UNITED STATES DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

RECOMMENDATIONS FOR ASSESSMENTS OF UNDISCOVERED MINERAL RESOURCES

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U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 95-82

CONTENTS

CONTENTS--CONTINUED

FIGURES

PART A: REPORT FROM THE FORUMS

A.1.0 EXECUTIVE SUMMARY

A.1.1 PURPOSE OF THE COMMITTEE

In May 1993, the committee that prepared this report was selected and instructed to obtain broad input about the applicability of the report by Harris, Rieber, and others (1993) titled "Evaluation of the United States Geological Survey's three-step assessment methodology" (hereafter referred to as the Arizona Report) as a guide for improvements in the program to assess undiscovered mineral resources. The Arizona Report was prepared by an outside contractor for the Geologic Division of the U.S.G.S. in response to intra-Survey criticism of the methodology. The approach used to obtain the desired broad response was to conduct workshops, or forums, in six U.S. Geological Survey Centers and Field Offices and to invite written comments. The discussions in the forums led to and included additional related topics. This report, therefore, addresses a broader array of issues than that covered in the Arizona Report and blends the information into a single extended discussion. This report thus goes well beyond the scope of the Arizona Report; however, it is not necessary to read that report in order to understand any aspect of this report.

A.1.2 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The Arizona Report is comprehensive and, in many places, exhaustive in its depth of coverage; in other places it is less so. It gives conditional support to the methodology for the assessment of undiscovered mineral resources that was developed and first applied by the Office of Mineral Resources. It contains recommendations for improvements in the methodology, and our forums contributed still more. Almost all of these recommendations are considered in this present report. The items summarized here are followed by a parenthetical expression (such as A.3.10) that identifies the section where the complete discussion is found. The index (A.7) contains a complete list of recommendations.

Overall, the forum process and the preparation and release of this report have relieved a contentious situation and have moved the Geological Survey toward a broad, though still-tentative, consensus that covers both the proper use of the existing methodology and appropriate plans for its improvement.

The primary recommendations of the committee are summarized here in descending order of importance. This summary is essentially an abstract of the more important issues and recommendations in this report. In addition to containing all of the committee's recommendations, all of the recommendations made in the Arizona Report itself are tabulated in the Index (A.7) and referenced to both that report and this one.

A.1.0 EXECUTIVE SUMMARY--CONTINUED

A.1.2 SUMMARY OF FINDINGS AND RECOMMENDATIONS--CONT.

- The most difficult challenges in the current assessment methodology concern: (1) estimating the numbers of undiscovered deposits in tracts judged to contain undiscovered mineral resources and (2) presenting probabilistic data to clients who want and need straightforward and unequivocal answers to complicated problems.

- Our recommendation regarding the first of these challenges is a program of research to seek ways to augment or replace the current subjective probability method; this is required to improve the methods of estimating the numbers of undiscovered deposits in an assessment tract. The program should include techniques needed to test the ability of assessment teams to produce consistent and reproducible judgements for a wide variety of mineral-deposit types. Also geophysical and other techniques should be improved and applied to enhance our understanding of the distribution of mineral deposits and thereby improve the estimates (A.3.4, A.3.10, A.3.11).

- Our recommendation regarding the second of these challenges is to design the format for presentation of quantified results specifically for the client. The format should vary with the client and their purposes. Clients generally want to know what, where, when, and what impact, as well as how much. However, in addition, all of the information gathered and used in an assessment itself should be archived in anticipation of now-unforseen future uses, (A.3.2.1, A.3.4.6, A.3.6, A.3.8, A.3.9).

- Because premature release of some preliminary assessment results has caused embarrassment to individuals, the Office, and the Survey; the Survey should resist attempts by clients, the Department, or the Legislative Branch to force premature release of information about the outcome of active studies. We should not divulge preliminary ideas and results that may not persist after more study. In particular, information release should not preempt established report-review procedures (A.3.6, A.3.7).

- The Survey should reduce the number of simultaneous assessment studies in order to assemble and utilize more balanced assessment teams, and should provide additional training for existing staff. Clear priorities should be established for assessment and non-assessment research. As of now, the Geological Survey has severely stretched its collective ability to perform high-quality assessments. There is a serious shortage of resource specialists and of fiscal support for assessments (A.3.2).

A.1.0 EXECUTIVE SUMMARY--CONTINUED

A.1.2 SUMMARY OF FINDINGS AND RECOMMENDATIONS--CONT.

- The Survey should prepare comprehensive but flexible guidelines or standards, and accompanying supporting materials, for the assessment process, including guidelines for the construction of mineral-deposit models. This is because assessment procedures have evolved unevenly and some conflicting strategies have resulted. Some current terminology is ambiguous. The supporting materials should therefore include a glossary with concise definitions and some examples of standardized text (aka boiler plate) to facilitate internal as well as external communication (A.3.2.2, A.3.3.2.2, A.6).

- The Survey should continuously improve its library of mineral-deposit-type models as they are the basis of all current assessments. Improvements should include the addition of new and revised models; improvement of electronic and other access to the model data base; identification of diagnostic geologic, geochemical, and geophysical features for different models; and the inclusion of new information, such as specific environmental concerns. Model construction and revision should involve the whole Office of Mineral Resources, the Geologic Division, and outside experts (A.3.3.2, A.3.4).

- Access to the Mark3 Monte-Carlo-type mineral-resource simulator, which is very important in the present process of preparing quantified assessments, should be improved by making it available on desktop computers and by enhancing its input and output capabilities. Easy access would aid greatly in improving assessment teams' understanding of the estimation process and would result in higher quality assessments (A.3.5).

- Geographic Information Systems (GIS) technology should be used to an increasing degree in assessments. GIS is the best tool for the manipulation, presentation, and archiving of spatial information. Although expensive in time and money, GIS would provide superior assessment results (A.3.3.1, A.3.4.3).

- The use of Gross-In-Place-Value (GIPV) for undiscovered mineral resources should be discontinued and replaced by some economically determined in-place value for those resources judged to be of near-term significance. GIPV is not a measure of economic value and is subject to abuse; however, it should be supplied in response to a client's specific request. Alternative ways of reporting value and procedures for determining economic value should be investigated (A.3.6.2, A.3.6.5, A.3.10). [This recommendation has already been implemented through the Office Chief's memorandum to the OMR branch chiefs dated July 14, 1994.]

A.2.0 INTRODUCTION

A.2.1 BACKGROUND AND PURPOSE OF THE COMMITTEE

The U.S. Geological Survey (USGS) has a long history of mineral-resource assessment. During the past thirty years such assessments have evolved from the qualitative assessments of undiscovered resources typified by reports for the U.S. Forest Service Wilderness Program from 1964 to 1984 into quantified estimates. These first appeared in reports of the Alaskan Mineral Resources Assessment Program (AMRAP) in the 1970's, then in reports to the Bureau of Land Management (BLM), the U.S. Forest Service (USFS), and, currently, as unpublished parts of an on-going National Assessment Program. Differences of opinion, focusing mainly on the methodology used to estimate undiscovered mineral resources, arose among participating geoscientists in a few of the most recent assessments. The discussion of these differences of opinion spread throughout the Geologic Division of the Survey.

In order to air these differences and recommend an appropriate course of action, the U.S. Geological Survey awarded a contract to the University of Arizona and Professor D.P. Harris in the spring of 1992. The contract called specifically for an examination of the methodology, a comparison with other methodologies, and recommendations for improvement. Harris assembled a committee and held a week-long workshop in Tucson in summer 1992; there, the committee heard extensive discussion from protagonists from both sides and geologist-users of the current methodology. In March 1993 a report titled "Evaluation of the United States Geological Survey's three-step assessment methodology" was completed; it has been released as Harris, Rieber, and others (1993) and is referred to hereafter as the Arizona Report. The Arizona report contains many recommendations for changes, but does support the basic premises and procedures of the current assessment methodology.

W.H. White, Chief of the U.S.G.S. Office of Mineral Resources (OMR), in a memorandum dated May 24, 1993, created the present committee and directed it "...to take the recommendations of the Harris Committee, gather the comments of our scientists, and formulate these into a plan for the modification and improvement of the quantitative assessment method." The committee was instructed to hold a series of workshops to receive input in the autumn of 1993, and to present a final report by May 1, 1994. The memorandum further stated that: "Whether or not a quantitative assessment should be made is not an issue, it is our responsibility to make such assessments. Our goal is to make them as accurately as possible, and to assure our methods are continually re-evaluated and improved." As the committee met with OMR and other personnel, it became obvious that the topics covered by the Arizona Report were logically intertwined with a fuller discussion of the whole subject of USGS mineral-resource assessment. The committee enlarged the scope of its study and report accordingly.

This report is the response to this charge; as such it is intended to accomplish two main objectives: (1) to communicate the recommendations of the forums, both as they referred to the Arizona Report and to the additional topics and material that were covered; and (2) to provide assessment-method information for later reference.

A.2.0 INTRODUCTION--CONTINUED

A.2.1 BACKGROUND AND PURPOSE OF THE COMMITTEE--CONT.

The first objective is accomplished here with the recommendations made in section A.3. Some of the topics discussed were of greater interest and concern than others and they were brought up over and over. They led to the recommendations in section A.3; in that section the "Recommendations" are preceded first by the topic itself, categorized as an "Issue" and by summary "Comments" that are based on the forum and written input. The recommendations made for each issue represent consensus obtained in the forums or the committee's best judgement after considering alternative points of view.

The second objective is accomplished in part by the "Comments" in section A.3 and by the organization of that section. The section is organized according to the sequence of processes that occurs during an assessment. Thus, in a general sense, section A.3 provides the outline for a set of guidelines for undiscovered-mineral-resource estimation, and the section can be referred to by assessment teams when general questions arise.

Information in this report that goes beyond the scope of the Arizona Report includes the selected bibliography in A.5 and a glossary in A.6. Both sections address problems of communication and information that emerged during the forums. Section A.7 is an index; listed there under "Recommendations" are the recommendations of this report and those of the Arizona Report.

Finally, although some readers may not like our use of an alphanumeric scheme for identifying different sections of this report, it has facilitated communication between the authors and has also has proven also to be an efficient aid in indexing and cross-referencing the report.

A.2.2 THE ARIZONA-REPORT-FORUM COMMITTEE AND ITS METHODS

The committee members appointed first were the chairman, P. B. Barton, and D.A. Brew., D.A. Lindsey, and S. Ludington. This core group was augmented by six additional members from other USGS Regional Centers and Field Offices: R.A. Ayuso, E.R. Force, B.M. Gamble, R.J. Goldfarb, D.A. John, and K.M. Johnson.

The committee used two main methods to gather information: (1) six forums, and (2) solicitation of written contributions from forum participants and others. The forums were advertised well in advance, both in the Geologic Division "Cross Section" newsletter article and by local flyers and announcements. Interested individuals were urged to read and study the Arizona Report before the forums and copies were made widely available for that purpose.

The forums all followed essentially the same format. The local committee members gave an introduction, and then moderated and facilitated the meeting. The introduction was followed by a presentation by Ludington on the current assessment method and on the Mark3 mineral-resource simulator. Then the recommendations of the Arizona Report were examined and the list of local-interest items solicited and prepared by the local committee member was discussed.

A.2.0 INTRODUCTION--CONTINUED

A.2.2 THE ARIZONA-REPORT-FORUM COMMITTEE AND ITS METHODS--CONTINUED

The main purpose of gathering comments on the Arizona Report was expanded on an *ad hoc* basis to include general discussion of all aspects of assessment methodology. The forums facilitated the flow of information and their educational function was retrospectively judged to be much more important than originally anticipated. Every forum was different because the participants brought different levels of experience, understanding, and concern regarding estimation methodology. In general, the exchange of information was vigorous, wellintentioned, and good-natured. A total of about 200 people attended the forums. Committee members took copious notes and met together after each event to discuss highlights and new contributions. The following table documents the forum dates and participation.

		Attendees		
Location	Dates	At Start	At End	At Social Hour
Menlo Park, CA	Oct. 13-14, 1993	>30 (~25)	~20	~7
Tucson, AZ	Oct. 18-19, 1993	16 (~15)	10	28 (dinner)
Anchorage, AK	Nov. 2-3, 1993	13 (11)	12	~10
Spokane, WA	Nov. 8-9, 1993	17 (14)	14	~9
Denver, CO	Nov. 30-Dec 1,1993	>60 (~35)	38	12-15
Reston, VA	Dec. 14-15, 1993	63 (~30)	32	10

The written contributions received consist of both items restated from the oral discussions at the forums and additional material. The purpose of soliciting written contributions was to afford the opportunity for concerned individuals to fully and clearly state their ideas and to ensure that the committee received input in exactly the form the contributor wished. A secondary purpose was to provide a venue for comments that otherwise might not be represented in this report. The written communications are Part B.2 of this report; they were not constrained by the guidelines discussed below.

The forum guidelines were that: (1) the controversial, confrontational, and political aspects of reports, such as East Mojave (Hodges and Ludington, 1991) and Red Cloud-Handies Peak (McCammon and others, 1991), were not to be considered as they predated the Arizona Report and had been thoroughly considered in its preparation; and (2) the political and managerial decision of the USGS to make quantified estimates of undiscovered mineral resources was not a topic for discussion. These guidelines were respected quite well in the workshops, but some of the attendees considered clearly these topics to be more important than those actually discussed.

Drafts of different parts of this report were prepared by Ludington, Lindsey, Brew, and Barton. Prior to writing this version, the committee prepared an abstract for the McKelvey Forum (Barton and others, 1994) and Barton presented the preliminary recommendations at that meeting on February 24, 1994. Preliminary reports were made to the Chief of the Office of Mineral Resources in December 1993, and May 1994. The present report is the consensus of all of the committee members.

A.3.0 ISSUES, COMMENTS, AND RECOMMENDATIONS

A.3.1 INTRODUCTION

The organization of this section parallels that of the mineral-resource assessment process. We present issues, comment on them, and propose recommendations in the sequence of that process:

1) Planning - including consideration of guidelines, project staffing, and identification of clients and their needs.

2) Preparation and information gathering - including presentation and communication of information, preassessment, training, literature study, and field work.

3) Selection of deposit types, delineation of tracts, and estimation of the numbers of deposits - including developing and tabulating criteria for deposit types, choosing deposit types, developing and tabulating criteria for delineation of tracts, presentation of geotechnical information, elicitation of estimated numbers of undiscovered deposits, and tabulation of rationale for estimates.

4) Simulation of undiscovered tonnages of metal and rock with MARK3 - including input and use of MARK3, and output.

5) Reporting assessment results - including selecting a format, economic filtering, and writing the report.

6) Reviewing the assessment report.

7) Communication and distribution of the report - including follow-up with users.

8) Archiving and documentation of data.

The statements of issues and our comments on them are based on our collective (and subjective) judgement applied to the forum discussions and written contributions. They are therefore not supported by documentation or references. We believe that documentation does not exist for many of the topics and that we are expressing some opinions and conclusions that have not been published previously.

