the subject matter, six reviewers are justified."

It is important that the authors requested that the manuscript be reviewed by six individuals. This suggests two issues: 1) that a review of this magnitude will indeed elicit lively scientific debate as desired by the authors; and 2) that the time requirement for six independent reviews has to be expected to be long. It seems natural at this point to conclude that with just three reviewers, lively scientific debate has certainly occurred and that the review process, was if anything, shortened from that requested.

But, during the Arizona Conference it was revealed that this review process has been more complex. Eric Force began his discussion with a summary of the events that lead to the writing of the Bultman et al., manuscript. He confirmed that the intent of the manuscript was to initiate debate within OMR in hopes of speeding improvement of the method. They decided to write up their thoughts as a position paper. The manuscript for an Open-file was intended as a position paper for an internal debate and that "open-filing it was not their first choice". Force stated that their effort began well before the circulation of Hamilton's memo and has continued entirely independent of it. The intent was to make the USGS self regulating.

Bultman, in response to panel questioning, agreed that this was submitted as a position paper. After submitting this to Glenn Allcott it was delayed for two months on the advice of Fred Fisher, the Supervisor and Assistant Branch Chief as it was a sensitive issue. It was later submitted as a manuscript and Fisher received a call saying not to distribute the manuscript to anyone. Nothing happened for quite some time so it was decided to submit the paper as a formal manuscript for formal publication because they felt trying to get internally for discussion wasn't working. The panel asked if they ever got a response to which Bultman replied no. As an open-file report it has received a much greater response.

On the day following the Force and Bultman presentation the panel began enquiry of allegations that had been made. They asked Bultman how he could get involved in research in assessment methodology. Furthermore, they questioned as to how he could get to the conference and not know this. This is part of the larger question of communication within the Survey. Is it that he didn't follow the proper lines of communication within the Survey or are there problems with respect to geologists getting involved? More specifically: 1) did Bultman contact the respective BORA people present to discuss conceptual problems with the methodology? 2) Was there close communication in preparing this manuscript? and 3) Did Force communicate with these BORA people? The short reply came that Force did and Bultman did not communicate with the respective BORA people. The panel enquired as to whether there were barriers to lines of communication? Force suggested that the Office Chief was so partisan to the method that he protected the method from criticism and therefore made it a closed system. Briskey disagreed, suggesting that it was originally encouraged that the paper be undertaken as an internal document to generate discussion. The principal piece of guidance was that the authors stay in close touch with the people in resource analysis in developing the document so that major misunderstandings wouldn't occur. This did not always happen, and the document had some inflammatory statements and ideas. Had they worked more closely with BORA people this would not have happened. The result was an emotional reaction to the point that the paper, for some period of time, could not be used as an internal document to improve the system and so "it sat for a while". When the final version arrived [it is not clear which one of the versions] it was virtually impossible to find internal people to review it because of the emotion generated by the earlier version. This is one of the reasons that the Survey asked for an external review.

The panel queried Force whether some of the separation and difficulty in communication arose from being affiliated with the Tucson Field Office? He responded that some of it arose from being in Tucson in combination with unfavorable factors of 1) the method became mandatory for USGS mineral resource assessment and 2) the use of the method was rapidly growing and being pushed into public policy issues. It seemed logical to them to write down their grievances and to use them in dialog.

The panel then queried Dave Menzie as to how a document that was so inflammatory could not be responded to by BORA. The following reply is critical to the cover-up allegation. Menzie stated that the Bultman et al. manuscript arrived at a very bad time, to which Force agreed. Menzie did not read the manuscript right away as this was immediately after the Hamilton document had circulated through the Survey. Charges of fraud had begun as a result of the Hamilton document. With a law suit pending on procedural issues, it was an extremely volatile environment, and as Branch Chief he "would not touch the manuscript". In that environment he would not assign a review because 'nothing he could do would improve things' and the atmosphere of criticism would overwhelm the objectivity of a critique. This was a conscious decision.

Drew stated that at this time he contacted Bultman to say that inflammatory statements had to be removed. The original document [Version 0] is alleged to have contained a claim that Glenn Allcott willfully started a conspiracy. Drew stated that he would only review it if it was a scientific document. The document was re-submitted but was largely the same in content. Drew then determined that head of the Coronado Forest, Branch Chief in Menlo Park, and Branch Chief in Central Mineral Resources had not read it. Drew felt that they stonewalled his request for them to read this early version.

It was made clear to the panel that the document had a longer history than the three versions that were provided to the panel. Menzie then explained the sequence of events:

- Bultman was originally in the BORA group, was sent to Tucson,
changed to Branch of Western Mineral Resources.

Coronado Forest Chapter J, August 1991 - Menzie, as Branch Chief arranged for the Chapter J to be reviewed May or June 1992. Drew reviewed Chapter J and the initial internal manuscript [Version 0].

- The initial manuscript [Version 0, the internal manuscript] - was different in content from Version 1 [1/21/92] and was more similar to Chapter J. Force suggests that 70% of the original document is still there, but the earlier versions had statements that seemed more personal.

The first manuscript went directly to Glenn Allcott - they were requesting an informal review before it even went out for discussion.

- Versions 1 and 2 were reviewed by Harris and Ludington.

QUALITATIVE VERSUS QUANTITATIVE ASSESSMENTS

There is confusion with regard to the stated objective of the document by Bultman et al. The authors state that the three main subjects of the paper are (Version 1, p.1): 1) the need and motive for quantitative estimates of undiscovered mineral resources; 2) the status of the method as a scientific hypothesis; and 3) an evaluation of the geologic and mathematical assumptions and statistical procedures used in the method. The first of these, the need for quantitative assessments is discussed under their title: **Why make quantitative estimates of undiscovered resources?** (Version 1, p. 2). The following quote begins in the second paragraph where the authors are discussing the USGS quantitative, mineral resource assessment based upon the Zapp hypothesis that a constant amount of petroleum is discovered for each foot of exploration well drilled.

> "These estimates were the source of much controversy and have since been shown to be incorrect. Thus, history shows us that the entire three-step method as it applies to the appraisal [assessment] of metallic mineral resources, deserves especially careful scrutiny. Here we would like to address the perceived need for such estimates.
>
> Two of us have been involved previously in mineral resource issues with elected officials and their staffs, economists, and the national security establishment. We find that the issues in such meetings are basically conceptual, as concluded also be Drew (1990, p.200), and that the understanding of basic relations is pivotal. We suspect that demands for quantification of undiscovered resources partly reflect a desire for understanding on the part of policy-makers."

This view persists on the third page of the Bultman et al. reply to Ludington's review of Version 1 where the authors state:

> "It is interesting that the reviewer noted the results of the GIPV of gold in the East Mojave Scenic Area (EMNSA). The .9 and .1 figures are 1.0e7 and 2.21e12 dollars respectively. Of what utility is an estimate that varies by five orders of magnitude? Does it really carry more information than high, medium, and low assessment values?"

And then the statement appears again in Version 3 (p.28):

> "Any mineral resource assessment based on the present OMR method actually contains less information than would be implied by the terms low, moderate, or high mineral resource potential, if these terms are properly defined, since these terms imply a measure of favorability for mineralization by geographic location, information which is lost by the use of only permissive terranes in the OMR method."

This assumes that one should infer from - Why Make Quantitative estimates of Undiscovered Deposits? that the authors take issue with this policy. Without this assumption the document's introduction misrepresents its intent. These quotations also suggest that the former methodology (favorability measures) remains a viable alternative to the current quantitative three-step method. Inclusion of such statements into the document and the choice of wording suggests that the authors entertain ideas of a return to favorability measures. But, this is in contradiction to the following statement by Bultman to Larry Drew (May 18, 1992):

> "First, I would like you to understand that I, nor others in Tucson, are anti-quantitative assessment. As you well know, I am a believer that quantitative assessments are important to economic, political and national security issues."

And their own stated purpose of the document in the memo to Allcott and Bagby (October 29, 1991):

> "We do not disagree with the concepts of quantification of resource estimates and ore deposit modelling. Nor do we question the sincerity, dedication, or expertise of the proponents to existing methods being used to quantify resource estimates. Also we are well aware of the need to supply to a diverse and demanding audience, data they can both understand and use to make intelligent land-use and other policy decisions."

The content of the manuscript suggests the consideration of favorability measures over the current OMR quantitative method, but the accompanying letter and other correspondence suggests otherwise. This leaves the reader confused and the authors indignant to criticism (memo to Bagby, March 17, 1992):

> "The authors believe that all reviewers of the manuscript should read the attached copy of a memorandum dated 10/29/91 from the authors to the Chief, OMR and the Chief, OMR (attached as an appendix). To reiterate the content of that memorandum, the author's objective in producing the manuscript was to simply put important issue on the table for discussion."

But the simple fact is that the content of this document suggests otherwise. If the intent is to discount the use of favorability measures then it should be clearly stated so or the authors will have misled the reader.

APPENDIX II -- PANEL REPORTS

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OUTLINE

REPORTS BY PANEL MEMBERS

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PERSPECTIVE

Members of the Panel to evaluate the USGS assessment program accepted responsibility for specific assignments as part of the Arizona Conference. These are identified in the agenda for the conference. In addition, various members volunteered to comment upon various topics that relate to some aspect of the assessment program or methodology. Although some of these comments have been integrated into other sections of the report, the individual reports are presented in this section. This strategy was adopted to provide each of these scientists the opportunity to express his individual opinion, which may differ with that of the principal investigator or other panel members. Moreover, this provides those who have interest in assessment the undiluted opinion of each of these highly regarded scientists. The expertise of each scientist is documented in his vita, which is included in the Appendix to the report.

The U.S. Geological Survey's
Mineral Resource Assessment Program

Draft BORA Report Contributions

Stuart E. Marsh
Office of Arid Lands Studies
and
Department of Geography
University of Arizona

1.0 Evaluation of Specific Mineral Resource Assessments

The Costa Rica, Spotted Owl, and Tongass Mineral Resource Assessments have been reviewed in regard to the acquisition and analysis of remote sensing data and the application of image processing and geographic information system (GIS) techniques.

1.1 Costa Rica

The Costa Rica mineral assessment publication is an extremely attractive and complete presentation of geoscience data. The study made use of a wide array of detailed geological, geophysical, and geochemical analyses. These were presented in a series of clear 1:500,000 scale maps and lengthy tables (#'s 5 and 11). The study made no use of photographic or spectral remote sensing data or computer-based integration and analysis techniques such as GIS. Given the range of information available and the objectives of the study, this is particularly disappointing.

1.1a Remote Sensing:

Spectral remote sensing data, such as that acquired by the Landsat Thematic Mapper (TM) may have been able to provide additional reconnaissance exploration information. The Landsat TM acquires 30 meter resolution data for an area 185 km on a side from six spectral bands in the visible to shortwave-infrared region of the electromagnetic spectrum. Obviously, the dense vegetation cover in this region of the world is a controlling factor in regard to what information remote sensing data might provide.

Biogeochemical anomalies resulting from elevated metals concentrations have previously been identified in a variety of remote sensing studies, (Birnie and Francica, 1981; Chang and Collins, 1983; Collins et al., 1983; Horler et al., 1980; Labovitz et al., 1985; Lyon, 1975; Milton et al., 1983; Yost

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and Wenderoth, 1971). Given the nature of many of the target deposits, particularly the epithermal gold, the use of spectral ratios or derived vegetation indices from the TM bands in the green (band 2), red (band 3), near- (band 4) and shortwave-infrared (band 5) could have been utilized to map vegetation reflectance characteristics. Anomalies could have been mapped, field checked, and integrated with other geoscience information.

The successful discrimination of both supergene and hypogene alteration using both coarse- and high- spectral resolution data has also been documented, (Abrams et al., 1983; Abrams et al., 1984; Goetz et al., 1983; Goetz et al., 1985; Hunt, 1979; Hunt and Ashley, 1979; Krohn, 1986; Kruse et al., 1990; Marsh and McKeon, 1983; Podwysocki et al., 1983). Though the extent of vegetation cover presents a significant problem in their recognition in a tropical region of the world. If there are areas where outcrop and soil are visible when viewed vertically, the delineation of hydrothermal alteration is possible using the Landsat TM bands in the blue-green (Band 1) and shortwave-infrared (Band 7) at 2.2 micrometers. Based upon information in the report, the use of remote sensing data to discriminate hypogene alteration (argillic & sericitic) associated with the epithermal gold deposits (or porphyry coppers) would be impossible as tropical weathering has obscured the characteristic mineralogical assemblages in almost all outcrops. Prophylitic alteration we are told is also widespread but not confined either spatially or genetically to the epithermal gold deposits. However, the report also states that all of the epithermal gold deposits have be weathered to some extent and a suite of alteration minerals characteristic of supergene alteration (limonite, goethite, jarosite, and bleached rocks containing kaolinite) should be easily discriminated using Landsat TM data.

A third potential exploration application of remote sensing in the Costa Rica study would involve structural mapping. The report states that "high-angle faults, particularly where they intersect, are the sites of highest grade ore in most Costa Rica precious-metal epithermal veins." A detailed structural analysis of satellite images, aerial photographs, or most appropriately radar images, could provide additional insights into the location of fracture zones. These synoptic data-sets, might also have provided additional insight into both small- and large-scale structural fabrics in the region.

1.1b Data Integration and Analysis:

The Costa Rica data-set is particularly well-suited to computer based integration techniques. The application of GIS technology would not only have greatly facilitated the production of maps and graphics, but would have provided the authors with analysis techniques that can be prohibitively time consuming when working with paper maps and tables.

The first stage in the application of a GIS would be to put all the <u>geographically</u> referenced data (i.e the 391 rock and soil samples with their rock type and alteration descriptions and elemental analyses) in a digital database. In addition, all the maps (locational, geological, geophysical) would be digitized and stored either as vector or raster data. In addition, each type of feature on the map (e.g.: formation type, faults, etc) would be stored as separate layers or elements. Though entering these data into a digital database would have been time-consuming, there are significant advantages once this front-end work is completed. Quick and efficient analysis of the cross-correlation between any of the map or tabular variables would be easily achieved and certainly a variety of insights may have been gained. In addition, point or contour maps could have been generated from the tabular data. As an example, the author's could have requested a map showing the location of all rock samples displaying argillic alteration or a contour map of the elemental values for any of the 31 elements analyzed. These information could then be displayed along with any other map information. Thus, providing the author's with the ability to integrate and overlay any of the variables in their data-set. Given the detail of this data-set, creating a digital GIS database from this information would be of significant value to any future studies.

1.2 Spotted Owl

1.2a Remote Sensing:

Spectral remote sensing was not utilized in the Spotted Owl study and its application could have provided additional insight into this porphyry copper assessment. As in Costa Rica, a dense vegetation cover limits our ability to discriminate characteristic mineral assemblages associated with either supergene or hypogene alteration. However, in areas above tree-line or with limited cover, the Landsat TM sensor could be used to discriminate alteration zones on a reconnaissance basis. More detailed information could be acquired with high spectral-resolution airborne systems which permit the identification of specific alteration minerals (Kruse et al., 1990). In addition to the identification of

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hydrothermal alteration zones, the relatively dense vegetation cover in the Spotted Owl study areas, again provides the opportunity to search for biogeochemical anomalies. In fact, such an anomaly has previously been recognized in the Spirit Lake Quadrangle of Washington, (Collins et al., 1983). Finally, relatively large scale structures (plutons - lineaments) may be recognized from the small-scale perspective of a satellite image and thus, remote sensing data could have been used in concert with the geophysical anomaly maps.

1.2b Data Integration and Analysis:

The digital integration of the available geological, geophysical, and geochemical data could have greatly facilitated the Spotted Owl study. A study such as this truly demands the use of converging lines of evidence to arrive at a final set of anomalies. The creation of a digital database and the utilization of the analysis capabilities of a GIS would have facilitated the authors' task of identifying Tertiary intrusives.

1.3 Tongass National Forest

1.3a Remote Sensing:

Spectral remote sensing data were not used in the Tongass National Forest study. Again, available airborne and satellite systems could have utilized to delimit biogeochemical anomalies, hydrothermal alteration, or geologic structures pertinent to exploration in this large study area.

The large size of this and many other mineral assessment study areas coupled with the time involved in acquisition and digital processing of the Landsat TM satellite data forces a variety of logistical decisions if these type of data is to be successfully integrated into the assessment process. Though each Landsat TM scene covers an area of over 34,000 square kilometers, a large number of scenes would have to be acquired and processed to cover the entire study area. Thus, if time and costs are an administrative constraint, the researchers will have to chose whether to utilizes a sampling of digital scenes which would be processed and analyzed in detail, or to simply purchase photographic products for the entire study area which could then be manually interpreted. Obviously, the type of Landsat photographic product and the scale chosen would depend on the researcher's objectives for the data.

1.3b Data Integration and Analysis:

In addition to the advantages already described for creating geographically referenced digital databases and utilizing GIS technology, the Tongass study points to an additional reason to adopt these techniques. Ten variables were used by the authors' to delineate a series of favorable tracts. Because the entire study was done with paper maps, pens and pencils, it was impossible for the authors' to spend the time to do a detailed evaluation of the importance of each of the ten variables to the creation of a tract. Such an analysis would have been simple and quick with the creation of a digital set of map layers. The Tongass study also made use of the Mineral Resources Data System (MRDS). This U.S.G.S. database is in digital form and could have been simply integrated into the mapping and analysis procedures if a GIS approach had be utilized.

2.0 Recommended Extensions and Modifications to Existing Methodologies

Use of Other Geoscience Information

2.1 Remote Sensing:

During the past decade, applications research and operational programs using remote sensing data and processing techniques have demonstrated the utility of this information in reconnaissance mineral exploration. Notable examples of this work have been conducted at the U.S.G.S., at many Universities, and within the exploration industry. The identification of alteration mineralogy and biogeochemical anomalies can provide important insights into the mineral potential of an area undergoing initial evaluation or mineral resource assessment. In addition, evidence of faulting and fracturing and the structural recognition of intrusions, veins, and dikes can be derived through synoptic structural mapping using airborne or satellite images.

Given the underlying need in mineral resource assessments for reconnaissance geoscience information, it is indeed unfortunate that electromagnetic remote sensing appears to have played so limited a role in the process. Easily available spectral data, such as that from the Landsat Thematic Mapper, coupled with digital information extraction techniques, can be utilized to discriminate areas displaying hydrothermal alteration mineralogy. For example, the minerals limonite, hematite, goethite, kaolinite, montmorillonite, muscovite, illite-sericite, alunite, phyrophyllite, calcite, chlorite, and others display characteristic spectral absorption features in the 0.45 micrometer region (Landsat TM

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band 1) and 2.2 micrometer region (Landsat TM Band 7). Techniques such as the generation of spectral ratio images can be used to delineate areas where these minerals are present and to supplement lithologic mapping. In densely vegetated terrain, spectral information acquired from the Landsat Thematic Mapper can also be utilized to differentiate anomalous reflectance characteristics of vegetation (Landsat TM bands 3,4, and 5). Additional structural information can also be gleaned from an informed interpretation of enhanced satellite images or aerial photographs.

Obviously, without field verification, the origin of vegetation anomalies, the presence of alteration mineralogy, or the mapping of suggestive geologic structures can not be directly attributable to mineralization. Nevertheless, on a reconnaissance basis, the identification of these areas and the examination of the spatial correlation of these areas with other geoscience indicators, can provide significant insight into the mineral resource potential of a study area. Certainly the first step in the U.S.G.S. methodology must rely on acquiring and interpreting as much geoscience information as possible. Inherent to the assessment process is the use of converging lines of evidence. Reconnaissance alteration, vegetation, or structural maps derived from Landsat TM data afford low-cost and easily generated data-sets that should serve as additional input to the analysis process.

Implementation of the use of electromagnetic remote sensing data will be constrained by the time and resources available for each assessment. The expertise and resources necessary to successfully utilize remote sensing are available from within the U.S.G.S. and other Federal agencies, as well as from University and private sector scientists and organizations. Ideally, a geoscientist with remote sensing expertise could provide direct input as a member of, or consultant to, an assessment team. This individual could determine what types of data (i.e. Landsat TM, SPOT, or airborne imaging spectrometer data) would be most appropriate to the area of study, the availability of the data, and the image processing techniques that should be utilized to extract useful information. These decisions would be constrained by the time available for the assessment. As a first step, the remote sensing consultant should be conferred with to determine what might be the contribution of remote sensing data. During the analysis phase of the assessment this individual should also help to rank the significance of remote sensing derived targets/ tracks in relationship to all other geoscience information. This input will be invaluable to the assessment team in terms of understanding and appreciating the significance of the remote sensing input.

2.2 Digital Integration and Analysis:

Whether or not remote sensing data are used as input, the use of digital integration software and analysis techniques (GIS) would be of enormous benefit to the process of mineral resource assessment. Research and demonstration projects during the past decade have amply demonstrated the utility of digital integration of geological, geophysical, and remote sensing data for mineral exploration (Agterberg, 1981; Bonham-Carter et al., 1988; Harris and Pan, 1991; Kowalik and Glenn, 1987; Missallati et al., 1979; Reddy and Carter, 1991). The digital and geographic integration of geoscience information coupled with the analytical tools of statistical, boolean, or arithmetic operators provides a means of quickly and efficiently assessing complex data-sets.

The use of GIS software would allow the assessment teams to spend far <u>less</u> time compiling and overlaying data by hand from maps at disparate scales and far <u>more</u> time interpreting the significance of available information. Obviously, time constraints on the resource assessment process again play a major role in what can be implement. Though many geoscience data-sets originate in digital form, it is inevitable that considerable effort would have to be devoted to digitizing maps and interpretations and geographically referencing tabular data-sets. These front-end efforts can invariably be handled by technicians. Thus, with sufficient lead time, the geoscience staff can reap the benefits of an integrated digital data-set rather than be overwhelmed with the tasks of creating it.

Once the digital data-set is created, the assessment teams must have access to software that will allow them to easily analyze the data. Most GIS packages currently being utilized by Federal and State agencies (e.g.: ARC/INFO, GRASS, IDRISI) provide a wealth of analysis routines. These include the ability, on a spatial basis, to establish the cross-correlation of all variables, to call upon boolean and arithmetic operators to model user selected layers of geoscience data, and to utilize statistical packages (e.g.: regression, discriminate and factor analysis) to assess the inter-relationships of multivariate data and the predictive capabilities of these data.

A project-by-project implementation could be of use, however, it would be far more efficient to select a GIS package or group of software packages to be adopted and implemented by the Office of Mineral Resources. Ideally, the package(s) selected should be able to integrate both raster and vector data, utilize robust relational database management software, provide appropriate analysis capabilities, include basic image processing routines, and provide a user-friendly

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interface. This implementation can not be done without a serious commitment of both financial and human resources. GIS personnel would therefore become an integral part of the assessment teams.

The benefits of this commitment would go beyond providing the assessment teams with a more efficient means of analyzing data and producing maps. The more far-reaching benefits would include establishing a complete institutional memory of useful data and successful procedures as well as the ability to effectively document, reproduce, and extend the results of mineral resource assessments. Ultimately the mineral deposit models and Mark 3 program could also be integrated into a complete data integration and analysis workstation. The first priority of the U.S.G.S. should be to establish these tools on an operational basis for the mineral resource assessment teams. Once implemented, more sophisticated artificial intelligence tools such as expert systems (Prospector II & III) and neural networks could and should be attached to the GIS.

3.0 Programmatic Problems and Recommended Changes

Having come to the project relatively unaware of the depth of controversy surrounding the mineral resource assessment program, I was startled by what I heard and read. Given the political sensitivity of the process and the national importance of the results of the assessments, I was dismayed that the scientific credibility of the assessment program had yet to be truly established.

Though the debate during the Conference between proponents and critics of the three step method was occasionally tainted by anger and insults, all involved seemed dedicated to their work and improving the process. In particular, Bultman, Force, Gettings, and Fisher must be commended for their courage and dedication. Though some of their criticisms may be invalid or simply a difference of opinion, they have brought to light a number of serious deficiencies in the assessment process which certainly warranted review. In turn, the BORA personnel should be commended for their willingness to participate in the review process and their desire to improve the methodology.

The most significant problems facing the U.S.G.S. program are the lack of procedural guidelines, adequate documentation, and strategies for verification. Given the intense scrutiny that this type of assessment generates, it is particularly unwise not to have detailed specifications on how assessment teams are selected, on procedural rules for the estimation process, on the level of documentation required for each assessment, and on policies for complete review of assessment prior to their release. In conjunction with development of these specifications, the entire methodology and associated software must be published with peer review and distributed to the applicable community. Updating and improving the deposit models would be an important part of this process. It is critical that the reproducibility and credibility of the assessment process be established. Without achieving these goals the scientific merit and reputation of the methodology will continue to be justly questioned.

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Report on USGS Mineral Resource Assessment Methodology

by

Lawrence D. Meinert
Department of Geology
Washington State University
Pullman, WA 99164-2812
FAX: 509-335-7816

General Philosophy of Resource Assessment

Cost/benefits of Assessments - It has been suggested that if there is only one potential land use or if the land characteristics are known with certainty, then there is nothing to be gained by an assessment. The outcome of such an assessment is negative. This presumes that the knowledge of an assessment has no value in itself and that we can know all possible uses of that knowledge. Such certainty is incompatible with the very nature of geology. The fact that we will never be able to see all of the earth means that all geologic hypotheses and activities must remain open to the possibility, no matter how small, that a different perspective or new exposure will transform previous knowledge and ways of study. Clearly, every study has a cost and there must be a balance between costs and expected benefits. However, benefits are likely to be known with far less certainty than costs.

A primary consideration in almost every resource assessment study considered by the panel was the short to very short time frame of the studies. Although the natural inclination of most scientists is to study problems thoroughly and carefully, a short time frame may have a positive effect in resource assessment as a necessary driver for making decisions. Especially in the difficult task of estimating unknown quantities, more time may not produce a better result. The short time frame in itself is probably not the positive factor. Rather, it is suggested that the presence of a definite and non-flexible deadline is the key to producing the desired result.

As with any assessment, the USGS resource assessments invite questions of both short term and long term societal cost/benefits. Although in the short term, congressional action to designate a given tract of land as wilderness, closed to mineral entry, can be viewed as a permanent action, in a long term view political winds can change dramatically. It is not inconceivable that economic or military situations could result in a revision or recision of Congressional actions, including now sacrosanct wilderness designations. Thus, it is useful to address reversible versus non-reversible legislative actions relative to mineral resource assessments in terms of what could happen as opposed to what, at this point in time, appears likely to happen.

The most common view of potential wilderness lands includes those which have experienced minimal development and which have significant scenic or wildlife values. Potential wilderness tracts which are designated as wilderness are closed to mineral entry, and as such forfeit all opportunity costs associated with the potential of existing or undiscovered mineral resources. Although this forfeiture is likely permanent, it could be overturned, instantaneously, by Congressional action at any point in time. In this regard, the cost of underestimating the extent or value of mineral resources is low and subject to remedy. In contrast, the cost of overestimating mineral resources is zero in terms of mining (if the resources are not there, they will not be mined regardless of accessibility), but very large in terms of the forgone wilderness "opportunity costs" if substantial development takes place. It is suggested that one of the driving forces of the environmental movement is this difference in potential opportunity costs between wilderness values and development activities. This difference is not incorporated into either the current USGS assessment methodology or the Bureau of Mines economic forecasting models. The above statements are not arguing for or against any particular political action, but are a recognition of societal forces which past resource assessments have not taken into account.

Another change in American society which has not been seriously incorporated into the USGS resource assessment methodology is the need to include representative samples of the populace in public decision-making activities. In most government and university endeavors, it would be considered unacceptable to have major studies or legislative actions, such as resource assessment, conducted with little or no involvement of women and minorities. A casual examination of existing resource assessments as well as the current panel examining such assessments, reveals a significant underrepresentation of such groups relative to the US population at large as well as the existing diversity within the USGS. Even if the technical assessments are perfect in other respects, it may be predicted that this lack of representation of American diversity will eventually be a source of criticism.

Evaluation of Specific Assessments

Costa Rica

The Costa Rica resource assessment is a visually impressive effort that differs from the other resource assessments considered by the panel. It appears to have had multiple goals including resource assessment, geologic research, and facilitation of future exploration activities. The combination of diverse objectives and a very short time frame make this a much different resource assessment than some others evaluated by the panel. The foremost contribution is the compilation of the 1:500,000 scale geologic map. Such a compilation represents a very large amount of work, especially considering the time constraints, and is both well done and a critical element of the resource assessment. Without this map, many critical resource questions could not even have been posed, much less answered. The inclusion of new 1:100,000 scale mapping, strip maps, rock photographs and sketches provides much valuable material for those who follow. For a geologist who has not been to Costa Rica, they are invaluable.

The presentation format is unusual. The large folio format is good for big maps, adequate for big tables, but very cumbersome to use for text, photographs, and other book-sized objects. There may be political reasons for the format (as there were for some aspects of data collection and presentation), but the panel found the folio format difficult to use. Other format considerations include the lack of a Table of Contents and Index, both of which would have been very useful for the average reader who desires to find treatment of a particular subject.

As previously discussed, the geologic maps are of high quality but could have been improved by the addition of geologic cross sections. Such sections would not require any new data, but rather, additional interpretation of existing data. Cross sections are an important interpretational tool to help users unfamiliar with the details of local geology. Other compilation and interpretation tools which could have been added include: 1) aerial photographs, landsat and/or SPOT images combined with remote sensing analysis would seem like natural tools for such a reconnaissance of a lightly mapped area, 2) stratigraphic sections, columns, and type localities would provide a valuable base of information for future detailed studies, 3) chemical analyses of plutonic and volcanic igneous rocks are an essential part of most economic valuations, 4) summary analysis of geology in neighboring countries to identify important geologic trends and deposit types, and 5) collection of stream, soil, and rock geochemical samples. It was explained to the panel that stream geochemistry was the responsibility of the Los Alamos part of the project. This is an understandable political difficulty but, nevertheless, the lack of coordinated publication of regional stream and soil geochemistry is a serious drawback to the effective use of this study. In evaluation of lightly prospected areas such as Costa Rica, regional geochemistry is the most effective method of highlighting anomalous areas and no resource assessment could be considered complete without such data.

Many of the USGS resource assessments do not evaluate all possible deposit models because of incomplete data, especially grade/tonnage models. Because the Costa Rica resource assessment appears to have at least partly attempted to include new geological studies and identification of exploration potential, the lack of consideration of some deposit models is noteworthy. Based upon the rock types identified on the geologic map it would appear that there is potential for low sulfide gold-quartz veins in some of the clastic sedimentary rock sequences, a variety of skarn deposits, and basalt-hosted copper mineralization.

The main deposit model that was used in the Costa Rica resource assessment is the Sado gold vein type. As will be discussed in the section on specific deposit models, the subdivision of volcanic-hosted vein mineralization appears to be based upon arguable genetic criteria. More importantly, the strong focus of the Costa Rica resource assessment upon a Sado deposit model may have led to less attention than warranted to other mineralization types which commonly occur in volcanic rocks. Examples of hot spring-type gold mineralization and Round Mountain, Nevada type disseminated and stockwork gold mineralization would seem like natural targets given the general geology of Costa Rica. This may serve as an example of the over-reliance upon deposit models to pidgeon-hole different styles of mineralization which may have important differences.

Because an important part of the Costa Rica resource assessment involved the training of local geologists, it would seem natural to include a section on remaining work to be done. The Costa Rica resource assessment represents a valuable contribution from work done in a very short time frame. Such a restricted time frame invariably means that many important projects could not be finished, and some, perhaps, not even started. It would be a valuable service to future geologists to provide a short listing of the most important projects that remain.

Specific Deposit Models and Tonnage/Grade Distributions

Sado

The descriptive model for Sado epithermal veins is not very satisfying and appears to be a case of over-subdivision of the general class of volcanic-hosted gold-quartz veins. The primary description lists the main features as, "Gold, chalcopyrite, sulfosalts, and argentite in vuggy veins hosted by felsic to intermediate volcanic rocks that overlie older volcanic sequences or igneous intrusions." What are the essential features from this list? Gold and volcanic rocks are present in all deposits as could be deduced from the general class of volcanic-hosted gold-quartz veins. The other mineralogical features are present in some but not in other deposits. The nature of the basement rocks appears to be the fundamental distinction for Sado-type deposits. Given that the true nature of basement rocks is unknown for many, if not most, deposits, this appears to be an inappropriate criterion. During the oral description of the Sado model by Don Singer, reference was made to fluid salinity characteristics that are related to or result from the composition of the basement rocks. Even if these hypotheses are correct, the fact that basement composition and fluid salinities are not observable features in the field, make these inappropriate criteria for a descriptive model.

There are also inconsistencies in some of the deposit description features. Under mineralogy the gangue minerals are listed as quartz+pyrite+adularia+calcite. Under alteration adularia is not listed but alunite is. There is a well known USGS classification of volcanic-hosted gold-quartz veins into a low-sulfide quartz-adularia type and a high-sulfide quartz-alunite type. This division is based upon observable mineralogical criteria which reflect underlying geochemical differences. The Sado description leaves confusion as to what, if any, are the essential characteristics of this deposit type. Application of this deposit model to Costa Rica illustrates this problem in that apparently dissimilar gold deposits, including hot spring-type gold mineralization and Round Mountain, Nevada type disseminated and stockwork gold mineralization, are lumped together because of the overriding importance of the presumed volcanic basement rock.

All deposit models should reference examples of the type which are clearly described and accessible in the literature. The general reference given, Boyle (1979), does not mention Sado and, if anything, presents a classification of gold deposits contrary to the Sado model. The specific example, Takeno, Japan (Soeda and Watanabe, 1981) may well be a good example but the literature cited is not available in three major research libraries searched by the author (Univ. Washington, Univ. Arizona, and Washington State Univ.). The other deposits listed as components of the Tonnage/grade model have variable characteristics and it is difficult to form a clear image of the essential features of the Sado model from the accessible literature cited.

Polymetallic Veins

The deposit model for polymetallic veins is very confusing in that the main identifying characteristic is the association with intrusions, yet several of the cited examples appear to be metamorphic in origin (e.g. Beaudoin and Sangster, 1992) and not associated with intrusions. Furthermore, many obvious examples of polymetallic veins associated with major porphyry deposits are not included. Assuming that the latter and not the former deposits are the intended subject of this deposit model, several comments are appropriate. This will be an extremely variable class of deposits. In some sense, it is a deposit class for all those vein deposits that do not fit easily into other deposit models. For ore deposits associated with plutons, three of the most important variables include: 1) composition of the pluton and associated hydrothermal fluids, 2) composition and physical properties of wall rocks, and 3) the depth of formation. The geologic features of polymetallic vein deposits in this environment will vary with these three factors, among others. Thus, the descriptive material on textures, mineralogy, alteration, and geochemical signature should be discussed or tabulated relative to these controlling factors. For example, the same vein that has a propylitic alteration envelope in mafic volcanic rocks may have a sericitic alteration envelope in felsic volcanic or clastic sedimentary rocks. Similarly, a vein may be associated with sericitic alteration high in the system and potassic alteration deeper in the system. Examples of these deposits need to be chosen carefully to encompass the range of expected variation for the deposit type as a whole.

Generalizations Regarding Deposit Models & Tonnage/Grade Distributions

Deposit models are a key element of the resource assessment methodology. In addition to publishing the models themselves, it is also necessary to publish a description or guidelines for how deposit models should be generated. This is an important issue for not only USGS deposit models but also those generated by other scientists. In general, it is best to have multiple inputs to a deposit model rather than a single person presenting their vision of the subject. The best methodology for assembling a model described in the literature (I think) is the "interview of experts" technique used in developing deposit models for the artificial intelligence system, Prospector. This involves a person who is reasonably conversant about ore deposits in general, interviewing a variety of people in industry, academia, and government who have expertise about particular deposit types. The interview technique ensures a consistency of terminology, both within a specific deposit model as well as among different models. The present USGS descriptive format is good but needs several additions. Every deposit model should have a table listing a hierarchy of critical features, arranged according to their usefulness and importance in discovering and identifying the deposit in question. This could be thought of as a list of "key words" from the descriptive deposit model.