The assessment process should be accompanied by: 1) continuing critical evaluation of assessment results, 2) research to improve assessment through new concepts and methodologies, including deposit model development, 3) organizational support for assessment, and 4) a reward system that recognizes the value of assessment in a manner consistent with its contribution to USGS programs and society. We discuss these accompanying issues and recommendations following discussion of the points listed above. Finally, we consider the increased scope of future assessments, the recommendations of the Arizona Report that were rejected by the Forum committee, and the content of the Arizona Report.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.2 PLANNING AN ASSESSMENT

Issue: What factors are important in planning an assessment?

Comment: The methodology, data, and models needed depend upon the assessment's objectives. The objectives should be identified first by dialogue between the user ("client") and the assessment team, followed by discussion with Survey management. The selection of the assessment team may depend upon the objectives.

Once the objectives of assessment have been identified and the assessment team has been selected, the assessment should follow a well-defined process. The process can and should be defined by guidelines.

Important questions that have to be answered before and during the assessment include: Does the anticipated use call for a quantified probabilistic assessment or some other kind? Can mineral resource tracts be defined with available data? Can estimates of numbers of deposits in the tracts be made? These questions in turn include these detailed questions: What kinds of data and models are available, what models need modification, what are the most appropriate methods for estimating numbers of deposits, and what unit of measurement (metric tons, value) is most appropriate to express the results? Most of these questions should be dealt with during the pre-assessment, as described below. Many of these issues and others are explored in "Decision points and strategies in quantitative probabilistic assessment of undiscovered mineral resources" (Brew, 1992), which serves as an example and a point of departure for guidelines to the assessment process.

Better and more timely planning and anticipation of assessments will improve estimates of undiscovered mineral resources. Planning and anticipation, in turn, depend on knowing the schedule of clients' requirements and on setting realistic schedules for the assessment.

Recommendation: **We recommend that all of the regionally oriented mineral resource branches devote significant effort and resources to proactive contacts with the land management agencies and others who are potential users of information on undiscovered mineral resources. Some branches are already doing this, but some apparently are not. We also recommend that assessment scheduling be based on information from branch level, where realistic planning is most likely.**

A.3.2.1 IDENTIFICATION OF THE CLIENT'S NEEDS

Issue: Who are the users of mineral-resource assessments and what do they need?

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS --CONT.

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.1 IDENTIFICATION OF THE CLIENT'S NEEDS--CONTINUED

Comment: Clients of mineral assessments fall into at least six groups: 1) planners, including land management agencies, 2) makers and implementors of national policy, whether in the legislative or executive branches of government, 3) mineral explorationists, both corporate and individual, 4) environmental groups, 5) the public, when individuals become involved in issues raised by activities ofthe first four groups, and 6) earth scientists, including those in the Geological Survey.

Clients use both the results of mineral assessments and the data upon which the assessments are based. Generally, land-management planners, environmental groups, policy makers, and the public are interested in the results, whereas mineral explorationists and other earth scientists are as interested in the supporting data as in the results.

The needs of clients vary. Planners need to know *where* exploration is likely; thus maps showing geology, mineral occurrences, and areas favorable for mineral discovery are important. Increasingly, land-management agencies want minerals information for ecosystem management around protected areas such as parks and wildernesses. National policy planners are most likely to be interested in the *value* of resources; thus quantified estimates and consideration of economics are important. "What," "where," and "how much" address the needs of most assessment users. Data users, on the other hand, are interested in documentation, accessibility, and applicability of data to their problems.

Clients and their uses for mineral-resource assessments change over time. For example, the original assessments done in Alaska were directed at land management agencies and policy makers, but Native Corporations have emerged as an additional client because of their efforts to develop mineral resources. Another example: mineral-resource assessment of the San Juan National Forest in Colorado was adapted recently to assess environmental hazards (Plumlee and others, 1993). In some parts of the nation, surface disturbance arising from recreational (not-necessarily-for-profit) mining is becoming a concern to land management agencies. Proposed changes in the mining law may affect needs of client agencies that manage federal land and minerals. Assessments that present a broad range of relevant, high-quality data, that document data and rationale thoroughly, and that carry the assessment process as far as possible are most likely to be used in the future.

All clients need user-friendly products; presentation of both assessments and the data must match the interests and level of expertise of the client. If more than one client is anticipated, a variety of products may be required. In many cases, a client may need assistance to understand and use the assessment.

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.1 IDENTIFICATION OF THE CLIENT'S NEEDS--CONTINUED

***Recommendation*: We recommend that, at the outset of the assessment, careful attention be given to identifying the client and the type of information needed. The client may be identified by Office of Mineral Resources staff who deal with client agency needs or by other means; in any case, the assessment team should make a final determination of information needed after dialogue with the local representatives of the client. The final-decision-makers' needs should be kept in mind, as well as the needs of the clients' data gathering teams.**

A.3.2.2 GUIDELINES

Issue: What guidelines are required for mineral-resource assessment? How rigid or mandatory should guidelines be?

Comment: The Arizona Report (p. 415) states "The recommendation most strongly and unanimously supported by the Arizona panel is to develop comprehensive guidelines and to make them easily available to all interested scientists". The Arizona Report goes on to advocate mandatory guidelines for: 1) construction of deposit models, 2) identification of deposit types, 3) delineation of permissive areas, and 4) application of subjective probability. Guidelines were advocated for at least three purposes: 1) to remove the mystery about assessment, 2) to inform and educate, and 3) to foster uniformity of methods and assessment products. Results from the forums are substantially in agreement with the recommendation of the Arizona Report but extend further, identifying all parts of the assessment process to be in need of guidelines. Guidelines should also address planning and staffing, preparation and information gathering, selection of deposit types and delineation of tracts, elicitation of numbers of undiscovered deposits in the tracts, simulation, use of economic values, reporting formats, review, distribution of reports, and documenting and archiving procedures and data.

Guidelines should address the range of objectives of the assessment process: whether an assessment is intended primarily for local land-use planning, for national decisions about withdrawal of mineral resources from access to mining, for policy decisions relating to mineral supply, or for other needs.

Guidelines are the tools through which managerial and other decisions are translated into actions. The Geological Survey needs a comprehensive set of guidelines, similar to the earlier "Guide to preparation of mineral survey reports on public lands" (Goudarzi, 1984), to foster consistency in method and reporting of quantified probabilistic assessments. Some technical guidelines, such as those involving basic concepts of quantified assessment (Singer, 1993), simulation by the Monte Carlo method (Root and others, 1992ab), and approaches to estimating numbers of deposits (Cox, 1993; Drew and Menzie, 1993) have been published, but

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.2 GUIDELINES

no comprehensive guide exists for preparing reports on quantified assessments of undiscovered mineral resources. Comprehensive guidelines should be accompanied by standardized text, hereafter referred to as "boiler-plate," that covers definitions of terms, descriptions, and caveats common to most reports. Use of boiler-plate would assure consistency in terminology, methodology, presentation, interpretation, and evaluation of uncertainties.

The Survey also needs guidelines for preparation of descriptive and grade and tonnage models. General aspects of mineral deposit models have been described and some terms defined (Cox and others, 1986); worksheets and tests for numerical comparison of individual deposits with models have been proposed (McCammon, 1992); definitions of terms and types of data have accompanied release of mineral deposit grade and tonnage data in digital form (Singer and others, 1993); and some issues and strategies for modeling complex data have been discussed (Bliss, 1992a). However, no overall description of quantified mineral deposit modeling exists.

Specific guidelines should generally take the form of suggestions, examples for imitation, and rules. In the forums, participants expressed agreement that guidelines for mineral-resource assessment were necessary but that they should neither stifle innovation nor be so rigid as to prohibit adaptation to limitations of the data and to local user needs. The phrase "guidelines, not cookbooks," was voiced repeatedly; as was the admonition that advances and innovations in mineral-resource assessment should come in part from the assessors themselves. Guidelines should not be so strict as to inhibit creativity and progress in assessment methods.

Recommendations: We recommend that a comprehensive "Guide to quantified probabilistic mineral assessment" be prepared and broadly distributed. The guidebook should address all steps of the assessment process and should take into account the potential range of objectives of assessment. The decision process used in assessment should be defined, and boiler-plate should be provided for definitions of terms, descriptions, and caveats common to most reports. Also, a separate "Guide to quantified mineral deposit modeling" should be prepared. All guidelines should be flexible and permit innovation. Both guides should be prepared by committees composed of experts in mineral resource assessment and appointed by the Chief, Office of Mineral Resources, and an opportunity for wide review provided.

A comprehensive glossary should accompany the guidelines. We have enclosed an incomplete, rough draft glossary as section A.6 wherein we define the terms used in this report and list others of probable use.

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.3 PREASSESSMENT

Issue: What is the role of preassessment in data gathering and processing and in a final assessment?

Comment: Preassessment is the term used to describe either the first stages of the assessment process or a separate step done before the initiation of a specific assessment project. It is intended to accomplish two objectives: (1) to evaluate the completeness (or incompleteness) of the information, staff, and facilities available for the assessment and thus to provide a basis for the planning and scheduling of assessment activities; and (2) to provide a preliminary list of materials to be gathered and used in the assessment. It appears that the preassessment step has essentially been ignored for some assessments.

A preassessment is required if the subsequent assessment steps are to take advantage of the pertinent information and personnel resources. In particular, preassessment should result in a focus on information gaps and identify critical topics that should receive more field or other study before the remaining assessment steps are started. Similarly, it should report the availability of the scientific personnel who should be involved. It should also identify the data processing needs for the assessment. In the long run, these activities will lead to more comprehensive, more timely, and more credible estimation reports.

> ***Recommendations:*** **We should accept preassessment as an essential part of the process for each assessment project. The assessment team leader should be identified well in advance and given the time and resources needed to do the preassessment. The preassessments should be the key to planning and scheduling of subsequent assessment activities. Closer communication with client agencies at the local level is essential to minimize false starts. The Office should support the position that preassessments are essential.**

A.3.2.4 STAFFING

Issue: What types and mix of geoscientists are needed for mineral-resource assessment? How can proper staffing be assured?

Comment: Choosing the team to perform an assessment is a critical part of the process. Resource assessment teams have traditionally been appointed by Branch Chiefs, commonly to assure the inclusion of an appropriate mix of talents and disciplines. This is a good way to assure that the team uses all the kinds of geotechnical information that might be needed for an assessment, but may not assure a well-functioning, qualified team. Geoscientists vary widely in their ability and comfort with subjective assessment. Communication is often poor between those who are comfortable with the process and those who are not. These factors have led in the past to the undertaking of assessments by teams that have

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.4 STAFFING--CONTINUED

Comment--Continued:

had neither the expertise in economic geology nor the basic understanding of the assessment process to do the job as well as it should be done.

Ideally, assessment teams should include the following type of individuals familiar with the assessment area; (1) at least one regional bedrock geologist, (2) an economic geologist, (3) an exploration geochemist, (4) an exploration geophysicist, (5) a resource-assessment specialist, (6) a regional surficial geologist/geomorphologist, (7) an expert geoscientist/facilitator, and (8) a geologist/recorder.

Proper staffing is complicated by two problems. First, a few well-qualified geoscientists have avoided assessment studies because of misgivings about parts of the assessment process. Second, the overall lack of expertise in economic geology among members of the Office of Mineral Resources, due largely to staffing and research opportunities during the last 30 years or more, means that relatively few experienced economic geologists are available for assignment to assessment projects. Nevertheless, if assessments are indeed one of the important program goals, then the Survey must staff assessment projects with employees who are both interested in and competent to produce quality products.

The committee recognizes that lack of expertise is a serious problem for almost all assessments, quantified or not. Although the obvious solution would be to hire experienced economic geologists, this is impossible in today's environment of shrinking budget and staff. To the greatest extent possible, experienced economic geologists should participate in assessments. This will require determination and skill in communication from management, because many economic geologists remain unconvinced of the need for assessments.

Recommendations:

1) Institute a vigorous mineral-resource-assessment training program for the staff. This is best done on an office-wide basis, and should include training in mineral deposit geology, as well as in probability, elicitation, GIS procedures and other details of assessment techniques (see also section A.3.3.3).

2) Support assessment projects (both person-years and expenses) at a level commensurate with their importance to OMR programs. In order to accomplish this, support must be withdrawn from some other activities that are deemed less critical.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.2 PLANNING AN ASSESSMENT--CONTINUED

A.3.2.5 STAFFING--CONTINUED

Recommendations--Continued:

3) Where practical, include the participation of persons from other Federal or local institutions, especially universities and state geological surveys, and informal consultation with representatives of mining companies. Such contacts can provide information and, except where a conflict-of-interest might exist, such persons might even participate in making estimates or reviewing conclusions.

4) The Arizona Report stated that exploration geologists could handle all exploration geochemistry matters in an assessment. We strongly disagree. Planning and execution of assessments should include specific consideration of exploration geochemistry in staffing and support.

A.3.2.5 TRAINING

Issue: What are the gaps in expertise for assessment? How may these gaps be addressed?

Comment: Three personnel-related shortcomings exist that severely affect the assessment program. One is the lack of expertise in both economic geology and in the probability theory that underlies the assessment methodology (A.3.2.5). Unfamiliarity with probability and with the elicitation procedure were cited frequently as being responsible for unreasonably high or low estimates. The second concerns leadership in that only a handful of people experienced, confident, and capable of conducting, leading, and directing a quantified mineral-resource assessment are available. Third, for differing reasons, a significant proportion of geoscientists are unwilling, or feel unqualified and unprepared to participate fully in assessments. If quantified mineral-resource assessment is essential to the USGS mineral-resource program, this means the Office is ill-prepared to carry out the program.

At all forums, significant numbers of participants have asserted that the most important thing the Office of Mineral Resources can do to increase the quality of our assessments is to provide training. We heard repeatedly that if there is money available for other forms of training and for committee meetings, then why not for scientific training?

The feeling is widespread that facilitators should be drawn from the entire Office, rather than to rely only on the small cadre from the Branch of Resource Analysis. Better assessments will be the natural result of training additional competent

Comment--Continued:

assessors. Some other positive results that could result from training include 1) a reduction in the uncomfortable feelings that exist between some of those who simply provide information and those who perform the assessment, and 2) the ultimate disappearance of the need to rely so heavily on our present few specialists in eliciting estimated numbers of undiscovered deposits.

The training situation does not have a simple solution. One difficulty is that, although we all need help in some areas, a class containing a cross section of our staff would contain some who would learn a lot, some who would be bored with the oversimplification, and others who would be completely lost. Another complication is the marked contrast between the levels of understanding of the assessment process by the individuals from different disciplines who are needed to perform an assessment. On one hand, the amount of knowledge of probability and statistics needed is not great, and enough might be acquired via a few hours training in a tried and true methodology, but the greater understanding needed to design and test the assessment process goes far beyond that. On the other hand, the amount of knowledge of economic geology needed is great, as understanding the geology of the diverse deposit types encountered really includes (1) all of general geology, (2) exploration and process geochemistry, (3) some geophysics, and (4) some familiarity with mineral economics and mining geology. We cannot "make" economic geologists with a few short courses; however, we might well upgrade the capability of the staff by using the deposit-model package as a training vehicle to move individuals from general geology to mineral deposit geology.

Recommendations: Areas requiring training include: 1) probability theory and methodology for quantified assessment, 2) economic geology, and 3) team leadership. The Survey has the expertise to teach the first two; the third would probably require outside help. In addition, some of these topics can be addressed by a mentoring approach and on-the-job training. Team meetings may have to be longer, more comprehensive, and certainly more efficient.

Expanding on this: office-wide training in probability and statistics as applied to mineral-resource assessment should start as soon as experts can be enlisted. Economic geology training can best be incorporated into preparation of the assessment team by having the economic geologists on the team train their associates regarding the deposits judged to occur in the tract. If no local economic geologist is available, this would be an excellent opportunity to bring in some experts not already involved in the assessment as teachers, even though they may well not be able to continue through the entire assessment process.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.3 ASSEMBLING INFORMATION

A.3.3.1 TIMELY GATHERING OF THE APPROPRIATE INFORMATION

Issue: How can we optimize information gathering for assessments?

Comment: Some forum participants expressed the opinion that, in some assessments, the information gathering process may have been truncated, and not all available data and interpretations were brought to the estimation process. This is judged to be due mainly to two factors: shortness of time available for the assessments and the absence of geoscientists who possessed critical experience, knowledge, and information. Both factors also affect the presentation and communication of information and the results of assessments. In addition, it was noted that the assembly and exchange of information would be more effective and timely if computer-based Geographic Information Systems (GIS) were utilized.

The time factor can be addressed by being more selective in assuming new assessment tasks. Doing an inadequate job of information gathering and assessment that is not up to our own standards, and that our personnel are not proud of, is more harmful than refusing the work. The present load of assessment projects is probably beyond the Survey's capacity to complete satisfactorily and in a timely manner.

Recommendations: As noted in A.3.2, we believe that planning is the key to much of the information aspect of the assessment process. We also reiterate the recommendation that assessment scheduling be based on information from branch level, where realistic planning is most likely.

Concerning the absence of individuals who are needed for a specific assessment, (1) scheduling assessment team meetings well in advance would facilitate participation, and (2) management incentives should be used to encourage otherwise reluctant scientists to participate in an assessment to the best of their ability.

Concerning computer support, we recommend that the Office of Mineral Resources commit itself not only to the refinement and improvement of established computer systems, but that it also provide the leadership, direction, and support needed to insure that ,future assessments are accomplished using GIS and other digital systems for the entry, manipulation, presentation, and documentation of the geologic, geochemical, and geophysical data.

A.3.3.2 LITERATURE STUDY AND MINERAL-DEPOSIT MODELS

Issue: What types of information must be gathered and used in assessments? What are the principal sources of that information? And, how can the data base be improved to enhance the assessment process?

A.3.3.2 LITERATURE STUDY AND MINERAL-DEPOSIT MODELS-- CONTINUED

Comment: As discussed above, assessments depend on personnel and information. The latter includes electronic files. The information used in estimates includes:

1) geologic - including (a) regional geology and (b) tectonic-units;

2) economic geology and mineral-exploration information - including metallogenic-belt information, deposit records in the MRDS (the USGS' Mineral Resource Data System), the Mineral Industry Locator System (MILS) of the U.S. Bureau of Mines (USBM); records in the local BLM and USFS offices, state geological surveys, and communications with mining industry.

3) geochemical - including (a) USGS stream-sediment, (b) USGS heavy-mineral-concentrate, (c) USGS bedrock, (d) NURE stream-sediment and surface- and ground water information, and (e) state-agency-provided geochemical information;

4) geophysical - including (a) USGS aeromagnetic, (b) USGS gravity, (c) NURE aeroradioactivity, (d) USGS remote sensing of different kinds, (e) NURE aeromagnetic information; (f) private-company-file; and (g) state-agency-provided geophysical information;

5) existing assessments for the same or parts of the same area;

6) existing assessments for analogous areas;

7) mineral-estimation methodology information, including (a) guidelines contained in various books, articles, and other publications, and (b) mineral-estimation methodology evaluations; and

8) mineral-deposit models and tonnage and grade curves.

A mineral-resource assessment will be inadequate if this array of information is neither sought nor used, or if critical information is poor or lacking. Seeking out and assembling this information requires time and resources.

This section (A.3.3.2) discusses the eight above-listed sources and the use of their information in response to the issues noted above, but the issue statement itself will not be repeated. The first part of this section is concerned with basic geoscience information; the second part with estimation methodology; and the third with deposit-type descriptions and tonnage and grade curves. Comments and recommendations are made for each of these.

A great deal of information resides in geoscientists outside of the USGS. We can improve our efficiency, effectiveness, and image by seeking out and utilizing such resources. Regular communication with company and State geologists is possible, as is study of the archived files of now-disbanded exploration companies.

A.3.3.2.1 Geological, Geochemical, and Geophysical Information

Comment: The geological, geochemical, and geophysical information categories are examined here in more detail, with the purposes of identifying some information sources that may have been unknown or underused in assessments up to this date and of providing some guidance on specific sources. Marcus (1991) provides additional information on sources for the western United States.

1) Geologic information:

Regional-geologic information is the starting point for all assessment tracts: the presence of a rock unit appropriate to (or permissive for) the occurrence of a specific deposit type is essential to an assessment; maps and personal knowledge of the regional geology are the basis for recognizing such units.

Information on metallogenic belts and tectonic units depends on the availability of such syntheses for the given assessment area. The value of tectonic information is that tectonic environment is one component used to classify mineral-deposit types; metallogenic-belt information provides an interpretative framework based on mineral-deposit and tectonic information and thus focuses attention on specific deposit types

2) Economic geology and mineral-exploration information:

Mineral-deposit and mineral exploration and development information aids in judging what types of deposits are likely to occur in a tract. It may include local information of possible value in estimating the numbers of undiscovered deposits. Compilations of much of these data are available in deposit-locality catalogs, and most deposits in the United States are represented in the USGS Mineral Resource Data System (MRDS; U.S. Geological Survey, 1989) and the USBM Mineral Industry Locator System (MILS). Additional sources are the local records of the BLM and the state geological surveys. All of these prior-assembled data bases generally require validation before incorporation into the assessment process. Exploration and development provide two different signals: on one hand, unsuccessful exploration tests ground and disproves the existence of significant mineralization in the part of the area tested, and thereby diminishes the probability for undiscovered deposits. On the other hand, exploration confirms that factors suggesting the presence of undiscovered deposits are present.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.3 ASSEMBLING INFORMATION--CONTINUED

A.3.3.2 LITERATURE STUDY AND MINERAL-DEPOSIT MODELS--CONTINUED

A.3.3.2.1 Geological, Geochemical, and Geophysical Information--Cont.

Comment--continued

3) Geochemical information:

USGS stream-sediment, heavy-mineral-concentrate, and bedrock data are available for many parts of the United States, probably including some where detailed mineral- resource assessments have not been made. Location and other coding information, together with results of analyses, are available both in published reports and in the USGS Rock Analysis Storage System (RASS) files (U.S. Geological Survey, 1992) and in the Survey's PLUTO files. In conjunction with the National Mineral Resource Assessment, summary geochemical anomaly maps based on NURE data have been prepared for most 1:250,000-scale quadrangles in the conterminous United States (U.S. Geological Survey, 1993b). The summary maps made for Alaska relied on USGS, instead of NURE, data.

The National Uranium Resource Evaluation (NURE) program hydrogeochemical and stream-sediment sampling covered much of the United States and is reported in an extensive series of 1:250,000-scale-quadrangle reports issued by the U.S. Department of Energy (Los Alamos National Laboratory, Grand Junction Office; and Oak Ridge Gaseous Diffusion Plant reports, various years).

4) Geophysical information:

USGS aeromagnetic and gravity survey results are available for most of the United States; the aeromagnetic information has been synthesized into a national map (Godson, 1984; Geological Society of America, 1987b), the gravity information has also been synthesized into a national map (Geological Society of America, 1987a) and a current index of gravity and other surveys by the USGS is maintained (U.S. Geological Survey, 1993a).

USGS remote sensing information of different kinds, ranging from aerial photography through SLAR imagery to derivative thematic maps of various kinds, have been produced for much of the United States; at the present time there apparently, is no central location for all of these, although the EROS Data Center in Sioux Falls, SD ((605) 594-6151) maintains a latitude- and-longitude-ordered index of much of it.

NURE reconnaissance aerial gamma-ray and aeromagnetic profiles were obtained for much of the western United States in the 1970's; they were released as regional (and 1:250,000-scale) reports (U.S. Dept. of Energy GJBX -Series Reports by various contractors). Gamma-ray, gravity, magnetic, and topographic data for the conterminous part of the United States are in Phillips and others (1993).

A.3.3.2.1 Geological, Geochemical, and Geophysical Information--Continued

Comment--continued

5) Existing assessment information:

USGS, USBM, and some State survey estimates of potential for undiscovered mineral resources for parts of the United States are available as published reports. Most of these are non-quantified and most were produced as part of the USGS and USBM studies of USFS and BLM Wilderness Study Areas, the USGS Alaskan Mineral Resources Assessment Program (AMRAP) regional assessments, and the Conterminous United States Mineral Resource Assessment Program (CUSMAP). Summaries of wilderness studies in National Forests are presented in USGS Professional Paper 1300 (Marsh and others, 1982).

6) Information concerning existing assessments of analogous areas:

Individual geologists may, based on their experience and knowledge, know of exploration or assessments completed for areas that are geologically and metallogenically analogous to a given area. The problem, of course, is recognizing what "analogous" represents.

The points numbered 7) and 8) above (in A.3.3.2.1) are too complex for terse commentary at this point, but they are discussed individually in the sections that follow.

***Recommendations:* Assure that complete study, interpretation, and use of all available geoscience information is made for each assessment, emphasizing those aspects of the data base most appropriate to the needs of the client.**

A.3.3.2.2 Information on the Methodology for Mineral Resource Estimation

Comment: Information on the methodology for mineral-resource estimation is a critical part of the estimation process, because it educates the practitioner as it guides his or her estimates. Such information has apparently not been read, studied, and applied by some individuals engaged in assessments.

Guidelines for and descriptions of different estimation methodologies, both quantified and unquantified, are available, see: Shawe (1981), Taylor and Steven (1983), Goudarzi (1984), Harris, (1984), Cargill and Green (1986), Brew (1992), Cox (1993), Harris and Pan (1993), McCammon and Finch (1993), and Singer (1993). Guidelines are discussed further in section A.3.2.2 of this report

A.3.3 ASSEMBLING INFORMATION--CONTINUED

A.3.3.2 LITERATURE STUDY AND MINERAL-DEPOSIT MODELS--CONTINUED

A.3.3.2.2 Geological, Geochemical, and Geophysical Information--Continued

Comment--Continued:

Evaluations of mineral-estimation methodologies are uncommon, but are implicit in workshop reports such as Shawe (1981) and Cargill and Green (1986), and specific in Harris (1984) and in the critique by Bultman and others (1993). In addition, there are unpublished USGS documents, some of which were discussed in the Arizona Report, and that report itself.

Because the Arizona Report was commissioned to evaluate the current USGS methodology, it may be construed by some as being a definitive statement on the development and features of that methodology and of how it has been used within the USGS. Although the Arizona Report contains much valuable information and supports the methodology, the report is a critique with extensive recommendations for improvements.

Recommendations: **Recommendations concerning guidelines are given in section A.3.2.2.**

Regarding methodology: Feedback should be encouraged from groups involved in mineral-resource assessment, regardless of whether it is positive or negative and regardless of the part of the estimation process concerned. Feedback should continue to identify the most difficult parts of the process and give insight into how those parts can be strengthened. If the process is to continue to be improved, then there must be response to such input from management and research staff.

One possible way of obtaining the feedback referred to above would be to hold a series of workshops to discuss and critique specific recent assessments. The concept is to have one workshop per year in one of the Centers or Field Offices and to focus on just one or two assessments, to examine all their aspects, and to report on ways of improving the estimation process. Improvements so developed should be incorporated into succeeding assessments via updated guidelines. The USGS should be doing research on other possible methods of estimating undiscovered mineral resources; this is discussed also in section A.3.11.

A.3.3.2.3 Models, Part 1: Mineral-deposit-type descriptions and tonnage and grade models—their construction and use

Comment: Descriptive mineral-deposit-models and tonnage and grade curves are critical to the assessment of undiscovered mineral resources. Mineral-deposit-type descriptions are contained in many textbooks and have been summarized by Eckstrand (1984), Cox and Singer (1986), Roberts and Sheahan (1989), DeYoung and Hammarstrom (1992), Bliss (1992a), Orris and Bliss (1991, 1992), Hoover and others (1992), and others as mineral-deposit models. Some have been distributed as computer files (Mosier, 1992; Singer and others, 1993). Because models are so often used and so important, they have received a lot of scrutiny and comment; most workers concerned with undiscovered resource information would like to have the models augmented and updated (see section A.3.4.1).

The clients dealing with land-use decisions are concerned with what will happen, where, when, and what the consequences of various alternative decisions might be. Identification of impacts of mining is an area in which the Survey already has considerable unused expertise, and we might well add to the models a summary of the environmental consequences of exploration for, and development of, mineral resources.

Recommendations: **Continual and systematic revisions of mineral-deposit-type descriptions and tonnage and grade curves should be undertaken; in these, descriptions of the geologic, geochemical, and geophysical attributes of each deposit type should be combined, rather than presented in separate documents. Those persons, whether inside or outside the Survey, most knowledgeable about each deposit type should be enlisted as authors or reviewers.**

Revisions should be made in the organization of deposit-model information and in the descriptions of the physical characteristics of the different deposit types; specific suggestions are:

a) reconsider and/or redesign the tectonic-environment classification now in use;

b) redesign to follow more hierarchical schemes, such as that used by Drew and Menzie (1993), that allow a "systems" approach to deposit-density factors and to associated deposit types;

c) revise on a model-by-model basis, with each model a separate chapter in an ongoing Bulletin series.

A.3.3.2.3 Models, Part 1: Mineral-deposit-type descriptions, and tonnage and grade models—their construction and use--Continued

Recommendations--Continued

d) use a consistent checklist, such as that advocated by McCammon (1992), for all descriptions to facilitate both hard-copy and computer searches for deposit-type matches and documentation of the matches;

e) provide a ranking of diagnostic criteria to identify deposit types;

f) emphasize and expand on attributes of deposits themselves and of their host lithotectonic units;

g) provide more information on geochemical and geophysical signatures of different deposit types, and include these under (e) above;

h) provide more references to articles concerned with examples of the individual deposit types;

i) expand as appropriate on the ore-, gangue-, and alteration-mineral information provided; and

j) include within the model format a specification of the nature of anticipated exploration and extraction operation(s), the environmental consequences, and possible amelioration strategies.