Given that there are multiple deposit models in the literature and likely to be a further proliferation in years to come, it appears that it would be desirable for some international entity to coordinate and regulate (?) their development. This is a different task than developing a nomenclature for rock types or minerals, tasks handled well by various commissions. Instead, this task needs a broader intellectual and academic guidance such as that provided for the past several decades by Economic Geology, both the Journal and the Society. Perhaps Economic Geology could coordinate an ongoing publication effort such as that currently developed by Geoscience Canada. Regardless of what happens on this front, the USGS must still have an active program of developing and updating deposit models for use in resource assessment. Many of the models in Cox and Singer (1968) are out of date, having been supplanted by more recent publications. The USGS deposits need to be updated on a continuous basis, incorporating new deposits and new information. This need for currency suggests that alternative publication forms to the bound Bulletin approach need to be considered. This may be the time for a bold step into the future in the form of electronic publishing. A USGS digital deposit model data base could be built so that subscribers or the general public could access the most recent version of any or all deposit models.

This need for currency is most important for deposit models which are relatively new and rapidly changing. Probably most important are those deposit models which do not yet exist. Particular attention should be paid to unconventional deposit types and deposits which just do not seem to fit any existing categories. Long before Olympic Dam or gold skarn deposit models were developed there were examples of such deposits (SE Missouri and Hedley, respectively) known in the literature. Yet-to-be-developed deposit types represent one of the largest potential errors in resource estimation. Perhaps, if it is possible to estimate the number of undiscovered deposits it may be possible to estimate the number of undiscovered deposit models, or at least to hasten their development.

Several concerns have been raised about potential bias in tonnage/grade models. One of these is based upon the hypothesis that, "the biggest deposits are found first". This phenomena has been demonstrated for some petroleum exploration (Arps and Roberts, 1958) and in a recent study for mercury deposits in California (Chung et al., 1992). However, there are reasons for questioning whether this is general case.

There are many factors that can contribute to the discovery of an ore deposit including: 1) understanding of the geologic model, 2) visibility of important deposit features, 3) depth of formation and preservation in the earth's crust, 4) size and continuity of ore horizons, 5) extent of exposure in prospect area, 6) exploration technology and 7) economics. Change in any one of these can lead to a new cycle of exploration. Many of these factors are linked as in the case of a change in price or technology that can allow for mining of an entirely new deposit type for which there had been no previous geologic model or exploration.

For petroleum there is a well understood occurrence model which has consistently guided exploration. Oil-bearing horizons are often large and laterally continuous. Thus, it makes sense that large fields would be found first in a given geologic environment. However, very large petroleum fields have been discovered in recent years in other geologic environments. Thus, caution should be used in applying Arps and Roberts (1958) study of petroleum exploration in a single sedimentary basin to other geologic environments.

Chung et al.'s (1992) study examined 132 mercury deposits discovered over a 118 year period and demonstrated that the biggest deposits were indeed discovered early in the exploration period. However, for geologic reasons, this may be a worst case scenario. The deposit model for mercury is well understood as most such deposits form by condensation of a vapor phase at relatively low temperatures within about 100 meters of the earth's surface. Most production comes from deposits in very young rocks close to the surface. Additionally, the main ore minerals are very brightly colored and likely to be noticed by prospectors. This combination of geologic characteristics makes it very likely that large mercury deposits will be discovered quickly and that the potential for blind deposits at depth or in complex geologic structures is limited.

Other deposit types are significantly different from petroleum or mercury. Several deposit types are not well-understood and presumed essential geologic features may be incomplete or in error. In some deposits the ore minerals are not visible to the eye and ore-grade rocks can look identical to non-mineralized rocks. Some deposits are discontinuous and not confined to particular geologic strata. The development of large tonnage open pit mining techniques and heap-leaching extraction techniques made ore deposits of rocks which previously were not prospected even in known ore districts. These and many other differences suggest that sampling according to size (finding the biggest deposits first) is not a universal phenomena and that tonnage/grade models should only be modified to account for this potential bias when there is a clear and demonstrated understanding of the 7 exploration factors discussed above.

Evaluation of Specific Controversies

Probability of occurrence models

For geologists, the goal of resource assessment is to estimate the number and characteristics of undiscovered deposits. Probabilistic models are necessary to cast the geologists estimations into a form that can be combined with tonnage/grade models. It has been suggested that the "at least x" method of estimating occurrence probabilities is confusing. The confusion seems to stem from the cumulative nature of the probabilities. This could be avoided by using intervals of number of deposits, e.g. 0-1, 2-5, 5-10, >10, and then summing the results. The exact method appears to be less important than clear and explicit guidelines issued to the expert panel estimators.

3 part USGS methodology

Overall, the 3 part resource assessment methodology appears to be sound, workable, and the best way of accommodating large variations in time, available data, and requested results. There are numerous suggestions (detailed in a subsequent section) for improvements in the general method, but they are intended as improvements and refinements rather than as a replacement of the existing methodology.

Presentation by Warren Hamilton

The presentation and manuscript by Warren Hamilton contain numerous errors of fact, judgement, and style. Several useful observations did surface from Hamilton's presentation including: 1) estimates and calculated values should not be presented with excess significant figures, 2) reporting the mean rather than median value out of Mark3 produces an overly large estimate of metal endowment and subsequent calculation of dollar value, 3) Because the Monte Carlo method of Mark3 can be repeated quickly with little cost, this source of variability should be quantified, at least at the one sigma level 4) the Harris panel should have received copies of letters from USGS personnel critical of the USGS resource assessment methodology, and 5) the Harris panel could have been better balanced in terms of representing diverse viewpoints and expertise.

Presentation by Mark Bultman & Eric Force

There are several important and valid suggestions in the report and presentations of Bultman et al. There are also a significant number of comments which are judged incorrect, personal opinion, or otherwise inappropriate to a scientific debate. That caveat notwithstanding, the courage and contribution of Bultman et al in highlighting weaknesses in USGS methodology can only be applauded as representing the highest dedication to improving and maintaining the quality of the USGS.

Two of the most important criticisms are the need for full publication and peer review of the USGS resource assessment methodology and a need for some estimation of the precision of the resulting numbers. There is much confusion in the Bultman et al. work with the terms accuracy, error, and precision. As is discussed in more detail in a later section, accuracy and error are inappropriate terms when discussing estimates of unknown quantities. In resource assessment, the target is not knowable but the precision can be estimated.

Other suggestions which have value include: 1) Mark3 should be written so that all or part of it can be used by commonly available personal computers so that real time calculations can be performed during estimation procedures, 2) GIPV is an inappropriate measure of undiscovered resources, 3) estimates and calculated values should not be presented with excess significant figures, 4) unconventional deposits are underrepresented in deposit models, 5) deposit models should better incorporate geologic time and the occurrence of some deposit types in restricted intervals of geologic time, 6) accounting for exploration maturity or previous exploration intensity needs a more rigorous approach, and 7) 10-, 50-, and 90-percent quantiles do not represent estimates of uncertainty of the method but only the probability of that particular value.

Some of the suggestions that are rejected as invalid or inapplicable include: 1) the method does not fully use available geologic data, 2) the method must anticipate a time when we know more than at present, 3) each and every deposit model (>60 and growing) must be blind tested, 4) estimation of deposits must be sequential, 5) genetic concepts should be used in the estimation process, 6) sufficient conditions for deposit formation must be or can be defined, 7) world-wide tonnage/grade models are never appropriate, 8) the USGS 3 part method is politically motivated or is predisposed to any particular outcome, 9) the fact that deposit models are not "perfect" is sufficient cause for abandoning the methodology, 10) without complete data, the "possibility of useful prediction vanishes".

How Well Does the Estimate GIPV Meet Meeds of Decision Makers?

Final output of assessment must be in dollars or other politically understandable units. The general guideline is that the answer, but not the study or methodology, needs to be framed in the context of the question, i.e. the initial request for an assessment. However, the current usage of GIPV is unacceptable and misleading. It should be possible to modify the current calculation of GIPV to take some account of reality, albeit short of a comprehensive economic analysis. The statement that other agencies report GIPV is disingenuous when geologists know that GIPV of undiscovered mineral resources is not comparable to GIPV estimates of real things. Even if the estimate of forest products value is in error, the actual lumber does have some finite value. The same may not be true for an undiscovered mineral deposit which even after discovery may have no economic value. Thus, it is desirable to apply some time of economic filter, even if crude, to weed out those undiscovered deposits which are unlikely to have a positive net value. Such a filter could be constructed as a relatively simple equation incorporating tonnage, grade, current price of main commodities, and a factor for the likely cost of exploration/development in the known geographic area. Such input parameters could be adjusted to approximate various degrees of certainty of economic value. In any case, such an economic filter will yield far more useful estimates of GIPV than is currently the case. As with the current metal endowment estimates, it will be necessary to supply a boilerplate explanation of the meaning of the reported values.

Recommended Methodological Changes

It is necessary to document the general assessment methodology as well as the particulars of individual assessments. The underlying scientific responsibility is to provide information with an audit trail so that questioned data or interpretations can be reexamined. Thus, a specific recommendation is that the general resource methodology must be published and subject to peer review. Furthermore, each individual assessment must be subject to peer review. This review should include reviewers from other branches of the USGS as well as outside the USGS. The review process provides an opportunity for input by industry and university experts who may be unavailable for inappropriate or service on an estimation panel. Systematic reviews of individual assessment by USGS geologists in other branches is an effective way of disseminating knowledge and facts about resource assessment throughout the USGS and minimizing the current climate of distrust and suspicion based upon lack of information.

Specific guidelines are necessary, along the lines of the deposit models, for how to treat other aspects of an assessment such as exploration maturity, deposit density, cost/ease of exploration and development. Since the single most important step, and the biggest cause of uncertainty, is the estimate of number of deposits by the expert panel, it is critically important to present some explicit guidelines for how to assemble and "run" a panel. This should include optimum size and member expertize. These guidelines should reflect the results of relevant operations research as well as the experience of previous panels and resource assessment assessments. The most important feature is that the guidelines are applied uniformly. The current variance in assessment panels (ranging from a single person to large groups of unconstrained individuals) is unacceptable and the source of a serious loss incredibility. Guidelines are also necessary for when and how to modify tonnage/grade models. It is recommended that world-wide tonnage/grade models be used except when local production statistics or geology indicate that the assessment tract is significantly different from the general case. It is expected that modifications of world-wide tonnage/grade models will be necessary in the majority of cases.

The Mark3 computer simulation program is presented as a translator of resource estimates into values for contained metal without significant distortions of the input data. This appears to be the case and is all the more reason for the program to be rewritten or modified so that it can be used on widely available personal computers. Such real-time use would be a significant addition to estimator panels in visualizing the results of their decisions. As with other suggests, this would require guidelines for proper use in individual resource assessments.

There must be an estimate and communication of the degree of uncertainty and precision in resource assessment. These are different concepts than accuracy and error, inappropriate terms when discussing estimates of unknown quantities. The oft-quoted analogy for precision and accuracy (error) is that of darts thrown at a dart board. Precision is the closeness of the darts to each other whereas accuracy (error) is the closeness of the darts to the bulls-eye (intended target). In resource assessment, the target is not knowable but the precision can be estimated. For the many steps of a resource assessment it is possible to estimate the precision of expert panel consensus, probabilistic models, etc. The final output, usually in dollars must have an explanation of what it means and how precise it is. A suggested model is the "boilerplate" explanation used for USGS emission spec analyses whereby the numbers are translated into categories, with appropriate explanation, so that the user can refer to "a number" even though in reality there is no single number generated.

There need to be more tests of resource assessment methodology. One test which has not been done to date is to have multiple estimator panels for a real resource assessment. These panels of comparable as well as different estimators should all have access to the same data. They will likely use it differently, requesting and weighting different data. Their consensus estimates undoubtedly will be different, but the differences will provide a very good check of the precision of the entire process.

There needs to be more follow-up of assessments. The USGS should hold public comment sessions, debriefing sessions with Congress or other requesting agencies, and studies of perceived effectiveness. Every assessment represents an opportunity to learn more about how to do effective assessments.

If the goal of resource assessment is to estimate the amount of undiscovered resources, then one of the largest deficits is the lack of estimation of entire categories of deposit types and resources such as industrial minerals, water, and energy. If in a hypothetical geographic area there exist ten categories of undiscovered resources, each with ten deposits, and the resource assessment only assesses two of those categories, then 80% of the resources are missed even if the two assessed categories are 100% accurate. This appears to be the case with current resource assessments. New and unconventional deposit types, as well as any without established tonnage/grade models, are systematically excluded from the resource assessment. A similar situation occurs with geographic areas that are covered or are not well characterized geologically. The reasons for this are understandable given the current methodology, but it appears to be desirable to create multiple categories within a resource assessment to deal with these different deposit situations. The bottom line is that a competent geologist as part of a resource assessment can make a far better estimate of undiscovered resources in each of the above "undesirable" situations than can an untrained politician or congressional staffer. This general problem is exacerbated in studies such as the Spotted Owl study, which are restricted to a single commodity. Although the restriction is clearly and explicitly stated in the study, it is likely that more than one user of that information has still equated the estimated GIPV with a total resource assessment.

Suggested Guidelines for Selection of the Deposit Estimation Team

Since the single most important step, and the biggest cause of uncertainty, is the estimate of number of deposits by the expert panel, it is critically important to present some explicit guidelines for how to assemble and "run" a panel. This should include optimum size and member expertize. These guidelines should reflect the results of relevant psychometric research as well as the experience of previous panels and resource assessment assessments. The most important feature is that the guidelines are applied uniformly. The current variance in assessment panels (ranging from a single person to large groups of unconstrained individuals) is unacceptable and the source of a serious loss of credibility.

The assessment process can be thought of as consisting of two steps, even though some of the steps and personal will be part of a continuous effort. The first step involves all geologists, resource specialists, and other personnel necessary to assemble and analyze all relevant data for the tract of land being assessed. This involves the first part of the USGS 3 part resource assessment methodology and consists of deposit model identification, permissive tract delineation, and evaluation of appropriate tonnage/grade models. In terms of time and resources, this will be the major part of any assessment. However, in terms of impact on the final resource estimates, the second step of estimating the number of deposits is, by far, the more important and the subject of the following paragraphs.

It is recommended that the assessment team consist of a minimum of four individuals and a maximum of seven. The minimum configuration consists of a regional geologist who is intimately familiar with the tract of land under consideration. Ideally, this person will have many years of experience with area geology and generally will be considered as "the expert" on the geology of this particular region. Another member is an economic geologist who has experience with a wide variety of different deposit types and their associated geochemical signatures. This person could also have expertise in regional geology, geophysics, or other USGS resource assessments. The third member of the "local" team is a geophysicist. This person could also have expertise in regional geology, economic geology, or other USGS resource assessments. Ideally, one or more of these three "local" people may have experience with previous resource assessments. The fourth member of the "minimum" assessment team is from the Branch of Resource Assessment (BORA) and has extensive experience with the USGS 3 part resource assessment methodology, geostatistics, and group dynamics. This person will lead the training session for the "local" members as well as being expected to provide leadership in applying national USGS assessment methods to the complexities of the local situation. All four members of the "minimum" assessment team will develop an estimate of the number of undiscovered deposits. Group discussions are encouraged, but each member must produce a separate estimate which will be run through the total simulation, filtering, and dollar value estimation process before being combined with the other team member estimates to calculate a consensus value, with uncertainty estimates.

For resource assessments which are likely to be contentious, it is recommended that there be an observer who is from outside the USGS or at least outside the branches involved in the resource assessment. This person will not produce an estimate of undiscovered deposits but will file an independent report recording impressions of the assessment process. This person would bring the "minimum" team to a total of five persons. Depending on the size of the assessment area and the experience of the "local" team, it may be advisable to add two more experienced BORA assessment personnel, bringing the total personnel to a maximum value of seven. This would make for a total of three BORA experienced assessment personnel and three "local" geologists/geophysicists. It is recommended that in this configuration, each local geologist be paired with an experienced BORA assessor to work as a team. To maintain balance, only one BORA assessor (presumably the most experienced) would make an estimate of the number of undiscovered deposits. It is expected that the assessment team will operate within the guidelines of recommended assessment methodology. This procedure should provide some measure of uniformity and comparability among assessment studies of different regions.

Recommendations for Programmatic and Institutional Change

The nature of requests for resource assessments has changed so that there is a more diverse political audience and shorter, more unpredictable time frames. This suggests that the USGS needs to take a more proactive approach to assessments. Since assessment requests are political it seems desirable to systematically accumulate data along political/geographical subdivisions such as nation, state, and county in anticipation of future requests. This database would allow educated response to very short time deadlines, albeit in less detail than a multi-year study.

The 3 part USGS resource assessment methodology needs to be modified to better fit the existing research culture of the USGS. It is apparent that some individual geologists have been reluctant to become involved, partly because resource assessment is not viewed as research. However, once the methodology is properly described with guidelines and examples then it becomes a general tool like mapping, chemical analysis, or paleontology that can be used and modified by individual scientists to solve problems and create understanding - vital characteristics of research. Dave Brew and the Tongass National Forest study appear to be prime examples of such an approach.

It has been questioned whether there is sufficient institutional support for resource assessment. Beyond the usual budgetary concerns, this comes down to priorities. If resource assessment was the #1 priority of the USGS then it is likely that sweeping organizational and personnel changes would occur to enable that to happen. It is not the panel's charge to set priorities for the USGS. However, it is recommended that the director and chief geologist of the USGS examine their priorities, goals, and vision for the USGS in the coming decades. It is likely that there will be changes and it is important that institutional structure and culture be redirected to support and not hinder those changes.

Comments about the Panel and Potential Conflicts of Interest

Many of the readers of the final report may wonder about the objectivity of the panel members since panel member's knowledge and personal involvement with the people and issues involved is part of the reason why they were chosen to participate. All the panel members (Harris, Skinner, Titley, Nielsen, Cook, Meinert, Sumner, and Marsh) have varying degrees of conflict of interest relative to the issue of resource assessment. Again, their knowledge and personal involvement with the people and issues involved is part of the reason why they were chosen to participate. In proceedings such as these it is important to balance familiarity with the technical matter (leading to inherent conflicts of interest) with objective and diverse points of view. Harris, as the director of the project and by virtue of his past, present, and future contract work with the USGS combined with his past, present, and future relationships with USGS personnel as teacher, mentor, co-author, and friend probably has the largest and most complex conflicts of interest in mediating a USGS resource assessment dispute. My personal opinion is that the director of the panel, Dr. DeVerle Harris, along with the other panel members have proceeded fairly and as gentlemen. It would be inappropriate for me to evaluate my own objectivity although I have tried to retain an open mind throughout the proceedings. I do feel that the panel would heve been strengthened by including more diverse points of view and members of society.

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STATISTICAL AND PROCEDURAL ASPECTS OF THE USGS THREE-STEP METHODOLOGY

Donald E. Myers

The following comments are predicated on the assumption that quantitative assessment of resources is a good thing and that it is appropriate for USGS to do such assessments. It goes without saying that as a general public organization neither the procedure and nor the personnel should skew the assessments in order to meet any particular political agenda. Both the mining/minerals industry and the public at large have a right to expect that the assessment process will not be biased and that it will be as objective as possible.

PUBLIC ACCESS

Particularly because of the relationship of resource assessment to the decision making with respect to proposed wilderness areas and with respect to more general environmental decisions it is crucial that USGS document in a public way the mechanism used in making assessments. While there may be some dispute about the extent to which documentation has been made available, the comments made by D. Menzie and other from BORA (at the Conference) confirm that neither the software nor the documentation were readily available for public or scientific appraisal either within or outside USGS. It is crucial that this be changed.The process/procedure will obviously not be static but versions could be identified and then when assessments are made there should be a clear identification as to the version used.In particular the tendency to do things in ar Ad Hoc fashion is not sufficient and must be changed. When a new "version" is prepared and ready for use there will have to be review process and then provision for public comment. There will have to be a procedure for formal adoption of such a new version.

There did not seem to be an understanding that when assessments are done in a quantitative form and when they are used for land use planning/decision making that USGS will have to establish creditability.

DATA/INFORMATION

It is not clear about the extent to which the assessment process ensures that the total data and information set used in the assessment process is clearly identified and retained. It is essential that USGS be able to make this identification and furthermore be able to provide such data/information to various parties in a reasonable manner. Again Ad Hoc handling of data/information will simply not be appropriate. It will be necessary to document all steps in the assessment process.

In some respects the data is only used by the panel in making their judgements and it is likely that the variability inherent in that step is larger than the variability in the data but if some measure of precision is to be attributed to the end product then attention must be given to the reliability of the input. This is especially important in formulating the tonnage and grade distributions.'There seemed to be considerable variation in the amount and kinds of information utilized in the reported assessments. This means that there will be considerable variability in the reliability/creditability of the final assessments.

Recognizing that there are problems with confidentiality it is essential that the data used to model the grade/tonnage distributions be publicly available. There has to somehow be a way of providing an independent evaluation of whether the grouping of the deposits is appropriate. It is clear that while it may not be possible to get complete unanimity on the grouping the existing grouping is not fully acceptable to a considerable number of geologists.

ASSESSMENT TEAM vs EXPERT PANEL

My impression from the various presentations was that there was considerable intermingling between the team overseeing/conducting the assessment and the panel of experts used to provide the estimates of the number of deposits in the tracts. This seemed particularly true in the presentations of D. Brew and D. Menzie. As a learning process it may be useful for the assessment team to continually interact with the panel but more generally these functions should be clearly separated.

PANEL SELECTION/FUNCTIONING

The document "Notes from a course on Resource Assessment" devotes some discussion to the question of how panels are selected and how they function. This may be adequate for a first version of the fully documented assessment procedure but it is not adequate for general credibility. There should be a reasonably detailed description of what kinds of individuals and experience should be represented on the panel, how and by whom the panel is to be selected. The standards should ensure that when assessments are made that the creditability of the assessments will comparable. Obviously the final report of the assessment will have to include the list of names and some documentation on how they were selected.

The same set of notes includes some information on the training of panel members(it was clear from the discussions that not all geologists are adequately prepared to provide estimates in the required format). The training should be standardized.

While it is clear that panel members will be making subjective judgements based on their knowledge and expertise together with the data/information provided as a part of the assessment process it should be possible to document the way in which they arrive at their judgements. The training of the panel and the subsequent activities of the panel should focus on making judgements in such a manner that they are both defendable and repeatable. It is entirely likely that if a court test occurs that one or more of the panel will be asked to testify and to defend their estimates.

It has been claimed that MARK3 is only a "translator". This claim seems to be questionable but if it is valid then the role of the panel is all the more important. The validity of this claim is in part dependent on whether the panel fully understands the manner in which their judgements are used in the subsequent steps. BORA seems to have paid little attention to this concern.

STATISTICAL ANALYSIS

Particularly in the presentation of D. Menzie there were a number of weaknesses in the statistical analyses that were given. For example, an 80% confidence level is of very little use since there is too great a change that the unknown parameter is outside the confidence interval but unfortunately it will not be possible to say where. It would be totally unjustified to assume that the true value is only slightly outside the 80% interval unless the 90% , 95% and 99% intervals were only slightly bigger (in which case why bother with 80%). To present such an interval is misleading or indicates that the presenter does not understand the considerable unreliability of the results.

The description of the process of fitting a theoretical distribution to the tonnage and grade data indicates a very casual approach. Given the importance of these in the later computations it is crucial that more attention be given to the reliability of the fitting process(in particular the practice of focusing on the cumulative distribution should be changed).They have used only a very simple minded technique.

The results presented to substantiate the claim that the "test" shows that panels can adequately estimate the number of deposits were simply not adequate. There was insufficient attention given to the way in which the panel worked and the statistical analysis was not appropriate. Worse yet the results given from the use of regression simply are to erratic to be of any value.

There was considerable discussion about the extent to which the sampling may be size biased. However there is an even more important problem that was not mentioned at all, namely randomness. When various statistical tests (such as for normality or lognormality or for the significance of a correlation coefficient) are applied the use of those tests implies the validity of certain underlying assumptions (some form of random sampling is the most common). It is extremely unlikely that any of the data represents a random sample. This problem should at least be acknowledged and caution should be exercised in reporting results of such tests.

It was clear that there is considerable variability in the amount and the reliability of the data used to identify the deposit characteristics and to model the grade/tonnage distributions yet apparently there has been no attempt to quantify the uncertainties associated with these results. Since any given assessment uses only a portion of the models (and associated distributions) the ultimate reliability of the assessments will vary substantially yet there was no recognition of this in any of the BORA presentations or in the documents.

In the "Notes ...." document and elsewhere there is some discussion of the identification of "outliers" particularly as it affects the fitting of tonnage and grade distributions. There was little real information on how this was/would be done. This should be documented case by case so that the analysis can be subjected to independent review.In an attachment to the "Notes ...." document there is a reference to the use of a "t"test" at the 5% confidence level. This is incorrect and misleading terminology. First of all there is "a" t distribution but there is not "a" t ' test. There are multiple test statistics that have a t distribution and hence for which a t table is used to determine critical values but one should be careful to indicate what the hypotheses are, what the underlying assumptions are and what the test statistic is. The phrase "5% confidence level" is based on a substantial mis-understanding. The confidence level pertains to the degree of certainty that a conclusion is right where as tests of hypotheses are described in terms of two types of errors (i.e., that the conclusion drawn is WRONG). The level of significance is the same as the Type I error probability, i.e., an incorrect rejection of the null hypothesis. Note that in this same attachment there is a an application of a test for the equality of two means, the test statistic used implies an assumption of equal variances (which is not mentioned).

There needs to be an investigation into whether the understanding of probability used by the experts is the same as is implicit in the algorithm in MARK3 (when they provide their estimates of the numbers of deposits).

MARK3

Given the limited amount of documentation provided and the short amount of time it was not possible to really evaluate the algorithm and since code was not provided it was certainly not possible to evaluate the program (these are two different problems). It seems very strange that they have not bothered to upgrade the software to a PC or to a workstation or at least to something standard such as a VAX. Given the very strong dependence of the final assessment on the use of simulation it is important to evaluate the random number generator, i.e., to what extent does it reproduce a given distribution? In particular the lognormal is not easily simulated and 4,999 runs is likely not adequate.

It was recognized in the various presentations and discussion that the question of how to ask the geologist for estimates of the numbers of deposits has not been resolved but there seems to be little recognition of how the restrictions have affected the results. When only three points on the cumulative distribution are provided then the model type (e.g.,lognormal) or the algorithm (for example the linearization technique in MARK3) is quite important in determining the simulation results. In general one would have to say that the procedure is only at a research stage and not at a production stage.

INTERPRETATION OF THE RESULTS

MARK3 produces the ultimate estimates that are used to produce the final assessment of metal contained by an averaging process. It is reasonable to consider the results as estimates of means BUT there seemed to be no consideration of whether a mean is the best number to present an assessment value and to ensure that the person(s)receiving the results understand that that is what they are getting. At the very least it should be given in the form of an interval with the width representing the reliability of the assessment. To do that means however that that all of the sources of error and variability must be identified and incorporated into the final result. The emphasis seemed to be only on the variability induced by the MARK3 algorithm. D. Brew indicated that the Forest Service routinely puts a +/_ 40% interval on their estimates. It was not clear whether that was done with the minerals assessment for the Tongass or not and if so what the justification was.

RECOMMENDATIONS

1. A complete set of documentation should be prepared including the description of the process for selecting, training and functioning of the panel of experts . This should include the library of deposit models and grade/tonnage distributions as well as the algorithm/code for MARK3. Finally the documentation should stipulate the nature and extent of the data/information to be used in an assessment. This package then should be subjected to independent review (while the process we went through this week was in part such a review it would not really constitute such a review since

they have not fixed the assessment procedure)

2. The library of models and distributions should receive its own review, there should be a provision for periodic review and update. The data/information used to determine this library should be made public and available for independent review.

3. The MARK3 algorithm and program should be upgraded to more standard code and made interactive. After this is completed the algorithm and code should be independently reviewed to ensure that it does what is claimed.

4. In general the level of statistical analysis and statistical presentation needs to be upgraded.

5. There should be a clear separation of the duties/functioning of the assessment team and the panel of experts used to provide the estimates for the numbers of deposits.

GEOCON, INC.
Exploration and Mining Geology

13741 Braun Drive • Golden, CO 80401
Phone/FAX (303) 279-3118

RICHARD L. NIELSEN • CONSULTING GEOLOGIST

13 August 1993

TO: DeVerle Harris, Univ. of Arizona and Participants in the Conference for Evaluation of USGS Assessment Methodology

FROM: R.L. Nielsen, Consulting Geologist

SUBJECT: Preliminary Notes and Comments

The following text are preliminary comments on various aspects of the methodology. Topics covered reflect the assignments given at the start of the conference. Additional comments will be provided in my contribution to the final report.

EVALUATION OF SPOTTED OWL ASSESSMENT

General understanding of the geologic setting and depositional environment of porphyry copper deposits is adequate for the purposes of making this resource assessment. In addition, individual porphyry copper deposits and prospects in the region have been studied; some have been drilled and evaluated. The regional geology has been mapped in detail sufficient for an assessment.

Porphyry copper deposits in the Spotted Owl region are significantly different than those of Southwestern U.S. Host rocks generally are batholithic intrusions rather than unmetamorphosed sediments. Regional structures control location of specific mineralized areas and provide control for the shape of mineralized zones. Alteration patterns as documented in studies are significantly different than those in deposits of the Southwest. Chloritic alteration mainly along veins and fractures is closely associated with the copper sulfide mineralization. Potassic alteration is broad and pervasive. Sericitic alteration is restricted to few structures and small areas. The point here is that "typical" porphyry copper mineralization of the Cascades significantly deviates from the model. This leads directly to the question: Are grade and tonnage models for porphyry copper deposit in general appropriate for the Cascade deposits in particular? Very likely the answer is **NO**. The grade and tonnage curves are heavily influenced by high grades associated with chalcocite enrichment blankets of Southwest porphyries and these are absent from Cascade porphyries.

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The weak link in the assessment and perhaps principal source of the credibility issue is estimated number of undiscovered deposits and the manner in which this number was achieved. Industry exploration in the region has been intense and repetitive, especially in Tract A of northern Washington, where mineralized bedrock exposures are widespread. An estimate of at least 14 undiscovered deposits at 0.5 probability was made for this area. Apparently the assessors estimated that of these fourteen deposits about half of the undiscovered deposits will come from the population of known prospects. The other half will be completely new discoveries. In view of the fact that many of the known prospects have been tested by drilling, it is uncertain what criteria the assessment panel used to arrive at the number of prospects that may become discoveries.

Very likely most or all very large deposits have been discovered in Tract A of the Spotted Owl Region thanks to the intensity of exploration activities. New discoveries will be relatively small and cluster on the "small deposit end" of the tonnage curve. Therefore the available grade and tonnage curves are not appropriate and if used wull provide unusually large estimate of expected metal endowment. This may be a major source of the credibility issue.

The number of individuals on the assessment panel was nine; probably more than ideal. Two members were experienced in porphyry copper geology; one a geophysicists; the others were experienced BORA personnel. Each member made an estimate of undiscovered deposits, followed by discussion and a consensus was reached by the entire panel. A critical piece of information lacking was complete information on extent and intensity of exploration activity.

Positive features of the Spotted Owl Assessment are:

1. Geologic data base used is good and was integrated with geophysics, geochemistry and metallogenetic data in an effective manner to define favorable tracts.

2. Available industry data, at least those which were released to State bureaus also were used to locate and evaluate known mineralized areas.

3. The product was completed and delivered in a timely manner.

Problems and negative features of the assessment are:

1. Lode gold veins and volcanic-hosted massive base metal sulfide deposits are very likely to be present in the region evaluated. Quantitative probabilistic assessment of these deposits also should have been included in the information provided to land use planners.

2. The region has received a large amount of industry exploration activity. Many of the known prospects and occurrences have been studied, evaluated and even tested by drilling. The Spotted Owl study should have provided some information on the criteria used by the assessment panel to arrive at the number of of undiscovered deposits that were derived from the number of known copper prospects. How was information regarding the amount of past exploration factored into the estimate of undiscovered deposits? Perhaps there should be some method for adjusting the available grade and tonnage curves for use in an area which has received strong exploration activity and and therefore the remaining deposits to be discoveries will be relatively small in size.

3. Problems exist with applying the descriptive ore deposit model for porphyry copper deposits in the Cascade Mountains area of Washington. No possibility of significant supergene enrichment exists in the region. Supergene enrichment has been significant factor in controlling large amounts of high grade ore in Southwestern porphyries. Relatively high grade ore will be controlled and localized by structures. Shape and distribution of potential ore-grade mineralization will be controlled by structures. This results in relatively smaller and lower grade "high-grade zones" than in Southwestern porphyries. The methodology of resource assessment should have procedures for modification of descriptive models and for modification of the grade and tonnage curves to account for changes in local geologic conditions.

EVALUATION OF THE TONGASS FOREST ASSESSMENT

The Tongass National Forest contains a wide variety of ore deposit types, owing in part to the large number of accreted terranes that comprises Southeastern Alaska. Several important resources region have no recognized or established ore deposit model. Examples are the Bokan Mountain U-Th-REE deposits and the titaniferous magnetite deposits in the zoned ultramafic bodies.

Some deposit models are appropriate for the Tongass. These include gabbroic Ni-Cu, podiform Cr, Skarn Cu, low-sulfide Au-quartz veins, and porphyry Cu-Mo. Some ore deposit modes are not directly applicable and need revision. These include Kuroko-massive sulfide, sedex Pb-Zn-Ag, Cyprus massive sulfide and Besshi massive sulfide. The mineral deposit models need to be modified for optimum use in the study.

Geology of the region is well described and documented, and probably is sufficiently well known for purposes of this resource assessment.

The assessment of undiscovered deposits was made by one person and reviewed by two or three persons. Other regional geologists, economic geologists and geophysicists with first-hand experience probably should have participated in the estimate of undiscovered deposits. Apparently these specialists refused participate in estimating undiscovered deposits as they did not feel comfortable with the procedure.

Strongest positive feature of this assessment is the manner in which the geologic team prepared a geologic data base prior to the estimation of undiscovered deposits. This preparation not only consisted of assembling relevant geologic, geophysical, and mineral deposit data, but also consisted of setting up a strategy and criteria for judging the appropriateness and completeness of the data. A series of data reviews and decision points were established as outlined in Open File Report 92-307 (Brew, 1992). In effect this series of strategies and decision points tended to standardize the assessment procedure. A second assessment team may well follow this same standardized procedure in evaluation of data and assessment and arrive at a similar results. This possibility should be investigated in a controlled experiment.

A second strength of this Tongass assessment is that fact that some ore deposit models were modified to be applicable and specific for the Southeast Alaska region. For example, the Bokan Mountain U-Th-REE deposits have no well defined descriptive or grade and tonnage models. The estimator apparently constructed a grade and tonnage model based upon local information to support a quantitative estimate for undiscovered deposits in the area.

Procedure for estimation of undiscovered deposits was somewhat standardized. Estimated undiscovered deposits in the Tongass assessment were defined as those deposits that can be discovered and developed using presently available and appropriate technology. The contraint of using this definition and supportive criteria eliminates the uncertainty and credibility problems associated with estimating undiscovered deposits that require discovery by undefined and imagined technology. Estimations of undiscovered deposits in all assessment areas probably should use similar or same parametersand constraints. This proceedure would serve to standardize the estimating procedures and tend to provide realistic estimates. This would serve to minimize the credibility issue.