Revision and expansion of the model books along these lines is an essential USGS effort; it must be given high priority. Much expertise to create and use deposit models resides outside of the USGS; we must aggressively seek, cooperate with, and utilize knowledge from outside sources, but maintain quality control of the product used for assessments.

A.3.3.2.4 Models, Part 2: Local and regional deposit models; and selectivity or bias in the global grade and tonnage models

These two topics are combined here because they are closely linked.

Comment: Globally based grade and tonnage models may not, in every case, be the best representation of the deposits inferred to be present in a given assessment tract. Thus, modified models may be needed locally or regionally, such as those for Chugach gold and Northern Cordilleran porphyry copper deposits (Bliss, 1992a; and Menzie and Singer, 1993; respectively).

We discuss selectivity and bias here specifically in response to criticisms expressed (Bultman and others, 1992; L.C. Hamilton, 1993; and the communication from W. Hamilton in B.2) that bias exists in the grade and tonnage compilations. Our purpose is to clarify some possible misunderstandings.

The word "bias" has several meanings; the definition from the Glossary of Geology (Bates and Jackson, 1987) is: "A purposeful or accidental distortion of observations, data, or calculations in a nonrandom manner." The statistical definition of bias is different and is summarized in the glossary; briefly, it concerns nonsampling errors, or systematic error that leads to a difference between true value and experimentally determined average value. The critics referred to above are concerned that the grade and tonnage models in use are based on selected data and do not include all metal concentrations in the earth's crust, including the large population of unsampled or inadequately sampled small (or low grade) occurrences that, if included, would bolster the low end of grade and tonnage distributions. These occurrences are excluded from the models, because they usually do not warrant the expenditure to test them definitively; they have not been drilled out, and their quantitative character remains unknown. The modeled population is, and always has been, mineral deposits, carefully defined in Cox and Singer (1986) as "...a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential." For use in construction of grade and tonnage models, they must have been well-explored. Singer (1993) addresses the issue of whether or not the means of the 67 tonnage distributions now in use in models may be biased in the statistical sense and at what confidence level.

A.3.3.2.4 Models, Part 2: Local and regional deposit models; and selectivity or bias in the global grade and tonnage models--Cont.

Comment--Continued:

Some critics believe that, in the past, some assessors have counted poorly-explored prospects in an area and judged them to represent deposits. Singer and his associates carefully and repetitively specify that deposits are to be assessed in accordance with the compiled tonnage and grade curves, not the undocumented population of unsampled small (or low grade) occurrences. They also stress that, during assessment, the probability that an untested prospect represents a significant deposit can too easily be overestimated, and caution against this error. (Singer, 1993; Cox and Singer, 1986; Drew and others, 1986; Menzie and Singer, 1980).

Few geoscientists deny that this population of small occurrences exists. There is abundant evidence that only a small proportion of the occurrences and prospects identified in mineral exploration are ever developed into mines. For example, Anderson (1982) estimates that 1000 reconnaissance examinations are required to be made to achieve a 75 percent probability of developing a single 3-million-oz gold deposit. The possibility that those occurrences that might, upon further exploration, become mineral deposits, is included in the undiscovered deposit estimate. The metal content of the rest of the occurrences has no perceptible impact on total resource availability because the cumulative metal content of such low-tonnage deposits is minuscule relative to the metal in the known large deposits.

Future extensions of known deposits may present special problems in assessment. Because they are not quantified, they do not appear in the tonnage models, and thus, individual deposits in the models may be assigned tonnages that are lower than their actual size. This results in a tonnage curve that is too low; thus resource estimates based on it might be too low as well. Hard evidence of this phenomenon has not been demonstrated, but it could be important in some cases. It may be important for deposits that were primarily mined in earlier times by underground methods when deposits were seldom "drilled out." It may also be important when a deposit type is newly recognized, and the discovered resource in existing deposits is expanding rapidly at the time the deposits are modeled. Sediment-hosted gold deposits are an example of this situation (Singer, in press).

A.3.3.2.4 Models, Part 2: Local and regional deposit models; and selectivity or bias in the global grade and tonnage models--Cont.

Another reason why data in the tonnage models may be smaller than the true tonnage is because governments may seek to enhance economic activity and encourage production by taxing reserves. Companies may respond by minimizing identified reserves. However, we do not believe this is a significant problem; companies often report "geologic" reserves or resources, which are not taxable.

In summary, estimates of resources using grade and tonnage models are based on mineral deposits which are well-explored and for which quantitative data are available. Smaller prospects and occurrences that are not quantified contain additional metal, but most do not have economic potential, and the amounts of metal are insignificant compared with the amounts in the larger deposits.

Recommendations: **Local and regional grade and tonnage models should be developed and utilized where conditions can be demonstrated to constitute a significant departure from those represented by the global models. In these instances, the explanation for the use, and the description of, the local models should be included in the report. If local models are used, they should be made up of well-explored mineral deposits, as defined in the glossary.**

A.3.3.3 ROLE OF FIELD WORK

Issue: To what degree is field work (and new site-specific data) a requirement for assessment?

Comment: Ideally, assessment goals and strategies would be built into a project before field work starts, and the group that does the field work would also make the resource estimate. All too often quantified assessments are made as an add-on after the field studies are completed, a scenario that may separate those knowledgeable about the geology from those making the assessment. Field data of some sort are, of course, an absolute requirement for any estimate of undiscovered mineral resources, and lack of adequate information should mean that no assessment will be made (Brew, 1992). The necessity for new field work is a different, but related, matter. How much new field work is necessary should be identified during the preassessment (See section A.3.2.3).

A.3.3 ASSEMBLING INFORMATION--CONTINUED

A.3.3.3 ROLE OF FIELD WORK--CONTINUED

The field data issue is not trivial, because it relates directly to field experience. Most geologists relate to field data, primarily through their own, on-the-ground, field experience. Lack of such experience handicaps their ability to evaluate existing field data. Field work in an area by the assessment team increases the strength of belief attached to an assessment.

This aspect of resource estimation is important because the estimation of undiscovered mineral resources is a task that pushes the capabilities and intellectual comfort of many geoscientists.

> ***Recommendation:*** **Assessments should be made by the individuals who have had significant field experience in the assessment area. When other persons must be involved, time and resources should be provided for them to visit and become familiar with the area.**

A.3.3.4 ROLE OF GEOPHYSICS

Issue: The Arizona Report, including individual comments by Sumner, Marsh, Titley and Meinert, recommends that greater use be made of geophysics (including remote sensing) in assessment activities. Is this recommendation valid, and, if so, is its acceptance feasible in view of the fiscal constraints on the assessment program?

Comment: Although the regional geophysical data bases noted above in A.3.3.2.1 may aid in tract identification, preexisting local data are not always sufficiently detailed to contribute to the quantified estimation of undiscovered resources. The need for upgraded technologies and additional geophysical coverage using them has long been recognized, but extensive acquisition of new data has not been made in connection with recent assessment programs.

The short lead times for many assessments may preclude securing new geophysical data, even though such data might prove very informative.

Geophysical data are extensively used by industry for exploration because they have proven to be useful adjuncts to geology and an economical and effective way to evaluate mineral potential before further exploration; we should not ignore industry's experience as a guide to efficient assessment methodologies. The data acquired by industry are valuable long after their collection, but industry's interest in them is often time-limited; thus, such data may become available to us at little or no cost, provided that we seek it when they are available.

A.3.3.4 ROLE OF GEOPHYSICS--CONTINUED

Recommendations: For those areas having poor exposure, or where physical access is difficult, it is essential that geophysical surveys be conducted to check for hidden deposits. The type and intensity of study must be tailored to the scale of the area under study, the nature of resource potential, and the needs, scheduling and financial support of the client. We should not allow the pressure to produce large numbers of assessments force us to work without appropriate geophysical information when well-established beneficial methodologies are available.

Access to data from industrial exploration should be sought to augment our own studies. Because geophysical data can easily become lost when industry shifts its interest, we must maintain a program of acquisition and preservation of data as they become available in anticipation of future use.

The geophysical subdiscipline provides some of the most promising avenues to improve our ability to make assessments; research and upgrading of capabilities must be an integral part of the assessment program. (See also the specific suggestions in the letter from D.L Campbell and R.C Jachens in B.2.1).

A.3.4. SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS

In this section we describe the difficulties involved in, and the criteria needed for, the most difficult parts of the entire process of estimation of undiscovered mineral resources. We present issues, comments, and recommendations for each part separately, but the different parts are closely intertwined. This part of the assessment procedure is the core of what has been identified as the "three-part" method.

A.3.4.1 DEVELOPING AND TABULATING CRITERIA FOR DIFFERENT DEPOSIT TYPES

Issue: What is the best way to identify the deposit types that represent the mineralization known or inferred to be present in an assessment tract?

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.1 DEVELOPING AND TABULATING CRITERIA FOR DIFFERENT DEPOSIT TYPES--CONTINUED

Comment: Identification of the type(s) of mineral deposits that are likely to occur in a given tract is required for the estimation of numbers of undiscovered deposits and for the selection of tonnage and grade curves to be used in the Mark3 mineral-resource simulator. There is usually some uncertainty regarding the type(s) appropriate to a given tract, so the goal should be to reduce that ncertainty. In particular, the choice of one type *versus* another similar type is viewed by many USGS geoscientists as a vexing problem.

Assessors rely heavily on the mineral-deposit model descriptions and tonnage and grade curves contained in the Cox and Singer model book (1986) and other compilations cited in section A.3.3.2.3 to make their decisions about deposit types. Most workers are (now) aware that they are estimating the occurrence of deposits that have both the physical characteristics and the tonnage and grade characteristics of the deposits described in the books. But they are also handicapped by the lack of ranked diagnostic criteria and by the relative lack of geochemical and geophysical criteria in the descriptive models. Most assessors believe that these shortcomings can be overcome in the future by revision of the deposit models.

Also, the criteria used in the past to decide what types of deposits are likely to occur in a specific tract have not always been documented thoroughly enough to recover the essential parts of the decision process.

> ***Recommendation:*** **Improvement of our ability to distinguish which deposit type most suitably fits the field observations demands an improved set of descriptive models including the tonnage and grade curves. Such a revision is discussed in section A.3.3.2.3 above and is not repeated here.**
>
> **As part of that revision, the suggested "checklist" approach (McCammon, 1992) should support an opportunity for a comprehensive testing of each tract for deposit types as well as for tabulation of 'results and documentation of which deposit type(s) are considered. A hierarchical description would minimize misidentifications arising from described features of incidental or trivial nature.**

A.3.4.2 CHOOSING DEPOSIT TYPES

Issue: **What is the linkage between deposit type and assessment tract?**

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.2 CHOOSING DEPOSIT TYPES--CONTINUED

Comment: One may logically ask "Which do we identify first, the deposit or the tract?" The answer is: "Both." Recognition of the attributes of a deposit type (e.g., host lithology is a carbonate rock adjacent to a hypabyssal silicic pluton) provide criteria to select and delineate tracts having that attribute (e.g., limestone intruded by quartz monzonite porphyry). Conversely, a particular geologic environment may become a candidate for an assessment tract if an appropriate model is identified (e.g., when a fine-grained, reduced, sedimentary unit associated with a continental-scale rift becomes a potential assessment tract for sediment-hosted copper deposits.)

As noted in the preceding section (A.3.4.1), the criteria used in selecting the deposit type(s) judged likely to be present in an assessment tract drive other, critical, parts of the estimation process. The selection depends on the use of criteria that are related to the physical attributes of the deposit type and its tonnage and grade curves. It is uncertain how different assessment teams use the available information to develop criteria (a topic discussed above) and to select the appropriate deposit type(s).

There are two related aspects to choosing deposit type(s); one is the proper classification of deposits and occurrences that are known to be present in a tract; and the other is choosing the appropriate deposit type(s) for undiscovered deposits judged to be present in the tract. The first aspect depends on the attributes observed for the known deposits; the second aspect depends not only on the classification but also on regional-scale metallogenic attributes of the whole tract.

Identifying the known deposits and choosing the appropriate deposit type(s) for estimation purposes depend on matching the geologic and other features in known deposits and their tracts with the attributes of the deposit type(s) and their larger-scale environment as described in the model compilations and in other reports. As described in sections A.3.3.2.1 and A.3.3.2.3, the same kinds of information are contained in both places; the questions are (1) is the information on the most important attributes available for the known deposits and the tract?; and (2) presuming that they are, how should the different factors be weighted in deciding about the deposit type(s)? Brew (1992) presented a weighted-factor scheme that is an example of how these types of decisions can be pursued; Chen and Fang (1993) used possibility, rather than probability, theory to appraise oil and gas prospects using information analogous to that used in mineral-resource estimation; and Gettings and Bultman (1993) used the same approach to an actual mineral-resource assessment situation.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.2 CHOOSING DEPOSIT TYPES--CONTINUED

Recommendation: The recommendations regarding information in general that are made in sections A.3.3.4.2 and A.3.3.4.3 apply here also. In addition, the USGS should actively pursue research on approaches that embody favorability and geographic information such as those suggested by Brew (1992), Chen and Fang (1993), and Gettings and Bultman (1993).

A.3.4.3 DEVELOPING, TABULATING, AND APPLYING CRITERIA FOR DELINEATION OF ASSESSMENT TRACTS

Issue: How do we delineate assessment tracts?

Comment: Boundaries of assessment tracts are based on the regional- and deposit-scale attributes of the deposit type(s) judged to be present. In the past, the criteria used for the delineation of these boundaries as well as the documentation of their application to specific tracts have been uncertain.

The boundaries of "permissive areas", "tracts", and "favorable areas" are all based on geologic, geochemical, and geophysical criteria. Any given tract may have its boundaries defined by different criteria at different points. Commonly, tract boundaries have been positioned, or delineated, by overlaying maps of different types of information. Geographical Information Systems (GIS) methods may be more rigorous, effective, and comprehensive (Elliott and others, 1992, p. 14-16; 1993, p. 11-12; a recommendation shared with the Arizona Report).