EVALUATION OF PORPHYRY COPPER DEPOSIT MODEL

The descriptive model can be improved with some modifications to the narrative relating to geologic environment of of porphyry copper mineralization.

Porphyry copper deposits are associated with high-level epizonal plutons. Mineralization generally is associated with one of a number of multiple intrusive phases in a magmatic center.

Commonly the center of magmatic activity has been uplifted or regionally domed by the intrusive activity and these features can be recognized in evaluation of regional geologic patterns. Presence of dike swarms are a common association. The association of trapezoids with a rift-zone as depicted in the present descriptive model probably is not valid and should be de-emphasized. Deep erosion of a magmatic center or igneous complex and lack of high-level intrusions are negative features.

Commonly the porphyry copper centers of mineralization are controlled by regional structures. The structure may be identified by linear structural trends along which plutons are emplaced. Structures can be recognized by faults, linear features in air photos, alignment or shapes of intrusions and geophysical patterns. Regional faults intersecting margins of large plutons are favorable locations for high-level porphyry intrusions. These features are useful in evaluating covered areas as these structural trends can be projected into covered areas. They should be incorporated into the deposit model.

Comments regarding the tendency for the grade and tonnage model to provide a bias towards large deposits because of historic high grade production from copper-rich supergene ore zones has been mention in a previous section. This feature has to be addressed when using grade and tonnage models to reach estimated metal content of undiscovered deposits.

EVALUATION OF CARBONATE-HOSTED Au-Ag DEPOSIT MODEL

Descriptive, grade and tonnage modes need to be revised, principally owing to the large amount of information that is available after publication of Bulletin 1693.

Following is a partial list of Carlin-type deposits for which new descriptions, grade and tonnage information are available. Principal sources are Symposium Proceedings and Field Trip Guidebook Compendium for Geologic Association of Nevada Great Basin Symposium (1991).

Chimney Creek, Humboldt Co. USNV (Gold Field)
Rabbit Creek, Humboldt Co., USNV (Santa Fe)
Lone Tree, Humboldt Co., USNV (Santa Fe)
Stonehouse, Humboldt Co., USNV (Rayrock et al)
Santa Fe, Mineral Co., USNV (Corona)
Marigold, Humboldt Co., USNV (Rayrock et al) - 4 deposits
Hilltop, Lander Co., USNV (Placer Dome)
Pipeline, Lander Co., USNV (Placer Dome - Gold Fields)
Gold Bar, Eureka Co., USNV (2 new Atlas operations)
Pan, White Pine Co., USNV (Aspen)
Meikle, White Pine Co., USNV (Barrick) - Large and high-grade
Post, Eureka Co., USNV (Barrick)

Deep Post, Eureka Co., USNV (Barrick)
East Bullion, Eureka Co., USNV (Teck)
Trout Creek, Eureka Co., USNV (Newmont)
Bald Mountain, White Pine Co., USNV (Placer Dome)
Little Bald Mountain, White Pine Co., USNV (Placer Dome)
White Pine Mine, White Pine Co., USNV (Western States Minerals)
Winrock, White Pine Co., USNV (USMX)
Casino, White Pine Co., USNV (USMX)
Yankee, White Pine Co., USNV (USMX)

Several other deposits besides those listed above have been reported on large extensive land blocks owned by Newmont and Independence Mining Company. Available data on at least 20 additional deposits not listed in Bulletin 1693 will nearly double information on grade and tonnage models.

In addition some suggested changes and modifications in the descriptive model are suggested and appropriate.

1. Favorable host rocks for sediment-hosted gold should include carbonaceous shale and siltstones in addition to the carbonates. Dioritic porphyry dikes and small porphyritic intrusions also are present in some deposits.

2. Deposits appear aligned along, or have distributions concentrated along "trends". These are linear structures up to 200 kilometers long and several kilometers in width. Trends are very large structures and major crustal features. They are excellent guides to tracts favorable for discovery of undefined deposits and should be included in the descriptive model.

3. Commonly individual deposits are stratabound replacements and impregnations of gold mineralizations in structurally-prepared zones near crests of anticlines where faults and fractures, both parallel and transverse to fold axes are concentrated.

4. Porphyry Mo and W-Mo skarns as likely associated deposits should be removed from the descriptive model. Presence of these types of deposits and presence of polymetallic veins probably result from super imposed and unrelated mineralizing events.

5. De-carbonitization of calcareous sediments leaving a residual deposit rich in carbon or replacement of carbonates by silica are common features. Generally illite and kaolinite alteration of argillic sediments are associated with ore. Gold deposits commonly are stratabound, and mineralization with up to several percent disseminated sulfides (pyrite, arsenopyrite) is disseminated in structurally prepared ground at intersections of fractures or faults with favorable stratigraphic units. Intersections of thrust faults with high angle faults also is a favorable structural setting.

Some of the above structural and alteration features can be used to define favorable tracts for sediment-hosted gold deposits. The obvious conclusion is that this model needs revision to take into account new information on recently discovered deposits. The revision should receive high priority.

EVALUATION OF THE CREEDE EPITHERMAL VEIN MODEL

The descriptive model for this type of deposit indicates it is a sub-class or variety of the Comstock epithermal vein model. Essentially all characteristics and features are shared by the Creede and Comstock models save two important characteristics: (1) the Creede modes has significantly greater base metal content than the Comstock model; and (2) the Comstock model has significantly higher gold content than the Creede model.

The need for the Creede model to be separated from other epithermal types is understandable as this allows for construction of grade curves needed to assess base metal values of undiscovered deposits. However, in a permissive area or tract to be assessed, one cannot determine or decide if a Creede or Comstock model is appropriate to use when no known deposits are present.

Classification and grouping of the various epithermal deposit types is very difficult. Few can agree on critical and definitive features that characterize classes. Probably the pragmatic approach is to separate out Creed epithermal vein deposits from other epithermal precious metal deposits so that grade and tonnage models can serve for assessment of base metal values in undiscovered deposits. Fossil hot spring gold deposits also may be separated from the pack. All other quartz-adularia epithermal veins and disseminated deposits can remain in the same model class. In effect this is recommending no change in the classification. However, I would recommend playing around with the descriptive model and try to separate and class epithermal deposits on easily recognizable geologic features. A simplistic notion may be to separate out gold-rich low sulfide deposits associated with high-silica rhyolites of a bi-modal magma suite from silver-rich deposits associated with calc-alkaline andesite accumulation.

The present descriptive model for Creede epithermal veins does not contain sufficient information to allow an assessor to make a confident judgement that a favorable tract is permissive for this deposit type. A geologist assessor must examine and evaluate the site specific data base to determine if an area is permissive for this type of deposit.

GENERALIZATIONS REGARDING DEPOSIT MODELS

1. Some of the deposit models need revision immediately as much new information on descriptive character of the deposits and new grade and tonnage information has become available. An example is the sediment-hosted gold-silver deposits.

2. Some deposit models need revision. Present grouping of deposits into models is not appropriate. Some models should be split and classified according to geologic environment and features in common. Examples are the Kuroko massive sulfide model. Archean volcanic-hosted massive sulfide deposits probably should be split out from the geologically younger deposits. Descriptive models need revision so that critical and observable features are listed that help define favorable and permissive tracts. Descriptive models for poly-metallic veins, epithermal vein deposits, and volcanic-hosted massive sulfide deposits need to revision to help clarify the geologic environment characteristic of these deposit types.

3. Some method is required to overcome the problem of inadequate or lack of appropriate tonnage and grade distribution models for some deposit types. For example, assessors in the Tongass assessment appear to have used some method to arrive at an estimated metal content for undiscovered deposits when a tonnage and grade model was not available or appropriate as for the Bokan Mountain U-Th-REE deposits.

CONCLUSIONS AND RECOMMENDED METHOD EXTENSIONS OR MODIFICATIONS

1. Improve descriptive ore deposit models and grade and tonnage curves. In addition, some alternative and compatible method for estimating metal content and gross in-place values should be developed to apply to unusual and "unique" deposits (Examples are the Bokan Mountain U-Th-REE deposits in Southeast Alaska and the Mountain Pass REE deposits in eastern California).

2. Some compatible method should be developed to estimate GIPV information on major resources for which there in no descriptive or tonnage and grade models (Examples are metallurgical limestone resources and bulk disseminated magnetite resources in ultramafic rocks of Southeast Alaska).

3. The flow sheet and methods described by Brew in USGS Open File Report 92-307 should be studied and perhaps modified and adapted so they can be widely used to make assessments of undiscovered deposits in other areas. Can this approach be used widely to make assessments? This type of flowsheet if widely adopted also may be used to standardize the assessment process and can serve as a basis for defining an experiment to test reproducibility of assessments. Successful use of this strategy for decisions can serve to minimize the credibility issue.

4. Each quantitative probabilistic assessment should estimate undiscovered deposits using the following criteria and features: (1) Each undiscovered deposit estimated must meet the test that it can be discovered by presently available exploration technology; and (2) Each undiscovered deposit should be amenable to development and exploitation by presently available technology. If each undiscovered deposit is consistent with these criteria then economic evaluations and projections can be done by the USBM. Undiscovered deposits that must depend on unavailable technology for discovery and development should not be included in the assessment. This also would serve to help overcome the credibility issue.

5. A very important and significant problem with probabilistic resource assessment as presently done is that a large amount of industry and private data are not used. Thus, only a small part of existing data is available and the resulting quantitative assessment is flawed or incomplete. Perhaps companies that have worked in an area should be contacted and requests for voluntary release of data can be make. State geologic surveys keep records of exploration activities in specific regions. Search for some acceptable method of bringing industry expertise into the process of resource assessment should be made.

Richard L Nielsen

Richard L. Nielsen

DRAFT

J.S. Sumner 8/18/92

EVALUATION OF SPECIFIC ASSESSMENTS

COSTA RICA GEOPHYSICAL STUDIES

Previously existing geophysical data were used in the Costa Rica resource assessment. This procedure apparently was due to the short time-frame imposed for the study and the low budget allowance for the entire program. As a result, both the coverage and the geophysical data analysis are a bit skimpy, both from the viewpoint of future mineral exploration and also for present mineral assessment purposes. The geophysical data assessment study is presented as part of the large map and narrative folio designated as USGS Miscellaneous Investigations Series Map 1-1985.

It appears that the principal beneficial use of the geophysical maps was to substantiate and supplement the compiled regional geologic map. However, wherever possible there is discussion of potentially mineralized regions in the geophysical analysis. Some of the surveys were continued offshore, mainly for petroleum exploration. The geophysical maps are quite useful for regional geological mapping purposes.

Because of the sparsity of geophysical survey coverage, the analysis of the existing data was somewhat academic and rather weak from a mineral resource assessment standpoint. However, good-looking colored maps were produced, and these will be useful to future interpreters.

No radiometric, Geographic Information System (GIS), or remote sensing analysis was made in the mineral assessment of Costa Rica. There is a brief mention of seismic work and areal seismicity in the folio.

Aeromagnetic Data Analysis

The quality of the aeromagnetic data appears to be acceptable. It probably was flown under contract for the Costa Rican government. The original data are almost 20 years old, and it might be difficult to obtain the original data for further processing, or for reinterpretion. Only about one-quarter of the country has been covered, so that completion of aeromagnetic surveying should be a high-priority item both for exploration incentives and for mineral assessment.

Several mineral resource targets are indicated on the aeromagnetic maps and are discussed in the folio, which proves the beneficial worth of the aeromagnetic method. References are given for the original surveys, which also contain interpretations.

The quality of data interpretation is very good, and the U.S. Geological Survey interpreters are trained and experienced. In this low geomagnetic latitude aeromagnetic anomalies are not readily, correctly interpreted by inexperienced persons.

Gravity Data Analysis

The regional gravity coverage of Costa Rica is about five years old, and it appears to be of good quality. However, the coverage in potentially mineralized areas is so sparse that very little can be said about applications to mineral assessment. The mapped contour interval is 10 milligals, so only major individual anomalies due to large features with strong density contrasts would show up. However, major lineaments that may be indirectly related to mineralization are brought out by the regional gravity survey and are described in the folio, even though their importance to assessment is not emphasized.

Some much more dense proprietary gravity coverage along the Atlantic coastal basins is integrated into the regional map. Also, several offshore gravity traverses were integrated into the mapped areas, rounding out the regional tectonic pattern of the area.

The gravity data reduction process appears to be thorough. The U.S. Geological Survey has applied their terrain and isostatic corrections to the data, giving a professional appearance to the colored Bouguer and isostatic maps.

Rock Property Studies

As an adjunct to the geophysical surveys, a number of physical properties measurements of rocks were determined by the USGS, and are tabulated along with previously determined rock property values. These values include density and magnetic susceptibility. These properties will prove to be quite useful to future geoscientists studying the region.

Remanent magnetic and electrical properties were not measured in the USGS laboratory, but remanence was noted from the magnetic signature of some airborne anomalies.

NORTHERN SPOTTED OWL AREA GEOPHYSICAL STUDIES

For this area only one deposit model was considered from the standpoint of geophysical surveying: porphyry copper systems. Of course, there are several other deposit types such as polymetallic vein systems, massive sulfide replacement bodies, and copper skarn systems that are genetically related to porphyry systems.

The primary method of analysis was to use existing aeromagnetic data, mainly in the form of maps, to delineate the outlines of intrusive igneous bodies from which the porphyrys would stem. The description and defense of the operational approach to data analysis is well documented in Open File Report 91-377, the descriptive document assessing the undiscovered mineral deposits in the Spotted Owl study area.

Aeromagnetic Data Analysis

Aeromagnetic maps along the west flank of the Cascades from Northern California to Northern Washington were reviewed by R. Blakely and D. Plouff for the purpose of outlining igneous plutons underlying the blanket of volcanic rocks extruded from the Cascade mountain chain. The logic was that the flat-lying volcanics, although erratically magnetic, would not mask the underlying more homogeneous, somewhat magnetic plutons. It was a satisfactory approach, given the financial and temporal restraints imposed in making the mineral deposit assessment. However, the magnetic nature of porphyry copper deposits together with their plutonic host rocks elsewhere shows that the magnetic contrast approach can be a rather shaky premise.

The 40 known and identified possible porphyry system deposits provided a substantiating guide to the inferred pluton mapping method. The report states that of the 40 known mineral occurrences, 31 are located within 4 km of the edge of a presumed pluton magnetic anomaly.

The aeromagnetic data quality is good, but in the state of Washington the flight line spacing was too large (8 km) to provide more than a regional field representation. The 1:500,000 scale aeromagnetic data are contoured at 50 gamma intervals, but flight lines are not shown. Presumably, the original source maps as prepared by Aero Service Corp. are more complete than those presented in the open file report.

The USGS geophysical data interpreters are very well qualified in their skills. However, industry experience probably would say that this pluton outline estimation method is speculative, and thus the assessment probabilities would have large errors, a matter which is not discussed in the report.

Gravity Data Analysis

Gravity data coverage near the west coast of the United States is fairly good from a regional standpoint, due to past Defense Department support over many years. The gravity data are shaky at 5 milligal intervals, which is too large to identify specific mineral deposits but did serve, when compared with the aeromagnetic maps, to sometimes substantiate the presence of buried plutons. A regional magnetic high, bounded by identified gradients, which is also a gravity low could indeed be a granitic pluton.

The gravity station locations are not shown on the open file report maps, but they are available from source files compiled by the Air Force Chart and Information Center (ACIC) in St. Louis, MO., and from USGS reports referenced in the open file mineral assessment report.

The interpreted gravity data does reveal the presence of lineaments cross-cutting the area. These features may be related to concealed mineralization, a matter alluded to in the assessment report.

Radiometric Data Analysis

Analysis of the National Uranium Resource Evaluation (NURE) airborne spectrometric radiometric data was presented in the assessment analysis. This method is not directly important for mineral assessment in this type of terrain because only a very thin soil cover will prevent any radioactive radiation to be detected by an airborne detector. And ideally the detector system should be flown very close to the ground, which is difficult to accomplish in the mountainous terrain of the subject survey. These facts are not mentioned in the open file assessment report.

The justification in using the airborne radiometric data in the assessment report is that some plutonic outcropping areas may be present, and also there may be a nearby alluvial train of plutonic material that would be identified.

The theory that radiometric signatures may be of importance in porphyry copper resource evaluation is that rather large amounts of potassium are introduced to a region during the mineralization process, and this potassic alteration halo can be identified by the airborne detector.

No mineralized tracts were identified from analysis of the NURE radiometric data; not a surprising finding.

Mining Company Data Analysis

Isotope geochemist S. Church mentioned that Anaconda Mining Company's exploration files were searched (with consultant Bob Grant) in Laramie, WY on activities in the Spotted Owl area. No further mention was made by Church on this matter, and I gather that their material was not too useful in a geophysical related assessment.

TONGASS FOREST AREA GEOPHYSICAL STUDIES

The Tongass Forest area comprises all of southeastern Alaska, and mineral assessment of such a large and varied area was a major undertaking. The evaluation process and results are summarized in U.S. Geological Open-File Report 91-10.

Having spent several summers exploring in the subject area and after playing a role in the discovery of two or three mineral deposits, I can fully appreciate the assessment problems in this area. The only readily prospectable areas lie between the upper tree line and the snow line, this is observable for only a few weeks in the late summer. From past discoveries in the prospectable areas, the mineral endowment under the forest cover must indeed be quite large.

Geophysical Data Analysis

There is no supporting geophysical data analysis contained in the supporting mineral assessment analysis in the open file report. Figure 5 of the report is a 1:2,5000,000 scale reference map with the caption "Map of southeastern Alaska, showing major sources of gravity and aeromagnetic information". It is an index map showing the location of the 14 1:250,000 quadrangles under study in southeastern Alaska. Outlines of 11 individual study areas are shown, together with the references to the U.S. Geological Survey maps covering this large area.

Judging from the geophysical index map and three references, 1:1,000,000 scale aeromagnetic coverage is available in southeastern Alaska. No mention is made of the gravity coverage, but I suspect that it is available from the ACIC mentioned previously.

No USGS geophysicist served on the mineral assessment team. Perhaps principal author and single assessor D. Brew understood geophysical survey matters sufficiently well to integrate them into his own mineral assessment report. However, I seriously doubt it.

D. Brew has prepared Open-File Report 92-307 "Decision Points and Strategies in Quantitative Probabilistic Assessment of Undiscovered Mineral Resources", a well written document that goes a long way toward developing an organized quantification procedure. In his paper, a team of geoscientists (page 10) is recommended, along with a <u>leader</u>, to carry out a mineral assessment. However, the Tongass Nation Forest assessment team (OFR 91-10) does not have a geophysicist-member, in violation of the recommendations of OFR 92-307.

In my opinion, the Tongass mineral assessment report is seriously flawed by only fleeting references to geophysical data located elsewhere. Also, there is only a single mineral assessor, putting a heavy load of credibility on Dave Brew's shoulders. Granted, Brew is an unusually experienced and accomplished field geologist, but, in my mind, this is no way to carry out and report on an important mineral assessment program in a well endowed region.

CORONADO NATIONAL FOREST GEOPHYSICAL STUDIES

Chapter J of the U.S. Forest Service's Forest Plan evidentially is the result of the U.S. Geological Survey's assessment of the probability of undiscovered mineral deposits. This assessment was given orally to our panel by Mark Bultman on Thursday, August 6, 1992.

Inasmuch as the Bultman group is rather hostile to the present three-step mineral assessment process, it is difficult for me to evaluate the geophysical studies in the subject area. However, both Bultman and coauthor Mark Gettings know the areal geophysics, and the existing regional coverage is reasonably good.

Evidentially, frustrations on the part of Bultman, Fisher, Force, and Gettings in attempting to compile an assessment report on the Coronado Forest triggered the questioning of the rational of the three-part assessment method. To me, their comments and questions are rather oblique to the assessment process, and are procedural and bureaucratic rather than scientific.

In the situation of the Cave Creek mineral withdrawal, it is pretty obvious that this was to satisfy news media and environmentalist pressures. The Tucson Mineral Branch group did not take a stand on this matter, which is going to be increasingly important in making objective mineral assessments and establishing future policies.

EAST MOJAVE AREA GEOPHYSICAL STUDIES

The mineral assessment of this area was one of the principal arguments of Warren Hamilton in his criticism of the BORA assessment method. Hamilton's criticisms have technical merit, but they have been strongly delivered in an unprofessional way, which, to me, tends to be self-defeating.

Hamilton's comments on the minimal niobium content of the operating carbonatitic Mountain Pass mine are not very relevant to the probability of other carbonatite deposits occurring in the East Mojave area. Evidentially he felt that there should be a distinction between two types of carbonatite deposits: niobium-bearing and rare earth-bearing. Geologically there is some difference, but it doesn't, to me, have a strong bearing on probability of occurrence.

Hamilton's comments on the pyrometasomatic Vulcan iron mine are well taken, in my opinion. Iron skarn deposits and particularly magnetite iron skarn occurrences are unique from a prospecting standpoint, but apparently are not so regarded by BORA mineral deposit assessors. The reason for their uniqueness is that the aeromagnetic exploration method reveals their presence very well, and the aeromagnetic coverage of the East Mojave area was rather complete.

One of Hamilton's remarks indicated to me that he does not have a thorough grasp of the aeromagnetic surveying method. He evidentially believes that fixed-wing aircraft cannot fly in a "draped" survey mode -- an incorrect assumption.

I suggest that the BORA group contact experienced iron prospectors such as Rodger Chapman, lately of the California Division of Mines, and others with extensive industry experience in order to learn of the probabilities of finding these deposits. I do believe that the present BORA probability model is wrong in this instance, and should be adjusted. The weakness of the BORA estimation of the magnetic iron resources in the East Mojave area is that the BORA estimators lack experience in this type of deposit. This weakness points up the fact that experienced economic geologists and geophysicists must be represented on the estimation team.

HANDIES AND REDCLOUD PEAK AREAS, COLORADO

W. Hamilton criticized the estimation of the Handies/RedCloud areas being unreasonably high, drawing comparison with the proximal Creede and Climax mineralization. R. Sanford defended his field work in the area, and I must say that my sympathy is with Sanford. However, very little geophysical work was displayed or analyzed in the Handies/RedCloud regional mineral assessment, although aeromagnetic surveying was referenced in U.S. Geological Survey Bulletin 1715.

SEWARD PENINSULA TIN GREISEN DEPOSITS

D. Menzie orally presented information on the Seward Peninsula mineral assessment on Tuesday morning, August 4, 1992. Evidentially existing Anaconda Mining Company exploration files were used to help assess the mineral endowment of this area. No particulars on the geophysical treatment in the analysis was discussed, but Anaconda had a strong geophysical group. No geophysicist appeared on the USGS assessment team on this particular area.

DISCUSSION OF ASSESSMENT OF MINERAL POTENTIAL IN OTHER AREAS

During the course of the conference, several areas other than those presented here were brought into the discussion. These included Kootenai, MT; foothills placers, CA; Idaho batholith, ID; and Arizona porphyry coppers, AZ. Primarily, the panel was looking into deposit models and the process by which the USGS employs the three-step assessment, and the use of the Mark III computer program.

In most of these mineralized areas a discussion of the employment of geophysical methods and their use in the analysis process was not warranted, except that it was agreed that the assessment team should include a knowledgeable geophysicist and that the final mineral assessment report review the geophysical aspects of the mineral assessment.

DEPOSIT MODELS; TONNAGE AND GRADE DEPOSITS;CRITIQUE OF SPECIFIC USGS MODELS

Iron Deposits (18d, 25i, 28b, 34a, etc.)

The reconnaissance aeromagnetic geophysical survey method is unique in identifying iron deposits. This statement includes sedimentary and metamorphic iron-formations, iron skarn, and volcanogenic iron. Even in deposits that are largely hematitic such as the earthy Mesabi ores, or in iron carbonates, and even in goethitic skarns, there is enough magnetite present for the deposit to be discovered by the aeromagnetic survey method. Now I will grant that there may be exceptions to this rule, but in my years of experience in the air, on the ground, and underground, in hundreds of iron deposits, I have yet to find one. At best the iron target is obvious, and at the worst it will require a ground follow-up.

Thus I recommend that in the case of suspecting iron skarns to be present in permissive area, that the reconnaissance aeromagnetic survey method be used, and that a knowledgeable geophysicist be retained in the assessment process.

RECOMMENDED EXTENSIONS AND MODIFICATIONS TO METHODOLOGIES

Use of Geophysics

The reconnaissance aeromagnetic survey method is a powerful means of rapidly obtaining geological and assessment at a very low cost. Equipment has evolved to the extent that a single-engine fixed-wing airplane with GPS navigational equipment can accomplish what a large twin-engine airplane used to do, and at a much lower cost. Several years ago a group at the University of Utah even successfully developed a system for an ultra-light airplane -- one weighing less than 254 pounds. In days gone by, the USGS was a leader in airborne geophysics; not so at the present time. At the very least, the Survey should sponsor contractors in the assessment program, should review their own contract specifications to be reasonable and up-to-date, and should themselves be up to date in the data processing and interpretive procedures. Some lessons should be learned from Canadian Geological Survey, which is far ahead of the USGS in the field of aeromagnetics.

The second most powerful reconnaissance geophysical survey method is gravity surveying. Here the Survey is to be commended for research in database processing. However, data gathering, data interpretation and database management have fallen far behind the industry norm. Here again, the USGS should regain leadership in this important assessment field. Without expertise here, and in aeromagnetics, how can the USGS provide the expert personnel to be on mineral assessment teams?

In some instances, other geophysical exploration methods can play an important role in the assessment process: for example, regional electrical surveying such as the audio-frequency electromagnetic surveying, and airborne electromagnetic surveying. An airborne VLF receiver can easily be carried in any aircraft, and thanks to GPS important data can readily be gathered.

Finally, a knowledgeable geophysicist must be on each and every mineral assessment team. And there must be a portion of the review document, together with supporting references and maps, discussing the geophysical relevance in the assessment interpretation. At the present time, this is not a routine procedure.

John S. Sumner

EVALUATION OF SOME MAJOR CONTROVERSIES IN THE METHOD.

S.R.Titley

Others of the review panel will address parts of the BORA 3 step method for resource evaluation. My general comments and fundamental recommendations concerning the geological aspects of assessment, the first stage, will be covered in this report. There will follow specific comments concerning aspects of the review designated for my study and comment. I fully appreciate the mission that BORA has undertaken and the work focused upon that objective and the financial constraints under which the mission is carried out. The comments that follow, therefore, even though dealing with specific aspects of the method should not be construed as, nor are they presented as criticisms of individuals or their efforts to develop the method of resource assessment. I simply see areas where the method and its credibility can be improved.

"ASSESSMENT VS. EXPLORATION"

No amount of statistical treatment and analysis of grade and tonnage will overcome a poor or unreasonable geological assessment, the first step in the evaluation process. And the Tongass paper (op.cit.) correctly, in my experience, identifies this stage and exercise as "the single most critical step in probabilistic mineral-resource assessment." Why then is not the highest level of expertise not always brought to bear on it? This is no criticism of those who are asked to do the job and do so the best way they can. It is a management (and perhaps fiscal) problem. Why not bring in the best people for the job? I appreciate the rhetorical nature of the question but I ask it to focus the attention of the U.S.G.S. on this matter. With some of the most critical decisions of the (my, our) time being made on land use, in a time of political/social/economic contention and diminishing resources, why is the first team, so much of the time, sitting on the bench? Where are the commodity and exploration experts?

The partial Course Notes (Menzies et al.) distributed to the Panel commence with part 4 in allusion to exploration, exploration programs, and comparisons and discussion, ending with the encompassing statement (Menzies et al notes, p. 32) that "Resource assessments frequently require the consideration of more types of deposits than do individual exploration programs, but they usually stop well short of physical discovery of deposits."

Notwithstanding stated emphases during the conference that assessment is not exploration, I don't see much difference between the intellectual mechanisms and data treatment in step 1 of the BORA3step from than of the first steps in exploration and further assert that the evaluation of deposit numbers in a tract is integral to private/corporate regional exploration programs. The BORA has assessed regions for mineral potential (i.e. Tongass) and has assessed regions for the occurrence of specific deposit types (i.e. porphyry ores in spotted owl) - those in the business of ore discovery carry out both kinds of search as well, and by the same means.

The fundamental test of quality of exploration is that of discovery. There should be some corresponding test of mineral assessment, even though it may not extend to exploration of the subsurface. In this matter, I propose the following action be included as a fourth step.

PROPOSAL Oversight of the results of an assessment is necessary. A review of the results by an independent group of experts, a small fraction of which might include members of the original assessment team, should be an integral part of the assessment process. Specialists within and without the Survey could (and should) be involved. The purpose of this review is basically to say that the assessment is credible on geological grounds, or that it is geologically unreasonable. All materials used as a basis for the assessment should be made available.

"ESTIMATION OF THE NUMBER OF UNDISCOVERED DEPOSITS IN TRACTS"

The following comments and questions deal with the partial "Course Notes", Parts 4 and 5. I am taking the information in this document as the existing "word" on operation and application of the method.

My search of this document does not reveal any specifics as to how numbers of deposits are determined. The document deals in some length concerning the problems of using subjective probabilities and group interactions and so on.

Straightforward statements of the criteria used in estimation of deposit numbers, in papers available to me, are in the manuscript by Brew, Drew, and Ludington, on the Tongass National Forest assessment, and specific criteria for discrimination of porphyry systems are stated in the Spotted Owl assessment. But still, I have not been able to grasp exactly how geologists derive a number. My presumption from study of the report is that geologists put pencil on map and said in effect, 'deposits are likely to occur here, here, and here.' Such implied (my reading) specific identification certainly could give high geological credibility to existence of deposits of the assessment. The reading of the Tongass report does not indicate that geologists believed, or had any basis to believe that certain numbers of deposits of specific sizes existed in a tract simply because a tract had a specific geological signature or that deposit numbers were determined by geometrical and analog criteria. Were that to be the case, the geological credibility, in my mind, would be considerably reduced.

"Undiscovered"(?) Resources

I can find no definition or discussion of what constitutes an undiscovered resource. Consequently, questions arise concerning what may be included in an assessment. Survey geologists have wide access to a great number of information sources, many of which, I appreciate, have to remain anonymous. But the question arises concerning Survey geologist John Doe who knows of a deposit of chrome-platinum ore that has been drilled in a tract by the Universal Mining Company, but the results of which have not been announced. Does such knowledge and such a deposit reach the inventory of an assessment as an undiscovered resource? If it does, should there not be a category of unannounced, or unreported resources in the assessment statement?

A Philosophical Point Concerning "Completeness of Exploration"

In unexplored regions, the criteria for search (and assessment?) are very

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different from those regions demonstrated to have a metallogenic inheritance. I have questions concerning the application of one assessment criterion given in the Tongass Report, that of the notion that "tracts already relatively thoroughly explored are less likely to contain undiscovered deposits." While the key word of this statement is "thoroughly" my point of view is that the criterion is not correct or can not be accurately applied because we don't know when exploration has been thorough except when discovery has been made and reserves established. This is not a trivial notion, nor, do I believe, are my reservations about this inconsequential. It seems a paradox that the first targets of corporate exploration are districts, or metallogenic regions, "well-explored" or not but that such districts may be much less favorably considered in resource assessment, than would be a region or district where geologists, for whatever reasons have consistently turned their backs.

So-called "Grass-Roots" exploration in many regions of the Pacific Rim, as well as in many other poorly explored regions continues to result in discovery of many kinds of ores. This "immature" state of exploration contrasts strongly with the mature state of exploration in the United States, a maturity that started to evolve at about the turn of the Century. In the main, exploration has progressed in this country since that time by a process of continuous re-evaluation of "waste" and old mining districts. To my knowledge, few mining districts have been added to the registers of districts in the western states and most of them in Nevada.

No new district, to my knowledge has been added in Arizona since statehood. Yet changing economics, technological advances, and reassessment based on revised views of habits of ore occurrence have resulted in a spectacular record of discovery of tonnage of copper ores, all of which have taken place in old districts, some of which - at the time- were considered thoroughly explored. Search in this region continues.

For this reason, I do not believe that any district can be excluded from inclusion in resource assessments, now or in the foreseeable future, until we are certain all possibilities have been exhausted and until our still-growing knowledge about the formation of ores has advanced well beyond its present state. Experience suggests that the existence of a resource and ores, of greater probability than that of hypothetical occurrence, is a reasonable expectations for dormant mining districts. Further exploration and development of some marginal ores of old districts await the impact of new ideas and changing economics and technology.

Geologists and Geology in the Assessment Process

I am concerned that incorrect perceptions may exist or evolve with evaluation of some parts of the assessment process that stem from an overemphasis on and use of porphyry copper deposits as the model of choice in tests and interpretations. The deposit type is one of the most sought, most studied, and except perhaps for iron basins and the Witwatersrand, probably one of the most geologically conspicuous deposit styles for which we search where it is formed in non-reactive host rocks. (Remote geophysical methods can detect magnetite/magnetite-bearing and radioactive ores). Distinctive terranes and distinctive geological-geophysical-geochemical signatures lend to a "discoverability" for regional assessment purposes that in my experience transcends that of virtually any other kind of epigenetic ore deposit.

Discoverability stems from the very large size (in non-reactive hosts) of the hydrothermal systems involved and the geological/chemical/physical contrasts that the system develops with its crustal hosts. Moreover, "discoverability" extends to ready and reasonable estimates of sulfide and mineral content that may be based on surface inspection, and the fact that many discoveries do not, or have not yet, manifested currently developable or minable grade, does not degrade the fact that they are discoverable with (comparative) ease if not buried by post ore cover or faulting. (In a 7 year period from 1965 to 1972, nearly 50 porphyry centers were discovered in the western-southwestern Pacific and southeast Asian areas, mostly through dense forest cover. Not all have been proven economic at this time, but anomalous (10xClarke) copper is reported from exploration of about 40).

These habits of "assessability or discoverability" contrast with search for veins which are areally smaller, 1 dimensional (length) targets, alteration-restricted or constrained, and lacking strong or significant supergene-related expression. Further, many epithermal veins lack surface exposure and geochemical-geophysical contrast, in comparison with a "typical" porphyry copper deposit. Discoverability is made more difficult because of common erratic occurrence of metals in such systems, stemming in part from an original reduced vertical interval over which hypogene mineralization was developed; many are barren of meaningful metal values through the extent explored. In my experience, these veins, paradoxically, may be underestimated in numbers or extent, and overvalued in monetary assessment. Unlike porphyry systems, assessment would require, in my experience, a higher level of ground-based geological knowledge and substantially more data than the porphyry copper system.

These two kinds of epigenetic ores contrast even more with stratabound Cu-Ag-Co ores, important deposits of which are present in the Belt Series of the northwest, and with the clastic-hosted Pb-Zn-Ag ores of the Brooks Range of Alaska. I am unaware that remotely sensed information, except for aeroEM, allows much confidence in assessment of undiscovered resources made on such a basis, rather, the level of geological input necessary to assess such undiscovered resources is even higher than that required for porphyry or epithermal ore systems. At the greatest stretch of my imagination, I can not conceive a way to assess deposit potential in such rocks without significant and detailed ground-based geological and geochemical information.

I contrast these three important styles of ore occurrence to emphasize my view that the whole structure of development and evaluation of the assessment method should not be predicated heavily upon results using the porphyry copper deposit. I can train and educate college sophomores and juniors to recognize the characteristics of porphyry copper deposits, simply from a descriptive standpoint. I can not do this with such a population for either the epithermal veins or stratabound ores, each of which requires progressively more detailed and sophisticated geo-information and interpretation.

"COMMUNICATION" and CREDIBILITY

Aside from recommendations that may be made concerning the physical and mathematical steps taken in making an assessment, a significant and serious problem that must be addressed is that of meaningful communication of results of an assessment. I sense among some geologists, to whom the results should be important, misunderstanding, or a lack of understanding, of the ultimate product of the 3 step process, which is a set of numbers derived from and couched in the context of some range of statistical implications. This lack of understanding would seem to extend to some survey personnel beyond the process; as such, the lack of understanding must be considered also to extend to outside users of the data. The BORA results can not be used in the correct way if the presentation of results can be understood only by a small and specialized audience. Misunderstandings lead to misinterpretation of the data. One fundamental reason beyond a lack of understanding of statistics, may be a lack of appreciation of the differences between resources and reserves.

Recommendation. Every resource assessment should carry a standard piece of boiler plate that explains the differences between resources and reserves, and the meaning of these terms in the context of statistically-derived assessment results. This statement could well be a diagram such as that shown below from the Bureau of Mines, Mineral Commodity Summaries (1986) and taken from Craig, Vaughn and Skinner (1988), on which are superimposed, in some way, the meaning of the probability estimates of grade and value. While exploration people deal with and certainly understand these differences, those not faced with the uncertainties of the exploration process and the creation of reserves from resources will not.

One way that this or a similar diagram might be annotated and used is suggested below, and although the rigorous statisticians of BORA may flinch at the way in which I have adapted two kinds of data, I believe that this kind of visual presentation, certainly modified in some way, would go a long way to clarify the results of assessments. Proven reserves have a probability nearly a value of 1.0, if not that value. Whereas the existence of an inferred resources (see diagram), which would include incompletely explored parts of mining districts may have a probability near 1.0 but assessments of value have diminished probabilities, which I have suggested lie at or above 0.9 in the diagram shown. The probability range of existence of an undiscovered resource might lie at values less than 0.9, with hypothetical or speculative undiscovered subeconomic resources nearly out of the range of consideration. Values of specific assessments could be assigned by area to such a diagram to more fully convey the degrees of certainty and uncertainty of results in the context of more familiar and comfortable terms. I <u>do</u> concede that this modified diagram is mixing oranges and apples, but I also submit there is a common thread that ties the reserve-resource concept and the place of BORA assessments that might be conveyed in a meaningful way.

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RESERVES		RESOURCES	
Proven Reserves	Inferred Reserves	Hypothetical Ores	Speculative Ores
Probabilities of __Existence__ of Ores in Such Categories			
0.95	*0.9*	*0.8 — 0.2*	*0.1 — 0.01*
Probabilities of Existence of Assessed Metal Content			
0.95	*0.9 — 0.7*	*0.5 — 0.1*	*0.1*

INFORMED JUDGEMENT AND SUBJECTIVE PROBABILITIES

At this time, notwithstanding evolution of programs such as "Prospector" and continuing developments in artificial intelligence, such information has yet to be hardened into "sanctified" quantitative terms that are acceptable by all exploration people in all regions for all ages of rocks for either specific or closely grouped ore deposit styles. The process of ore search and resource assessment has been and remains one of applying informed judgments, based upon available and usually insufficient data, by individual explorationists making independent or group-developed decisions from the standpoint of their own experience or backgrounds. There is usually some economic target that is based upon the circumstances and expectations of the group concerned, but such tonnage-grade targets have, in my experience, been flexible so far as they might constrain the interpretations of the geologists actually involved in ore-finding. One simply can not predict tonnage and grade on the basis of geology for most deposit types. If that were the case, development drilling would be unnecessary or expensively redundant. The basic philosophy of ore search by groups with which I have associated is that "you have to catch the rabbit before you can cook it." I have yet to be involved in any corporate or entrepreneurial-backed exploration program (most of which have been successful) that was developed on a basis of statistics. The spending of private and corporate money in the search for ore remains based upon the "informed judgement" by individuals as the basis of ultimate success or failure.

The matter of "informed judgement" merits comment. Exploration, as well as assessment of mineral potential proceeds on the basis of available information. Ideally, judgement should be based upon complete geological mapping, upon existence of regional and local geophysical information, upon results of surface geochemistry, and upon knowledge of the surface. Only rarely is there quality information of this scope and, consequently only rarely is there sufficient information to establish high confidence in predictability. As a consequence, among professionals whose job it is to find ore deposits, an "informed judgement" is sole basis on which decisions to spend money are made. These are educated estimates, enhanced in many cases by intuitive knowledge, difficult to harden, based upon experience of experts.

The nature of this intellectual exercise is difficult to convey to those who have not carried out the exercise or who have no experience with it. One major exploration group, which has been extraordinarily successful in discovery of ore deposits by conventional and conservative methods, allows certain of its successful professionals an annual allocation of drilling footage to explore "hunches" with no questions asked or justification required. Over a period of ten years, two "hunch programs" (based on informed judgments and experience-based intuition) have resulted in significant economic discovery.

These statements lead to a concern with perceptions of how this process is carried out and concern with the sinister cloak given to the word "guess" - and to concern with the near and long-term effects on National Resource Analysis of such perceptions. Of course these are "guesses" but, hopefully, they are "best guesses" or informed judgments. Geologists, geophysicists, and geochemists "guess" very commonly when making interpretations of past events, drawing cross sections and projecting the future geological events. If both the data for evaluation and the ultimate understanding of it existed, resource evaluation would be beyond the stage of making informed judgments (assessments? guesses?), and there would be no need for further exploration and the resources of the nation would all be tabulated. Exploration and mineral assessment might no longer be the expensive and uncertain exercise and gamble that it now is.

A guess is defined as an opinion reached with insufficient evidence and an. example of a guess is given in my dictionary as "to guess a person's weight". If this is done by looking at a person's name, the uncertainty is great; if one listens to that person's voice, the uncertainty is reduced - and if given after seeing a person, the range of uncertainty is diminished considerably. Moreover, a few experienced individuals become very competent at "guessing" the weight of people and do so at levels with very high accuracy. Thus, a "guess" has a broad range of probability of being correct depending upon the evidence on which it is based and the experience of a "guesser". The exercise of ore search steadily seeks to diminish uncertainties and enhance predictability but even in 1992, exploration and resource evaluation remain activities with continuously uncertain results. Exploration remains an applied "art" involving varied degrees of hard information. The negative spin given to "guessing" and the semantic games played with this process by those unfamiliar with the world of day to day exploration are at the very minimum born of ignorance and contribute nothing substantial and positive to the problems involved in exploration and mineral resource assessment.

An objective of the U.S.G.S. should be that of giving this first step of resource assessment a credibility that it presently lacks. The fact that such estimations are made with degrees of uncertainty based upon data abundance and quality, together with many shades of experience, requires consideration when the further steps in the resource analysis are consummated. Good sense, born of experience, should override obviously or apparently absurd results with cautious conservatism ruling the day.

General Comments on Bulletin 1693

The bulletin serves a useful purpose in the compilation of many geological and metallogenic characteristics of deposit types. Its classification follows a general scheme of current thought in separating ores on the basis of associated (the bulletin uses the term "related") rocks. To the extent that the organization of the Bulletin serves this kind of classification the only criticisms that can be made are quibbling and inconsequential. The organization does, however, result in some strange bedfellows in those instances where one genetic ore type may occur in a variety of kinds of rock associations. For example, as discussed further, one result is to break the genetic deposit type of intrusion-centered or porphyry ores into various subtypes based upon either wall rock effects on alteration or on metallogenic habits. Further, sediment-hosted ores with many common properties are also widely (in pages) separated because ores in "carbonates" are separated from those in clastic rocks, blurring habits and characteristics of some genetic types that commonly occur in strata of the shelf environments.

The utility of this organization in mineral resource assessment is not obvious. Most, if not all, styles of ore deposits have characteristic signatures, which may or may not separate them from other ore types, but distinctive signatures nonetheless. Such signatures may include either observable (rock type, oxidation) phenomena, or interpreted (rift settings, marginal basins, island arcs) settings - as well as others.

Time has precluded a thorough review of specific models and included deposits. However, users of the Bulletin will have to read the fine print on page 10 to realize that the Coeur d'Alene alluded to in the index and described under the category of "simple antimony deposits" (27b) may not be what it seems to be. The uneveness of this treatment is enhanced by the fact that similarly categorized (to C.de`A) types, Kipushi and Olympic Dam, have model names and descriptions. An unknowledgable user is easily misled. Beyond this point, however, there is a place for the Coeur d'Alene and other Ag-Pb-Zn vein ores that occur in clastic rocks, even though our understanding is imcomplete (as it is in many of the deposits shown on p.10, with (contentiously) somewhat less understanding.

There are good reasons to rework and check the models of Bulletin 1693, and while I appreciate the pressures and the fiscal problems, such work should be of high priority.

Sufficient and Necessary Criteria as Elements of Ore Deposit Models Used in Assessment and/or Exploration

Geologists may disagree on the issue of establishing criteria that may be considered as sufficient and necessary to the recognition of mineral potential in the Bora 1st step, but I believe that certain of the ore styles in Bull. 1693 may be so treated. As the descriptive models stand, a user who is unfamiliar may not recognize that there are certain elements and characteristics contained in the written outlines that have more importance than do others but are not indicated as such. As an exploration-oriented person my natural inclination is to search for and sort those listed criteria that lead step by step to increasing degree of certainty of the existence of an "undiscovered resource". I sort these criteria into those that are "sufficient" and those that are "necessary".

If plans are being considered to upgrade 1693, perhaps these ideas and suggestions may be considered, but if excluded from consideration there, I strongly recommend that individual resource assessments outline those criteria or models that have been used in the specific region, with its specific geologic habits, for those specific kinds of deposits reported.

The most important of the sufficient criterion is the known presence of ores of a specific kind in a tract. In the absence of such, however, basic and sufficient criteria for undiscovered ores are those that, in some styles, may lie in the 2-ring of a target and that are the minimum necessary to further examine a block of crust for a specific style of resource occurrence. Degrees of uncertainty exist but if described they would considered as "including but necessary be limited to--." They are scale, terrane, and time dependent. And the criteria may be more easily designated for some styles than for others. Considered here, such sufficiency precludes known exposure of mineralization because if exposed, it falls outside of the "undiscovered" category as I understand that notion in the evaluation process. When favorability of a tract can be established by sufficient features, those criteria that are "necessary" to more confidently enhance the probability of existence of a resource may be applied. These are 5-10 ring features that generally involve data developed at larger scale than sufficient criteria. Examples follow.

Sufficient criteria for consideration of porphyry copper occurrence above thinned or absent continental crust are the presence of subaerial trachyte-andesite-dacite volcanic rocks and alluvial trains or deposits of Au. A great number of deposits or districts of isolated or accreted arc terranes share this minimum pair of habits. In cratonic terranes, the same volcanic rocks with geochemical trains of Pb, Zn, (Ag) and W are sufficient to attract interest. Necessary geological criteria to assert the presence of a resource include, at the top of a pyramid of combinations, the presence of a leached capping, copper oxide in skarn, and the presence of inter-or synvolcanic porphyritic dikes and stocks, followed by combinations of dense fracturing, zoning of alteration and metal habit, appropriate mineral-alteration parageneses, and fluid history as deduced from fluid inclusions, each group requiring more intensified study at progressively greater scale. Geophysical habits of these deposits may also lie at the top of the pyramid if the magnetic and radiometric expressions conform to those found with these deposits. Most of these criteria are listed in 1693 but are given no relative significance.

Sufficient criteria for stratabound Cu-Ag (30b) or Pb-Zn-Ag (31a) would include recognition of ancient cratonic or oceanic continental margin rifts and redbed-evaporitic successions for Cu ores, and reduced carbonate-clastic succession for the Pb-Zn-Ag ores. One of the most important of the sufficient features is that of appropriate ages. Necessary characteristics would stem from studies at greater scale that detail redox signatures such as algal mats and pyrite, the presence of evaporite, dolomite, or pyrite-bearing stratigraphy and geochemical properties. Whereas these features are listed in the descriptions of the deposits, no indication is given of their significance or relative importance.

Sufficient criteria for polymetallic replacement deposits (19a) are the presence of shelf carbonate successions above craton in regions where post-depositional intrusions are present. [In my experience, many skarns including those of Pb-Zn (i.e. 18c) may not be comparably restricted to occurrence above cratonic basement.] Necessary criteria to infer a resource would include evidence of thermal recrystallization of carbonate sections, localized dolomitization, jasperoid, and manganese-silver alteration of both proximal and distal carbonates.

Sufficient criteria for ""Kuroko" ores (28a) are the presence of a submarine felsic-mafic volcanic succession, containing pryoclastic facies, with known iron silicate or iron oxide strata (hematitic cherts in ores younger than mid-Proterozoic and BIF in the pre-2.0Ga systems. (Actually this model is very poorly described in 1693 as it omits some significant detail and omits criteria for the Archean and Proterozoic ores.) Necessary criteria include massive sulphide gossans and stratigraphically constrianed sulphide occurrences. Different necessary criteria will apply to different terranes of age and setting. Distinctive Applied Potential, EM and aeroMag signatures.

Sufficient criteria for some commodities may be as simple as the existence of a tract of appropriate rocks, such as chromite in some obducted oceanic basement successions or layered mafic intrusions, or as simply as a basin of iron formation.

I appreciate that these examples may be contentious with some but I also suggest that the use of Bull. 1693 as a basis of resource assessment would be enhanced by some consideration of those properties of specific deposit types that are really important. For those who might lament the absence of real research being done by BORA, I would point out that this is a very fertile area of study with meaningful basic, practical and societal output.

Porphyry Copper Model. The general descriptive model of the porphyry copper system (No. 17, p.76) can not be separated from that of the skarn-related porphyry copper deposit (No. 18a, p.82), nor from that of the porphyry Cu-Au (No. 20c), p.110), nor from that of the porphyry Cu-Mo (No. 21a, p.115). There are features in common to all of these different metallogenic styles that should constitute features at a high level in the hierarchy of significant geological properties to be considered. Distinctions of the subclasses above, as described in Bulletin 1693, are based upon certain limiting proportions of Cu to Mo. That they may differ metallogenically may be a function of intrusion compositions (i.e., alkalic vs. calc-alkalic), wall rock types (i.e. the skarn-altered ores) or of setting (i.e., the contrast between cratonic and oceanic settings).

The view of what essential criteria constitute the signature of porphyry-centered ore systems certainly varies according to the "eye of the beholder" and varied experience in varied terranes. With due recognition of the expertise of the author of the various descriptive models cited above, it is

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also appropriate to question the basis for such subdivision and to suggest that, in this case, some sort of "tree" of sufficient or necessary criteria could be set forth that would better describe and constrain the data of the Bulletin; further, in the Bulletin treatment, deposit types are puzzlingly separated on the basis of both alteration (i.e. skarn) and on metal endowment. The index separates the different metallogenic subsets of the same style (porphyry-centered systems) on the basis of wall rock. Consequently the different porphyries are further separated by pages of distance in the Bulletin.

A significant omission from the porphyry models is their geophysical signatures. Airborne magnetic and radiometric data constitute important bases for determination of occurrence and position of these ore deposits. Similarly, properties of magnetic susceptibility and gamma-ray spectrometry are significant components of the characteristics of these systems.

Inasmuch as the regional resource analyses that were described on the basis of ore deposit type or style, rather than on (in this case) wall rocks, a much more meaningful organization would appear to deal with deposit style. Such an organization more fully supports the mechanics of appraisal of deposits, in this instance, than does the wall rock separation.

Because tectonic elements (arcs, edges, cratons, ocean floors, etc.) carry their own distinctive signature of metals or deposit styles, any reconsideration of data in the bulletin should consider addressing a classification based upon such separation. An organization so-based leads directly to consideration of specific groups of kinds of deposits and is more easily and fundamentally addressed than a classification based on rock type association.

A further criticism is that the models of the bulletin lack clear definition of specific characteristics of style signatures. Such criteria would appear to be essential to those evaluating metal endowment by the methods outlined. No clear picture was gained during the conference of what it was that geologists used as necessary or essential criteria to infer the presence of a specific deposit type.

Use of the characteristics set out in the Bulletin to assess a region for occurrence of porphyry systems brings one very quickly to a stage of bewilderment as there is no establishment of or rank-ordering of criteria. A hierarchy of features that would extend from presence of a porphyry in a present or once active continental margin or island arc, extending to presence of zoned fractures and fracture abundance values, through alteration and the presence of favorable capping seems a reasonable train of criteria. But nowhere is such a list provided. I see this as a serious shortcoming in Bulletin 1693, <u>if</u> it is to be used as the basis for resource evaluation of porphyry-centered systems.

Sedimentary Exhalative Model. This model deals with a specific genetic ore type in sedimentary rocks formed by processes acting in the submarine environment acting on or near a contemporary surface. Whereas the interaction of a complex series of processes, including diagenesis, synsedimentary

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sulphide deposition, and perhaps epigenetic replacement has been satisfactorily demonstrated in only a few locations, the apparent and grossly stratabound habits of these ores remain an important signature. Ores of some occurrences may be disseminated and some may be massive. The application of the characteristics of this model, as detailed in Bulletin 1693, p.205, leaves open interpretations leading to other kinds of genetic models. This criticism is germane if Bulletin 1693 classifications are utilized as a basis for detailing expectations. The General Description of page 211 does not constrain a unique genetic type and may be applied as a description in part of geological characteristics in the polymetallic replacement deposits (19a) as well as other massive ores in sedimentary strata.

In this classification, the tectonic settings described are arguably incomplete and "muddy" in description. Important controls also include rifts (the Carpentarian of Australia) and rifted continental margins (Rocky Mountain Trench and the Selwyn Basin) but are not considered. A hierarchy of basin order as control is utilized instead; although such basin types may arguably be correct, a focus upon metal associations with certain sedimentary packages is a more practical basis for assessment as it bypasses the requirement for the detailed structural and lithological analyses required to hypothesize basin order.

Grade tonnage data make no distinction as to age and setting of ores, a fact that should be tested on that basis. Wide variation in reporting of the nature of grade and tonnage, as in the copper ores, leaves the meaning of the grade-tonnage figures in doubt. How does one compare the 500+M tonne, 5% zinc ores and the 50+M tonne 15% zinc ores of the Selwyn Basin? Are the 5% zinc ores really economic? And can they be compared with the high-grade giants of the Proterozoic?

Frequency Distribution Curves, Bulletin 1693.

Use of proprietary tonnage and grade data in building the grade/tonnage frequency curves is open to both specific and philosophical criticism in those instances where regional variations in given ore styles appear to be present and where temporal contrasts in metal habit may be demonstrated. Concern with this matter, even after the week of discussions on the methodology where these aspects of evaluation were unresolved in my mind, should raise warning flags related to the credibility accorded these data by those even less-well acquainted with the BORA three-step method.

These are criticisms difficult to detail because of lack of access to the data used to construct the curves. Occasional allusion to the fact that these curves were modified to accord to specific regional differences in certain ore deposit classes, such as the porphyry ores, were not further detailed by any specific examples. Statements that the data fit the world curve, made on several occasions in reference to regional metallogenic contrasts, seem difficult to reconcile in view of known temporal or regional metallogenic differences. And the notion, as stated, that regional differences fit the curves is at least suspect if not highly questionable. Thus, criticism must, reluctantly, be developed from the standpoint of "straw-man" models, and from the data of my files, which can not be compared with USGS data because no one outside of the Survey knows what those data are. My data are subject to inspection, but the U.S.G.S. data are not.

The focus of this criticism is the use of world-wide data to evaluate geographically restricted ores of specific time of formation, of specific and usually constrained settings, and post-ore histories in orebodies that are believed on the basis of my information to occupy only a small and discrete part of the complete world spectrum.

Frequency distribution values in porphyry copper ores should reflect to the extent possible, regional contrasts between enriched and hypogene ores. An early conceptual view of the deposit type and an early definition (Parsons, 1933) holds secondary enrichment as an essential element of the deposit and ores of that time, as well as some ores now, mined rich chalcocite blankets; conversely current mining of hypogene ores at Globe and Sierrita Arizona mine low-grade hypogene ores. This transition in grades should be reflected in considerations of evaluation of deposits of regions.

Mining of this class of orebody has traditionally commenced on low-tonnage high-grade ores and evolves, as plants are amortized, into large-tonnage low-grade operations. This evolution is not only a historical fact, it is also a modern practice as manifested by the search not only for high-grade hypogene ores but also for discovery of secondary enrichment. A small (few 10sM) tonnage of enriched ore may constitute economic discovery where it overlies a great tonnage of lower grade hypogene ore, not economic by itself.

Although the tradition may be changing and the U.S.G.S. has data not available to others, mining companies in Arizona have reported only small reserves because of taxation; the reserve picture may be known to some in specific deposits but the taxing of reserves has precluded at least some exploration and the resources/reserves are doubtlessly are low compared to what may ultimately be mined and what may be strongly inferred in corporate offices.

Is it reasonable to compare the porphyry copper deposits of the Cascades, or for that matter the Philippines, with a world distribution that contains the high-grade secondarily enriched ores of Chile? - Conceding that nothing has a probability of 0, the climatic history of western Washington would appear to have been completely different from that of the high Andes thus precluding virtually any enrichment of the scale of grade and tonnage seen in the Andean systems. Ores of the Cascades appear to be mostly hypogene and near what is conventionally considered as "protore" grade (i.e., 0.2-0.3%). Do ores of such grade constitute economic deposits now or in the foreseeable future? There is little question that they may constitute resources, but of questionable economic recovery with present prices and technology.

Spotted Owl Assessment

Enrichment in the Philippines is more advanced than that seen in the Cascades, but tonnages are order of magnitude smaller and grade considerably diminished from that reported (in my records) from that of the Chilean systems. And mining of the Philippine (Cu-Au) porphyry systems started in

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supergene enriched Cu-Au ores, whereas Panguna, another Cu-Au system of the western Pacific commenced mining in high-grade hypogene ore. Mining of Ok Tedi, in Papua New Guinea commenced with processing of Au-bearing "stripping" overlying chalcocite copper ores above a lower-grade chalcopyrite-dominated hypogene assemblage. This spectrum of contrasts in this deposit type in different regions, exemplifies the difficulties and uncertainties that I see in evaluating deposits on the basis of world-wide, generalized habits of geology and grade-tonnage. Regional contrasts in tonnage, grade, and ore style, most of which are geological rational, must be addressed in evaluation; and without knowing what has been done, especially in evaluation in the Cascades, I am uncertain of the quality of the value assessment.

A second point with the Cascade ores and the assessment as presented deals with what is known (discovered) and what is undiscovered. The concern stems from quotation marks and their implication on the word "undiscovered" on page 46 of 91-337, and detail shown for Area A in Figure 2, p. 9. Some 22 spots shown as porphyry Cu prospects are indicated and 6 points indicate "possible porphyry Cu prospects." What does this mean? - possible prospects? or prospects of possible porphyry copper deposits? Red herring notwithstanding, this is confusing. The 91-337 report leaves open in my mind the question concerning what is included in the assessment; districts with porphyry copper-like habits are discussed as are buried plutons - are both, in whole or in part included in the assessment? and is the hierarchy of assessment, first the notion that half must lie above the median value, and second geological assessment? If this is the case, it seems backward. Geological assessment as step 1, and grade-tonnage fitting step 2 is my understanding of how the process should work but it is not clear in my reading of the material on p. 44-47 (91-337 op.cit.)

A SUMMARY OF OBSERVATIONS AND COMMENTS

There follow some numbered comments that summarize and encompass comments made above. However, three important (to me) basic recommendations concerning major elements of the analysis process lead the list and include the following:

a. MEANINGFUL COMMUNICATION OF THE RESULTS. Improvement here should at least start the process of improvement of credibility.

B. OVERSIGHT AND REVIEW OF RESULTS OF RESOURCE ASSESSMENT. This step, too, will enhance the credibility of results when they are finally put out and is a step that could very likely broaden the base of expertise in making assessments.

C. REGIONAL GEOPHYSICS. I fully appreciate the budgetary constraints on this recommendation and realize that it has extraordinary low probability of implementation. But it is a plea that I will take this medium to make. The potential importance of the use in and application of regional geophysics to this program is practically immeasurable, for both direct and indirect location of resources and as a basis for geological interpretation. Airborne magnetic and radiometry, as well as airborne electromagnetic surveys are integral parts of assessment methodologies in other countries. Yet no

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systematically collected data, of which I am aware, exists at a useful scale. These data should constitute the highest priority of acquisition in continued work of the USGS.

1. The determination of whether or not undiscovered resources exist in an area of concern should be based upon the best range of judgments of experts on regions, ore styles, ore signatures and commodities, a great number of whom exist in the organization. Further, this important task requires the highest level of expertise available and should draw from individuals outside of the USGS who, if they can be found, should have no vested interest in the outcome.

2. Bulletin 1693 is the sole geologic basis on which the criteria for occurrence of resources is based. Whereas it must be conceded that there is much of use in the Bulletin, it must also be noted that it spite of earnest and professional attempt to describe some ore styles, its credibility could be greatly enhanced by wider involvement of the interested and expert community.

3. The treatment of ore-deposit types in the Bulletin is very uneven. One gets an impression that ore types (e.g. precious metal veins; porphyry copper deposits) have been split to pieces in different categories (because a great number of Survey personnel know a lot about them?) while other similarly separable styles (massive sulphides, MVT ores) are poorly and only grossly addressed (from lack of knowledge?).

4. The information in Bulletin 1693 should be augmented to include, for each deposit type considered, that brief and necessary list of sufficient and necessary criteria that are used in assessment. (i.e., pyrite is present in many kinds of deposits, but how is it used to define one? The list of criteria are overwhelming when considered as bases for regional assessments). This is not a criticism of what is included, but a suggestion that such criteria be considered.

5. Many deposit types have distinctive geophysical signatures, which with geological data, may influence estimates. Yet, geophysical signatures for some distinctive ore styles are not alluded to in Bulletin 1693, nor was it evident during the conference that geophysics was always available or applied. It remains a puzzling aspect of funding and management that quality regional geophysics at useful scales is not available but if a national program is to be completed such data useful at 1:125,000 scale would seem an almost desperate requirement for a quality assessment.

6. Consideration should be given to a revision of grade and tonnage data in many cases to more fully address and compare certain kinds of deposits in the context of different attributes in different regions, and different metallogenic habits in time. Credibility of tonnage potential is seriously damaged when world-wide data that include mineral deposit giants of other ages and terranes than those that occur in the United States are used as a basis for estimation of in-place-values.

Nay if I understand anything, greater wealth now lies hidden beneath the ground in the mountainous parts of your territory than is visible and apparent above ground. Farewell. Agricola, 1556, De Re Metallica.

APPENDIX III --VITAE OF PANEL MEMBERS

BIOGRAPHY

DOUGLAS R. COOK

PERSONAL DATA

Date/Place of Birth: December 30, 1925; London, England

Office/Home Address: 2485 Greensboro Drive, Reno, Nevada 89509
Phone - (702) 826-0599; Fax - (702) 826-8291

Status: Retired but active as a director of three operating mining companies and as a geological consultant.

EDUCATION

B.Sc., Mining Engineering, University of Durham, England, 1945
M.A.Sc., Mining Geology, University of Toronto, Canada, 1948
D.Sc., Mining Geology, Colorado School of Mines, 1952

EMPLOYMENT RECORD

1991 - Present	The Winters Company, Tucson, AZ; Consultant
1990 - Present	Pegasus Gold Corporation, Spokane, WA; Director
1990 - Present	Independence Mining Company Inc., Reno, NV; Consultant
1989 - Present	Zapopan N.L., Australia; Alternate Director
1988 - Present	Atlas Corporation, Denver, CO; Director and Chairman of Technical Committee
1988 - Present	Ventures Trident (Fulcrum Management, Inc.), Denver, CO; Consultant
1986 - 1990	Freeport Minerals Company, Reno, NV; Senior Exploration Consultant
1986 - Present	Cook Ventures Inc., Reno, NV (International Exploration and Acquisition Consultants); Consultant
1985 - 1986	Freeport-McMoRan Gold Company (public company), Reno, NV; Senior Vice President and Director
1974 - 1986	Freeport Exploration Company (a division of Freeport-McMoRan Inc.), Reno, NV; President
1973	Freeport Minerals Company, New Orleans, LA; Vice-President

1972	Esso Eastern, Inc., Houston, TX; Minerals Advisor-Regional Studies Coordinator
1970	Esso Australia, Sydney, Australia; Exploration Manager
1967	Humble Oil and Refining Company (Exxon, USA), Denver, CO; Western District Manager
1952	Bear Creek Mining Company (domestic exploration subsidiary of Kennecott Copper Corp.), various locations in western U.S.A.; Field Engineer, Senior Geologist, Chief of Coordinating Unit, Exploration District Manager
1951	Colorado School of Mines, Golden, CO; Instructor
1948	Ontario Department of Mines, Ontario, Canada; Senior Geological Assistant
1946	Consolidated African Selection Trust, Ltd., Sierra Leone, West Africa; Junior Mining Engineer
1942	Londonderry Collieries Ltd., England; Student Mine Surveyor

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PRINCIPAL PROFESSIONAL ATTAINMENTS AND AWARDS

1958	President, Utah Geological Society
1964	Chairman, Mining and Exploration Division, SME of AIME
1966	Trustee and Program Chairman, Northwest Mining Association
1968	Director and Vice President, AIME
1977	Member, Colorado School of Mines Research Institute
1978-Present	Mining Engineering Member of Mackay School of Mines Advisory Board
1981	Trustee, SEG Foundation, Inc.
1983	Distinguished Achievement Award, Colorado School of Mines
1984	Chairman of Finance Committee, Society of Economic Geologists
1987	President, Society of Economic Geologists
1991	Honorary Member, Geological Society of Nevada

PRINCIPAL PUBLICATIONS

"The Ore Deposits of the Main Tintic Mining District," by D.R. Cook, in Guidebook to the Geology of Utah, No. 12, Utah Geological Society, 1957, D.R. Cook, ed.

"The Chief Oxide-Burgin Area Discoveries, East Tintic District, Utah: A Case History," by J.B. Bush, D.R. Cook, T.S. Lovering, and H.T. Morris, Geology, Vol. 55, 1960.

"The Bonanza Project, Bear Creek Mining Company," by D.R. Cook, AIME Transactions, vol. 217, 1960.

"Geology of the Bingham Mining District and Northern Oquirrh Mountains," by D.R. Cook, in Guidebook to the Geology of Utah, No. 16, Utah Geological Society, 1961, D.R. Cook, ed.

"Relation of Some Metal Mining Districts in the Western United States to Regional Tectonic Environments and Igneous Activity," by S.E. Jerome and D.R. Cook, Bulletin 69, Nevada Bureau of Mines, 1967.

"The Ore Deposits of the East Tintic District, Utah," by W.H. Shepard, D.R. Cook, and H.T. Morris. Graton-Sales Volume. Published by the AIME in 1968.

"To Find More Ore, Use Better Exploration Techniques," by D.R. Cook, Mining Engineering, July, 1969.

"The Effective Use of Exploration Techniques for Ore Search," by D.R. Cook, Australian Society of Exploration Geophysicists, Bull. no. 1, vol. 2, January, 1971.

"Exploration or Acquisition: The Options for Acquiring Mineral Deposits," by D.R. Cook, American Mining Congress Journal, vol. 69, no. 21, 1982.

"Case History of the Discovery of Disseminated Gold Deposits in the Jerritt District, Elko County, Nevada," by D.R. Cook, in Case Histories of Mineral Discoveries, vol. 1, SME, 1985.

"Analysis of Significant Mineral Discoveries in the Last 40 Years, and Future Trends," by D.R. Cook, Mining Engineering, vol. 38, no. 2, 1986.

"A Crisis for Economic Geologists and the Future of the Society," by D.R. Cook, SEG Presidential Address, Economic Geology, vol. 82, no. 3, 1987.

"Discovery of the Ertsberg East Copper-Gold Deposit, Irian Jaya, Indonesia," by D.R. Cook, in Case Histories of Mineral Discoveries, vol. 3, SME, 1991.

CURRICULUM VITA

DeVerle P. Harris

RESIDENCE:

3330 North Jackson Avenue
Tucson, Arizona 85719

PERSONAL DATA:

Born January 21, 1931
Married, 6 children
Wife: Sandra Ellen Harris

EDUCATION:

Ph.D., Mineral Economics, 1965, The Pennsylvania State University
M.S., Mineralogy and Petrology, 1958, Brigham Young University
B.S., Geology, 1956, Brigham Young University

CURRENT POSITION AND TITLE:

Professor of Mineral Economics, and Professor of Geological Engineering
Director of the Mineral Economics Program (M.S. and Ph.D.) Department of Mining and Geological Engineering, The University of Arizona
1974-Present

PREVIOUS FULL TIME EMPLOYEMNT:

1966-1974 Assistant, associate, and full professor of mineral economics, Department of Mineral Economics, The Pennsylvania State University

1965-1966 Research geologist and geostatistician, Research Department, Union Oil Company of California

1962-1965 Research Assistant in Operations Research, Department of Mineral Economics, The Pennsylvania State University

1957-1960 Structural and Photogeologist, Geophoto Services, Inc., Denver, Colorado (1957-1959), and Geophoto Services, Ltd., Calgary, Canada (1960)

PREVIOUS PART TIME EMPLOYMENT:

1960-1962 Graduate Assistant, Department of Mineral Economics, The Pennsylvania State University

1956-1957 Economic Geologist, Ran Rex Mining Company

CONSULTING:

Industrial

Gayle Sherie Leslie Corporation
Cities Service Oil Company
Human Resources Development Corporation
San Diego Gas and Electric Corporation
Dunavan, Leisure, Newton & Irving, Inc.
Science Applications, Inc.
Doyon, Ltd.

Research

Hedlin Menzies and Associates
Charles River Associates, Inc.
Pan Heuristics
CONSAD
Synergy, Inc.
Teledyne Corporation
Edison Electric Institute
British Columbia Research

Government

Commission of Mining, Puerto Rico
Marine Minerals, U.S. Bureau of Land Management
U.S. Energy Research and Development Administration
Department of Energy, Mines, and Resources - Canada
U.S. Federal Energy Office
U.S. Army Corps of Engineers
U.S. Energy Information Administration, DOE
U.S. Department of Energy, Grandy Junction Office
U.S. Bureau of Mines
Department of Natural Resources, State of Alaska

Banks

The Inter-American Development bank, Washington, D.C.
The World Bank, Washington, D.C.

ACADEMIC ACTIVITIES:

Requested to serve as Chairman of the Steering Committee for the Development of a Mineral Resources Center at the University of Arizona, 1988 -

Requested to be Chairman of the four-man committee to submit the Proposal to the Board of Regents for the creation of the Mineral Resources Center, 1988 -

Requested to serve as a Member of the Site Advisory Board established to provide advice concerning the interrelation of the Arizona Field Office and the University of Arizona, 1988 -

Supervising seven Ph.D. dissertations, 1990.

Developed the only educatinal and research program in the United States or the world on methods for the quantitative appraisal of mineral and energy resources.

Director of the Mineral Economics Program, which currently (1988) consists of three full professors and approximately 30 graduate students.

Chairman of the College of Mines Committee on Promotion and Tenure 1980-1983 (member of committee, 1985).

Member of committee appointed by President Koffler to investigate the merger of the Colleges of Mines and Engineering, 1984.

Chairman of the University of Arizona Committee on Sabbatical Leave, 1980.

Founder of the University of Arizona mineral economics graduate degree program in 1976.