It is appropriate to examine how these different terms are defined and how they have been used. "Permissive areas" and "favorable areas" are defined differently: Singer (1993, p. 73) defines a permissive area as one outside of which the probability of occurrence of the type(s) of deposit under consideration is negligible, that is, less than 1 in 100,000 to 1,000,000. Within such permissive areas, Singer (1993, p. 73) recognizes favorable areas, which have a higher probability to contain an occurrence than non-favorable areas, and which may extend outward from known deposits, if any exist. However, the term "favorable area" has also been used in many other ways. Because of this, the term may conjure up different meanings for different individuals and thus needs to be defined whenever used.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.3 DEVELOPING, TABULATING, AND APPLYING CRITERIA FOR DELINEATION OF ASSESSMENT TRACTS--CONTINUED

Comment:--Continued

A slightly different approach is used by Brew and others (1991, 1992) and Brew (1992), who define mineral-resource "assessment tracts" as those subsets of permissive areas for which quantile-type estimates of the numbers of undiscovered deposits can be made. There are two reasons for this approach: (1) in many parts of the western United States and Alaska essentially all rock units possess regional-scale attributes that make them broadly permissive for one or another type of deposit; but deposit attributes constrain a large proportion of such areas to have relatively small probabilities (low deposity densities) of containing undiscovered deposits; and (2) within those very large permissive areas there may be smaller areas for which estimates of undiscovered deposits are made, and that are judged to have more than a 1 in 20 to 1 in 100 chance of containing an undiscovered deposit. Assessment tracts are therefore a specifically quantifiable variety of favorable areas, but "assessment tracts" lacks the long and ambiguous use of the term "favorable area." Using the Brew approach, the unestimated parts of the permissive areas therefore have a probability of between 1 in 20 to 1 in 100 and 1 in 100,000 to 1,000,000 of containing an undiscovered deposit. Estimates of undiscovered deposits in this probability range are exceedingly difficult, and non-estimation might be appropriate. There are two additional rationales for this "assessment tract" approach: (1) If more information that indicates the presence of undiscovered deposits becomes available for the non-estimated areas, then the boundaries and estimates can be revised; (2) It preserves and uses all the geographical information and can, therefore, be used to answer the "where?" types of questions from the client. One of the main consequences of using "permissive areas" as defined above is that it results in very large permissive areas being postulated as containing undiscovered deposits, even in the absence of evidence or even suggestion that mineralizing events have actually occurred. Permissive areas do, on the other hand, contain virtually all undiscovered deposits so that land designated as not permissive is unlikely to be the scene of mineral activity.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.3 DEVELOPING, TABULATING, AND APPLYING CRITERIA FOR DELINEATION OF ASSESSMENT TRACTS--CONTINUED

Comment:--Continued

Regarding the question of whether or not a tract may be estimated as containing more than one type of deposit, two approaches are currently in use, illustrated in Figure A.3.4.3-1. The approach described by Singer (1993, p. 73) and also utilized by Brew and others (1991, 1992) and Brew (1992) accepts one or more deposit types within a given tract (B, below). In contrast, the terminology used by D.P. Cox and Steve Ludington for the ongoing National Assessment (S.D. Ludington, oral comm., 1993) identifies a separate tract for each deposit type (A, below), even when multiple tracts may have identical boundaries. There is (or should be) no difference between the two approaches as far as estimates of overall undiscovered resources go, but the approach that has more than one deposit type in a tract facilitates communication with land managers. They are commonly interested in the total undiscovered resources in a specific management unit and the more-than-one-deposit type approach may be simplest in that regard. The other approach treats each tract as an entity with a single resource attribute, and facilitates analysis of a complex assessment database.

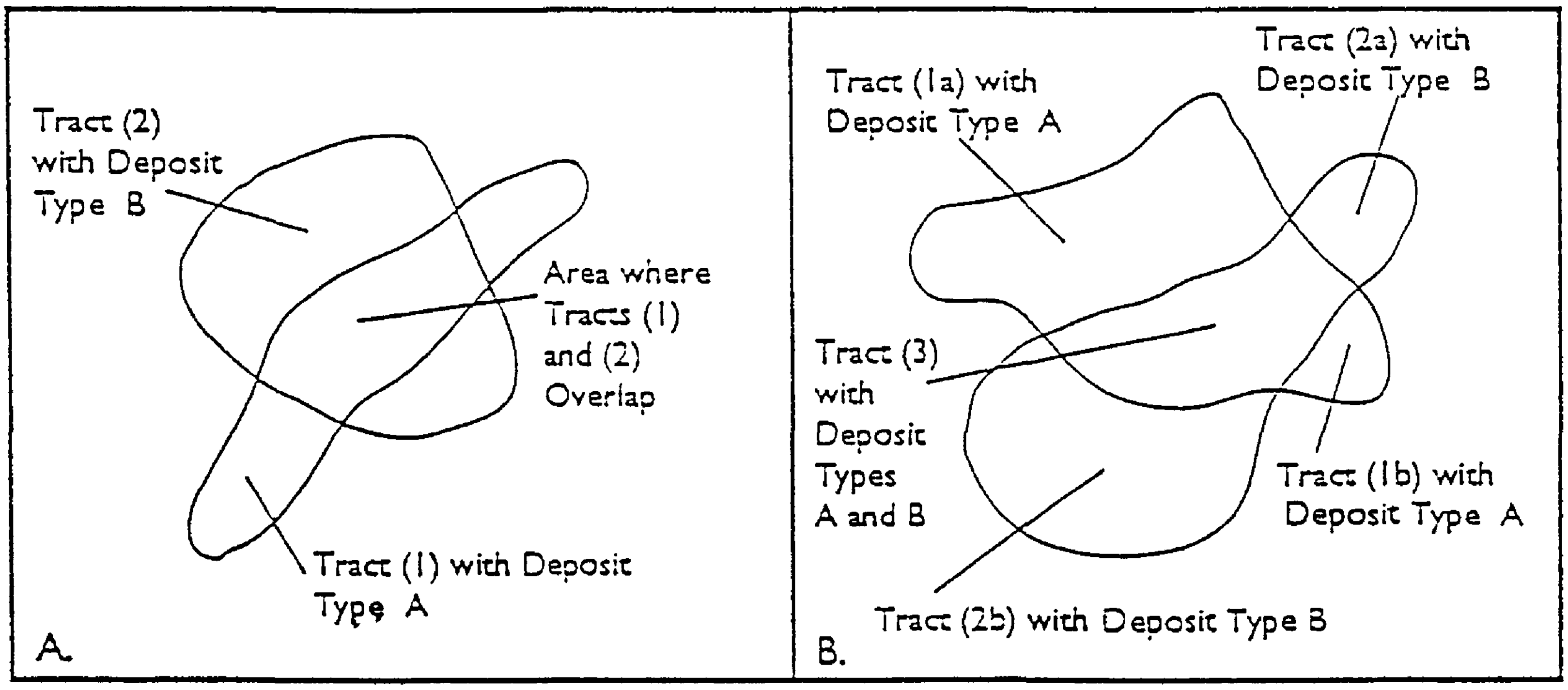

Figure A.3.4.3-1. Relations between one-deposit-type-only and multiple-deposit-type mineral-resource assessment tracts. A. two overlapping tracts (1) and (2), each judged to contain one type of deposit; B. adjacent tracts (1), (2), and (3), with (1) and (2) judged to contain different types of deposits and (3) both.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.3 DEVELOPING, TABULATING, AND APPLYING CRITERIA FOR DELINEATION OF ASSESSMENT TRACTS--CONTINUED

Recommendations: Assessment teams should clearly document their criteria for the delineation of each permissive area and assessment tract. The application of those criteria to each boundary delineation should be carefully recorded. Either the geographically overlapping or geographically exclusive tract type may be used, but the assessment team should take their main client's needs into consideration and should specify which way they proceeded.

A.3.4.4 CHOOSING A RATIONALE FOR ESTIMATION

Issue: On what basis are probabilities of the occurrence of specific numbers of deposits to be estimated?

Comment: For each deposit type in each tract, the assessment team, individually or collectively, must choose a rationale most appropriate for estimation. The elicitation results will provide a comparison of estimates, but it is essential that prior discussion within the team ensures that some rationale is used by each assessor. The superior rationales are the ones that produce low variance results.

Cox (1993) outlines two of the many possible alternatives: the "target counting" and "deposit density" methods; both apply the logic of analogy. In the former, observed and remotely sensed features are individually or collectively assigned a probability that they represent one or more mineral deposits, based on their being analogous to similar features in other areas with known deposits. The sum of the probabilities gives the mean expected number of deposits in the tract. This may be the better procedure where there are good geologic and exploration-experience data. The deposit density method is an application of analogy wherein similar areas elsewhere that have extensive exploration histories are used to construct a deposit density model. It has particular application in regions where there is little direct information about mineral deposits, but where there is sufficient geologic information to make a meaningful analog. A significant problem is the immature state of our knowledge about what constitutes an appropriate analog; consequently, some estimators have little confidence in it. A variant of the second type of analogy is "internal analogy." In it the geologically determined tract is subdivided into explored and unexplored subsets; from the former a deposit density is determined, and that density is applied by analogy to unexplored parts. An example is the estimation of undiscovered mineral resources concealed beneath pediments among explored mountains.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.4 CHOOSING A RATIONALE FOR ESTIMATION--CONTINUED

Estimators and respondents have expressed little confidence in analogy as a basis for estimation because the bases for the analogies are too often ambiguous. The use of multiple assessors is the main approach to dealing with varying, and often high, degrees of uncertainty for the different individuals.

Recommendation: **Uncertainty in estimation should be minimized by the choice of the best rationale to assign probabilities. Where there is sufficient information, target counting and "internal analog" reasoning are the best choices. Research into the uses of analogy should continue, and guidelines should provide criteria to identify the superior strategies.**

A.3.4.5 ELICITATION OF ESTIMATES OF NUMBERS OF UNDISCOVERED DEPOSITS

Issue: How should estimates of numbers of deposits be elicited?

Comment: The process of obtaining estimates of numbers of deposits from assessors is referred to as elicitation, and its successful execution may involve teaching, coercing, nagging, and leading. It is not an easy task, as the estimation of numbers of undiscovered deposits is undoubtedly the most difficult and controversial part of the assessment process. How best to capture and make usable the expert judgment of assessors remains a challenge. In order to render this judgment numerically, it seems necessary to use subjective probability. Many geoscientists have little familiarity with probability, and are reluctant to make estimates. Part of this problem can be mitigated by continuing education in probability theory (see section A.3.2.5).

Some assessment participants have found the estimation process uncomfortable, and are not sure if they are expressing themselves correctly. The Arizona Report (p. 418-19, with discussion on p. 351-352) recommends that the elicitation of probabilities for specific events (numbers of deposits) is a better procedure than the current procedure of elicitation of least numbers of deposits for specified cumulative probabilities. Thus, a probability density function (PDF) would be constructed directly, rather than calculated from a cumulative density function (CDF). Figure A.3.4.5-1 illustrates this difference.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.5 ELICITATION OF ESTIMATES OF NUMBERS OF UNDISCOVERED DEPOSITS--CONTINUED

Comment--Continued:

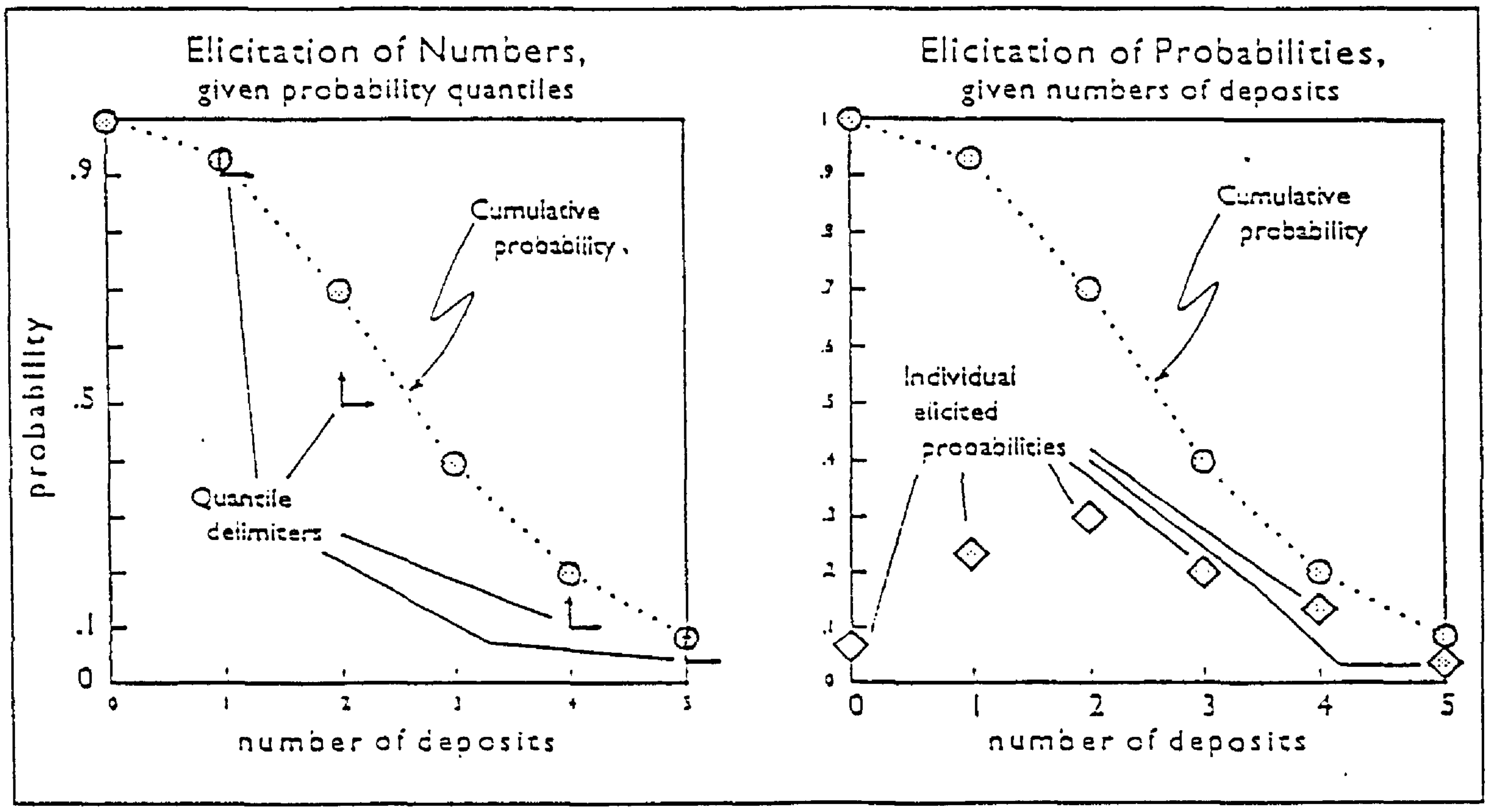

Figure A.3.4.5-1. Examples comparing elicitation of numbers of deposits (left) vs. probabilities (right). On the left, current practice asks the estimator for the least number of deposits at a specified cumulative probability or more. As in: "There is a probability of 0.5 or more of how many deposits?" The joined arrows (↑→) show the limits established by answers to these questions, e.g., for the 0.5 quantile, the answer is "2 or more." The shaded circles show cumulative probabilities arising from those answers and the algorithm for default probability distribution given by Root and others (1992). On the right, the estimator is asked for the probability of specific numbers of deposits. As in: "What is the probability that there are 2 deposits?" The cumulative density function (CDF) may then be calculated from the probability density function (CDF).'

Many of our geologists have not clearly understood how they have been estimating deposits, and their estimates therefore may not have been of the highest quality. During forums USGS geologists felt that direct elicitation PDFs is more intuitive, especially if a visual representation of their PDF estimates is available in real time. Working with both approaches is a way of confirming opinions and is a good teaching tool. The comprehensive record of each assessment should include the individuals' estimates made for each tract before averaging or reaching a consensus so that the range of estimates is documented.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.5 ELICITATION OF ESTIMATES OF NUMBERS OF UNDISCOVERED DEPOSITS--CONTINUED

Comment--Continued:

Several forum participants and contributors of written material reported negative feelings towards elicitations in which they were asked to vote on the estimated number of undiscovered deposits. One inference that may be drawn from this is that, for those individuals, discussion leading to consensus would have been better. This may be because voting tends to polarize both individuals and groups.