Courses recently taught include:

Mining/MnEc 418	Mine Investment Analysis, 3 credits
MnEc 450	Economics of Metal Industries, 3 credits
MnEc 500	Economics of Mineral Resource Development and Production, 4 credits
MnEc 600	Readings in Mineral Economics, 3 credits
MnEc 650	Advanced Principles of Mineral Economics, 3 credits
MnEc 651	Quantitative Analysis and Models in Mineral Economics, 4 credits
MnEc 660a-660b	Estimation of Mineral Resources by Quantitative Methods (2 semesters, 3 credits each)
MnEc 665	Forecasting for Mineral Industries, 4 credits
MnEc 696d	Advanced Mineral Commodity Analysis, 3 credits
MnEc 696f	Decision Analysis and Operations Research in Mineral Exploration, 3 credits

SHORT COURSE PRESENTATIONS:

Invited by G. Gaal, Chairman of COGEODATA (Commission on Storage, Automatic Processing, a Retrieval of Geological Data), a subcommittee of the International Union of Geological Sciences (IUGS), to present a two-day pre-symposium short course on mathematical methods in mineral resource appraisal in Ouro Preto, Brazil, November 19-22, 1987.

Invited by Dr. Yuwei Li, Chief of Mathematical Geology, the Chinese Academy of Geological Sciences, to be one of two non-Chinese lecturers for the postgraduate short course on computerized mineral resource assessment held in Beijing, China, October 25 - November 7, 1985.

"Topics in Minerals Resources Appraisal," short course presented to personnel of the U.S. Bureau of Mines, Denver, Colorado, May 28 and 29, 1985; and Spokane, Washington, May 30 and 31, 1985.

"Mineral Resources Appraisal," a three-day short course presented to the U.S. Bureau of Mines, Denver, Colorado, February 10-13, 1985.

"Probability Theory and Statistical Techniques for the Quantitative Appraisal of Mineral Resources," a three-day short course for the U.S. Department of Energy, Grand Junction, Colorado, March 17-19, 1976.

"Quantitative Methods for the Appraisal of Regional Mineral Resource Potential," Mineral Industry Economics, McGill University, 1972.

"Computer Technology for Practicing Petroleum Engineers," a two-week short course presented by Human Resources Development, June 7-23, 1972, Delft, Netherlands. I presented one week:

Application of Linear Programming
The Transportation Problem
PERT and Critical Path
Dynamic Programming and Applications
Fundamentals of Statistics and Probability
Analysis of Statistical Distributions
Queue Theory and Applications

"Analysis of Intangibles (Risk and Uncertainties) in Mineral Property Evaluation," Mineral Management Seminar, The Pennsylvania State University, November 10-14, 1969.

"Evaluation of Mineral Resources on the Public Domain," short course for U.S. Bureau of Land Management, 1969.

RECENT FUNDED RESEARCH:

"Enhancement of Intra-IS Information Fields for Estimation of Epithermal Gold-Silver Endowment," $72,379, under contract to U.S. Geological Survey, 9/1/88 - 8/31/89.

"Research on Methods for the Synthesis of Geoscience Information on Intrinsic Samples for the Estimation of Mineral Resources Case Study: Epithermal Gold and Silver Deposits of Walker Lake Quadrangle, Nevada," ($64,289), under contract to U.S. Geological Survey, 9/1/87 - 8/31/88.

"An Investigation of Quantification Methods and Multivariate Relations Designed Explicitly to Support the Estimation of Regional Mineral Resources," ($61,203), and "Digital Geology for the Walker Lake Region," ($17,436), under contract to U.S. Geological Survey, total amount of $78,639, 1986-1987.

"Improved Methods for Long-Range Forecasting of Mineral Demands," under contract to the Department of the Interior's Mineral Institutes program administered by the Bureau of Mines under allotment grant numbers G1154105 and G1164104, $16,000, 1986-1987.

"Potential Supply Systems: An Integration of Uranium Endowment, Exploration, Exploitation, and Economics," under contract to U.S. Department of Energy, $320,606, completion date August 1981.

"An Improved Appraisal System: An Integration of Opinion, Bayesian Inference, and Computer Communications," under contract to U.S. Department of Engery, $393,089, completion date March 1981.

HONORS AND PROFESSIONAL SERVICE:

Appointed by the President of the International Association of Mathematical Geology as a member of the 1990 Krumbein Medal Award Committee, 1991.

Invited to serve on the Advisory Board of a new journal, Nonrenewable Resources, to be published by Oxford University Press.

Chairman and organizer of the Exploration Session, The 23rd International Symposium on Computer Applications in the Mineral Industry (APCOM '92), to be held April 7-12, 1992, Tucson, Arizona.

Translation of my book Mineral Resources Appraisal (published in 1984 by Oxford) into Chinese, to be published by China Publishing House, 1990.

Appointed by the U.S. Department of State, at the request of the International Atomic Energy Agency, as a uranium consultant, July 5-7, 1989, Denver, CO.

Chairman of Data Integration and Resource Assessment, a session of :"Colloquium on Statistical applications in the Earth Sciences, hosted by the Geologic survey of Canada, Nov. 14-18, 1988.

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Invited (June 1988) to be a member of the Internationale Programme Committee for the XXII International APCOM Symposium to be held in Berlin in 1990, and to co-chair one of the sessions at the conference.

Asked (July 1988) by Gabor Gaal (Chairman of COGEODATA) and Dr. Sinding-Larson (member of IUGS) to be the COGEODATA Regional Representative for the North American Continent.

Invited by Dr. Pena Zhao (President of Wuhan College of Geology, China) to be one of the few non-Chinese participants in a Mineral Resources Appraisal Conference being held in China in 1989.

One of the few experts selected to constitute a National University Advisory Committee to a U.S. Bureau of Mines "outreach program initiative" to university programs in mineral economics and policy, 1988.

Consultant to the Inter-American Development Bank (IADB). Performed field work in Argentina through the Argentine Ministry of Mines and submitted a report entitled "A Preinvestment Economic Analysis of Argentine Mining Projects," to IADB and the Argentine Ministry of Mines, November 1986, 153 p.

Organizer and Chairman of a conference session entitled "Mineral Exploration Modelling and Resource Estimation," Joint National Meeting of ORSA/TIMS, Los Angeles, California, April 14-16, 1986.

Invited to participate in the Dahlem Konferezen Workshop on Resources and World Development: Energy and Minerals held in Berlin, January 12-17, 1986.

LISTED IN:

American Men and Women of Science, 1986.
The Directory of Distinguished Americans, 4th edition, 1986.
The International Book of Honor, 2nd world edition, 1986.
The International Who's Who of Contemporary Achievement, 1985.
The Dictionary of International Biography, vol. XIX, 1985.
Who's Who in the World, 7th edition, 1984.
Who's Who in Frontier Science and Technology, 1984, 1985.

Elected Member of U.S. National Committee for the International Association for Mathematical Geology (1985-1988).

Invited by Dr. Yuwei Li, Chief of Mathematical Geology, the Chinese Academy of Geological Sciences, to be one of two non-Chinese lecturers for the Seminar on Computerized Mineral Resource Assessment, Beijing, China, October 25 - November 7, 1985.

Invited Member of International Union of Geological Sciences Commission on Storage, Automatic Processing, and Retrieval of Geological Data (IUGS-COGEODATA), Working Group 2 on Resource Data and Resource Assessment, September 1985.

Appointed by the International Atomic Energy Agency (IAEA) to co-author (with Dr. Ruzicka, Canadian Geological Survey; and Dr. Finch, U.S. Geological Survey) a manual on a standardized uranium appraisal method for members of the IAEA. This manual is to be distributed by IAEA to all members in 1987.

Invited by the International Atomic Energy Agency, Vienna, to participate in an Advisor Group Meeting (September 30 - October 2, 1985) and a Consultants' Meeting (October 3-8, 1985) on world uranium resources and their estimation.

Co-chairman of session of the International Symposium on Major New Trends in Quantitative Methods for Predicting and Resources Evaluation of Mineral, Oil and Gas Deposits held in Alma-Ata, USSR, September 23-29, 1985.

Invited by Dr. D. A. Rodionov of the Soviet Academy of Sciences to attend and participate in a closed (restricted to only invited scientists) symposium on "Major New Trends in Quantitative Methods for Predicting and Resources Evaluation of Mineral, Oil and Gas Deposits," Alma-Ata, USSR, September 23-29, 1985.

Invited participant in a NATO-sponsored workshop of the Advanced Research Institute on "Marine Minerals: Resource Assessment Strategies," Newtown, Wales, June 10-16, 1985.

Invited (declined) to join the delegation of energy specialists invited by the China Energy Research Society of the China Association for Science and Technology to visit the People's Republic of China, summer 1985.

Program Chairman, Session on Mineral Exploration, 18th International Symposium on the Application of Computers and Mathematics in the Mineral Industries, London, England, March 1984.

Invited (declined) to be a member of the Editorial Board of a new international journal Ore Geology Reviews (ORGE) to be issued by Elsevier as of January 1985. Also invited to write a summary/review paper for the OGRE journal.

Requested by New Mexico Institute of Technology Presidential Search Committee to declare candidacy for president, 1983.

Chairman of the 1983 AIME all-institute session on "Cartels and Commodity Agreements in Minerals and Energy Industries."

Invited (June 22, 1982) contributor to Handbook of Natural Resource and Energy Economics to be published by North-Holland Publishing Company. I will author Chapter 26, "Mineral Resource Information, Supply, and Policy Analysis," in Vol. 3 - Economics of Energy and Minerals.

Advisor to Dr. Fred W. DeMoney, President of Montana Tech, on the design and strategy for an academic program in Mineral Resource Management, Fall 1981 and Spring 1982.

Invited participant in a Fission Reactor Uranium Fuel Assurance Symposium, sponsored by Electric Power Research Institute, May 1982.

Member of National Academy of Sciences Panel to Review the Statistical Program of U.S. Bureau of Mines, Committee of National Statistics, National Research Council, 1981.

Member of panel to review the program of the Kansas Geological Survey and provide advice on Future directions, 1981.

Member of National Academy of Sciences Committee on Critical and Strategic Materials, 1979, 1980, 1981.

Member of Planning Committee for 75th Anniversary Volume of the Society of Economic Geologists, 1980, 1981.

Editor of the Mineral Economics Section of the 75th Anniversary Volume of Economic Geology, 1980, 1981.

Member of an advisory committee to the joint DOE-USGS program for the appraisal of uranium resources, 1979, 1980, 1981.

Requested by the U.S. Department of Interior to research and prepare a manuscript which establishes the preferred structure of a leasing system to replace the location/patent system for tenure of mineral lands of the public domain, 1979-1980.

Member of President of University of Arizona's "Kitchen Cabinet," 1980.

Program Chairman for the 1980 National Meeting of the Society of Economic Geologists on Mineral Resource Appraisal.

Chairman of session on "Mineral Policy Analysis" of the 16th International Symposium on Application of Computers and Operations Research in the Mineral Industry, 1979.

Member of panel to advise the Energy Information Agency, U.S. Department of Energy, on a program for the acquisition and analysis of petroleum reserves and resources of the United States, 1978.

Discussant for session on Uncertainties in Oil and Natural Gas Resources, Workshop on Energy Alternatives and Risks, University of Chicago, November 2-4, 1978.

Invited participant in U.S./West German Nuclear Energy Policy Conference sponsored by American Council on Germany in collaboration with Center for International Studies, MIT; Program for Science and International Affairs, Harvard University; and Max Planck Institute, Sternberg, 1977.

Chairman of all-institute session of American Institute of Mining, Metallurgical and Petroleum Engineers on Economic Analysis, Atlanta, Georgia, 1977.

Provided the summary and conclusions (Wrapup) of a DOE/USGS Workshop Don "Potential Resource Estimation Methodologies for Uranium - Present Methods and Alternatives," Grand Junction, Colorado, December 5-6, 1977.

Invited participant in Workshop on Oil and Gas Reserve and Resource Information, Marriott-Dulles Hotel, Washington, D.C. sponsored by Federal Energy Administration and conducted by William Vogely, The Pennsylvania State University, June 1-2, 1977.

Chairman of the advisory task force for the Federal Power Commission's appraisal of the resource base for natural gas, 1976.

Requested by the National Science Foundation to make an in-depth critique of the methods and estimates of U.S. oil resources may by M. King Hubbert, 1974.

Participated (invited by Resources for the Future) in preparation of a document for National Science Foundation that identified critical problems in energy which merit research support, 1973.

Appointed to and served on the Penn State Solid Earth Sciences Long-Term (1985-1990) Planning Committee, a five-man committee reporting to Vice President for Planning on Future directions for the College of Earth and Mineral Sciences, The Pennsylvania State University, 1973.

Member of a select panel on "Mathematical Models in Mineral Exploration - How Can the Computer Really Help You Find Ore," 11th International Symposium on Computer Applications in the Mineral Industries, April 17, 1973.

Chairman of the Session on Exploration of the 10th International Symposium on Applications of Computer Methods in Mineral Industries, Johannesburg, South Africa, 1972.

Requested by the University of Queensland (Brisbane, Australia) to apply for a Fulbright-Hayes appointed to said University, 1972.

Approached by the Center for Planning and Economic Research of Athens to assist in constructing a long-term plan for development of the mineral industries of Greece, 1972.

Requested (declined) by Dr. James Boyd, Executive Director of the National Commission on Materials Policy, to serve as a member of the commission, 1972.

Chairman of the Session on Ore Search of the 9th International Symposium on Decision Making in Mineral Industries, Montreal, Canada, 1971.

Requested (declined) to provide several lectures to the Logan Club of the Canadian Geological Survey on mineral resources and evaluation, 1969.

Newsletter Editor of the Council of Economics of AIME, 1965, 1966.

Secretary of the Council of Economics of AIME, 1965, 1966.

Recipient of the Sigma Xi award for the Outstanding Master's thesis at Brigham Young University, 1957.

PRESENTATIONS:

Invited plenary speaker at the Fifth South American COGEODATA Symposium, April 20-21, 1989, Caracas, Venezuela; title of presentation: Geoinformation for the Estimation of Mineral Resources.

"Intrinsic Sample Methodology," invited presentation at the COGEODATA - IAMG Symposium on Computer Applications in Resource Exploration: Prediction and Assessment for Petroleum, Metals and Nonmetals, held in Espoo (Helsinki) Finland, July 21-23, 1988.

The Evaluation of Argentine Mining Projects in Mineral Development Potential, a seminar presented at the Pennsylvania State University, October 1986.

New Methods for the Quantification of Geoscience Information and the Estimation of Mineral Resources by Objective, Multivariate Models, seminar presented to the U.S. Geological Survey, Menlo Park, California, October 1986.

"Geostatistical Crustal Abundance Resource Models," invited presentation at the NATO Advanced Study Institute on Statistical Treatment for Estimation of Mineral and Energy Resources, June 22 - July 4, 1986, Lucca, Italy.

Presentation entitled "Mineral Exploration and Production Costs and Technologies - Past, Present, and Future" at the Dahlem Konferenzen Workshop on Resources and World Development: Energy and Minerals, held in Berlin, January 12-17, 1986.

"Estimation of Mineral Endowment by a Geologic Decision Model - General Comments and Case Study," invited presentation at the International Symposium on Major New Trends in Quantitative Methods for Predicting and Resources Evaluation of Mineral, Oil, and Gas Deposits, Alma-Ata, USSR, September 23-29, 1985.

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"Thoughts on Appraising Marine Mineral Resources," invited presentation at the NATO-sponsored workshop of the Advanced Research Institute on Marine Minerals: Resource Assessment Strategies, June 10-16, 1985, Newtown, Wales.

Invited papers at the 27th International Geological Congress, Moscow, USSR, August 4-14, 1984. Title of presentations: "Estimation of Mineral Resources and Potential Supply by Geostatistical Crustal Abundance Models - Some Recent Investigations," and "World Oil Resources: Statistical Appraisals."

18th International Symposium on Computer Applications in the Mineral Industries, London, England, March 26-30, 1984. Title of presentation: "Modeling Dynamic Supply of Uranium - An Experiment in the Integration of Economics, Geology, and Engineering."

Joint AEA/AERE Session on Modeling Resource Supply, 1983 Convention of Allied Social Science Associations (ASSA), San Francisco, California, December 17-30, 1983. Title of presentation: "Modeling Dynamic Mineral Supply - An Experiment in the Integration of Economics, Geology, and Engineering."

Conference on Earth Sciences and Mineral Policy making sponsored by Carnegie Institution of Washington, May 1983. Title of paper: "Mineral Resources Appraisal and Policy - Controversies, Issues, and the Future."

Session on Predictive Metallogeny of the Joint Annual GAC-MAC Meeting, sponsored by the Geological and Mineralogical Societies of Canada, Winnipeg, Canada, May 17-19, 1982. Title of presentation: "An Investigation of the Estimation Process of Predictive Metallogeny."

Invited paper on "Multivariate Geostatistical Analysis for the Prediction of Mineral Occurrence" at the Workshop on Interactive Graphic Computer Programs, sponsored by the Canadian Geological Survey, Ottawa, October 21, 1981.

Invited paper at the Tenth Geochautauqua on Computer Applications in Earth Sciences, Ottawa, October 23-24, 1981, entitled "An Experiment in the Subjective Geological Estimation of Uranium Endowment."

Conference sponsored by NUS on the Appraisal of U.S. Uranium Resources, February, 1981. Title of presentation: "Estimates of Uranium Endowment of San Juan Basin by Formalizing of Geologic Opinion."

26th International Geological Congress, Paris, July, 1980. Title of presentation: "Estimates of Uranium Endowment by Formalizing of Geological Opinion."

Eighty-Fifth Annual Convention of the Northwest Mining Association, December 6-8, 1979. Title of presentation: "The Macroeconomic Policy Implications of a Leasing System for Locatable Minerals."

Workshop on Energy Resource Potentials, Stanford University, April 26-27, 1979. Title of presentation: "World Oil Resources Estimates."

Conference on Broad Mineral Resource Appraisal (sponsored by National Science Foundation), West Virginia University, 1978. Title of presentation: "System Estimation of Mineral Endowment."

International Nuclear Fuel Cycle Evaluation (INFCE/NASAP) Summer Study, Aspen, Colorado, 1978. Title of presentation: "Uranium Resources and Potential Supply."

Workshop on RFF/NSF Project: The Implications of Potential Resource and Environmental Constraints on Growth, September 18-19, 1978, Resources for the Future. Title of presentation: "Long Term Mineral Supply."

Forty-Eighth Annual Conference of the Southern Economic Association, Session on Energy and Fuel Supply Modeling, November 9, 1978. Title of presentation: "Uranium Resources and Potential Supply."

Workshop on Energy Alternatives, University of Chicago Center for Policy Analysis, November 2-4, 1978. Title of presentation: "Extent and Timing of Uranium Availability."

DOE/USGS Workshop on Potential Resource Estimation Methodologies, December 5-6, 1977. Title of presentation: "Ongoing Research in Geostatistical Methods."

Workshop on Energy Information, Institute of Energy Studies, Stanford University, December 15-16, 1977. Title of presentation: "Uranium Resource Estimation."

National Academy of Sciences Workshop on Concepts of Uranium Resources and Producibility, September 20-21, 1977. Title of presentation: "Undiscovered Uranium Resources and Potential Supply."

American Institute of Chemical Engineers, Session on How Much Usable Fuel Do We Have Left?, November 28 - December 2, 1976. Title of presentation: "Comments on the Estimates of Uranium Reserves."

Gordon Conference on Statistics in Chemistry and Chemical Engineering, 1974. Title of presentation: "Concepts and Methods for the Estimation of Metal Endowment."

Arid and Semi-Arid Natural Resources Program, University of Arizona, November 14, 1974. Title of presentation: "Methods and Uses of Mineral Resource Appraisals in Lesser Developed Regions."

The Brookings Institution Round Table on Policies for Growth and Counter Growth, 1973. Title of presentation: "Constraints on Growth-Minerals."

The Sound of Progress - Penn State Television Series: "Computing Ore Reserves," 1973.

Rocky Mountain Geological Society, Penn State, 1972. Title of presentation: "Quantitative Resource Models."

"Quantitative Techniques of Resource Analysis," Department of Mining and Geophysics, Columbia University, 1970.

"Methods of Mineral Resource Appraisal," Department of Energy, Mines and Resources, Ottawa, Canada, 1970.

"The Discounted Cash Flow System," Mineral Economics Group, U.S. Bureau of Land Management, 1970.

"Multiple Discriminate Analysis," Operations Research Section of British Columbia Research, B.C., Canada, 1969.

"Factor Analysis," Operations Research Section of British Columbia Research, B.C., Canada, 1969.

MANUSCRIPT REVIEWS:

Quantitative Prediction for Gold Lodes in Gold Mineralization Series Based Upon Large Scale Mineralization Information, a manuscript submitted to Math Geol. by Liu Anzhou; Lu Shaohua, and Li Xujun, 1991.

"Integration of Geophysical and Geological Data Using Evidential Belief Function," for GEOPHYSICS, 1989.

"Application of Recent Developments of Regression Analysis in Regional Mineral Resource Evaluation," by F. P. Agterberg, for Proceedings of NATO ASI Conference on Statistical Treatments for Estimation of Mineral and Energy Resources, Lucca, Italy, 1987.

"Integrating Spatial and Frequency Information in the Search for Kuroko Deposits of the Hokuroku District, Japan," by D. A. Singer and R. Kouda, for Economic Geology, 1987.

"Optimal Exploration Strategies and Policy Decisions: The Synthesis of Resource Assessments and Operations Research," by M. J. Shulman, for Proceedings of NATO ASI Conference on Statistical Treatments for Estimation of Mineral and Energy Resources, Lucca, Italy, 1987.

Reviewed, per request of Glenn Allcott, Chief of Office of Mineral Resources, U.S. Geological Survey, the manuscript for a book on Mineral Resource Assessment, authored by Dr. Larry Drew, Chief of Branch of Resource Analysis, USGS, 1987.

Book titled Designing Optimal Strategies for Mineral Exploration by J.G. DeGeoffroy and T. K. Wignall, for Economic Geology. Review published in Economic Geology, V. 81, no. 6, 1986, pp. 1567-1568.

"Multiple Cutoff Estimation of Global, In Situ Ore Reserves," by A. Fustos, A. Boyer and R. Boyle, for Canadian Institute of Mining and Metallurgy Bulletin, 1986.

"Short-Term Price Formation in the U.S. Uranium Market," by A. D. Owen, for The Energy Journal, 1984.

"Probability Mapping Using a Monte Carlo Simulation," by M. J. Shulman, for Transactions of SME, 1984.

"Theoretical Aspects of Grade-Tonnage Calculations," by G. M. Philip and D. F. Watson for International Mining Journal, 1984.

"Sustainability: A Resource Planning Concept of the 1980's," by A.H. Purcell, for The Journal of Resource Management, 1984.

"Materials and the Brave New World," by Alvin Kaufman and K. K. Nelson, for The Journal of Resource Management, 1984.

"Cost-Sensitive Mine Planning of Project Pillar Dimensions: A Case Study," by A. D. Smith for The Compass, 1983.

"Maximum Economic Recovery of Federal Coal," by W. D. Watson and R. Bernknopf for The Energy Journal, 1983.

"A Note on Exploration Efficiency and Petroleum Industry Behavior," by E. D. Attanasi for The Energy Journal, 1983.

"Crude Oil Resource Estimates in the United States," by Noel D. Uri, for The Energy Journal, 1980.

"Forecasting Copper Consumption in the U.S. Using Statistical Time Series Analysis," for Transactions of SME, 1973.

Planning for Common Mineral Resources: A Computer Simulation Approach, by W. H. Wallace, J. R. Dunn, and D. Besko, 1969.

Factor Analysis and Magnetite Formation and Distribution in the Smallwood Iron Ore Mine, Labrador, Newfoundland, by Erwin Zodrow, 1969.

PROFESSIONAL SOCIETIES:

American Institute of Mining, Metallurgical and Petroleum Engineers (Society of Mining Engineers)

American Economic Association

International Association of Energy Economists

Society of Economic Geologists

International Association for Mathematical Geology

NOTEWORTHY COMMUNITY SERVICE:

1991 - Present - Bishop of the University Third Ward, Tucson Stake of the Church of Jesus Christ of Latter Day Saints

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1988 - 1991 - High Councilman, Tucson Stake of the Church of Jesus Christ of Latter Day Saints

1987 - 1988 - Bishopric (1st Counselor) of 19th Ward, Tucson Stake

1986 - 1987 - High Priest Group Leader, 19th Ward, Tucson Stake

1985 - 1986 - High Priest Group Leader, 23rd Ward, Tucson Stake

1984 - 1985 - High Priest Group Leader, Tucson 2nd Ward, Tucson Stake of the Church of Jesus Christ of Latter Day Saints

1979 - 1983 - Bishopric (1st Counselor) of Tucson 2nd Ward, Tucson Stake of the Church of Jesus Christ of Latter Day Saints

1972 & 1973 - President, State College Branch, Church of Jesus Christ of Latter Day Saints, State College, Pennsylvania, Eastern Atlantic States Mission.

BOOKS:

Mineral Resources Appraisal - Mineral Endowment, Resources, and Potential Supply: Concepts, Methods, and Cases, Oxford Geological Sciences Series, Clarendon Press, Oxford, 1984, 445 p.

Mineral Exploration Decisions: Guide to Economic Analysis and Modeling, John Wiley & Sons, Inc., New York, 1990, 425 pages.

PUBLICATIONS AND RESEARCH REPORTS:

With Guocheng Pan, "Geoscience Information Synthesis and Estimation of Discoverable Resources and Endowment", Geochataqua '91 Proceedings, Sept. 21-24, 1991, Clark A. Roberts, editor, Lakewood Colorado, pp. 220-232, 1991.

With Guocheng Pan, "Geology-Exploratin Endowment Models for Simultaneous Estimation of Discoverable Mineral Resources and Endowment", Math Geology, v.23, pp. 507-540, 1991.

With Guocheng Pan, "A New Multidimensional Scaling Technique Based Upon Associations of Triple Objects: Pijk--Application to Analysis of Geochemical Data, Math Geology, v.23, pp.861-886, 1991.

With Guocheng Pan, "Consistent Geological Areas for Epithermal Gold-Silver Deposits in the Walker Lake Quadrangle of Nevada and California Delineated by Quantitative Methods," in press, Economic Geology, v. 86, 1991.

With Guocheng Pan, "Subdividing Consistent Geologic Areas by Relative Exceptionalness of Additional Information: Methods and Case Study," Economic Geology, v. 85, 1990, pp. 1078-1083.

With Guocheng Pan, "Quantitative Analysis of Anomalous Sources and Geochemical Signatures in the Walker Lake Quadrangle of Nevada and California," Geochemical Exploration, v. 38, 1990, pp. 299-321.

With Guocheng Pan, "Intrinsic Sample Methodology, in Computer Applications in Resource Exploration: Prediction and Assessment for Petroleum, Metals, and Nonmetals," editors G. Gaal and D.F. Merriam, Computers and Geology Series, v. 7, 1990, Riverside, New Jersey: Pergamon Press, p. 53-74.

Research on Objective Methods for the Estimation of Mineral Resources, Research report to the United States Geological Survey, Nov., 1990, 390 pages.

With Saul B. Suslick, "Long-Range Metal Consumption forecasts Using Innovative Methods: The Case of Aluminum in Brazil to the Year 2000," Resources Policy, v. 16, no. 3, Sept., 1990, p. 184-199.

With Guocheng Pan, "Three Nonparametric Techniques for the Optimum Discretization of Quantitative Geologic Variables," Mathematical Geology, v. 22, no. 6, August, 1990, pp. 699-722.

"Model Design for Sequential Decisions Based Upon Valuation of Exploration Information by Capital Markets--Case Study, Roll-Type Sandstone Uranium Deposits," Application of Computers and Operations Research in the Mineral Industry, Proceedings of the 21st International Symposium, edited by Alfred Weiss, Port City Press, Baltimore, Maryland, 1989, p. 105-115.

"Crustal Abundance Modeling of Mineral Resources: Recent Investigations and Preliminary Results," in (D.F. Merriam, ed.) Current Trends in Geomathematics: An International Symposium, Plenum Press, p. 207-252, 1988.

"Mineral Exploration and Production Costs and Technologies - Past, Present, and Future," in (D.J. McLaren and B.J. Skinner, eds.), Resources and World Development: Energy and Minerals, Water and Land. Dahlem Konferenzen. John Wiley & Sons Ltd., Chichester, England, 1987, pp. 423-442.

With G. Pan, An Investigation of Quantification Methods and Multivariate Relations Designed Explicitly to Support the Estimation of Mineral Resources: Intrinsic Samples, Research Report to the U.S. Geological Survey under Grant No. 14-09-0001-G1399, September 30, 1987, 205 p.

"Thoughts on Appraising Marine Mineral Resources," in (P.G. Teleki, M.R. Dobson, J.R. Moore and U. von Stackelberg, eds.), Marine Minerals: Advances in research and Resource Assessment, D. Reidel Publishing Co., Holland, 1987, pp. 433-466.

With G.J. Jeon, Improved Methods for Long-Range forecasting of Mineral Demands, Research Report to the Mining and Mineral Resources Research Institute, under U.S. Bureau of Mines allotment grant #G1164104, July 1987, NTIS #PB 88-133541/AS.

"Mineral Resource Information, Supply, and Policy Analysis," in (W. Vogely, ed.), Economics of the Mineral Industries, 4th edition, AIME, New York, 1985, pp. 181-224.

With M. Roberts, "Structure of Mineral Use - A Case Study of Potash Use and Future Requirements," Journal of Resource Management and Technology, V. 13, No. 2 (October 1984), pp. 69-84.

"Evolution of Concepts and Methods of Mineral Resource Appraisal," Materials and Society, V. 8, No. 4, 1984, pp. 607-642.

"Mineral Resources Appraisal and Policy - Controversies, Issues, and the Future," Resources Policy, V. 10, No. 2 (June 1984), pp. 81-100.

With Luis Chavez, "Modeling Dynamic Supply of Uranium - An Experiment in the Integration of Economics, Geology, and Engineering," Proceedings of the 18th International Symposium on the Application of Computers and Mathematics in the Mineral Industries (APCOM), March 26-30, 1984, Institution of Mining and Metallurgy, London, 1984, pp. 817-892.

"An Investigation of the Estimation Process of Predictive Metallogeny," Geoscience Canada, V. 10, No. 2 (June 1983), pp. 82-96.

With D. E. Myers, "World Oil Resources: A Statistical Perspective," in (P. Auer and D. Douglas, eds.), Advances in Energy Systems and Technology, V. 4, Academic Press, 1983, pp. 89-164.

"Mineral Endowment - Geostatistical Theory and Methods for Appraisal," in (R. T. Newcomb, ed.), Future Resources: Their Geostatistical Appraisal, West Virginia University Press, Morgantown, West Virginia, 1982, pp. 83-135.

With Brian J. Skinner, "The Assessment of Long-Term Supplies of Minerals," in (V. K. Smith and J. V. Krutilla, eds.), Explorations in Natural Resource Economics, The Johns Hopkins University Press, Baltimore (for Resources for the Future, Inc.), 1982, pp. 247-326.

With F. P. Agterberg, "The Appraisal of Mineral Resources," 75th Anniversary Volume, Economic Geology, 1981, pp. 897-938.

With F. J. Carrigan, "Estimation of Uranium Endowment by Subjective Geological Analysis - A Comparison of Methods and Estimates for the San Juan Basin, New Mexico," Economic Geology, V. 76, No. 5, (August 1981), pp. 1032-1055.

With Salvador Ortiz-Vertiz, Luis Chavez, and Emmanuel Agbolosoo, Systems and Economics for the Estimation of Uranium Potential Supply, Research Report to the U.S. Department of Energy, Grand Junction Office, Colorado, on BFEC Subcontract # 78-238-E, July 1981, 609 p.

Part I - Potential Supply Systems Based upon the Simulation of Sequential Exploration and Economic Decisions - Systems Designed for the Analysis of NURE Endowment.

Part II - Crustal Abundance and a Potential Supply System.

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Appendix II - Mathematical Theory, 27 p.

Appendix III - Computer System Documentation

Part A - System Overview, 128 p.
Part B - PLATO User's Manual, 418 p.
Part C - PLATO Lessons JAYMO, FLASH 1, 219 p.
Part D - PLATO Lesson FLASH 2, 173 p.
Part E - PLATO Lessons ERDA1, ERDA2, ERDA3, 140p.
Part F - PLATO Lessons ERDA4, ERDA5, 178 p.
Part G - PLATO Lessons ERDA6, ERDA7, ERDA8, ERDA9, ERDA10, 210 p.
Part H - PLATO Lesson PLATO 4, 167 p.
Part I - PLATO Lessons STRAT, VOCQUIZ, 200 p.
Part J - PLATO Software References
Part K - PLATO Hardware Guide
Part L - Off PLATO Programs: Program MASTER, 414 p.
Part M - Off PLATO Programs: Other Programs, 339 p.

Appendix IV - Participants' Data and Results

Part A - Data, Volume 1 of 5 (BETA), 270 p.

Data, Volume 2 of 5 (CURLY), 270 p.
Data, Volume 3 of 5 (HADRIAN), 270 p.
Data, Volume 4 of 5 (SHIVA), 270 p.
Data, Volume 5 of 5 (VELMA), 270 p.

Part B - Results, 350 p.

Appendix V - Geologists' Information Package

Part A - Literature Survey

Vol. 1 The Conceptual Geologic Model, 53 p.
Vol. 2 USGS San Juan Basin Study, 107 p.
Vol. 3 San Juan Basin, 275 p.
Vol. 4 Chama Embayment, 80 p.
Vol. 5 Uranium Mineralization and Ore Reserve Data, 180 p.

Part B - Charts, Maps, and Slides

Appendix VI - CDC and DEC-10 Fortran Computer Tapes

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"The Geology of Dutch Peak Area, Sheeprock Range, Tooele Country, Utah," Bringham Young University Research Studies, Geology Series, v. 5, no. 1, 1958. 82 p.

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"Mineral Resource Stocks and Information," Chapter 26 in Volume 3, Economics of Energy and Minerals, of the Handbook of Natural Resource and Energy Economics being published by North Holland Publishing Company as part of a series, Handbooks in Economics (Kenneth J. Arrow and Michael D. Intriligator, eds.).

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(With Saul Suslick)

"Latin American Metal Consumption--Recent Trends and Determinants," Materials and Society (in press), 1991.

BOOKS FORTHCOMING:

(With Warren Finch and Vladimir Ruzicka)

"Methods for the Estimation and Economic Evaluation of Undiscovered Uranium Resources", to be published by The International Atomic Energy Agency, Vienna, Austria, 1991.

UNPUBLISHED MANUSCRIPTS:

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"Uranium Economics - Current and Future Outlook," Presented at the Western Energy Conference, College of Eastern Utah, Price, Utah, March 22, 1980.

"Lead Time in U308 Production Capability," Presented at a Workshop on Alternative Energy Strategies, Center for Policy Study, University of Chicago, November 6, 1978.

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A Critique of the Estimation of the Value of Alaska Mental Health lands made by Metz, Delong, and Associates, A consultant's report prepared for the Alaskan Department of Natural Resources, Division of Land and Water Management, Anchorage, Alaska, may 30, 1989, 40 p.

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(With Michael Rieber)

"U.S. Mercury Marketing and The Impact of Government Stockpile Releases", An Independent Market Study for McDermott Mine JV, Placer Dome, U.S. Inc., June, 1990

"Rejoinder to Bureau of Mines Comments on a Report by Michael Rieber and DeVerle Harris entitled U.S. Mercury Marketing and the Impact of Government Stockpile Sales, September, 28, 1990, 9 pages.

September 1992

Stuart E. Marsh

CURRICULUM VITAE

CURRENT TITLE: Associate Professor - Arid Lands Resource Sciences and Geography and Regional Development. Associate Director Arizona Remote Sensing Center.

ADDRESSES:

Office - Office of Arid Lands Studies
University of Arizona
845 North Park Avenue
Tucson, Arizona 85719
Telephone (602) 621-7896

Home - 4318 W. Bunk House Road
Tucson, Arizona 85741
Telephone (602) 744-0015

EDUCATION:

Date	*Degree*	
1979	Ph.D.	Stanford University Stanford, California Applied Earth Sciences Dissertation: "Quantitative Relationships of Surface Geology and Spectral Habit to Satellite Radiometric Data" Major Professor: Ronald J.P. Lyon
1975	M.S.	Stanford University Stanford, California Applied Earth Sciences (Exploration Geology) Thesis Topic: "Feasibility of Satellite Thermal Infrared Remote Sensing for Geothermal Resources" Major Professor: Ronald J.P. Lyon
1973	B.S.	George Washington University Washington, D.C Geology

PROFESSIONAL EXPERIENCE:

1988 - 1992 Associate Professor - Arid Lands Resource Sciences and Geography and Regional Development; Associate Director Arizona Remote Sensing Center, University of Arizona.

1986 - 1988 Manager, Geoscience Computer Services, Sun Exploration, Sun E&P, Dallas, Texas.

Responsible for the design and management of technical projects and personnel (14) involving the application of geoscience exploration workstations, digital data integration, and computer mapping techniques to exploration. Technical management of computer systems and contract software development staff (5). Budget planning and administration $3.5 MM.

1983 - 1986 Manager, Remote Sensing Processing and Field Systems, Sun Exploration, Sun E&P, Dallas, Texas.

Project manager and principal scientist responsible for a group (5) applying remote sensing and digital data integration and processing techniques to hydrocarbon and mineral exploration.

1981 - 1983 Senior Geologist/Instrument Specialist, Sun Exploration, Sun E&P, Dallas, Texas.

Senior geologist responsible for the application of remote sensing techniques to hydrocarbon and mineral exploration. Responsible for the utilization and analysis of Landsat MSS, TM, radar, and field and airborne spectrometer data. Projects encompassed basin analysis, photo-interpretation, geomorphology, geochemistry, and the analysis of visible and near-infrared spectral data. Developed advanced processing techniques for the analysis of digital exploration information.

1980 - 1981 Research Geologist, Gulf Science and Technology, Gulf Oil Corporation, Pittsburgh, Pennsylvania.

Responsible for the processing and interpretation or of satellite, airborne, and laboratory reflectance data. Initiated the first successful application of high resolution spectral techniques for alteration mapping within Gulf Oil Corporation.

1979 - 1980 NRC Resident Research Associate,
Geology and Geophysics Group,
Jet Propulsion Laboratory, Pasadena, California.

Research involved a detailed ground spectral and thermal measurement program that was used in conjunction with JPL image processing and thermal modeling of aircraft and satellite spectral and thermal radiometry.

1974 - 1978 Geologist, U.S. Geological Survey, EROS Program,
Reston, Virginia.

Part-time employment during my graduate work designed to support my research efforts in spectral sampling and geologic mapping.

MEMBER/SERVICE:

Association of American Geographers
American Soc. of Photogrammetry & Remote Sensing
American Water Resources Association
Geological Society of Washington

Director, S. Arizona:
Arizona-Nevada Academy of Sciences

Associate Editor (Geology/Water Resourcs/Hydrology):
Photogrammetric Engineering and Remote Sensing

AWARDS/FELLOWSHIPS:

HEW Resource Development Fellowship, Stanford University - 1975-1976.

National Research Council Post-Doctoral Fellowship - 1979-1980.

NASA Certificate of Recognition - 1983.

Distinguished Manager Citation, SUN Professional Management Program - 1985.

Marquis Who's Who in The West - 23rd Edition 1991

GRANTS AND CONTRACTS:

Year	*Amount$*	
1989-1990	100,000	National Aeronautics and Space Administration The Use of Remote Sensing and GIS Technologies to Quantitatively Assess Agricultural Land Use Co- Principal Investigator
1989-1990 1990-1991	17,500 21,500	Arizona Department of Environmental Quality Interagency Agreement for Remote Sensing Support Co- Principal Investigator
1989-1990 1990-1991	21,000 75,000	Jet Propulsion Laboratory End-to-End Sensor Simulation Co - Investigator w/ R.A. Schowengerdt
1990-1991	27,113	U.N. Food and Agricultural Organization Design of an Integrated Computer Workstation for the Global Information and Early Warning System Co- Principal Investigator
1990-1991	3,890	Texaco Exploration and Production Company A Short Course in Remote Sensing and GIS Technologies Principal Investigator
1990-1991	15,601	City of Tucson - Tucson Water A Multistage Remote Sensing Study to Assess and Monitor Relationships Between Ground Water and Riparian Habitat in the Tanque Verde Wash Principal Investigator
1990-1991	9,611	U.S. Environmental Protection Agency EMAP-LC Hexagon Pilot Field Study Verification Data Collection Program Principal Investigator
1990-1992	224,956	The Ford Foundation U.S. - Mexico Transboundary Water Resources Management Co- Investigator
1990-1991	20,000	Mobil Research and Development Corporation Donation of Field Spectrometers and Radiometers Principal Contact
1990-1991	29,500	ORYX Exploration Company Donation of Field Spectrometers and Computers Principal Contact

1991-1992	80,000	U.S. Bureau of Land Management Evaluation of Global Climate Change in the San Pedro Valley, Arizona Co- Investigator
1992-1993	75,792	U.N. Food and Agriculture Organization Development of a Computer Workstation for the Global Information and Early Warning System Co-Principal Investigator
1992-1993	30,900	International Center for Scientific Culture Advanced Remote Sensing and GIS Training Program for Scientists from the Peoples Republic of China. Principal Investigator
1992-1993	4,479	The Mining Remedial Recovery Company (MRRC) Acquisition and Processing of Airborne Video Remote Sensing Data for Selected Test Sites Principal Investigator

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Marsh, S.E., Schieldge, J.P., and A.B. Kahle, 1982. In situ measurement of thermal inertia for remote sensing studies. Photogrammetric Engineering and Remote Sensing, Vol. 48., p. 605-607.

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Marsh, S.E., Walsh, J.L., Lee C.T., and L.A. Graham, 1991. Multitemporal Analysis of Hazardous Waste Sites Through the Use of a New Bi-Spectral Video Remote Sensing System and Standard Color-IR Photography. Photogrammetric Engineering and Remote Sensing, Vol. 57, No. 9, p.1221-1226.

Marsh, S.E., Walsh, J.L., Lee, C.T., Beck, L., and C.F. Hutchinson, 1992. Comparison of Multitemporal NOAA-AVHRR and SPOT-XS Data for Mapping Land Cover Dynamics in the West African Sahel. International Journal of Remote Sensing, (in press).

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Williams, R.S. Jr., and S.E. Marsh, 1983. Definition of geological remote sensing; in Geological Applications (Chapter 31), R.S. Williams, Jr. - editor. Manual of Remote Sensing, 2nd Edition, American Society of Photogrammetry, p. 1667-1672.

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Collins, W., Chang, S., Yu, T., and S.E. Marsh, 1984. "High Spectral Resolution Imaging Systems for 1984;" in Proceedings International Symposium Remote Sensing of Environment Third Thematic Conference: Remote Sensing for Exploration Geology, Colorado Springs Colorado, Vol. I, p. 293-294.

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Marsh, S.E., Lyon, R.J.P., and F.H. Honey, 1975. "Evaluation of NOAA satellite data for geothermal reconnaissance studies." *Second United Nations Symposium on the Development and Use of Geothermal Resources*, Vol. 2, p. 1135-1141.

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Marsh, S.E. and J.A. Newcomer, 1983. "Comparison of calibrated and uncalibrated Landsat and Airborne Thematic Mapper data for geologic mapping." in *Digest 1983 International Geoscience and Remote Sensing Symposium* (IEEE - IGARSS'83), San Francisco, Ca., Vol. II, p. 4.1-4.7.

Newcomer, J.A., and S.E. Marsh, 1983. "Integration of geological and geophysical point and multispectral data for exploration." in *Proceedings National Conference on Resource Management Applications*, CERMA, San Francisco, Ca., Vol. IV, p. 35-47.

Marsh, S.E., Townsend, T.E., Podwysocki, M.H., Goetz, A.F.H., Vane, G., and P.N. Slater, 1983. "Imaging systems for the delineation of spectral properties of geologic materials in the visible and near-infrared." in Frontiers for Geological Remote Sensing from Space, Fourth Geosat Workshop, American Society of Photogrammetry, p. 13-19.

Walsh, J.L. and S.E. Marsh, 1991. "Application of multispectral remote sensing and geographic information system technologies for land use mapping in Africa." in Third Forest Service Remote Sensing Applications Conference 1990, Tucson, Arizona, American Society of Photogrammetry and Remote Sensing, p. 219-231.

Walsh, J.L., Hutchinson, C.F., and S.E. Marsh, 1991. "Integration of aerial video and satellite image data for mapping land cover in Africa." in Resource Technology 90 Conference, Washington, D.C., American Society of Photogrammetry and Remote Sensing, p. 148 - 157.

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Marsh, S.E., Walsh, J.L., C.T. Lee, and L.A. Graham, 1991. "Multitemporal Analysis of Hazardous Waste Sites Through the Use of a New Bi-Spectral Video Remote Sensing System and Standard Color Photography. in Proceedings Eighth Thematic Conference on Geologic Remote Sensing, Denver, Colorado, Environmental Research Institute of Michigan, vol. 1, p. 239-251.

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Curriculum Vitae

LAWRENCE DAVID MEINERT

<u>Business</u>:
Department of Geology
Washington State University
Pullman, WA 99164-2812
(509)335-2261
FAX: (509) 335-7816

<u>Home</u>:
SW 820 Viento Drive
Pullman, Washington 99163
(509)334-7759

<u>Personal</u>: Married with two children

<u>Education</u>:
Stanford University, Stanford, California - Ph.D. Geology, 1980
Carleton College, Northfield, Minnesota - B.A., 1975

<u>Honors</u>:
Listed in Who's Who in Frontiers of Science and Technology
Logan Lecture - Geological Survey of Canada
Keynote Speaker - MDSC Symposium, Finland
United Nations UNDP Lecturer - Chile

Professional Experience:

1993-present	Professor, Geology Department, Washington State University - Duties include teaching and research in economic geology.
1986-1993	Associate Professor, Geology Department, Washington State University
1988	Visiting Professor, Geology Department, LaTrobe University, Australia
1981-1986	Assistant Professor, Geology Department, Washington State University
1981	Instructor, Department of Applied Earth Science, Stanford University
1980-1981	Post-doctoral Research Associate, Geology Department, Stanford University

Professional Societies:

American Institute of Mining Engineers
Geological Society of America
Geological Association of Canada
International Association on Genesis of Ore Deposits
Society of Economic Geologists

5-30

Publications:

Meinert, L.D., Newberry, R.J., and Einaudi, M.T., 1980, An overview of W, Cu, and Zn-bearing skarns Western North America: in Mineral Deposits of the Pacific Northwest, Field C., and Silberman, M eds., U.S. Geological Survey Open File Report 81-355, p. 303-327.

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Read, J.J., and Meinert, L.D., 1986, Gold-quartz vein mineralization at the Big Hurrah Mine, Seward Peninsula, Alaska, Economic Geology, v. 81, p. 1760-1774.

Meinert, L.D., 1987, Skarn zonation and fluid evolution in the Groundhog Mine, Central Mining District, New Mexico, Economic Geology, v. 82, 523-545.

Meinert, L.D., 1987, REF - A multi-user bibliographic data base application for geological sciences, Geoscience Information Society Proceedings, v. 16, p. 39-52.

Meinert, L.D., 1987, Aladin - Software evaluations of leading programs, in Nolan, J.M., ed., Micro Software Evaluations, Meckler Publishing Corp, London, v. 3, p. 15-25.

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Meinert, L.D., Myers, G. L., and Brooks, J.W., 1990, Skarn deposits in Nevada: Great Basin Symposium - Geology and ore deposits of the Great Basin, Geological Society of Nevada Fieldtrip #2 Guidebook, 208 p.

Hawksworth, M.A., and Meinert, L.D., 1990, Alteration and fluid inclusion study of the Groundhog vein system, Central Mining District, New Mexico, Economic Geology, v. 85, 1825-1839.

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Ettlinger, A. D., Meinert, L.D., and Ray, G.E., 1992, Gold skarn mineralization and fluid evolution in the Nickel Plate Deposit, Hedley, District, British Columbia: Economic Geology, v. 87, p. 2085-2112.

Gemmell, J. B., Zantop, H., and Meinert, L.D., 1992, Genesis of the Aguilar zinc-lead silver deposit, Argentina: Contact metasomatic versus sedimentary exhalative, Economic Geology, v. 87, p. 1541-1565.

Meinert, L.D., 1992, Skarns and skarn deposits : Geoscience Canada, v. 19, (in press).

Meinert, L.D., 1992, Igneous petrogenesis and skarn deposits: in Kirkham, R.H., and Sinclair, D., (eds.) Proceedings of the IAGOD conference on ore deposit models, (in press).

Franchini, M,B, Montenegro, T., Malvicini, L., and Meinert, L.D., 1993, Iron skarn deposits at Caicayén Hill, Neuquén Province, Argentina: Characteristics, composition and evolution of ore forming fluids: Revista de la Asociacion Geologica Argentina, v. 48, (in press).

Reviewed Abstracts and minor publications:

Meinert, L.D., 1979, Development of mineralized skarns, mantos, and breccia pipes in sedimentary rocks in the Cananea district, Sonora, Mexico, Geological Society of America, Abstracts with Programs, v. 11, p. 477.

Meinert, L.D., 1980, Evolution of metasomatic fluids by transport over large distances: An example from the Paymaster zinc skarn, Esmeralda County, Nevada, , Geological Society of America, Abstracts with Programs, v. 12, p. 482.

Meinert, L.D., Newberry, R.J., and Einaudi, M.T., 1980, Characteristics of W, Cu, and Zn-bearing skarns in Western North America: An overview, Geolgoical Society of America, Abstracts with Programs, v. 12, p. 120.

Meinert, L.D., 1982, Large scale (2 km) mineralogical zoning as an indicator of fluid transport at the Groundhog Mine, New Mexico, Geological Society of America, Abstracts with Programs, v. 14, p. 564.

Meinert, L.D., 1982, Petro-tectonic setting of skarn deposits - contrasts between Fe, W, Cu, Zn-Pb, Mo, and Sn-bearing skarns, 6th IAGOD Quadrennial Symposium, p. 247-248.

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Meinert, L.D., and Hawksworth, M.A., 1983, Fluid inclusion composition and temperature evolution in a zoned skarn system, Groundhog Mine, New Mexico, Geological Society of America, Abstracts with Programs, v. 15, p. 642.

Hawksworth, M.A., and Meinert, L.D., 1984, Fluid inclusion characteristics and mineral zoning in the Groundhog vein system, Central District, New Mexico, Geological Society of America, Abstracts with Programs, v. 16, p. 532-533.

Meinert, L.D., 1985, The use of microcomputer databases for geologic education and research: Bibliographies, budgets, commodity profiles, admissions, and grades, Geological Society of America, Abstracts with Programs, v. 17, p. 661.

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Meinert, L.D., 1986, The occurrence of gold in skarns - An example from the Whitehorse District, Yukon, Canada, TERRA cognita, v. 6, no. 3, p. 520.

Meinert, L.D., 1987, *Review of*: The conglomerate-hosted Repparfjord copper ore deposit Finnmark, Norway. Monograph Series on Mineral Deposits No. 24 (Bernhard Stribrny): Economic Geology, v. 82, p. 1976-1977.

Meinert, L.D., 1988, Gold and silver in skarn deposits: Geol. Soc. Australia, Abstracts with Program, v. 23, p. 614-616.

Myers, G. L., and Meinert, L.D., 1988, Zonation of the Copper Canyon-Fortitude gold skarn system, Geological Society of America, Abstracts with Programs, v. 20, p. A93.

Brooks, J.W, Meinert, L.D., Kuyper, B.A., Lane, M.L., and Pettit, P.M.,1989, Mineralogy and Petrology of the McCoy gold skarn, Lander County, Nevada:, Geological Society of America, Abstracts with Programs, v. 21, p. 59-60.

Ettlinger, A. D., Meinert, L.D., and Ray, G.E., 1989, Mineralogy and hydrothermal fluid characteristics of the Nickel Plate Deposit, Hedley, British Columbia:, Geological Society of America, Abstracts with Programs, v. 21, p. 76.

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Ettlinger, A. D., and Meinert, L.D., 1990, Gold in Russian Skarns: An example from the Siniukhinskoe District, Siberia, USSR: Society for Mining, Metallurgy, and Exploration, Abstracts with Programs, p. 99.

Myers, G. L., and Meinert, L.D., 1990, Geochemical controls on gold distribution in skarn ore at the Fortitude Deposit: Society for Mining, Metallurgy, and Exploration, Abstracts with Programs, p. 99.

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Myers, G. L., and Meinert, L.D., 1990, Geology of the Fortitude gold skarn, Battle Mountain, NV : Geological Society of Canada, Abstracts with Programs, v. 15, p. 94.

Myers, G. L., and Meinert, L.D., 1990, Fluid inclusion and stable isotope study of the Fortitude gold skarn, Battle Mountain, NV: 8th IAGOD Quadrennial Symposium, Abstracts with Programs, p. A200-201.

Meinert, L.D., 1990, Exploration models for skarn deposits: 8th IAGOD Quadrennial Symposium, Abstracts with Programs, p. A163.

Meinert, L.D., 1990, Avances recientes en geologia y exploracion de yaciamentos de Cu y Au tipo skarn: Taller Sobre Yacimientos Tipo Skarn Y Otras Mineralizaciones Magmatico- Hidrotermales, United Nations Development Project CHI/88/021, p. 2.

Meinert, L.D., 1991, Metamorphism and the formation of ore deposits in the earth's crust: Res Terra, Ser. A, No. 5, p. 49.

Johnson, T. W., and Meinert, L.D., 1991, Paragenesis and mineralization zonation of the McLaren Cu-Au-Ag skarn and replacement deposit, New World District, Park County, Montana: Geological Society of America, Abstracts with Programs, v. 23, p. A 292-293.

Meinert, L.D., 1992, Exploration criteria for skarn deposits: Society for Mining, Metallurgy, and Exploration, Abstracts with Programs, p. A 125.

Meinert, L.D., 1992, Aspects generaux des gisements de skarn: Association des Prospecteurs Gaspésiens, Abstracts with Programs, p. 37.

Meinert, L.D., 1992, Exploring for skarn deposits in the new world of mining: Northwest Mining Association, Abstracts with Programs, v. 98, p.

Meinert, L.D., 1992, Skarn deposits in the porphyry copper environment: Northwest Mining Association, Porphyry Copper Model Short Course Workbook, p.

Zimmerman, B. S., Myers, G.L., Meinert, L.D., and Larson, P.B, 1992, Stable Isotopic Evidence for Magmatic Fluid Dominance in the Fortitude Gold Skarn Deposit, Lander County, Nevada: Geological Society of America, Abstracts with Programs, v. 24, p. 144-145.

BIOGRAPHICAL SKETCH

May 1992

Donald E. Myers (Ph.D. Mathematics, Univ. Illinois, 1960)

I. Professional Positions

Professor of Mathematics (on faculty since 1960, Professor since 1968)
Dept. of Mathematics
University of Arizona
Tucson,Arizona 85721
(602) 621 6859
Bitnet MYERS2@ARIZRVAX
Internet myers@math.arizona.edu

Sabbatical, Stanford University (Statistics and Applied Earth Sciences) Spring 1988

Maitre de recherche (Associe) Centre de Geostatistique, ENSMP, Fontainebleau, France, Spring 1987

Professeur (Associe) Universite Paris-Val de Marne, Spring 1986

Sabbatical, Centre de Geostatistique, ENSMP, Spring 1981

Part-time apptmt, USGS, Denver, Col. 1982-1985

Consulting

Consultant to the United Nations Technical Development Office (April 1991- June 1991). This work involved spending a month in the Peoples Republic of China working with the Ministry of Geology and Mineral Resources conducting a short course on geostatistics and consulting with various ministry personnel on the use of computers and geostatistics for the analysis of mineral exploration data Consultant to A-1 group at Los Alamos National Lab (July 1991 to present, expected to last several years). This work involves the analysis of data used to characterize former hazardous waste sites and to design sampling plans to determine the need for remediation.

Consultant to EES-1 group at Los Alamos National Lab (Jan 1990 to present, expected to last 3-5 years). This work pertains to the merging of geostatistical techniques and geographic information systems as a part of the Environmental Restoration Program for waste management at DOE sites.

Consultant to DOE, Golden, Colorado (Feb 1990 to July 1991). This work included conducting seminars and short courses on geostatistics for DOE and EG & G personnel as well as providing advice on the design of sampling networks for the collection of data as well as the subsequent analysis of data to detect and evaluate contamination of groundwater near the Rocky Flats plant.

Morrison and Knudsen, San Antonio 1986-1987, statistical analysis for mine reclamation project

Union Carbide (OakRidge Gaseous Dif. Plant), 1979-1981, analysis of data collected as part of the NURE project

Various research grants at Un. Arizona, Y.Kim or Deverle Harris PI's, 1975-1987

II. Publications(Selected)

To appear

1992 (with Hannah Rhodes) GRASS used in the Geostatistical Analysis of Lakewater data from the ELS-Phase I. to appear in Proceedings of 1st International Conference/Workshop on Integrating GIS and Environmental Modeling, Boulder, CO 16-19 September 1991 (INVITED PAPER)

1992 Spatial-Temporal Geostatistical Modeling in Hydrology. to appear in Proceedings of International Workshop on Geostatistical Methods: Recent Developments and Applications in Surface and Subsurface Hydrology, Karlsruhe, Germany 17-19 July 1990 (INVITED PAPER)

1992 Interpolation, Estimation Methods and Positive Definiteness. to appear in An International Journal of Computers and Mathematics with Applications (INVITED PAPER)

1991 On Variogram Estimation. in Proceedings of the First Inter. Conf. Stat. Comp., Cesme, Turkey, 30 Mar.-2 April 1987, Vol II, American Sciences Press

1991 Multivariate, Multidimensional Smoothing. in Spatial Statistics and Imaging: Proceedings of an AMS-IMS-SIAM Joint Summer Research Conference, June 18-24, 1988, Bowden College, Maine. Lecture Notes-Mongraph Series, Institute of Mathematical Statistics, Hayward, CA 275-285

1991 Interpolation and Estimation with Spatially Located Data, Chemometrics and Intelligent Laboratory Systems, 11, 209-228 (INVITED PAPER)

1991 (with H. R. Rasmussen) Correspondence Analysis used in the evaluation of lakewater chemistry in the Adirondacks. J. Chemometrics, 5, 273-290

1991 Pseudo-Cross Variograms, Positive Definiteness and Cokriging. Math. Geology 23, 805-816

1990 (with A. Journel) Variograms with Zonal Anisotropies and Non-Invertible Kriging Systems. Math. Geology 22, 779-785

1990 (with J. Carr) Efficiency of Different Equation Solvers in Co- Kriging. Computers and Geosciences 16, 705-716

1989 Borden Field Data and Multivariate Geostatistics. in Hydraulic Engineering, M.A. Ports (ed), Amer. Soc. Civil Eng. 795-800

1989 Vector Conditional Simulation, in Geostatistics, M.Armstrong (ed), D. Reidel Pub. (Proceedings of the Third International Geostatistical Congress, Avignon, France 5-9 September 1988), 283-293

1988 Kriging Hydrogeochemical Data, in Current Trends in Geomathematics, D.F. Merriam (ed) Plenum Press 117-142

1988 Multivariate Geostatistics for Environmental Monitoring. Sciences de la Terre, 27, 411-427

1988 Interpolation with Positive Definite Functions. Sciences de la Terre, 28, 251-265

1988 Some Aspects of Multivariate Analysis. in Quantitative Analysis of Mineral and Energy Resources, C.F. Chung et al (eds), D. Reidel Publishing Co., Dordrecht, 669-687

1987 (with J.Carr, C. Glass and H. Yang) Application of Spatial Statistics to Analyzing Multiple Remote Sensing Data sets. in Geotechnical Applications of remote sensing and remote data transmission, ASTM STP 967, A.I. Johnson and C.B. Peterson (eds), 138-150

1985 (with J. Carr) Cokriging and Principal Component Analysis: Bentonite Data revisited. Sciences de la Terre, 21, 65-77

1984 (with J. Carr) Application of the Theory of Regionalized Variables to the Spatial Analysis of LANDSAT data. in the Proceedings of the Ninth Pecora Symposium on Remote Sensing, 2-4 Oct., IEEE Computer Society Press

1984 Cokriging: New Developments. in Geostatistics for Natural Resource Characterization, G.Verly et al, eds., D. Reidel Pub. Co., Dordrecht, 295-305

1984 (with DeVerle Harris) World Oil Resources/A Statistical Perspective. in Advances in Energy Systems and Technology, Vol 4, Academic Press

1983 Estimation of Linear Combinations and Cokriging. Math. Geology, 15, no.5, 633-637

1982, Matrix Formulation of Cokriging. Math. Geology, 14, no.3, 249-257

1982 (with C.L. Begovich.T.L. Butz and V. Kane) Variogram Models for Regional Groundwater geochemical data. Math. Geology, 14,no.6, 628-644

1982 (With V. Kane, C. Begovich and T. Butz) Interpretation of Regional Geochemistry. Computers and Geosciences, 8, no. 2, 117-136

1981 (With Begovich,Butz and Kane) KUR/44 DOE publ.

1977 (With Kim and Knudsen) Advanced Geostatistics in ore reserve estimation and mine planning. GJBX-65(77) Tech. report for Dept. Energy

III. Talks (INVITED)

A. Scheduled

1. Seventh International Conference on Multivariate Analysis, Penn State Univ., 5-9 May 1992
2. 7th IMACS International Conference on Computer Methods for Partial Differential Equations, Rutgers University, 22-24 June 1992
3. Pedometrics-92: International Agricultural Centre, Wageningen, The Netherlands, 1-3 September 1992

B. Department of Statistics, University of Arizona, Dec. 1991

C. Universidad Nacional Autonoma de Mexico, Mexico City, 4 Dec 1991

D. I Reunion de Estadistica y Contamincaion, Guanajuato, MEXICO, 25-29 November 1991

E. First International Conference/Workshop on the Integration of Spatial Statistics and Geographic Information Systems, Boulder, CO 15-19 September 1991

F. Department of Mathematics, Colorado State University, 18 September 1991

G. Department of Mathematics, Kansas State University, 26 April 1991

H. Centro Internacional de Metedodos Numericos en Ingenieria, Universitat Politecnica de Catalunya, Barcelona, Spain, 8-14 April 1991

I. International Workshop on Geostatistical Methods: Recent Developments and Applications in Surface and Subsurface Hydrology, Karlsruhe, West Germany, 17-19 July 1990

J. One week lecture series on geostatistics at UNAM, Mexico City, 22-29 April 1990

K. Geostatistics in Water Resources, ASCE 17th Annual Water Resources Planning and Management Division Specialty Conference, Fort Worth 17-20 April 1990

L. Workshop on subsurface flow, Ascona, Switzerland, Sept 1989

M. Geostatistics Workshop, IV Foro de Estadistica, Monterrey, Mexico, September 1989

IV. Current and Recent Research Support

Geostatistical sampling analysis, A-1 group, Los Alamos National Laboratory, September 1991- August 1992, PI Donald E. Myers

RICHARD L. NIELSEN
13741 Braun Drive
Golden, Colorado 80401
(303)279-3118

EDUCATION

B.S. (1955), M.S. (1957), Geology, Caltech, Pasadena, California
Ph.D. (1964) Geology, University of California, Berkeley, California
Short Courses: Photogeology, Management Training, Geostatistics, Uranium Industry, Management of Exploration, Interpersonal Relationships, Economic evaluation of ore deposits and others.

PROFESSIONAL EXPERIENCE

1980 - Date Consulting Geologist. Locate prospects, properties and targets for gold-silver deposits mainly in the southwest U.S. Activities include geologic evaluations, economic appraisals, geochemical surveys, land status studies, running drill programs and coordinating permitting or reporting to government agencies. Clients include Hecla, Hanna-Getty, Anaconda, Billiton, Cominco and Pancontinental. I helped define ore target at Republic Washington that resulted in discovery of new ore shoots which will prolong life of Hecla's Knob Hill mine.

1977 - 1980 District Geologist, Anaconda Company. Uranium exploration, development and management in the Rocky Mountains and Colorado Plateau. I was involved in major uranium exploration projects; and managed and organized a major drilling program that resulted in discovery of a large uranium resource at Green Mountain, Wyoming. I maintained stewardship over a budget up to $5 million and a staff of up to 15 professionals, technical people and contractors.

1974 - 1977 Chief, Geologic Research Division, Kennecott Exploration, Inc., Salt Lake City, Utah. Organized and managed several research projects aimed at improving discovery of porphyry copper deposits in western U.S.; managed geochemical laboratories. Groups under my supervision had an operating budget up to $2 million and staff of about 50.

1964 - 1974 Senior Geologist, Geologist, Kennecott Exploration, Inc. Exploration research, geologic problem solving and prospect evaluation with experience in North America, Asia, Australia and Caribbean. Familiar with ore deposit models and economics for gold, silver, copper, molybdenum, lead, zinc, nickel and many stratigic and industrial non-metallic commodities. I helped define ore targets resulting in discovery of porphyry copper mineralization in Indonesia, and participated in early recognition of ore potential at Equity silver deposit in British Columbia and the Pueblo Viejo gold property in Dominican Republic.

PROFESSIONAL ACTIVITIES

Mineral Exploration Coalition, Member of the Land Use Planning and Government Action Committees. Society of Economic Geologists, Councilor and member of Publications and International Lectures Committees. Geological Society of America, Fellow. Denver Region Exploration Geologist Society, Program Chairman 1980-1984. National Western Mining Conference and Exhibition, 1985 Geology session Chairman. Adjunct Professor, University of Utah 1974-1976, and University of Colorado 1981-1985. Author of 15 technical and scientific articles.

PROFESSIONAL RESUME - RICHARD L. NIELSEN

13741 Braun Drive
Golden, CO 80401
(303) 279-3118
FAX (303) ~~674-3855~~
279-3118

EDUCATION

1955	B.S.,	Geology, California Institute of Technology, Pasadena
1957	M.S.,	Geology, California Institute of Technology, Pasadena
1964	Ph.D.,	Geology, University of California, Berkeley Thesis: Stratigraphy and Structure of the Pilot Mountains Area, Mineral County, Nevada.

Seminars and Short Courses: Photogeology, Management Training, Geostatistics, Uranium Industry, Management of Exploration, Interpersonal Relationships, Economic Evaluation of Ores, and others.

PROFESSIONAL EXPERIENCE

1980-1991 Consulting Geologist and President, Geocon, Inc. Evergreen, CO. Expert in prospect evaluation, detailed and regional evaluation of ore potential, alteration studies and geochemical surveys. Defines and tests ore targets for epithermal bonanza and disseminated Au-Ag ores in volcanic rocks, fossil hot springs gold, Carlin-type gold, uranium, massive sulfide, porphyry copper. Skills include mapping, sampling, drill program supervision, economic and financial evaluation. Clients include Anaconda, Billiton, Chevron, Coca Mines, Cominco, Fulcrum Mgt., Hanna-Getty, Hecla, Homestake, Pancontinental, Pioneer Nuclear, United Nations and Western States Mining. Areas of experience: western U.S., Australia, Chile, Costa Rica, Ecuador, Haiti, Peoples Republic of China. I helped define ore targets at Republic, Washington, that resulted in discovery of new ore shoots that will prolong life of Hecla's Knob Hill mine.

1978-1980 District Geologist, Rocky Mountain District, The Anaconda Company, Denver, CO. Uranium exploration, development and management - uranium deposits, western U.S., Grants area, New Mexico, Wyoming basins, Montana Precambrian. I was involved in major uranium exploration projects; managed and organized a major drilling program that resulted in discovery of a large uranium resource at Green Mountain, Wyoming. I maintained stewardship over a budget up to $5 million and a staff of up to 15 professionals, technical people and contractors.

1977-1978 Senior Regional Geologist, The Anaconda Company, Salt Lake City, UT. Exploration and management, uranium deposits, western U.S. and Canada.

1964-1977	Geologist (1964-1968), Senior Geologist (1968-1974), Chief (1974-1977), Geologic Research Division, Kennecott Exploration, Inc. Salt Lake City, UT; Tucson, AZ; Sydney, Australia. Exploration, research, geologic problem solving and management with experience in the following geographic regions and deposit types: Mt. Isa, Queensland (stratabound Cu-Pb-Zn exploration); New South Wales (volcanogenic Cu-Zn sulfide exploration); East Queensland (porphyry Cu exploration); Ok Tedi and Yandera, P.N.G. (Porphyry Cu-Au exploration and research); Guadacanal, B.S.I.P. (epithermal Au evaluation); Sulawesi, Indonesia (porphyry Cu evaluation); Afghanistan (porphyry Cu reconnaissance); Arizona-New Mexico-Nevada-Montana-Utah (porphyry Cu research and exploration); British Columbia, Alice Arm, Galore Creek (porphyry Cu-Mo research and exploration); Alaska (porphyry Cu); Dominican Republic, Jamaica (porphyry Cu-Mo, bulk Au reconnaissance); Cerro, Colorado, Panama (porphyry Cu evaluation). I helped define ore targets resulting in discovery of porphyry copper mineralization in Indonesia, and participated in early recognition of ore potential at Equity silver deposit in British Columbia and the Pueblo Viejo gold property in Dominican Republic. As Chief of Geologic Research Division, I organized and managed several research projects aimed at improving discovery of porphyry copper deposits in western U.S.; also organized, planned and participated in technical programs for new employees, seminars in management of exploration, and technical symposia on ore deposits and models; and managed geochemical laboratories. Groups under my supervision had an operating budget up to $2 million and staff of about 50.
1964	Exploration Geologist, Hecla Mining Company, central Nevada (bulk Au exploration).
1963-1964	Instructor, University of Nevada, Reno. Courses taught: economic geology, optical mineralogy, petrography, ore microscopy.
1960-1962	Summer job, eastern California (Au evaluation), northern California (oil exploration).
1957-1959	Geologist, Bear Creek Mining Company, Wisconsin, Michigan (stratiform Cu exploration); Arizona (porphyry Cu exploration and evaluation).
1955-1959	Summers (4), Geologist, U.S. Steel Corporation, Alaska (bulk Fe in ultramafic rocks, limestone, coal).

PUBLICATIONS

1963	Right-lateral strike-slip faulting in west central Nevada, in Geological Society of America Abstracts for 1962, p. 53-54, Geological Society of America Spec. Paper 73, p. 355.
1964	Geology of the Pilot Mountains and Vicinity Mineral County, Nevada: Ph.D. dissertation, University of California, Berkeley, p. 161, map scale 1:3000, Dissertation Abstract International, V. 25/07, p. 4082.
1965	Right-lateral strike-slip faulting in the Walker Lane, west-central Nevada: Geological Society of America Bulletin, V. 76, p. 1301-1308.
1968	Hypogene texture and mineral zoning in a copper-bearing granodiorite porphyry stock, Santa Rita, New Mexico: Economic Geology, V. 63, p. 37-50.
1969	Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits: Economic Geology, V. 64, p. 755-777 (with Sheppard, S.M.F., and Taylor, H.P., Jr.).
1970	Mineralization and alteration in calcareous rocks near the Santa Rita stock, New Mexico: New Mexico Geological Society, 21st Field Conference Guidebook, Oct. 29-31, 1970.
1971	Hydrogen and oxygen isotope ratios in minerals from porphyry copper deposits: Economic Geology, V. 66, p. 515-542 (with Sheppard, S.M.F., and Taylor, H.P., Jr.).
1975	Geology and geochronology of the Yandera porphyry copper deposit, Papua New Guinea: Economic Geology, V. 70, p. 1157-1174 (with Grant, J.N.).
1976	Recent developments in the study of porphyry copper geology - a review: Canadian Inst. Min. Metallurg. Special Vol. 15, p. 487-500.
1976	Ore forming fluids of metamorphic origin: AIME, Arizona section meeting, Dec., 1976 (abstract).
1978	Regional structure control for emplacement of Laramide porphyry copper systems, Arizona-New Mexico: 5th Symposium International Association, Genesis of ore deposits, Snowbird, Utah, August, 1978 (abstract).