Recommendations: The committee agrees with the recommendation of the Arizona Report that elicitations should be done directly, using probabilities, not quantiles.

If the decision is to produce and record PDF's for each assessor, then a major drawback is that it requires more time, especially without a major investment in computer hardware. When just one computer is used to model PDFs, elicitation must be done individually, with each estimator in turn. This could easily double the amount of time that each team must spend together. With training, a minor amount of software development, and a computer in front of each estimator, most of this extra time could be eliminated. Mark3 must be modified slightly so that it can accept probabilities directly. The time and effort necessary to make this change are worthwhile. Implementation at the lowest level will consist of training a group of people to use existing software.

In agreement with the recommendation of the Arizona Report, individual members of the assessment team should, after thorough discussion of the factual information, be free to make their estimates independently, without being forced to a consensus. If consensus is apparent, then it should be used. Otherwise the individual PDF's should be used.

Criteria for, and the character of, subsequent refinements of estimates were not resolved in the forums and remain a topic for guidelines. In any event the initial and any subsequent estimates of the individual assessors should be recorded.

A.3.4 SELECTION OF DEPOSIT TYPES, TRACT DELINEATION, ESTIMATION OF NUMBERS OF UNDISCOVERED DEPOSITS, AND RELATED TASKS--CONTINUED

A.3.4.6 TABULATION OF RATIONALE FOR ESTIMATED NUMBERS AND OF INDIVIDUALS' ESTIMATES

Issue: Having discussed both the rationales used in estimation (A.3.4.4) and the actual estimates elicited (A.3.4.5), to what degree is it necessary to preserve the rationale for estimation of numbers of discovered deposits and the estimates made by individual assessors?

Comment: Previous assessment reports have been characterized by a cursory documentation of the rationales for estimates and of individual's estimates. This has been especially true for reports compiled under duress or within very tight time frames (c.f. Hodges and Ludington, 1991; McCammon and others, 1991).

The lack of documentation has several undesirable features: 1) it means that the assessment report is not very useful if an updated assessment is needed; 2) it makes it difficult or impossible to compare rationales between different areas and different assessments; and 3) it leaves the Survey open to challenge on the magnitude of the estimates.

Clearly, Survey assessment reports need better documentation of the rationales for estimates. It is less certain that individuals' estimates need to be preserved. Those who have led assessment meetings were virtually unanimous in their contention that it is simply impossible to lead the meeting and take the notes that allow a clear exposition of the reasoning later. One way to correct this is to appoint a recorder. Although the recorder need not be an estimator, he or she must be competent to comprehend and synthesize the arguments of all the other team members. The recorder could be involved only for the short time of the assessment meeting; extensive preparation probably would not be necessary. A corollary idea is to select recorders as apprentices to become future meeting leaders. Someone in training to lead assessments could learn much from documenting assessment rationale. (see also, Staffing, A.3.2.4).

Recommendations: **The rationales for estimations in assessment tracts should be documented. Each assessment team should decide whether or not to preserve the individuals' esimates. However, our clients need for geologic and assessment documentation may be minimal, and our report to them should crisply emphasize the mineral deposits without imposing a burden of what they may view as extraneous detail. A geotechnical paper trail (preferably published, see A.3.8) should emerge from the assessment process so that any future need to re-examine the assessment, or the information it represents, is readily met.**

Each assessment team should select a member to act as a recorder. Neither the team leader nor the elicitor should be the recorder.

A.3. ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.5 SIMULATION OF AMOUNTS OF METAL WITH MARK 3

A.3.5.1 INPUT AND USE OF MARK3

Issue: How do we improve the understanding of the Mark3 mineral-resource simulator and its use? Is there a way to let assessment teams interact with the program in real time?

Comment: Mark3, the simulation program that converts estimates of numbers of undiscovered deposits into distributions of contained metal, is perceived by some to be mysterious and inaccessible. Results have not been available in a real-time mode during assessment meetings, and the program is presently cumbersome to use in a "What if?" mode. Numerous anecdotes related during the Forums revealed that assessment teams have been surprised by tonnage and grade outcomes of their assessments after processing through Mark3. In some cases, this revelation came only after finalization of the report.

> ***Recommendations:*** **Mark3 should be made available to run in real time, so that the results can be examined, discussed, and, if needed, revised during assessment meetings. This can be done in at least three ways, the first two of which could be implemented within a week or less.**
>
> **1) The Mark3 program on BORA's workstation (Data General Avion "rgborafsa") in Reston can now be used, with minor access modifications, over the Internet.**
>
> **2) Mark3 can be ported and run on any other Avion in the USGS. Suitable computers are available in Menlo Park, Denver, and Spokane.**
>
> **3) The best solution, albeit with the highest cost, would be to adapt the program (which is written in FORTRAN) to run on desktop computers. This might require a few person-months of work.**

A.3.5.2 OUTPUT OF MARK3

Issue: Is the output of Mark3 easy for assessment teams to use and understand? Can the output format be improved?

Comment: Results from Mark3 are generally received by assessors as paper copy long after the team meeting. This format is cumbersome and hard to convert for graphical display and statistical analysis. Although the program can generate an ASCII file, much time is required to reenter or edit data during report writing.

A.3.5 SIMULATION OF AMOUNTS OF METAL WITH MARK 3--CONTINUED

A.3.5.2 OUTPUT OF MARK3--CONTINUED

Recommendations: For assessment reports, graphic images in the form of cumulative curves (see Fig. A.3.6.1-1), and histograms (see Fig. A.3.6.1-2) are needed to facilitate communication with clients. The Mark3 results should be in a form that makes them easy to import into PC spreadsheets for possible further manipulation.

These additions to Mark3 will require some modest programming, probably measured in person-weeks. In addition, provision for economic filtration (A.3.6.2) will require further modification of Mark3 output formats.

A.3.6 REPORTING OF ASSESSMENT RESULTS

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION

Issue: What format most clearly communicates assessment results? How can the potential for misunderstanding be minimized?

Comment: Communicating probabilistic assessments unambiguously is difficult. The role of probability in such communication is expressed in the quotation below, excerpted from the National Research Council (1991) report on undiscovered oil and gas resources:

"Why Resource Assessments Vary

A common problem with resource assessments is that the way they are reported often underemphasizes the uncertainty inherent in the final estimates. Users of [petroleum] assessments (for example, members of Congress) tend to focus on only one number, the mean value, as providing a definitive answer to the question of how much undiscovered [petroleum] the United States possesses. The focus on the mean value is misleading. In reality, what an assessment offers is a broad range of possible values--like the 33 to 70 billion barrel crude oil range from the DOI assessment--based on the best knowledge available at the time. No two groups of experts asked to predict the volume of undiscovered [oil and gas] will produce exactly the same figures.

...A third cause of variation among assessments is the role played by the subjective judgments of the scientists who prepare the estimates...Given the same set of geologic data about an oil and gas province, experts may disagree about the likelihood that each of these factors is adequate to have promoted the formation of an [oil or gas] accumulation."

These issues are also discussed at some length in "Energy- and Mineral-resource assessments--How are they done? Who are they for? How effective are they?" (McCammon and others, 1992).

A.3.6 REPORTING OF ASSESSMENT RESULTS

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION--CONTINUED

COMMENT:--continued

Results of our quantified assessments are reported in a form that many of our clients do not understand. To be effective, the results must be expressed in a way that is simple enough for the client to use directly; otherwise the results are only qualitative assessments. At the same time the degree of uncertainty associated with assessments must be conveyed to the client.

The crux of the problem is the "single number" answer wherein the recipients are unwilling or unable to deal with more than a single value.

One could assert that this is an insoluble problem. During the Forums, we often heard something like "No one format is right" and "Different clients will need different formats." Yet we must do our best to solve this quandary because most of the time there will be only one report to the client (plus detailed documentation, at least in archives). The most difficult part of reporting is to communicate the uncertainly inherent in the estimates.

As an illustration of alternative formats, we next describe five ways to report the same data concerning an assessment dealing with a hypothetical array of porphyry copper-gold deposits. The estimates of undiscovered deposits has the following probabilistic description: 0.9 or greater probability of 3 or more deposits; 0.5 or greater probability of 5 or more deposits; 0.1 or greater probability of 9 or more deposits; 0.05 or greater probability for 15 or more deposits; and 0.01 or greater probability for 20 or more deposits. This estimate yields a mean, or expected value of 6.015 deposits. (Note that, while the mean, as a calculation, is perfectly precise, it is not properly presented as an estimate to more significant figures than the original estimates.)

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION--CONT.

Comment--Continued:

1) Cumulative histograms of contained metal:

The cumulative histogram of contained metal offers several advantages. Chief among them is that all quantiles can be read directly from the curve. In addition, it is possible to show results for many metals, deposit types, or assessment areas on a single graph. And, it is relatively easy to construct from presently available Mark3 output. The chief disadvantage is that few clients are familiar with it, and many may not know how to interpret it. Figure A.3.6.1-1 displays the cumulative histogram.

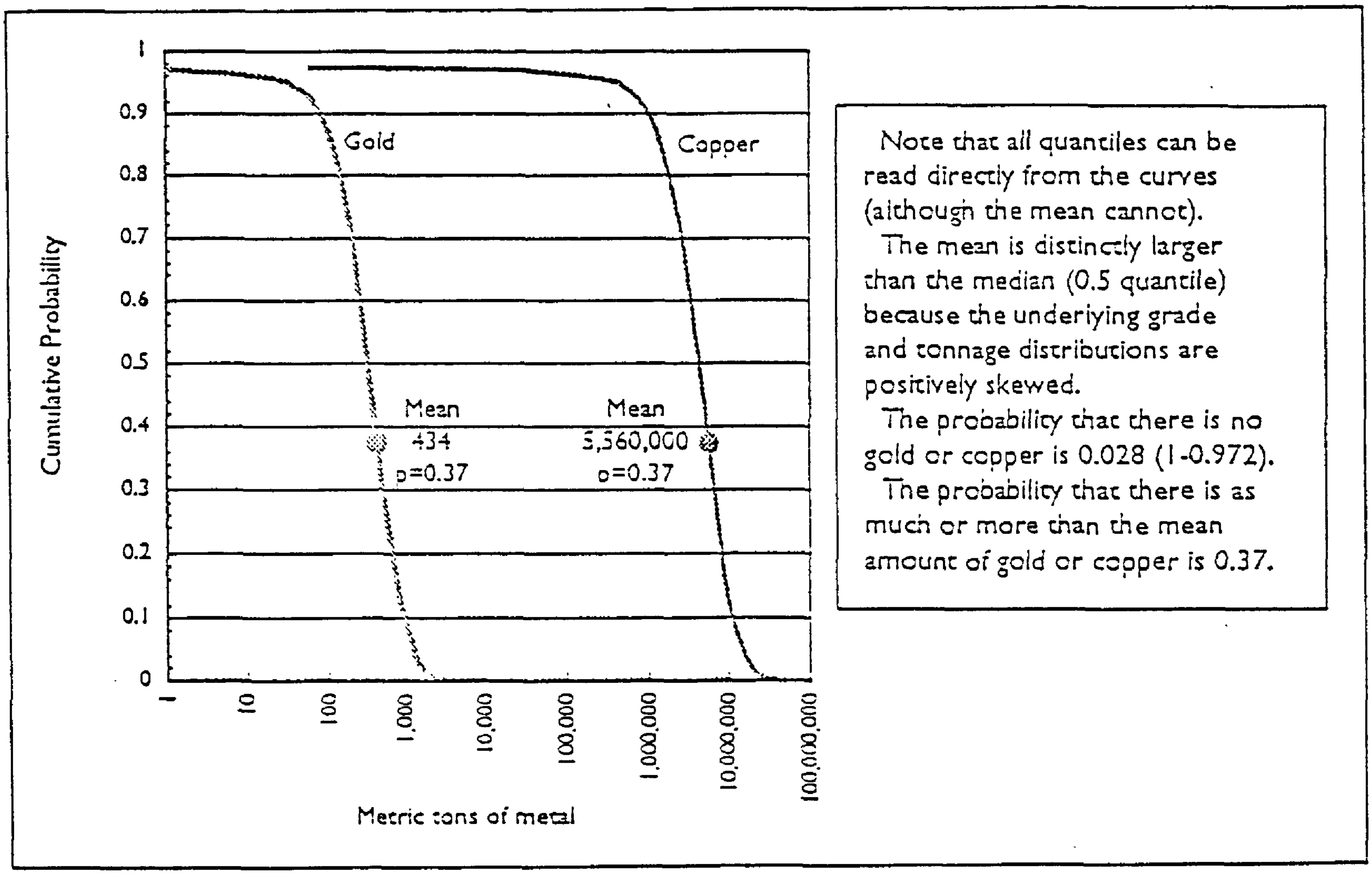

Figure A.3.6.1-1. Cumulative histogram showing results of porphyry Cu-Au assessment.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION--CONTINUED

Comment--Continued:

2) Histograms of contained metal:

Histograms ("bar graphs") are more widely known than cumulative histograms; they are familiar to most people because of their use by the news media and in business analysis. They show the central tendency of a distribution very clearly. Disadvantages are that no statistical parameters can be read from them, their appearance is sensitive to the subjective choice of the size of the class intervals, and there is no provision for this type of output in the present version of Mark3. Figure A.3.6.1-2 shows histograms describing an assessment of porphyry Cu-Au.