PUBLICATIONS (CONT.)

1979	Regional tectonics and emplacement of Laramide porphyry copper intrusions, Arizona-New Mexico: Nevada Bureau of Mines and Geology, <u>Papers on Mineral Deposits of Western North America</u>, p. 49-56.
1980	Geologic Map, Reno N.W. Quadrangle: Nevada Bureau of Mines and Geology, Reno Area Map 40g (with Soeller, S.A.).
1984	Epithermal precious metal deposits in volcanic rocks of the Western U.S. - Geologic setting and exploration models: Seventh Australian Geologic Convention, Sydney, 1984 (abstract), V. 12, p. 408.
1984	Evolution of porphyry copper ore deposit models: Mining Engineering, V. 36, N. 11, p. 1637-1647, Dec.
1986	Use of high-grade mineralized rock-chip geochemistry in resource evaluation and generative exploration programs: Soc. Exploration Geochem., GEOEXPO tech. meetings, Vancouver, B.C., May 1986. (abstract - with E.R. Laskowski).
1987	Rock chip geochemical values of mineralized samples from Nevada mining districts - an exploration tool?: Bulk minable precious metal deposits of the western U.S., Geol. Soc. Nevada Symposium, April 6-8, 1987 (abstract).
1987	Geologic setting, ore potential and mining in northern Xinjiang province, northwest China: (Lecture and abstract) DREGS and Geol. Soc. Nevada, Jan-Feb.
1987	Geology and gold deposits of central Mineral Ridge, Esmeralda County, Nevada: Geol. Soc. America, Abstracts with Programs, Rocky Mt. Section, p. 260 (with L.B. Bercaw and W.W. Atkinson, Jr.)

Also authored many unpublished company reports.

HONORS AND PROFESSIONAL ACTIVITIES

Society of Economic Geologist - Member
  Councillor - 1986-1989
  Chairman - Nomination Committee 1986-87
  Member - Funding Priority Committee 1986-89
  Member - International Exchange Lecturer Committee 1986-88
  Chairman - Publications Committee 1979-80

HONORS AND PROFESSIONAL ACTIVITIES (CONT.)

Geological Society of America - Fellow

Denver Region Exploration Geologist Society (DREGS) - Member
Program Chairman 1983-1985

Geological Society of Nevada - Member
Lecturer on China

Mineral Exploration Coalition - Member
Member - Government Affairs Committee
Member - Land Use Planning Committee

University of Colorado, Boulder
Adjunct Professor 1984-1990

University of Utah, Salt Lake City
Adjunct Professor 1974-1976

Colorado Mining Association
Chairman, Exploration and Mine Geology Session,
89th Nat. Western Mining Conference, Denver, February 1986

American Association for Advancement of Science - Member

Society of Mining Engineers - Member

Northwest Mining Association - Member

Internat. Assoc. Genesis of Ore Deposits (IAGOD) - Member

Colorado Scientific Society - Member

Society of Sigma Xi - Member

January 1991

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- Completed regional mapping and geochemical study at Gilt Edge gold district, South Dakota. Subsequent drilling of targets resulted in disovery of gold mineralization for Brohm Mining Company.
- Prepared a geologic gold ore reserve estimate at the Gilt Edge deposit for Brohm Mining Company.
- Evaluated ore discovery and development opportunities at the Chevron's Andacollo, Chile gold property for Homestake Mining Company.
- Completed assessment of mining business and gold ore development opportunities in Equador, Costa Rica and Uruguay for Homestake.
- Evaluated gold mining investment opportunities in Brazil for Pancontinental Mining Ltd.; in Alaska for Fulcrum Management, Inc.; and in Czechoslovakia and Portugal for Eastmaque Gold Mines Ltd.
- Organized and supervised small exploration drill projects, California, Wyoming and Grenada W.I.
- Organized and carried out regional evaluation and geochemical programs to define gold ore discovery potential on several Caribbean Islands; massive lead-zinc-silver sulfide mineralization and low grade disseminated copper-gold mineralization discovered.
- Defined potential zinc-silver-gold ore zones by examination of old mine records at Butte, Montana.
- Have field experience with greenstone and Precambrian exhalative gold deposits in South Dakota, California and Alaska; expert in Carlin-type gold in sediments; contact replacement gold around porphyry intrusions and epithermal vein and disseminated gold deposits.
- Personal data files are extensive with many unpublished reports on mines and prospects in Arizona, California, Nevada, Utah and several overseas countries.
- Prepared a comprehensive compilation of geologic data with distribution of mines and prospects throughout Nevada (1986).

PROFESSIONAL RESUME - RICHARD L. NIELSEN

13741 Braun Drive
Golden, CO 80401
(303) 279-3118
FAX (303) ~~674-3855~~ 279-3118

EDUCATION

1955 B.S., Geology, California Institute of Technology, Pasadena
1957 M.S., Geology, California Institute of Technology, Pasadena
1964 Ph.D., Geology, University of California, Berkeley
Thesis: Stratigraphy and Structure of the Pilot Mountains Area, Mineral County, Nevada.

Seminars and Short Courses: Photogeology, Management Training, Geostatistics, Uranium Industry, Management of Exploration, Interpersonal Relationships, Economic Evaluation of Ores, and others.

PROFESSIONAL EXPERIENCE

1980-1991 Consulting Geologist and President, Geocon, Inc. Evergreen, CO. Expert in prospect evaluation, detailed and regional evaluation of ore potential, alteration studies and geochemical surveys. Defines and tests ore targets for epithermal bonanza and disseminated Au-Ag ores in volcanic rocks, fossil hot springs gold, Carlin-type gold, uranium, massive sulfide, porphyry copper. Skills include mapping, sampling, drill program supervision, economic and financial evaluation. Clients include Anaconda, Billiton, Chevron, Coca Mines, Cominco, Fulcrum Mgt., Hanna-Getty, Hecla, Homestake, Pancontinental, Pioneer Nuclear, United Nations and Western States Mining. Areas of experience: western U.S., Australia, Chile, Costa Rica, Ecuador, Haiti, Peoples Republic of China. I helped define ore targets at Republic, Washington, that resulted in discovery of new ore shoots that will prolong life of Hecla's Knob Hill mine.

1978-1980 District Geologist, Rocky Mountain District, The Anaconda Company, Denver, CO. Uranium exploration, development and management - uranium deposits, western U.S., Grants area, New Mexico, Wyoming basins, Montana Precambrian. I was involved in major uranium exploration projects; managed and organized a major drilling program that resulted in discovery of a large uranium resource at Green Mountain, Wyoming. I maintained stewardship over a budget up to $5 million and a staff of up to 15 professionals, technical people and contractors.

1977-1978 Senior Regional Geologist, The Anaconda Company, Salt Lake City, UT. Exploration and management, uranium deposits, western U.S. and Canada.

1964-1977	Geologist (1964-1968), Senior Geologist (1968-1974), Chief (1974-1977), Geologic Research Division, Kennecott Exploration, Inc. Salt Lake City, UT; Tucson, AZ; Sydney, Australia. Exploration, research, geologic problem solving and management with experience in the following geographic regions and deposit types: Mt. Isa, Queensland (stratabound Cu-Pb-Zn exploration); New South Wales (volcanogenic Cu-Zn sulfide exploration); East Queensland (porphyry Cu exploration); Ok Tedi and Yandera, P.N.G. (Porphyry Cu-Au exploration and research); Guadacanal, B.S.I.P. (epithermal Au evaluation); Sulawesi, Indonesia (porphyry Cu evaluation); Afghanistan (porphyry Cu reconnaissance); Arizona-New Mexico-Nevada-Montana-Utah (porphyry Cu research and exploration); British Columbia, Alice Arm, Galore Creek (porphyry Cu-Mo research and exploration); Alaska (porphyry Cu); Dominican Republic, Jamaica (porphyry Cu-Mo, bulk Au reconnaissance); Cerro, Colorado, Panama (porphyry Cu evaluation). I helped define ore targets resulting in discovery of porphyry copper mineralization in Indonesia, and participated in early recognition of ore potential at Equity silver deposit in British Columbia and the Pueblo Viejo gold property in Dominican Republic. As Chief of Geologic Research Division, I organized and managed several research projects aimed at improving discovery of porphyry copper deposits in western U.S.; also organized, planned and participated in technical programs for new employees, seminars in management of exploration, and technical symposia on ore deposits and models; and managed geochemical laboratories. Groups under my supervision had an operating budget up to $2 million and staff of about 50.
1964	Exploration Geologist, Hecla Mining Company, central Nevada (bulk Au exploration).
1963-1964	Instructor, University of Nevada, Reno. Courses taught: economic geology, optical mineralogy, petrography, ore microscopy.
1960-1962	Summer job, eastern California (Au evaluation), northern California (oil exploration).
1957-1959	Geologist, Bear Creek Mining Company, Wisconsin, Michigan (stratiform Cu exploration); Arizona (porphyry Cu exploration and evaluation).
1955-1959	Summers (4), Geologist, U.S. Steel Corporation, Alaska (bulk Fe in ultramafic rocks, limestone, coal).

PUBLICATIONS

1963	Right-lateral strike-slip faulting in west central Nevada, in Geological Society of America Abstracts for 1962, p. 53-54, Geological Society of America Spec. Paper 73, p. 355.
1964	Geology of the Pilot Mountains and Vicinity Mineral County, Nevada: Ph.D. dissertation, University of California, Berkeley, p. 161, map scale 1:3000, Dissertation Abstract International, V. 25/07, p. 4082.
1965	Right-lateral strike-slip faulting in the Walker Lane, west-central Nevada: Geological Society of America Bulletin, V. 76, p. 1301-1308.
1968	Hypogene texture and mineral zoning in a copper-bearing granodiorite porphyry stock, Santa Rita, New Mexico: Economic Geology, V. 63, p. 37-50.
1969	Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits: Economic Geology, V. 64, p. 755-777 (with Sheppard, S.M.F., and Taylor, H.P., Jr.).
1970	Mineralization and alteration in calcareous rocks near the Santa Rita stock, New Mexico: New Mexico Geological Society, 21st Field Conference Guidebook, Oct. 29-31, 1970.
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1978	Regional structure control for emplacement of Laramide porphyry copper systems, Arizona-New Mexico: 5th Symposium International Association, Genesis of ore deposits, Snowbird, Utah, August, 1978 (abstract).

PUBLICATIONS (CONT.)

1979	Regional tectonics and emplacement of Laramide porphyry copper intrusions, Arizona-New Mexico: Nevada Bureau of Mines and Geology, Papers on Mineral Deposits of Western North America, p. 49-56.
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1984	Epithermal precious metal deposits in volcanic rocks of the Western U.S. - Geologic setting and exploration models: Seventh Australian Geologic Convention, Sydney, 1984 (abstract), V. 12, p. 408.
1984	Evolution of porphyry copper ore deposit models: Mining Engineering, V. 36, N. 11, p. 1637-1647, Dec.
1986	Use of high-grade mineralized rock-chip geochemistry in resource evaluation and generative exploration programs: Soc. Exploration Geochem., GEOEXPO tech. meetings, Vancouver, B.C., May 1986. (abstract - with E.R. Laskowski).
1987	Rock chip geochemical values of mineralized samples from Nevada mining districts - an exploration tool?: Bulk minable precious metal deposits of the western U.S., Geol. Soc. Nevada Symposium, April 6-8, 1987 (abstract).
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HONORS AND PROFESSIONAL ACTIVITIES

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Denver Region Exploration Geologist Society (DREGS) - Member
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University of Utah, Salt Lake City
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  89th Nat. Western Mining Conference, Denver, February 1986

American Association for Advancement of Science - Member

Society of Mining Engineers - Member

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Internat. Assoc. Genesis of Ore Deposits (IAGOD) - Member

Colorado Scientific Society - Member

Society of Sigma Xi - Member

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December 1991

Michael Rieber
Professor of Mineral Economics
Department of Mining and
Geological Engineering
College of Engineering and Mines
University of Arizona
Tucson, Arizona 85721
(602) 621-4281

Born: 13 October 1932
Status: Married

EDUCATION

Syracuse University	A.B.	Economics and Organic Chemistry 1952
University of Tennessee	--	Organic Chemistry 1952-1953
University of Tennessee	M.S.	Economics and Statistics 1954
Syracuse University	--	Economics 1954-55
Massachusetts Institute of Technology	Ph.D.	Economics 1963

Employment at The University of Arizona, Tucson.

1978 - present: Professor of Mineral Economics, Department of Mining and Geological Engineering, College of Engineering and Mines

Course Responsibility (graduate):

Mineral Economics (Survey)
Advanced Principles of Mineral Economics
Economics of Petroleum and Natural Gas
Economics of Coal, Nuclear, and Alternative Energy Sources
Minerals and Economic Development
Economics of Non-Metallic Minerals
Process Analysis and Costing
Minerals and the Environment

Doctoral Theses Supervised:

Agbolosoo, E., "Mineral Processing in the Less Developed Countries: Bauxite Processing in Ghana," 1991, Mineral Economics.

Al-Rawahi, K., "Embodied Consumption of U.S. Copper and Sulfur: Implications for Intensity of Use Estimation and Forecasting," 1990, Mineral Economics.

Emerson, M., "The Economics of Crude Oil Futures Spreads," 1990, Mineral Economics.

Mangano, C., "Exchange Rates, Refinery Flexibility, and Petroleum Demand," 1989, Mineral Economics

Fetyani, A., "An Economic Analysis of the Saudi Arabian Gas Utilization System," 1988, Mineral Economics.

Vent, G., "A Simulation Study of the Full Cost and Successful Efforts Methods of Accounting: The Petroleum Industry," 1983, Accounting.

Okech, B., "The International Sulfur Market: Regional Supply/Demand Balances, Projections, and Impacts on the International Market for Sulfur," 1982, Mineral Economics.

Contract Research:

Principal Investigator, "Government Stockpile Releases and U.S. Mercury Prices," Placer Dome U.S., Inc., 1990.

Principal Investigator, "The Future Competitiveness of U.S. Copper," Arizona Mining and Minerals Resources Research Institute, U.S. Bureau of Mines, 1989-1990.

Co-Principal Investigator, "Economic Concepts of Demand and Demand Elasticity as Applied to the Demand for Copper," (with D. Harris and R. Newcomb), International Copper Research Association, 1984.

Co-Principal Investigator, "Copper Demand Forecasts for Less Developed Nations," (with D. Harris and R. Newcomb), International Copper Research Association, 1984.

Principal Investigator, "Coal Slurry Tanker Movements of Western Coal to East Coast Utilities," Maritime Administration, U.S. Department of Transportation, Contract No. MA-81-SAC-10026, 1981-82.

Principal Investigator, "Smelter Emission Controls: The Impact on Mining and the Market for Acid," Office of Surface Mining, U.S. Department of the Interior, Grant No. G5105013, 1980-81.

Co-Principal Investigator, "Analysis of Coal Slurry Pipelines," (with S. L. Soo), Electric Power Research Institute, 1980-81.

Principal Investigator, "The Impact of Stack-Gas Cleanup on the Sulfur Industry of Texas and Louisiana," U.S. Bureau of Mines, J0188144 (Amend. 1), 1979-80.

Principal Investigator, "Sulfur Pollution Control: The Disposal Problem," U.S. Bureau of Mines, J0188144, 1978-79.

Faculty Projects:

Committee on Academic Freedom and Tenure, University, 1991.

Border Policy Group - Udall Center, University, 1988-1990.

Salary Committee - Department of Mining and Geological Engineering, 1985, 1986, 1988, 1989.

President's Advisory Review Committee on the Reorganization of the Colleges of Mines and Engineering -- University, 1984-1985.

Promotion and Tenure Committee - College of Mines, 1984-1985.

Associate - Arizona Mining and Mineral Resources Research Institute, January-April 1982.

Undergraduate Council - University, 1981-1983

University Energy Research Committee, Member, 1981

University Committee Member, Arizona Academy/Town Hall, Energy Working Group, 1981.

Advisory Committee Member, Division of Economic and Business Research, College of Business and Public Administration, 1979-1980.

Graduate Studies Coordinator, Department of Mining and Geological Engineering, 1979-1981.

Computer Committee, College of Mines, 1978-1984.

Previous Employment:

1977-1978: Research Professor, Center for Advanced Computation, University of Illinois at Urbana-Champaign.

Contract Research

Project Director, "Career Patterns of Scientists and Engineers," (R. DauffenBach, Principal Investigator), National Science Foundation, NSF-SRS-76-22550, 1978.

Principal Investigator, "An Analysis of the Demand for Energy and Fuels in the Ohio River Basin Energy Study Region," supplementary study for "Impact Assessment of Energy Conversion Facilities in the Ohio River Basin," (Phase II, Year 1), U.S. Environmental Protection Agency R804821-01, (J. Stukel, Project Manager, University of Illinois), 1977-1978.

Project Director: "A Study of Projected Balances Between Requirements for and the Supply of Scientific and Technological Manpower in the U.S. Economy Through 1980 and 1985 with Emphasis on Energy Related Employment," (H. Folk and R. DauffenBach, Principal Investigators), National Science Foundation, NSF-C-SRS76-80591, 1977-1978.

Faculty Project

Technical Advisor to the Director, Office of Energy Research, University of Illinois at Urbana-Champaign.

1976-1977: Acting Director, Center for Advanced Computation, University of Illinois at Urbana-Champaign.

1974-1977: Research Professor, Center for Advanced Computation, University of Illinois at Urbana-Champaign.

Contract Research:

Principal Investigator, "Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge, Coal Slurry and Pneumatic Pipelines," Federal Energy Administration and the U.S. Bureau of Mines, BM/J0166163, 1976-77.

Associate Investigator, "Regional Crop Acreage Monitoring via Computer Analysis of LANDSAT Imagery," (R. Ray, Principal Investigator), USNASA/AGR14-005-002, 1976-77.

Principal Investigator, "Energy Transportation/Distribution," special study, (Task IV), for "Impact Assessment of Energy Conversion Facilities in the Ohio River Basin," U.S. Environmental Protection Agency, R804821-01, (J. Stukel, Project Manager, University of Illinois), 1976-77.

Principal Investigator, "Route Specific Cost Comparisons: Unit Trains, Coal Slurry Pipelines and Extra High Voltage Transmission - Western Energy Development Integrated Technology Assessment (Transportation)," Subcontract with the Science and Public Policy Program, the University of Oklahoma, "Technology Assessment of Western Energy Resource Development," (E.P.A. Contract 68-01-1916), 1976.

Co-Principal Investigator, "Report and Evaluation of the Ilok 4-micron Coal Grinding Process," (with S. L. Soo), Federal Energy Administration, Office of Coal, 1975.

Principal Investigator, "Feasibility of Coal Mine Cooperatives," Federal Energy Administration, Office of Coal, 1975.

Principal Investigator, "The Coal Future: Economic and Technological Analysis of Initiatives and Innovations to Secure Fuel Supply Independence," National Science Foundation (RANN), GI-35821A1, 1974-75.

Volume 1. Summary and Conclusions
2. Nuclear Power to 1985: Possible vs. Optimistic Estimates

3. Capital and Fuel Cycle Energy Costs of a 1000 MWe Nuclear Reactor
4. Low Sulfur Coal: A Revision of Reserve and Supply Estimates
5. Reserve and Resource Estimation (Coal)
6. Unit Train Transportation of Coal
7. Coal Transportation: Unit Trains, Coal Slurry and Pneumatic Pipelines
8. Flue Gas Desulfurization and Low Btu Gasification - a Comparison
9. Medium Btu Coal Gasification

Faculty Project:

Technical Advisor to the Director, Office of Energy Research, University of Illinois at Urbana-Champaign.

1972-1974: Visiting Research Professor, Center for Advanced Computation, University of Illinois at Urbana-Champaign.

Contract Research:

Principal Investigator, "The Effect of Oil Import Restrictions on Sulfur Oxide Pollution Control," National Science Foundation (RANN) GI-35821, 1972-1974.

Associate Investigator, "Environmental Aspects of Energy Consumption," (B. Hannon, Principal Investigator), National Science Foundation (RANN) GI-35179X, 1972-1974.

1970-1972: Professor of Economics, Kent State University, Kent, Ohio.

Courses Taught: Micro-economic Theory (graduate and undergraduate)

Faculty Project: Proposal for the Establishment of a Ph.D. Program in Economics (the Graduate School), 1971.

Doctoral Theses Supervised:

Kapur, L.K., "A Generalized Model for Scheduling Products Involving High Labor Content, 1972, Administrative Sciences.

1967-1970: Associate Professor of Economics, University of Missouri at Columbia, Missouri.

Courses Taught:
Micro-economic Theory (graduate and undergraduate)
Macro-economic Theory (undergraduate)
Structure of Industry (graduate and undergraduate)
Principles of Economics

615

Contract
Research:

Principal Investigator, "World Crude Oil Prices," United States Treasury, Internal Revenue Service, Contract No. TIR-25655, 1969.

Principal Investigator, "Residual Oil Prices," United States Treasury, Internal Revenue Service, Contract No. TIR-25655, 1969.

Principal Investigator, "Residual Oil," United States Senate, Subcommittee on Antitrust and Monopoly, 1969.

Faculty Project:

Long Range Development Plan, Graduate Studies, Department of Economics, 1971.

Doctoral Theses Supervised:

Ellingson, E., "The Supply-Price of Domestic Natural Gas," Economics.

1963-1967: Assistant Professor of Economics, Wayne State University, Detroit, Michigan.

Courses Taught:
- Micro and Macro-economic Theory (undergraduate)
- Structure of Industry (graduate and undergraduate)
- Fiscal Policy (graduate)
- Business Fluctuations (undergraduate)
- Principles of Economics

Doctoral Theses Supervised:

Kataoka, T., "A Statistical Analysis of the Size Structure of the Japanese Manufacturing Industries," 1966, Economics.

Kvasnicka, J.G., "Asset Preference Theory and the Portfolio of a Commercial Bank," 1966, Economics.

Lumas, G., "The Shifting of the Corporation Income Tax: A Theoretical and Empirical Study with Special Reference to India," 1966, Economics.

Makinen, G.E. "The 'Pay-Off' Period of Direct Foreign Investment by the United States Automotive Industry," 1966, Economics.

Griffin, J.B., "Resource Allocation in Central City School Systems: A Case Study," 1968, Economics.

Riggs, B.R., "Stabilization Policy and the Individual Income Tax," 1968, Economics.

1961-1963: Research Associate in Economics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Contract Research:

Future Crude Oil Prices, National Science Foundation - Ford Foundation, 1961-1963 (Principal Investigator, M.A. Adelman).

1960-1961: Assistant Industrial Economist, Federal Reserve Bank of Boston, Boston, Massachusetts.

Research:

Impact of Crude and Residual Oil Import Restrictions
New England Pulp and Paper Industry
New England Fabricated Steel Industry
Industrial Use of Nuclear Generated Process Heat

1957-1960: Teaching Assistant, Department of Economics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Courses Taught: Principles of Economics

1954-1955: Teaching Assistant, Syracuse University, Syracuse, New York.

Courses Taught: Beginning Probability Theory
Principles of Economics

1953-1954: Research Assistant, Department of Economics, University of Tennessee, Knoxville, Tennessee.

Courses Taught: Principles of Economics
Managerial Economics

617

PUBLICATIONS

Monographs

U.S. Mercury Marketing and the Impact of Government Stockpile Releases with D.P. Harris, McDermitt Mine J.V./Placer Dome U.S., Inc., 20 June 1990, 45 pp.

An Economic Analysis of the Prospects for Increasing the Consumption of Copper in Developing Countries to Year 2000 with D. P. Harris and R. T. Newcomb, New York City, International Copper Research Association, 31 January 1984, 124 pp.

Coal Slurry Tanker Movements of Western Coal to East Coast Utilities, Final Report 267 pp., U.S. Maritime Administration, Contract No. MA-81-SAC-10026, February 1983, NTIS PB83-183095.

Smelter Emission Controls: The Impact on Mining and the Market for Acid, Final Report, Office of Surface Mining, Grant G5105013, 684 pp., March 1982, NTIS PB83-134866.

Coal Slurry Pipelines: A Review and Analysis of Proposals, Projects and Literature, with S.L. Soo, Electric Power Research Institute, 247 pp., EPRI EA-2546 (1982)

The Impact of Stack Gas Cleanup on the Sulfur Mining Industry of Texas and Louisiana, Final Report, Bureau of Mines, Contract BM/J0188144 (Amend. 1), 1981, 103 pp., NTIS PB81-222820.

Sulfur Pollution Control: The Disposal Problem, Bureau of Mines, Contract BM/J0188144, Final Report, 1981.

Vol. 1. Summary and Conclusions, January 1981, 63 pp.
Frasch Sulfur, July 1980, 95 pp.
Recovered Sulfur Overview, July 1980, 27 pp.
Canadian Recovered Sulfur, January 1981, 72 pp.
NTIS PB81-222796.

Vol. 2. Sulfur Recovery from Petroleum Refining and Natural Gas Processing, January 1981, 57 pp.
Sulfur Values from Electric Utilities, July 1980, 67 pp.
Recovered Sulfur from Synfuels, In Situ Coal Gasification, Heavy Oil and Heavy Crude Oil, January 1981, 38 pp.
NTIS PB81-222804.

Vol. 3. Sulfuric Acid, July 1980, 117 pp.
Secondary Impacts of Rest of World Production of Sulfur, Sulfur Values and Fertilizer, January 1981, 110 pp.
NTIS PB81-222812.

<u>Comparative Coal Transportation Costs: An Economic and Engineering Analysis of Truck, Belt, Rail, Barge and Coal Slurry and Pneumatic Pipelines,</u> with S.L. Soo, Final Report, Bureau of Mines and Federal Energy Administration, Contract BM/J0166163, August 1977, 8 Volumes, 541 pp.

Vol. 1. <u>Summary and Conclusions</u>, 64 pp., NTIS PB274-379/AS.
2. <u>Unit Trains</u>, 107 pp., NTIS PB274-380/AS.
3. <u>Coal Slurry Pipelines</u>, 51 pp., NTIS PB274-381/AS.
4. <u>Barge Transport</u>, 85 pp., NTIS PB274-382/AS.
5. <u>Conveyor Belts</u>, 61 pp., NTIS PB274-383/AS.
6. <u>Truck Haulage</u>, 62 pp. NTIS PB274-384/AS.
7. <u>Pneumatic Transport</u>, 71 pp., NTIS PB274-385/AS.
8. <u>Yellow Ball Rail</u>, 7 pp. NTIS PB274-386/AS.

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Advisory Committee, The Energy Journal, Special Issue on World Oil, 1991-1992.

Invited Paper, "Mercury Pollution: The Impact of U.S. Government Stockpile Releases," International Conference - Mercury as a Global Pollutant, Electric Power Research Institute, Monterey, May 31-June 4, 1992.

Panel Member (Mining), Arizona Strategic Planning for Economic Development, 1991.

Invited Paper, "The Future Competitiveness of U.S. Copper," International Symposium, Cobre 91, Ottawa, Canada, 18-21 August 1991.

Guest Lecturer, "Copper and Sulfur Forecasting," Michigan Technological University, 26-28 March 1990.

Coordinator/Assoc. Editor, AIME/SME, SME Engineering Handbook, Second Edition, Section 2 - Mineral Economics, 1989-1990.

Advisory Panel/Reviewer, The Energy Journal, Special Issue on Global Warming, 1989-1990.

Editorial Board Member, The Energy Journal, International Association of Energy Economists, 1979-1990.

Invited Paper, "The Economics of Smelter Acid Plants in the 'Gray Triangle,'" U.S.-Mexico Conference on Border Smelter Emissions, University of Arizona and National Autonomous University of Mexico, Tucson, AZ 6-7 February 1986.

Invited Paper, "The Economics of Smelter Pollution Control in the Gray Triangle," The International Sulphur '85 Conference, 10-13 November 1985, British Sulphur Corporation, London, England.

Session Chairman, Sulphur Production, The International Sulphur '85 Conference, 10-13 November 1985, British Sulphur Corporation, London, England.

Workshop Chairman, The Environmental Compatibility of the Federal Coal Leasing Program, Office of Technology Assessment, U.S. Congress, Denver, CO, January 1-4, 1984.

Invited Paper, "International Commodity Agreements: The Role of Consuming Nations," 112th AIME Annual Meeting, Atlanta, Georgia, 6-10 March 1983.

Contributor, Arizona's Energy Future: Making the Transition to a New Mix, Frank, H.J. (ed.), Tucson, Arizona: The University of Arizona Press, 1982.

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Working Group member and University Review Committee member, Arizona's Energy Future: Making the Transition to a New Mix, research report directed and prepared by the University of Arizona, sponsored by the Arizona Academy, 39th Arizona Town Hall, October 25-28, 1981.

Guest Lecturer, Energy Alternatives Workshop, John A. Logan College, Carterville, IL, (DOE Sponsor), Nuclear Energy and Solar Power, 1980.

Session Chairman, Application of Quantitative Methods to Mineral Economics, Council on Economics, AIME Annual Meeting, Las Vegas, February 1980.

Co-Chairman, Program Committee and Session Coordinator, Alternative Energy Sources, International Association of Energy Economists, Washington, D.C., June 4-6, 1979.

Commentator, Office of Surface Mining, U.S. Department of the Interior, Draft regulatory analysis for permanent program regulation of surface mines, 1978.

Technical Advisory Committee Member, Argonne National Laboratory, Evaluation of the Market Potential and Environmental Effects of Increased Western Coal Transportation in the Great Lakes and Northeastern U.S. Regions, 1978.

Discussant, "National Energy Supply Strategy," Southern Economic Association - International Association of Energy Economists, Washington, D.C., November 9, 1978.

Invited Paper, "Coal Slurry Pipelines vs. Unit Trains: Western Examples and Eastern Hypotheses," Northeast Regional Science Association, Baltimore, Maryland, May 11-13, 1978.

Invited Paper, "Coal Transportation Models: The Use, Misuse, and Abuse of Data," Conference on Energy Modeling, The University of Kentucky, Lexington, April 27-28, 1978.

Planning Committee Member, Illinois Economics Association, Energy Economics, 1978.

Workshop Leader, Transportation of Coal, the Products of Coal, and Electricity, Illinois Coal Conference, Southern Illinois University, Carbondale, December 10, 1977.

Invited Paper, "Relative Coal Transportation Costs," Southern Economic Association, New Orleans, Louisiana, November 2-4, 1977.

Guest Lecturer, "Comparative Coal Transportation Costs," West Virginia University, March 28-29, 1977.

Invited Paper, "Tricentennial Coal, 1976-2076: The Use of Coal to Meet the Energy Crisis," Bicentennial Horizons: A Club of Rome Symposium on Systems Science and America's Next Hundred Years, Southern Illinois University, Carbondale, April 23, 1976.

Invited participant, Electric Power Research Institute, "Workshop to Identify Research and Data Required to Improve North American Long-Term Coal Supply Analysis," Tampa, Florida, December 8-10, 1975.

Guest Lecturer, "Low Sulfur Coal - High Sulfur Coal: The Trade Interface," Seminar Series, "The Energy Problem, The Case of Coal," West Virginia University, Morgantown, West Virginia, October 8-9, 1975.

Invited Paper, "The Coal Future," Inter-University Energy Conference on Coal, Lake Bluff, Illinois, March 14-16, 1974.

Section Leader, Alternative Energy Sources, American Economics Association, Annual Meeting, Chicago, December 1974.

Fuels Advisor, listing, 1970-1973
- Ohio - Citizens Task Force on Environmental Protection
- Indiana - Air Pollution Control Division
- Pennsylvania - Bureau of Air Pollution Control
- Chicago - Department of Environmental Control
- Cleveland - Department of Public Health and Welfare
- Philadelphia - Department of Public Health
- New York City - Environmental Protection Administration

Discussant, Michigan Economics Association, Symposium, Ann Arbor, Spring 1965.

Section Leader, Steel Industry Problems, American Iron and Steel Institute/Wayne State University, Symposium, Detroit, 1964.

REFEREE

Past:

Energy Journal

Resources and Energy
Office of Technology Assessment
Energy Systems and Policy
Growth and Change: A Journal of Regional Development
Journal of Money, Credit and Banking
National Science Foundation
Quarterly Review of Economics and Business
Journal of Finance
Management Science (B)

ASSOCIATIONS

American Economic Association
International Association of Energy Economists
American Institute of Mining, Metallurgical and Petroleum Engineers/
Society of Mining, Metallurgy, and Exploration.
American Arbitration Association

VITA

Brian John Skinner

Born: Wallaroo, South Australia, December 15, 1928

Education:
B.Sc. (Hon.) University of Adelaide, Australia, 1950
A.M. Harvard University, 1952
Ph.D. Harvard University, 1955

Positions:
Various field and mining geology positions, 1948- 1954, with North Broken Hill Ctd; Aberfoyle Tin N.L., International Nickel Co.; Reynolds Metals Co.
Lecturer in Crystallography, University of Adelaide, Australia, 1955-1958.
Research Geologist, U.S. Geological Survey, Washington, D.C., 1958-1962.
Chief, Branch of Experimental Geochemistry and Mineralogy, U.S. Geological Survey, Washington, D.C., 1962-1966.
Professor of Geology and Geophysics, Yale University, 1966-present.
Chairman, Department of Geology and Geophysics, Yale University, 1967-1973.
Eugene Higgins Professor of Geology and Geophysics, 1972-present.

Honorary Positions:

Board of Directors, Economic Geology Publishing Company, 1964-present.
Member, Lunar Science Planning Team, 1965-1970.
Executive Committee, Division of Earth Sciences, National Research Council, 1966-1969.
National Committee for Geochemistry, 1968-1970.
Guggenheim Fellow, 1969-1970.
Lunar Science Review Board, 1971.
Committee on Mineral Resources and the Environment, National Academy of Sciences -- National Research Council, 1973, Chairman, 1974-1976.
U.S. National Committee for Geology, 1974-1977, 1986 -, Chairman 1987 - present.
Education Advisory Committee to Comptroller General, 1978-1980.
Consultant to National Science Foundation, Office of President's Science Advisor, NASA, U.S. Geological Survey, General Accounting Office, Nuclear Reg. Commission, Resources for the Future.
Chairman, Panel on Mineral Resources, Continental Scientific Drilling Committee, 1980-1981, Member, 1982-1986.

Honorary Positions: (Continued)

Member of the Advisory Committee to the Director, U.S. Geological Survey, 1983 - 1988.
Member Scientific Committee, International Geological Correlation Program (UNESCO-IUGS), 1984 - 1989. Chairman 1986 - 1989.
Member, Board of the International Geological Correlation Program, 1989 -
Chairman, U.S. National Committee on Geology, 1986 - present.
Chairman, Board on Earth Sciences (NRC) 1987 - 1988.
Co-Chairman, Board on Earth Sciences and Resources (NRC), 1989 - 1990.
Nominating Committee, International Union of Geological Sciences, 1990-.
Member, ASCEND-21, International Council of Scientific Unions, 1991 - 1992.

Editorial Functions:

Editor, "Economic Geology", 1969 - present.
Editorial Board, "American Scientist", 1974 - 1990.
Chairman, 1986 - 1990.
Chairman, Board of Overseers, "American Journal of Science", 1972 - present.
Consulting Editor, Oxford University Press, Monographs in the Geological and Geophysical Sciences, 1980 - present.