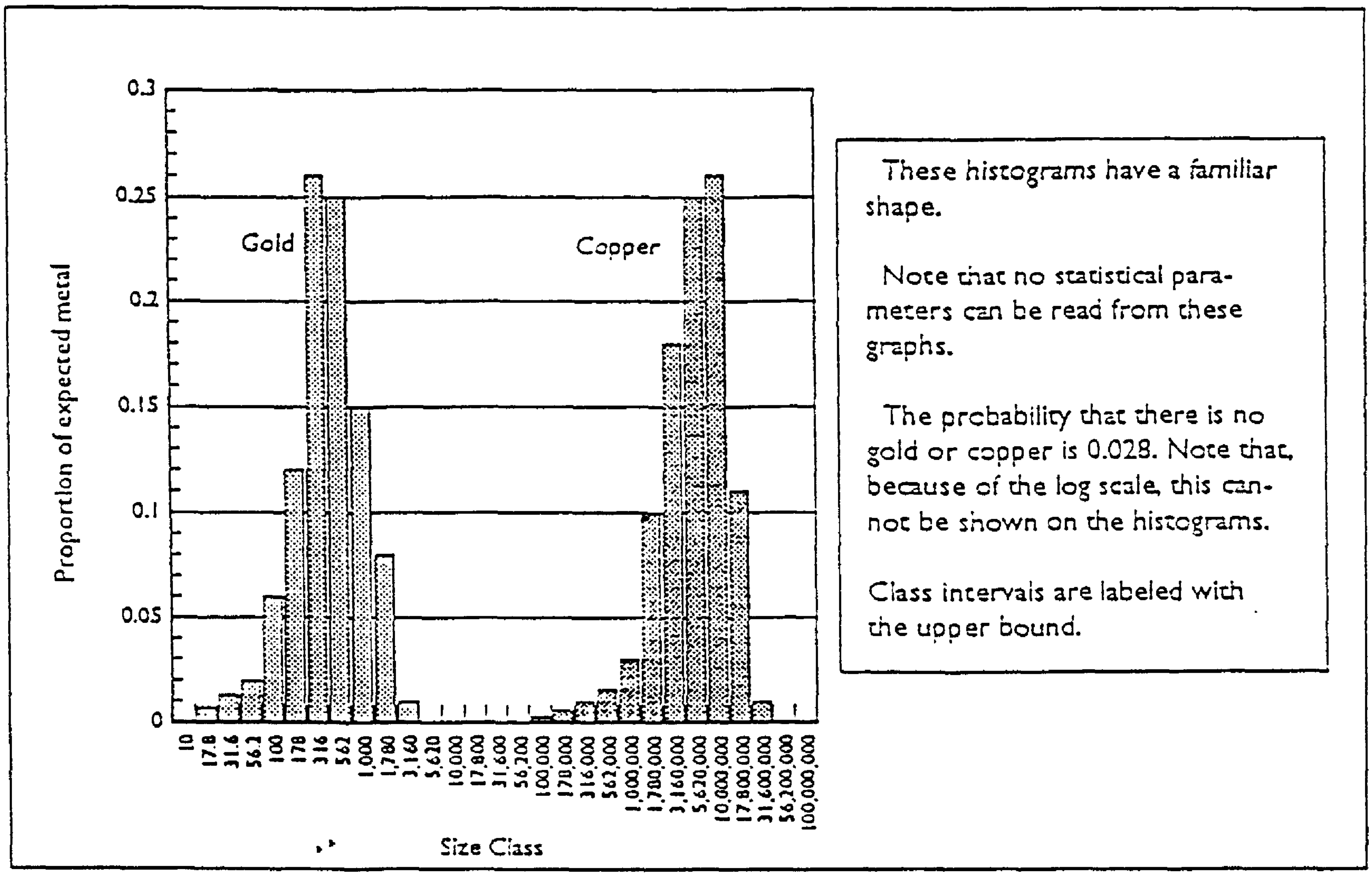

Figure A.3.6.1-2. Histogram showing results of porphyry Cu-Au assessment.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION--CONT.

Comment--Continued:

3) Tables of quantiles:

This is the form of reporting that has been most prevalent to date. It has the advantage of being easy to construct from the present Mark3 output. However, the choice of which quantiles to present is subjective, and the motives behind those choices are always open to criticism. We anticipate that a standard reporting scheme like the one shown could minimize such criticism. Table A.3.6.1-1 is a typical table. Note that the mean is the mean, or expected value, for the entire distribution. It has no relationship to the arithmetic average of some selection of quantiles.

Table A.3.6.1-1. Typical distribution of quantiles for Porphyry Cu-Au example given in text

	METRIC TONS OF METAL	
QUANTILE	GOLD	COPPER
0.95	33	435,000
0.90	80	1,050,000
0.50	325	4,260,000
0.10	955	11,900,000
0.05	1,260	15,600,000
mean	434	5,560,000

4) Confidence intervals:

Confidence intervals are used by statisticians to represent uncertainty, and, in the often misused "plus-or-minus" form, are familiar to some of the general public. Because of the positive skewness of metal distributions, typical statements about confidence intervals commonly seem peculiar.

For example, from the table of quantiles above:

"There is a 90% chance that the amount of gold is between 33 and 1,260 metric tons, and there is a 90% chance that the amount of copper is between 435,000 and 15,600,000 metric tons."

"There is an even chance that the amount of gold exceeds 325 metric tons."

"There is an even chance that the amount of copper exceeds 4,260,000 metric tons."

"For the 90% confidence interval, the mean amount of gold is 434 $^{+826/-391}$ metric tons; the amount of copper is 5,560,000 $^{+10,000,000/-5,130,000}$. metric tons."

The 95% confidence interval would express even larger uncertainties. Although 95% confidence intervals are widely used in hypothesis testing, that convention is irrelevant here.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.1 FORMAT FOR REPORTING QUANTIFIED INFORMATION--CONT.

Comment--Continued:

5) Means:

Many resource-information users expect to receive some measure of central tendency; and means and medians have commonly been used. There is a tremendous amount of controversy surrounding the use of mean (instead of the median) metal amounts in summary statements and tables. On the one hand, the mean is the unique parameter of a distribution that may be appropriately combined with means of other distributions. No other properties are additive. Furthermore, many clients want to know what is the single "best" number to represent our assessments; the mean estimates the amount of metal present in the same way that grade is based on the mean, not the median. On the other hand, the fact that the mean is much greater than the median for positively skewed frequency distributions (such as those of contained metal) is difficult to grasp for many people who are unfamiliar with statistics. For positively skewed distributions, the probability of an individual deposit containing the mean or larger amounts of metal is always less than 0.5, and it may even be less than 0.1. Many apparently view the mean as an overestimate, but, statistically speaking, this is not the case.

Recommendations: The committee acknowledges that presentation of probabilistic, quantified information is an important problem. Although for most assessment applications, the mean is an appropriate measure, we must always emphasize that probability distributions _cannot_ be adequately represented by a single number. Uncertainty must be presented, and the number of significant figures must be consistent with the uncertainty. Assessment teams should consider each of the presentation formats carefully in the context of the user of the results, and choose the format or formats that best serve that user. It might be useful for a few typical situations to be identified in order to tailor some "boiler-plate" for each appropriate client situation. Words like those already quoted from the petroleum assessment might well be a model for all.

A.3.6.2 ECONOMIC FILTRATION

Issue: How should assessments address the potential economic value of undiscovered deposits?

Comment: Gross In-Place Value (GIPV) is derived by multiplying the gross in-place metal content derived through Mark3 by current or time-averaged metal prices. GIPV assigns value to materials in undiscovered deposits without regard as to whether they are likely to be produced. Almost all USGS assessors agree that this measure has many shortcomings, is liable to be misused, and should be dropped or replaced with a meaningful alternative measure of value.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.2 ECONOMIC FILTRATION--CONTINUED

Comment:--Continued

The Arizona Report (p. 415–416; 241–260) recommends that the use of GIPV be discontinued immediately because it is not a useful measure of the economic or societal value of mineral resources. Some kind of economic filtering would make our assessments more useful to decision makers. The use of GIPV has left us, rightly or wrongly, open to charges of advocacy.

There is sentiment that any reporting of monetary values will be misunderstood, will lead to adverse publicity for the USGS, and will increase the risk of challenge to the estimates. However, land management agencies want value estimates; in the past, they have relied on sporadic economic analyses provided by the USBM for high-priority areas. By providing an estimate of the value and location of undiscovered mineral deposits that are likely to be discovered and developed, we would be providing a large part of the information that is needed and wanted by land management agencies. Such information would help tie assessments to current and near-future economic conditions. The uncertainties associated with our estimates of metal content are large compared to short-term economic uncertainties; thus cumulative uncertainty will not be increased substantially by going through an economic analysis.

Some forum participants suggested that only the net value should be considered in the economic analysis, thereby providing a "value" that is only a small fraction of the in-place value. Although such a downsized value would have significance to the board of directors of a mining company and would influence their decision of whether or not to mine, it does not account for the net benefit accruing to society. Society's gain includes the wages paid and their down-stream expenditures, the materials purchased, the taxes paid, and so on, as well as the profits; in short, the gross, not the net. Gross value also supplies an analysis comparable to the gross values provided for alternative uses such as tourist, recreational, logging, or grazing activities.

Economic filtration can be done at various levels of complexity, ranging from a truncation based on current metal prices and simple estimates of costs of exploration, development, and mining; to a sophisticated treatment considering factors such as future mining costs, future environmental impacts, future metal prices, future labor costs, sufficiency of future infrastructure, and so on. Sophisticated economic estimates take time and resources, and would require input from mining engineers, mineral economists, and economic geologists. Implementation would add significantly to the effort required for each assessment. Moreover, competency within our staff to perform such analyses is neither broadly distributed, nor clearly identified.

Recommendations: **The use of GIPV should be abandoned immediately. It should be replaced by an in-place value for only those undiscovered deposits that are judged to have near-term economic potential.**

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.2 ECONOMIC FILTRATION--CONTINUED

Recommendations--Continued:

How this is best done should be investigated soon. A comparative study of economic methodologies, such as those employed by the USBM, should be undertaken to recommend criteria and procedures for future value assignments. In-house expertise and the necessity for additional training or staffing should be identified. The basis and uncertainties for the estimates must be clearly characterized and made part of the final documentation. [Most of this recommendation has already been implemented through the Office Chief's memorandum to the OMR branch chiefs dated July 14, 1994.]

A.3.6.3 SCOPE AND CONTENT OF FINAL REPORT

Issue: To whom should reports be addressed, and what should they contain?

Comment: A fundamental requirement is that assessment reports be addressed to the clients. The client's needs will determine the presentation format and style of the report. The assessment team must clearly recognize who the client is, and what the client's needs are, before writing begins. Commonly, more than one client will be identified, but one will be considered primary. The report must meet the needs of the primary client, but should not be so narrowly designed that it precludes present or future use by others. Secondary needs and future clients may require additional products, including economic analysis, if that was not a requirement of the primary client.

In the past, some assessment reports have contained much backup geoscience data as well as methodology and results. Generally, however, a simplified report to the client has been the only record of an assessment activity. Data and the details of the assessment procedure must be archived and, if of use to the geoscience community, should be released separately.

Recommendations:

1) Each final report should begin with a summary of a) client needs and assessment objective, b) methodology and rationale, and c) results. Results should specify the nature, location, and quantity (if estimated) of undiscovered resources. One or two illustrations or tables should accompany the summary. Boiler-plate definitions of key terms and descriptions of the nature and magnitude of uncertainty in estimates should accompany the summary. The summary should be written so that an educated layperson (nontechnical college graduate) can understand it.

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

Recommendations--Continued:

2) Only data pertinent to the assessment should be summarized in the final report. Data (geology, geophysics, etc.) should be published or archived separately and referenced in the assessment report. Guidelines should be referenced and used. Methodology and rationale for assessment should be documented completely in the report. The body of the report should employ technical language to the extent required by the assessment process.

A.3.6.4 DOCUMENTATION OF THE ASSESSMENT PROCESS AND ARCHIVING OF DOCUMENTATION AND FINAL RESULTS

Issue: Is there a need for electronic and other documentation of assessment-process steps and results?

Comment: The Arizona Report strongly recommends (p. 417) both formal and electronic documentation of the rationale for each step in the assessment process and archiving of that information. Archiving documentation would allow recovery of decision information, should that become necessary, and would facilitate both subsequent analysis and the preparation of subsequent assessments.

The Forum committee agrees with this recommendation. In addition to the above-listed advantages, requiring documentation throughout the assessment process would ensure careful procedures and consideration at each step and provide a basis for defense against any possible challenges to the conclusions.

The Arizona Report did not deal directly with what we consider to be an important aspect of the documentation process. As noted in A.3.4.6, the workshop committee received many comments about the difficulties that a team leader experiences in the assessment meetings when he/she is serving as leader, facilitator, assessor, and recorder for the group. Clearly this diminishes the team leader's contributions to the assessment process and it is probably a major reason for inadequate documentation in the past.

***Recommendations*: The following specific items are those we suggest should be documented:**

1) geologic and/or other characteristics, including world-wide, regional, or local tonnage and grade curves, used to define the candidate mineral-deposit types and the types considered likely to occur in each tract;

2) geologic and/or other characteristics used to decide that the specified part of the earth's crust is permissive for the occurrence of undiscovered mineral deposits of the types considered likely to occur;

3) geologic and/or other characteristics used to delineate the boundaries of each assessment tract;

A.3.6 REPORTING OF ASSESSMENT RESULTS--CONTINUED

A.3.6.4 DOCUMENTATION OF THE ASSESSMENT PROCESS AND ARCHIVING OF DOCUMENTATION AND FINAL RESULTS--CONTINUED

Recommendations--Continued:

4) methods used in eliciting estimated numbers of deposits at different quantile levels or as probability density functions and the results thereof for each assessor;

5) methods used in progressing from individual estimates to the final assessment;

6) working definitions of terms used by the assessment/estimation team; and

7) the members of the team and their roles.

Permanent electronic or other documentation would facilitate both release and later retrieval of the assessment information. The USGS Digital Information Release Series should be used, rather than leaving the information in unpublished files.

Each assessment team should include a geologist who does not lead, estimate, or facilitate, but, instead, functions as a recorder and takes notes and gathers material to document the entire estimation process. This person could well be someone who is being introduced to the activity of assessing undiscovered mineral resources.

A.3.6.5 ALTERNATIVE FORMATS FOR PRESENTATION OF ASSESSMENTS

Issues: How should the Survey respond to requests for assessments in instances where the time is impossibly short, or where the information is insufficient for quantified assessment? How are such situations recognized?

Comment: These issues are going to be with the Geological Survey for as long as it is performing mineral resource assessments. Some protocols are needed to make decision-making less difficult and more defensible. Various alternatives are possible, including the suggestion that we report orders-of-magnitude estimates such as "10 - 100" or "1 to 10 million." There may also be situations for which the "high, medium, and low" estimates are useful. In some cases, a verbal briefing without any formal briefing notes or charts, may be appropriate. In some cases, the estimate, or answer, should be no estimate.

Recommendation: The formulators of guidelines should consider alternative reporting formats for special situations and create protocols concerning their use.

A.3.7 REVIEW OF REPORTS

Issue: Are the current standards and procedures for review of mineral assessments sufficient?

Comment: Quantified assessments of undiscovered mineral resources normally receive the same level of review as other Geological Survey reports. For the Bulletin series, this consists of two (or more) peer reviews, review of geologic names, editorial review by the technical reports branch, and review for policy when submitted for Director's approval. Reports released in the Open-File series require only one peer review, even though they may represent significant contributions from several branches. Moreover, no review of geologic names or editorial review is done. Many mineral resource assessments are released as Open-File Reports so that the results are available in time for use by the client. If intransigent authors are combined with inadequate review(s) and acquiescent supervisors, an unacceptably low quality of report may result.

The assurance of quality of review becomes lower still when the preparation and review process is telescoped or even interrupted and terminated by political pressure or by unauthorized release of draft copy. In the recent past, the biggest problems with both peer and public perception of quantified assessments have arisen in the few situations where the review process was not allowed to operate normally.