Societies: Geochemical Society (President, 1973).
Society of Economic Geologists.
Geological Society of America (Fellow; Council Member 1975-1978; Publication Committee 1977-1979; Committee on Committees 1970; Chairman of Nominating Committee 1976; Grants Committee 1966-1968, Chairman, 1968; Scientific Steering Committee, 1968-1970; Convener of first Penrose Conference, 1969; Chairman, Special Committee on Publications, 1981; Vice-President, 1984; President, 1985; Chairman, "Path to Year 2000 Committee", 1987; Investment - Committee, 1986 - present).
Geological Society of America Foundation, Trustee 1987 - present.
Mineralogical Society of Canada (Council Member, 1975-1978).
Mineralogical Society of America (Fellow).
American Association Advancement of Science.
Mineralogical Society, London.
Connecticut Academy of Science and Engineering (Charter Member; Nominating Committee 1976-1978; Council

Member, 1982-1987).
Geological Association of Canada (Fellow).Geological Society of South Africa (Fellow).
Geological Society of Australia.
Geological Society of South Africa (Fellow).

Recent Invited Lectures and Awards:

Lowell Lecturer, Boston Museum of Science, 1976.
Phillips Lecturer, Haverford College, 1977.
University Lecturer, Cornell, 1977.
Frontiers of Science Lecturer, Vassar, 1977.
Sandia Labs. Dist. Lecturer, University of New Mexico, 1977.
National Conference on the Advancement of Research, 1977.
Royal Society of Canada, 1977.
Hugh Exton McKinstry Memorial Lecturer, Harvard, 1978.
Alexander L. du Toit Memorial Lecturer, Geological Society of South Africa, 1979.
Distinguished Contributions Award, Association of Earth Science Editors, 1979.
Silver Medal, Society of Economic Geologists, 1981.
Thayer Lindsley Memorial Lecturer, 1983-1984.
Cecil and Ida Green Lecturer, University of British Columbia, 1983.
Society of Economic Geologists International Lecturer, 1985.
Hoffman Lecturer (Harvard, 1986).
Joubin-James Visiting Professional Lecturer, University of Toronto, 1987.
Keynote Speaker, 100th Anniversary Celebrations for discovery of the Witwatersrand Goldfields, 1988.
Keynote Speaker, Opening Session of Geological Society of America Centennial Meeting, 1988.
Keynote Speaker, Opening Session of the 28th International Geological Congress, 1989.
Keynote Speaker, Opening Session of the Pacific Rim Conference, 1990.
Millercom Lecturer, University of Illinois, 1990.
Inaugural Speaker, Sclar lectures, Lehigh Univ.; 1990.
Hedburg Lecturer, Kansas University, 1991.
Invited Speaker, 1991 Meeting, Brazilian Association for the Advancement of Science.
Invited Speaker, Conference of Directors of Geological Surveys, in honor of the 150th Anniversary of the founding of the Canadian Geological Survey, 1992.

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Published Reports:

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Chao, E.C.T., Evans, H.T., Jr., Skinner, B.J., and Milton, C., 1961, Neighborite $NaMgF_3$, a new mineral from the Green River formation in Utah: Am. Min., v. 46, p. 379-393.

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Skinner, B.J., and Bethke, P.M., 1961, Relationship between unit-cell edges and composition of synthetic wurtzites: Am. Min., v. 46, p. 1382-1398.

Skinner, B.J., Stewart, D.B., and Morgenstern, J.C., 1962, A new heating stage for the X-ray diffractometer: Am. Min., v. 47, p. 962-967.

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John S. Sumner

CURRICULUM VITAE

Address

728 N. Sawtelle
Tucson, AZ 85716
(602) 881-5054

Personal

Born in Bozeman, Montana, June 24, 1921
Married to Nancy Griebel, August 14, 1943; three children
Residence: 728 North Sawtelle, Tucson, Arizona 85716

Education

Washburn High School, Minneapolis, Minnesota, 1939
University of Minnesota, 1939-1942, 1946-1948; B.S. Geology, B. of Physics
University of Wisconsin, 1952-1955; Ph.D. in Geophysics

Military Service

U.S. Marine Corps, 1942-1945, 1951-1952; Fighter Pilot
Commissioned Major, 1951-1959

Military Awards

WWII and Korean Theaters with engagement stars, Presidential Unit Citations, Distinguished Flying Cross, Air Medal with three clusters, Purple Heart

Professional Registrations

Arizona: Geologist; Geophysical Engineer; Land Surveyor
Idaho: Civil Engineer; Land Surveyor
Commercial Pilot, FAA License No. 257324 with instrument and flight instructor ratings

Academic Experience

University of Minnesota, 1947-1948; Teaching Assistant, Andrews Scholar
University of Wisconsin, 1954; Research Assistant, Teaching Assistant
Western State College, Gunnison, Colorado, 1955-1956; Assistant Professor of Geology and Geophysics
University of Arizona, College of Mines, Tucson, Arizona, 1963-1972; Professor of Geophysics; College of Earth Sciences, Tucson, 1972-1986; Professor; Professor Emeritus; presently. Adjunct Professor, Department of Mining and Geophysical Engineering

Professional Experience

Cleveland-Cliffs Iron Co., 1948-1951; Exploration Geologist, Geophysicist
Jones and Laughlin Steel Corp., 1955; Staff Geophysicist
McPhar Geophysics Inc., 1957; Manager
Phelps Dodge Corp., 1958-1963; Chief Geophysicist

Activities include:

Electromagnetic, magnetic, gravity, resistivity, magnetotelluric, complex-resistivity, self-potential, induced-polarization exploration, and groundwater exploration.

Geophysical instrumentation in magnetic, electromagnetic, resistivity, and induced-polarization methods; experience with airborne, surface, and drill-hole equipment

Laboratory measurements of physical properties of earth materials, including magnetic susceptibility, resistivity, and induced-polarization techniques

Geophysical interpretation methods, using computers, mathematical analysis, analog models, and groundwater models

Geological environments, including permafrost, placer deposits, Precambrian rocks, porphyry copper and replacement deposits of western North America, iron formations and massive sulfides, laterites of southeastern USA and Puerto Rico, midcontinent base metals deposits, ground-water exploration and underground surveys, and engineering site examinations and testing.

Consultant, 1955-present, on mining geophysics, research, and mineral exploration to mining and exploration companies, including Anaconda Copper Co., Cleveland-Cliffs Iron Co., Jones and Laughlin Steel Corp., U.S. Steel Corp., Kennecott Copper Co., Freemont mining Co., W. S. Moore Co., Phelps Dodge Corp., Homestake Mining Co., Copper Range Co., Lindgren Exploration Company, Eagle Picher Industries, El Paso Natural Gas Co., Cities Service Minerals Co., Superior Minerals Co., FUGRO Inc., SIGESA, PEMEX, United Verde Exploration, and others.

Society Memberships

American Geophysical Union
Society of Exploration Geophysicists
    Mining Committee Chairman, 1960
    Mining Associate Editor, 1961-1963; 1967-1969
    Editor and Chairman, Mining Volumes I and II
    Representative at Large, 1963-1965
    Reviews Associate Editor, 1963-1966
    Mining Program Chairman, 1973
European Association of Exploration Geophysicists
Exploration Geophysics Society of Japan
Australian Exploration Geophysical Society

- American Institute of Mining Engineers
  - Publications Chairman, Geophysics Section, 1964
- Engineering Geophysics Examiner for ECPD
- Sigma Xi
- Seismological Society of America
- University of Arizona Geophysical Society (SEG Chapter)
- Arizona Geological Society
- American Association for the Advancement of Science, Fellow, 1980

Lectureships

- American Geophysical Union, Visiting Scientist, 1965-1971
- Visiting Lecturer to Universities and Professional Societies
- Visiting Lecturer to universities in the People's Republic of China. 1987

Other Affiliations

- Rotary Club, Tucson, Arizona, Secretary, 1978
- Aircraft Owners and Pilots Association
- Order of Daedalians, Davis-Monthan Flight 12; Flight Captain, 1987
- Marine Corps League
- Westerners; Sheriff, 1988
- Pima Air Museum, Board of Directors, 1991-1994

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1955 Geophysical studies of the Waterloo area, Wisconsin: Ph.D. dissertation, University of Wisconsin.

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1964 Resistivity and induced polarization interpretation from analog models [abs.]: 34th Annual Meeting, Society of Exploration Geophysicists, November.

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1965 Geophysical exploration in 1964: Mining Eng., Feb., p. 84-87.

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1966 (with R. N. Schnepfe), Underground gravity surveying at Bisbee, Arizona, in Mining Geophysics, Vol. 1, Case histories: Tulsa, Oklahoma, Society of Exploration Geophysicists, p. 243-251.

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1966-67, Mining geophysics, Vols. I and II, Associate Editor: Tulsa, Oklahoma, Society of Exploration Geophysicists.

1967 The problem of negative induced polarization anomalies: Symposium on Induced Electrical Polarization, Engr. Geoscience, Dept. of Mineral Technology, University of California, Berkeley, February 1967, Proceedings, p. 32-50.

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1970 (with W. A. Sauck and K. L. Zonge), Comparison of time, frequency, and phase measurements in induced polarization [abs.]: 40th Annual Meeting, Society of Exploration Geophysicists, November.

1970 (with J. R. Sturgul and W. C. Peters), Computer applications in exploration geophysics, Section 3 of Peele's mining engineer's handbook: New York, Society of Mining Engineers of AIME.

1970 (with L. M. Gould), Continental drift: University of Arizona TV Film Series.

1970 The metal factors [abs.]: 40th Annual Meeting, Society of Exploration Geophysicists, November. (Best Presentation Award, SEG, 1971.)

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1978 Review of geophysical data in the Hualapai Reservation area for groundwater exploration: Office of Arid Lands Studies, University of Arizona, open-file report.

1978 Land subsidence in the Picacho basin, Pinal County, Arizona: Open-file report to the Office of Water Resources Research, National Technical Information Service, Washington, D.C.

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1979 (with W. S. Wojniak), Deep resistivities under Tucson, Arizona, from magnetotelluric sounding [abs.]: 49th Annual Meeting, Society of Exploration Geophysicists, New Orleans.

1979 Gauss's theorem and the interpretation of magnetic exploration data [abs.]: 49th Annual Meeting, Society of Exploration Geophysicists, New Orleans.

1979 The induced-polarization method, in Hood, P. J., ed., Geophysics and geochemistry in the search for metallic ores: Geological Survey of Canada, Economic Geology Report 31, p. 123-133.

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1980 (with J. Lysonski, J. Schmidt, and C. Aiken), IGSN71 residual Bouguer gravity map of Arizona: Tucson, University of Arizona Geophysical Society.

1980 (with J. C. Lysonski), The IGSN71 Residual Bouguer gravity anomaly map of Arizona. Paper presented at the 50th Annual Meeting and Exposition, Society of Exploration Geophysicists, Houston.

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1980 (with J. M. Oppenheimer), Regional geophysical assessment of southwest alluvial basins. Report submitted to the U.S. Geological Survey, Contract No. 14-08-00001-18228, Open-File Report.

1980 (with J. M. Oppenheimer), Depth-to-bedrock map, Basin and Range Province, Arizona: Laboratory of Geophysics, University of Arizona.

1980 (with K. L. Zonge), Induced polarization for exploration geophysicists. Short course sponsored by the South African Geophysical Association at the University of the Witwatersrand, Johannesburg, South Africa, August 18-21, 1980.

1981 (editor), Advances in induced polarization and complex resistivity. Short course presented at The University of Arizona, January 5-7, 1981.

1981 The mise-a-la-masse induced-polarization method [technical paper]: 51st Annual Meeting, Society of Exploration Geophysicists, Los Angeles.

1981 (With C. L. V. Aiken, J. C. Lysonski, and W. R. Hahman, Sr.), A series of 1:250,000 complete residual Bouguer gravity anomaly maps of Arizona, in Stone, C., and Jenney, J. P.(eds.), Digest XIII: Tucson, Arizona Geological Society, p. 31-39

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1981 (with F. Stevenson, K. Kretvix, L. O'Conner, S. Calvo, M. Sbar, and R. Richardson), Report of geophysical surveys in the Madera Canyon alluvial fan and Arivaca Wash areas, Pima County, Arizona: Open-File Report.

1981 (with J. Lysonski), Free-air gravity map of Arizona: Laboratory of Geophysics, University of Arizona.

1981 (with J. Lysonski, C. Aiken, and J. Schmidt), Residual Bouguer gravity anomaly map of Arizona (ISGN71): Laboratory of Geophysics, University of Arizona.

1982 (with J. Lysonski and C. Aiken), The complete residual Bouguer gravity anomaly map of Arizona (set of 23 maps; scale 1:250,000; 2-mgal contours): University of Arizona.

1982 Crustal geology of Arizona as interpreted from magnetics and gravity and geologic data, in Technical program, abstracts, and biographies. Society of Exploration Geophysicists 52nd Annual International Meeting and Exposition, Dallas, Texas, October 1982: Tulsa, Oklahoma, SEG, p. 298-299.

1983 (with P. F. Halvorson), Geophysical exploration surveys for ground water in the San Pedro Basin, Arizona: Research Project Technical Completion Report A-108-ARIZ.

1984 Coriolus deflection of moving lithospheric plates [abs.]: EOS, Transaction of American Geophysical Union, v. 65, no. 16, p. 275.

1985 Crustal geology of Arizona as interpreted from magnetic gravity and geologic data, in Hinze, W. J. ed., The utility of regional gravity and magnetic anomaly maps: Tulsa, Oklahoma, Society of Exploration Geophysicists, p. 164-180.

1986 Untapped potential groundwater supplies [invited speaker abs.], Rocky Mountain Groundwater Conference, Scottsdale, Arizona.

1987 Regional geophysics of Arizona [abs.], GSA Annual Meeting, October 21, Phoenix, Arizona: Abstracts with Programs, v. 19, no. 7, p. 859

1988 Geophysical prospecting, Chapter 4.4.1., in Hartman, H. L., sr. ed., SME mining engineering handbook, 2nd ed.: Society of Mining Engineers, Inc., in preparation.

1988 (with Cole, K. C.,), Repeated gravity measurements and GPS elevation control in the estimation of aquifer properties and temporal changes in subsurface water levels within the Tucson Basin of southern Arizona [poster]. AGU Fall Meeting, San Francisco: Dec. 6-11, EOS, v. 69, p. 1185.

1989 Regional geophysics of Arizona, in Jenney, J. P. and Reynolds, S. J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society, Digest 17 Page No.

1991 Regional magnetic anomalies related to sulfide mineralization and geohydrology, International Union of Geology and Geophysics Poster Session, Symposium 5.18.

1991 (with K. L. Schwartz). Geohydrology of the volcanic rocks of the Galiuro Mountains, southeastern Arizona.

1991 (with Hatch, M. A.), Global positioning system measurement of subsidence in the Tucson Basin, Pima County, Arizona (abs.) Geological Society of America, Abstracts with Programs, 1991 Annual Meeting, San Diego, p. A324.

VITAE OF S.R.TITLEY
STATEMENT OF INTERESTS, SCIENTIFIC WORK AND RESEARCH FOCUS

This statement precedes the details of professional activity and publications presented in the formal vitae, which is attached. References noted as attached are listed in the formal bibliography.

The geology of base and precious metal deposits has been the principal broad focus of study. A wide variety genetic types of different ages have been studied from perspectives of both basic research problems and applied work. This work has been carried out during parts of sabbatical leaves and during non-appointed release time during summers away from the academic environment. These independent studies have been applied to and integrated with many of the more than 100 theses and dissertations directed during a 32 year period of time as a University teacher. The geography of my study has been and remains broad; much of my study has been carried out in the western and southwestern Pacific Island regions and Australia. Other work, some which has been carried out during sabbatical leaves has been in southeast Asia, in Peru and Ecuador, during a Fulbright Senior Lectureship in the northern Amazona and Guyana shields, and in the Archean and Proterozoic of western Australia and the Republic of South Africa.

Ore deposit styles in which the field work and these studies have been carried out range from Precambrian BIF and Pb-Zn-Ag and Sn-Granite ores of Archean and Proterozoic shields, through the young Sn-granites of Malaysia, to hydrothermal ores of vein, replacement, and porphyry styles in the epithermal and mesothermal environments of continental margins of the Pacific Rim. Results of these studies in the southwest Pacific, Mexico, Peru and the United States have been described in articles of the peer-reviewed literature since about 1975 (see attached list of articles and abstracts), and two regionally constrained collections of papers on porphyry copper deposits have been published as books (see attached list). In addition, some 50 (unlisted) confidential reports and papers have been provided employers and supporters of this work in foreign countries.

The nature of work involved has ranged from prospect and project evaluation, through supervision and oversight of development drilling and intensive field study of ore systems at deposit scale, to physical grass-roots exploration, mostly carried out in the Pacific Islands and Australia. Principally, this has been ore-search utilizing field geology, geochemistry and geophysics in integrated ways to identify areas of economic potential with subsequent use of geological concepts of wide latitude in their interpretation. My skills and background in teaching have enabled me to carry out such work as a teacher in the field where I have worked in many places with young geologists, providing continuing education and assisting them in reaching geologic and economic conclusions concerning their geological problems. In so doing, I have developed a "loop" of continuing education of myself and students through field experience, and bring to the classroom results of this kind of field work.

Most recently, as seen in the attached bibliography, my interests have shifted from two decades of process-intensive studies to environment-focused consideration of metal occurrence and to broader problems of metallogenesis in general. My recent work has focused on the nature of those characteristics of the geology and geological history of regions where metals are found, concentrating now upon the metallogenic habits of tectonic elements, terranes, and provinces. I am testing the notion that properties of the upper and lower crust have an importance comparable with or exceeding that of processes, in epigenetic ore deposits, in controlling the quality of metal endowment of metal provinces. Such work has as its purpose a development of regionally discrete criteria that will allow reasonable development of metallogenic expectations in unexplored regions. A second major part of these studies deals with the problems of metallogenic overprinting of continental margin belts. In these regions, concentration of metal in ores of different styles has taken place at different times, the Great Basin and southern Basin and Range province of North America, the Sierra Madre Occidental and Mesa Central of Mexico, and the Altiplano of Peru, notable examples. The development of base-line geochronologic information and its relationship to ore concentration should be a significant part of regional assessments, which require serious evaluation. consideration and study of the application of models in unravelling the metallogenic history and potential of ancient and modern, accreted and cratonic continental margins and island arcs.

VITAE

Spencer R. Titley December 1991

Personal Data

Name	Birth Place and Date	Citizenship
Spencer Rowe Titley	Denver, Colorado 9/27/28	U.S.A.

Social Sec. No.	Address (Home)	Address (Business)
	6920 Taos Place Tucson, AZ 85715	Dept. of Geosciences Univ. of Arizona Tucson, AZ 85721
Telephone	602-298-8205	602-621-6018(6024)

Education

East Denver High School	1946 (Grad.)
Sullivan School, Wash. D.C.	1946-1947 (College Prep.)
Colorado School of Mines	1951 (Grad.) Geol. Engr.
University of Arizona	1958 (Grad.) Ph.D.

Employment

1960 - Present	University of Arizona; successively Asst., Assoc. and Full Professor in Geology, and Geosciences.
1958-1960	Regional Exploration Geologist, New Jersey Zinc Co., Southwestern United States Exploration and Operational Geology (Arizona and New Mexico)
1956-1958	Half-time and full-time Instructor, University of Arizona
1955-1958	Graduate Studies, University of Arizona and summer field studies, New Jersey Zinc Co., Magdalena, New Mexico.
1953-1955	Staff Geologist, New Jersey Zinc Co., Gilman, Colo. Operational Geology
1951-1953*	Armed Services, Corps of Engineers, U.S.Army
1951	Junior Geologist, New Jersey Zinc Co. (Gilman, Colorado. (3 mos.))
1963-1975	Geologist (WAE) U.S.Geol.Survey, Branch of Astrogeologic Studies, Flagstaff, AZ
Summers, 1946,1947, 1948.	Hardrock Miner, Front Range Mines Co., Colorado; Gold mines at Idaho Springs, Cripple Creek, and Boulder, Colorado

*Service Record: Enl. Colo.National Guard 23/6/48, 199th Engr(C) Bn. Activated for Korea 1/10/50, Honorable Discharge, 25/5/51; Commissioned, Corps of Engineers, U.S.Army Reserve (CE-USAR), 25/5/51, (Distinguished Military Graduate, Colo. Sch. Mines) Active duty, CE-USAR 8/51-8/53; Korean War, 4/52-6/53,194th Engr.Combat Bn, 36th Engr(C)Gp, IX Corps, Combat Engineer-Platoon Leader/Co.Commander. Decorated. U.S.Army Reserve (Active and Inactive) 8/53-6/64. Honorable Discharge USAR 15/6/64.

Professional Affiliations

Society of Economic Geologists - Fellow
Geological Society of America - Fellow
Australasian Institute of Mining and Metallurgy - Fellow
Mineralogical Society of America - Fellow
Society for Geology Applied to Mineral Deposits (SGA)
American Inst. of Mining, Metallurgical and Petroleum Engineers
Society of Exploration Geophysicists
American Geophysical Union
International Association for the Genesis of Ore Deposits (IAGOD)

Professional Activities

- Society of Economic Geologists
  - Councilor (1980-1982)
  - Lindgren Award Committee (1978-1980). Chairman,1978
  - Society and Penrose Medal Committee (1984-1986)
  - Chairman, Program Committee, Phoenix S.E.G. Mtg., 1987.
  - Membership Committee 1988-1991; Chairman,1990-1991.
- Society of Economic Geologists Foundation, Inc.
  - Secretary (1973-1983)
  - Member, Board of Trustees, (1979-1982)
- Economic Geology Publishing Co.
  - Member (1976-Present)
- Mineralogical Society of America
  - Program Chairman, 1st Annual Meeting, Tucson, 1974.
- Economic Geology and the Journal for the Society of Economic Geologists; Member of Editorial Board, (1970-1975)
- Ore Geology Reviews (Elsevier), Member of Editorial Advisory Board 1985---
- National Science Foundation; Member of Advisory Committee and panel for Biological, Mathematical, and Geophysical Sciences and Engineering, Division of Applied Research, EAS, 1978-1981.
- Lunar Orbiter Photo Data Screening Group, NASA, Member, 1967-1968.
- Apollo Field Geology Investigation Team (U.S.G.S./NASA)
  - Co-investigator, Apollo 15-16-17
- Arizona Geological Society
  - President, 1974-1975.
  - Treasurer, 1968-1969
  - Councilor, Various Years and Terms, 1960-1985.

University Activities

Graduate Study Committee: 1966-1971
Faculty Senate: 1980-1983.
Gould-Simpson Building Design and Building Committee, Department of Geosciences: 1981-1986
Graduate Council: 1986-1991.
Academic Program Review Committees:
  School of Renewable Natural Resources: 1987
  Department of Nutrition and Food Science: 1988
  Graduate Program in Nutritional Sciences: 1989
  Department/Program in Applied Mathematics: 1990/1992.
  Department of Pharmacy: 1991/1992.
Graduate College Commencement Marshall: 1980 - Present
Graduate College, Committee on Natural Resources
Water Resources Administration Advisory Committee

Other

Licensed Commercial Pilot
Registered Geologist (#4066), State of Arizona

Awards

Phoebe Apperson Hearst Distinguished Lecturer, Department of Minerals Science and Engineering, University of California - Berkeley, March, 1988.

Fulbright Senior Lecturer, Federal Univ. do Para', Belem, Para', Brazil, August-October, 1986.

University of Arizona Foundation, Creative Teaching Award, April, 1986.

Thayer Lindsley Distinguished Lecturer in Economic Geology 1985-1986. Society of Economic Geologists.

Burlington Northern Foundation, University of Arizona, Faculty Achievement Award for Teaching Excellence, 1984-1985.

Medal for Distinguished Achievement in Mineral Engineering, Colorado School of Mines, 1975.

Grants and Contracts

Occidental Minerals Corp. $33,000 for study of weathering of sulfide-bearing potassium silicate minerals (1975-1977) with D.L.Norton.

National Science Foundation.$67,500 for study of fracture evolution in porphyritic rocks (1979-1981) with R.E.Beane.

(EAR78-22897).

National Science Foundation $96,000 for study of evolution of Laramide porphyries (1983-1985). (EAR82-18775).

National Science Foundation $39,600 for study of trace elements in productive and barren Laramide intrusions (1988-1989). (EAR87-19971).

National Science Foundation $50,100 for study of trace elements in productive and barren Laramide intrusions (1989-1990). (EAR89-44119).

Petroleum Research Fund (ACS) $40,000 for study of oxic and anoxic lower Paleozoic Strata (1991-1993).

Phelps Dodge Corp., $20,024 for study of secondary enrichment in the porphyry copper deposit at Tyrone, New Mexico. (1991-1993). (S.Cook dissertation).

BHP-Utah, $20,000 for study of massive sulfide ores at in Oaxaca, Mexico. (1991-1993). M. Miranda G., dissertation.

Cominco U.S.A., $20,000 for study of Red Dog ore deposit, Alaska. (1991-1993). Dan Sims, Ph.D. Dissertation.

EXMIN, $6,000 for study of lode gold deposits of the Bradshaw Mountains. (1989-1991). Brooke Clements, M.S.Thesis.

Industrial Grants for Student and Logistical Support - various corporations including Duval Corp., Asarco Inc., Homestake Mining Co., Occidental Minerals Corp., Kennecott (Bear Creek Min. Co.), and others: Aggregate over $175,000 since 1970.

National Aeronautics and Space Administration: Equipment Grant, 1966-1968: $35,000 for infrared spectrophotometer and support equipment.

Publications

Books and Special Issues Edited

Titley, S.R., 1982, (ed.) Advances in Geology of the Porphyry Copper Deposits, Southwestern North America: Tucson, Univ. Ariz. Press, 560p.

Titley, S.R., 1968, (ed.) Southern Arizona Guidebook III: Tucson, Ariz. Geol. Soc., 354p.

Titley, S.R. and Hicks, C.L., 1966, (eds.) Geology of the Porphyry Copper Deposits, Southwestern North America: Tucson, Univ. Ariz. Press, 287p.

Gustafson, L. B. and Titley, S.R., 1978, (eds.) Porphyry Copper Deposits of the Southwestern Pacific Islands and Australia: Econ. Geol., Spec. Issue, v.73, no. 5, p.597-985.

Norton, D. Titley, S.R., Gerlach, T., and Knight, J., 1975, Hydrothermal Systems Notebook: Dept. Geosciences, Univ. Ariz. Short Course Vol., 95p.

Articles

Titley, S.R., 1991, Phanerozoic ocean cycles and sedimentary rock hosted gold ores: Geology, v.19 p.645-648.

Titley, S.R., 1991, Correspondence of ores of silver and gold with basement terranes in the American southwest: Mineral. Deposita, (Berlin), v.26, p.66-71.

Gray, Matthew D., and Titley, S.R., 1990, Gold occurrence in the Black Cloud #3 orebody, Leadville mining district, Lake County, Colorado: Econ. Geol. Mon. 7, p.417-424.

Beaty, D.W., Merchant, J.S., O'Neill, T.F., and Titley, S.R., 1990, Origin of the ore deposits at Gilman, Colorado: Part II, Alteration, veining, and carbonate-replacement patterns surrounding the main manto/chimney complex: Econ. Geol. Monograph 7, p.203-219.

Titley, S.R., 1990, Evolution and style of fracture permeability in intrusion-centered hydrothermal systems: NAS/NRC, Studies in Geophysics, The Role of Fluids in Crustal Processes, p. 50-63.

Titley, S.R., 1990, Contrasting metallogenesis and regional settings of circumPacific Cu-Au porphyry systems: Proc. Pacific Rim 90 Congress, v.II, p.127-133.

Titley, S.R., 1990, High-temperature carbonate-hosted massive sulfide ores in the American Cordillera: Proc. Pacific Rim 90 Congress, v. II, p.549-556.

Titley, S.R., 1990, Contrasting characteristics of precious metal-bearing porphyry systems: Preprint, 95th Annual Northwest Mining Association Convention, Spokane, Washington, Dec. 1989. 11p.

Titley, S.R., and Anthony, E.Y., 1989, Laramide mineralization in Arizona, <u>in</u>, Jenney J.P., and Reynolds, S.J., eds., Geological Evolution of Arizona: Tucson, Ariz. Geol. Soc. Digest 17, p. 485-514.

Titley, S.R., 1989, Regional variation of silver and gold ratios in vein ores of Arizona: Econ. Geol., Mon. 6, p.618-628.

Clarke, Mike, and Titley, S.R., 1988, Hydrothermal evolution in the formation of silver-gold veins in the Tayoltita mine San Dimas district, Mexico: Econ. Geol., v. 83, p.1830-1840.

Megaw, P.K.M., Ruiz, Joaquin, and S.R.Titley, 1988, High-temperature, carbonate-hosted Ag-Pb-Zn(Cu) deposits of northern Mexico: Econ. Geol., v.83, p.1856-1885.

Anthony, E.Y., and Titley, S.R., 1988, Pre-mineralization igneous processes at the Sierrita porphyry copper deposit, _in_, Zachrisson, E., ed., Proc. Intl. Assoc. Geol. Ore Deposits, 7th Ed.: Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung, p.535-546

Anthony, E.Y., and Titley, S.R., 1988, Progressive mixing of isotopic reservoirs during magma genesis at the Sierrita porphyry copper deposit, Arizona; inverse solutions: Geochim. et Cosmochim. Acta, v.52, p.2235-2250.

Titley, S.R., 1988, Silicates flushed with copper: Nature, v.334, p.472-473.

Titley, S.R., 1987, The crustal heritage of silver and gold ratios in Arizona ores: Geol. Soc. America Bull., v.99, p.814-826.

Titley, S.R., Thompson, R.C., Haynes, F.M., Manske, S.L., Robison, L.C., and White, J.L., 1986, Evolution of fractures and alteration in the Sierrita-Esperanza hydrothermal system, Pima County, Arizona: Econ. Geol., v.81, p.343-370.

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Titley, S.R. and Megaw, P.K.M., 1985, Carbonate-hosted ores of the western cordillera - an overview: Littleton, Colo., Soc. Min. Engrs. of A.I.M.E., Preprint 85-115, 17p.

Titley, S.R. and Beane, R.E., 1981, Porphyry copper deposits; Part I, Geologic settings, petrology and tectogenesis: Econ. Geol., 75th Anniv. Vol., p.235-269.

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Titley, S.R., 1981, Porphyry copper: Am. Scient., v.69, p.632-638.

Titley, S.R., 1981, Geologic and geotectonic setting of porphyry copper deposits in the southern Cordillera, <u>in</u> Dickinson, W.R., and Payne, W.D., (eds.), Relations of Tectonics to Ore Deposits in the Southern Cordillera: Tucson, Ariz. Geol. Soc., Digest XIV, p.79-97.

Haynes, F.M. and Titley, S.R., 1980, The evolution of fracture-related permeability within the Ruby Star Granodiorite, Sierrita porphyry copper deposit, Pima County, Arizona: Econ. Geol., v. 75, p.673-683.

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Titley, S.R., Fleming, A.W., and Neale, T.I., 1978, Tectonic evolution of the porphyry copper system at Yandera, Papua New Guinea: Econ. Geol., v.73, p.810-828.

Titley, S.R. and Heidrick, T.L., 1978, Intrusion and fracture styles of some mineralized porphyry systems of the southestern Pacific and their relationship to plate interactions: Econ. Geol., v.73, p.891-903.

Titley, S.R., 1978, Copper, molybdenum, and gold content of some porphyry copper systems of the southwestern and western Pacific: Econ. Geol., v.73, p.977-981.

Titley, S.R., 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: Tucson, Ariz. Geol. Soc. Digest X, p.71-101.

Titley, S.R., 1976, Porphyry copper deposits of Arizona: Ariz. Exec. Off. Tech. Briefg. Note 76-10, 3p.

Titley, S.R., 1975, Geological characteristics and environment of some porphyry copper occurrences in the southwestern Pacific: Econ. Geol., v.70, p.499-514.

Titley, S.R. and Bell, E.B., 1975, The porphyry copper prospect at Plesyumi, New Britain, Papua New Guinea, <u>in</u> Taylor, G.A.M., (ed.) Porphyry copper deposits of the South-West Pacific:

Sydney, Geol. Soc. Australia-CSIRO Spec. Publication, p.45-55.

Titley, S.R., 1973, Geological environment and characteristics of some porphyry copper deposits in the southwestern Pacific: Soc. Min. Engrs. of A.I.M.E., Preprint 73S65, 25p.

Titley, S.R.,1973, "Pyrometasomatic" - an alteration type: Econ. Geol., v.68, p.1326-1329.

Titley, S.R., 1972, Mesozoic tectonic patterns and the distribution of porphyry copper deposits in southeastern Arizona: Yearbook, Natl. Western Mining Congr., p.87-92.

Titley, S.R., 1972, Intrusion, and wall rock, porphyry copper deposits: Econ. Geol., v.67, p.122-123.

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Titley,S.R.,1972, Copper Mining and Arizona Land Use Planning: A geologist speaks: Field Notes, Ariz. Bur. Mines, v.2, no.4,

Titley, S.R., 1972, Mesozoic paleotectonic environment of the porphyry copper deposits of southwestern North America: Tokyo, Soc. Min. Geol. Japan, Spec. Issue 3, p.14, (Proc. IMA-IAGOD Mtgs., 1970.

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Titley, S.R., 1968, Southern Arizona - the view from Gemini: Ariz. Geol. Soc. Guidebook III, p.2-6.

Elston, D.P., and Titley, S.R., 1966, Manned exploration of the lunar surface: Ann.N.Y. Acad. Sci., v.140, Art. 1, p.636-646, (Planetology and Space Mission Planning).

Titley, S.R., 1963, Lateral zoning as the result of a monoascendent hydrothermal process in the Linchburg Mine, New Mexico: Symposium, Problems of post-magmatic ore deposits, Prague, p.312-316.

Titley, S.R., 1963, Some behavioral aspects of molybdenum in the supergene environment: Trans. AIME, p.199-204.

Titley, S.R., 1963, Reply to discussion - molybdenum in the supergene environment: Trans. AIME, March 1964, p.39.

Lacy, W.C., and Titley, S.R., 1962, Geological developments in the Twin Buttes district: Min. Congr. Jour., April 1962, p.62-65..

Titley, S.R., and Damon, P.E., 1962, Investigation of color centers in fluorite: Jour. Geophys. Res., v.67, p.4491-4495.

Titley, S.R., 1962, Geology along the Diamond Rim and adjoining areas, Gila and Navajo Counties, Arizona: New Mex. Geol. Soc., 13th Field Conf. Guidebook, Oct. 1962, p.123-128.

Titley, S.R., 1961, Genesis and control of the Linchburg orebody, Socorro County, New Mexico: Econ. Geol., v.56, p.695-722.

Titley, S.R., and Anthony, J.W., 1961, Some preliminary observations on the theoretical geochemistry of molybdenum under supergene conditions: Ariz. Geol. Soc. Disgest IV, p.103-116.

Titley, S.R., 1959, Geological summary of the Magdalena mining district, Socorro County, New Mexico: New Mex. Geol. Soc. 10th Field Conf. Guidebook, p.144-148.

Titley, S.R., 1959, Igneous rocks of the Basin and Range Province in Arizona: Ariz. Geol. Soc. Guidebook II, p.85-88.

Titley, S.R., 1958, Structural and mineralogical control of ore, Linchburg Mine, Socorro County, New Mexico: Ariz. Geol. Soc. Digest I, p.31-36.

Chapters in Books

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