Recommendations: **Because of the potential high visibility and societal impact of mineral resource assessments, we recommend that at least two rigorous peer reviews, representing the principal contributing branches, be required for assessment reports released in the Open-File series. Where possible, formal or informal reviews should be conducted by specialists familiar with the area, deposit types, or commodities. Authors should document their reasons for rejecting substantive comments by the reviewers.**

Emergency requests for assessments should be answered with verbal briefings, and not with hastily prepared, incompletely reviewed reports (See A.3.6.5). The results of the ongoing National Assessment should be used to address those requests having short time limitations. Both headquarters staff and experts from the field should be involved in briefings to assure the highest quality information possible. Personal briefings also allow Survey staff to help the client understand the available information and the conclusions that can be drawn from it.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.8 PRESENTATION OF GEOTECHNICAL INFORMATION

Issue: How and in what degree of detail should geotechnical information be presented in assessment reports?

Comment: Geotechnical information is the foundation for the estimation of undiscovered mineral resources, but its use and the degree of detail in reports are viewed in different ways by different groups. The focus here is on the geoscientific user.

Geoscientists responsible for assessments generally support the reporting of all of the basic data and of intermediate syntheses used in the assessment process. Their rationale is that complete and clear elucidation of the components and the process are necessary to support the assessment's conclusions and to establish its credibility. Geoscientists are most comfortable with presentation formats that are designed for fellow earth scientists. Inclusion of all supporting material makes the preparation of assessment reports more time- and resource-consuming, but geoscientists reading and using assessment reports are likely to appreciate and understand the need for comprehensive presentations.

As discussed in sections A.3.6 and A.3.9, the land manager (or similar user) is, on the other hand, relatively uninterested in the supporting material, but is interested in the conclusions. Such an individual generally does not want to be burdened with caveats, complicated diagrams, or tables, but instead wants a simple map and a "bottom-line" conclusion.

This comment and the recommendation below focus on the level of geotechnical information that should be included in every assessment report, rather than specifically for the land manager or similar user. However, it may be that two types of reports are required, one the geotechnical report discussed here, and the other a simplified summary report.

The full array of geotechnical information that goes into an assessment can be daunting, with tens to hundreds of reports and maps being considered at different stages in the process. As noted above in various sections and discussed in section A.3.6.4, documentation of how this material is used is critical. Both the basic information and the documentation are not only important as the foundation for the assessment, but they are also important for any reassessments of the same area. All basic non-proprietary and intermediate-analysis information used in any assessment must be made available. The question is, how is this best accomplished? The currently available method is the preparation and archiving of hard-copy materials; the near-future alternative is to operate, store, and release all material in digital form.

A.3.8 PRESENTATION OF GEOTECHNICAL INFORMATION--CONT.

Recommendation: The USGS should continue its long-established practice of publishing all basic maps and other materials generated for assessment. In addition, assessment reporting should include all documentation for decisions regarding mineral-deposit-type identification and selection, tract boundary delineation, and also the estimation of the numbers of undiscovered mineral deposits (see section A.3.4.5). In the long run, the sooner the U.S.G.S moves to digital methods of presentation, the more efficient and less expensive it will be to provide the full complement of materials to support assessment. The reports discussed here are in addition to, and supplementary to, the semi- or non-technical reports to the client.

A.3.9 COMMUNICATION AND DISTRIBUTION OF ASSESSMENT REPORTS

Issue: How can we distribute reports to, and communicate with, users most effectively?

Comment: We must make our results readily accessible and easy to use. Assisting the user following publication of assessment results is an important aspect of communication and distribution. The Office as a whole, and particularly the assessment team, need to be responsive to opportunities for follow-up communication. Often, effective use of our conclusions is limited to a few key planners, so that personal briefings and offers of assistance in using the report are the most effective communication of assessment results.

Recommendations: Communication of information in reports should involve much more than just publication and listing in the Survey's Monthly List of Publications. Copies of the report should be provided by the assessment team to users identified during the project and responses made to any inquiries they may make in return.

If the report is newsworthy, the assessment team should consider a press release. If a press release is needed, the team leader should contact the Geological Survey's Public Affairs Office for assistance in preparation and release. If the results of the report would be of interest to segments of the public or to professional groups, the team should consider a public meeting. However, public meetings should be used sparingly and only after considerable public interest can be verified, in order to avoid wasting time and funds.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.10 VALIDATION OF THE RESULTS OF ASSESSMENTS

Issue: Can we measure the predictive value and precision of assessment results, and, if so, how?

Comment: We use the term "predictive value" here in the sense of indicating that the estimated undiscovered resources are indeed present. Predictive value is used loosely to replace the term "accuracy", because the accuracy of an assessment can not be determined without complete and exhaustive exploration of a given tract. We use the term "validate" here in the sense of examining the results of an assessment in terms of their agreement with other results and their internal consistency.

Validation may involve several issues: 1) precision of the estimation methodology, meaning the consistency in estimates made by different estimators using the same information, 2) precision versus predictive value of the estimates made in an assessment, 3) level of precision and predictive value required by the user, and 4) confirmation of the designation of a permissive area by an actual discovery. Precision can be estimated by statistically designed experiments and by repeating estimates as information and methods change, but precision is not a measure of predictive value. Consistency is a measure of agreement among estimates made by different experts using different data and methods. It is important because it affects user confidence. Other issues concerning validation of estimates were discussed in a forum on "Energy- and Mineral-resource Assessment" (McCammon and others, 1992).

To date, experience with the validation of quantified mineral-resource assessment methodology consists of the results of an ongoing controlled experiment in estimating numbers of porphyry-copper deposits (W.D. Menzie, 1993, written commun.). In this experiment, geologists are given a packet of information (geologic maps, stream sediment geochemistry, aeromagnetic data, and mineral occurrence data) on 13 areas in the North American Cordillera. Features that might identify areas (geographic names, etc.) have been removed from maps. Some of the areas are believed to contain no porphyry-copper deposits. Others are known to contain more than one. Based on the underlying assumption that no undiscovered deposits still exist in these areas, the experiment is designed to investigate the precision of estimates (of number of undiscovered deposits) by experts, how much uncertainty is associated with the estimates, and whether groups can make better estimates than individual experts. The assortment of areas assigned to any individual estimator was varied to test the effect of different groups of areas with varying numbers of known deposits. Areas ranged in size from 22 to 468 square miles (median size of 132 square miles).

Results to date show that estimates of number of deposits are gratifyingly consistent. S. R. Titley (p. 3 of letter in Appendix II of the Arizona Report) points out that, in selecting the porphyry-copper model for testing, Menzie chose an optimum deposit type that constitutes a large, geologically conspicuous target with mineralization and alteration that are both well established and broadly recognized among the community of resource geologists and that one should not necessarily anticipate similar success if other deposit types are tested similarly. Menzie (1993, written comm.), however, was and is well aware of this aspect of the experiment. Even in this optimum test, substantial scatter of estimates among individuals may be expected and will occur. Combining results from several

A.3.10 VALIDATION OF THE RESULTS OF ASSESSMENTS--CONT.

Comment--Continued:

geologists improves the estimates because it minimizes the impact of one aberrant estimate. Finally, the results to date indicate that geologists do not recognize areas where estimation may be difficult and do not adjust their estimates to reflect greater uncertainty.

Tests of assessment methodology are needed to examine other factors, such as the effects of different estimators and data sets, as well as of different degrees of completeness of data sets, different geometries, different deposit models, and different truncations of data. Precision of estimates could also be estimated by replicating estimates under actual team working conditions and involving ongoing projects. Measurement of precision by this method would involve careful experimental design. Testing is time-consuming, and should only be undertaken with full involvement of experts in statistics and quantified assessment methodology.

An example of validation of an estimate made in a U.S.G.S. report is the discovery of the Pebble Beach porphyry copper-gold deposit (500 million short tons at 0.35 percent Cu and 0.012 opt Au; *Northern Miner*, March 9, 1992) in southern Alaska by Cominco. That deposit is within a tract that, 12 years previously, was assigned a 90 percent chance of containing one or more porphyry-copper deposits (MacKevett and others, 1978). The discovery was not guided by the assessment, but it did confirm that the assessment was appropriate.

Because of the immense cost of "exhaustive" testing, verification of estimates is virtually impossible. Even well-explored areas, such as the Carlin trend in Nevada, or the Hokuroko basin in Japan, remain prospective despite many years of exploration. Exploration successes in areas where undiscovered deposits are judged to exist confirm that the tract selection was appropriate, but such successes do not verify the quantified estimate.

The requirements of the user are a prime concern. Although predictive value (as measured conceptually by how close an estimate approaches the real number of deposits or the real amount of contained metal) would seem to be most important, it is seldom, if ever, actually known. Attention is therefore directed to precision (as measured by variation among estimates where different experts use the same data and method) and consistency (as measured by variation among estimates by different experts using different data and different methods). We believe that highly precise assessments are not necessary for most decisions about large-scale land use and public policy. For planners, an assessment that misidentifies areas either with or without undiscovered deposits may have a bigger negative impact than imprecision or inconsistency in quantified resource estimates.

Consistency in estimates (as defined above) is an indication of expert consensus. Clients who use assessments to influence decisions are uncomfortable with disagreement; they prefer consensus. A good illustration (Fig. A.3.10-1) of consistency in estimates and how it can be useful is presented by the U.S. Department of Interior's report on undiscovered recoverable oil and gas in the United States (Mast and others, 1989, figs. 17 and 18). All estimates of conventional oil resources except two are below 200 billion barrels and their ranges overlap;

A.3.10 VALIDATION OF THE RESULTS OF ASSESSMENTS--CONT.

Comment--Continued:

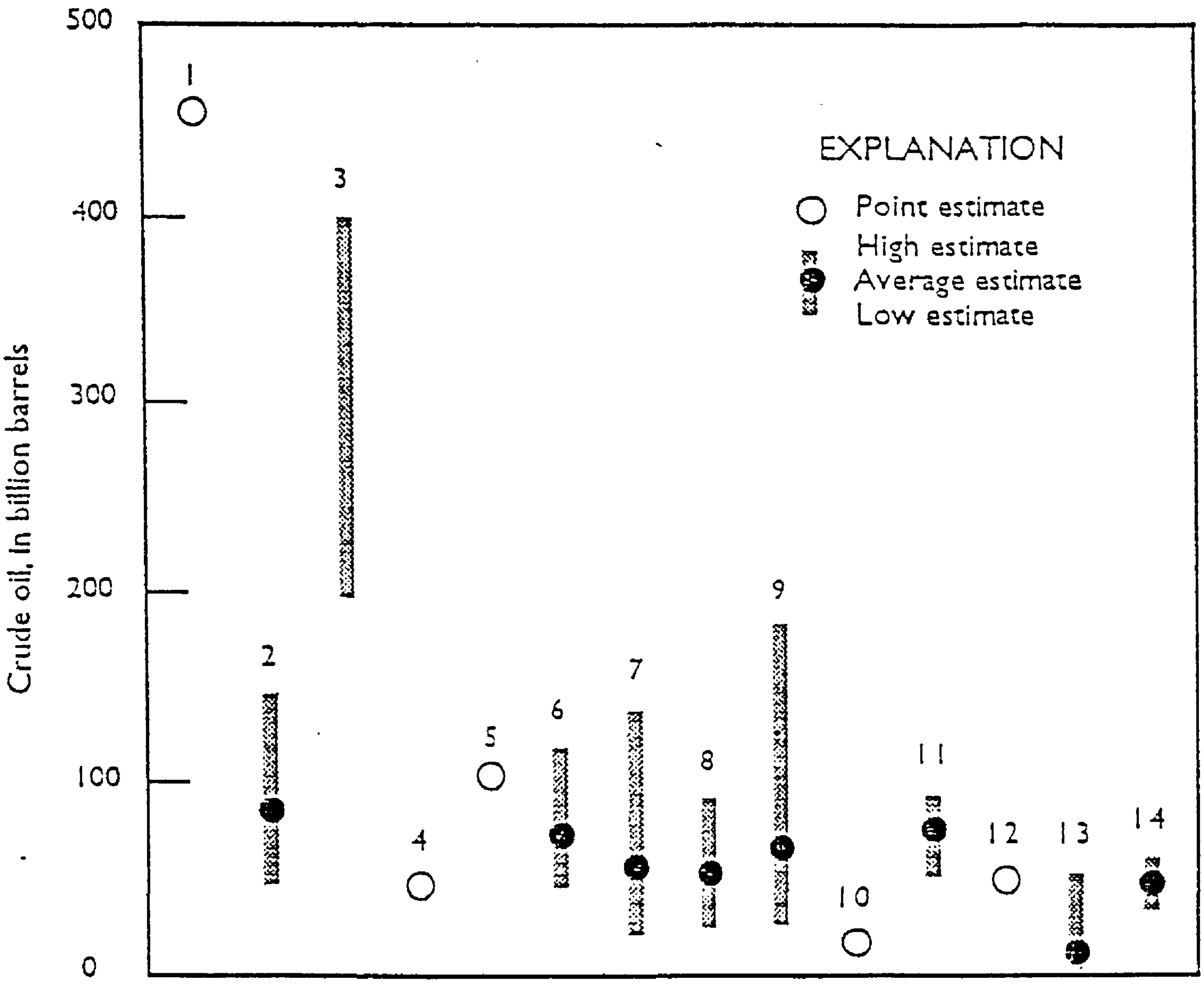

Figure A.3.10-1. An example of consistency in resource estimates. Undiscovered recoverable oil in the United States, estimates from 1979–1989 (Modified from Mast and others, 1989, fig. 17). Estimates are by 1) USGS, 1972, 2) Mobil, 1974, 3) USGS, 1974, 4) Hubbert, 1974, 5) NRC, 1975, 6) USGS, 1975, 7) Exxon, 1976, 8) Shell, 1978, 9) Halbouty and Moody, 1980, 10) Nehring, 1981, 11) USGS, 1981, 12) Shell, 1986, 13) Sohio, 1986, 14) This report (i.e., Mast and others, 1989). See Mast and others (1989) for these citations.

two estimates are significantly higher and they do not overlap the ranges of other estimates. In reporting estimates, care should be taken to compare them with previous estimates and to document changes in definitions and methodology that might account for differences.

Recommendations: **We recommend a continuing, Office-wide, long-term effort to test the validity of quantified mineral-resource assessment methodology through studies like the porphyry-copper experiment. The description and results of that experiment should be published as soon as possible.**

A.3.11 RESEARCH ON NEW ESTIMATION METHODOLOGIES

Issue: What better or alternative methods for estimating undiscovered mineral resources exist or are anticipated?

Comments: Over the past two decades the USGS has devised and steadily improved the method of estimating undiscovered mineral resources using subjective probability and simulation (see the descriptions in A.3.3 through A.3.5). Estimation of grades and tonnages of undiscovered mineral resources is a relatively new contribution to the process of mineral-resource assessment (Singer, 1993, and references therein). These estimates are obtained from the Mark3 mineral-resource simulator using a Monte Carlo simulation to derive probabilistic estimates of tonnages of metal and rock. To stay on the forefront of the development of assessment techniques, and, more importantly, to perform our assessment in an optimum manner, the USGS must continue to develop the present methodology and to investigate other approaches.

At the present time, most USGS quantified estimates of undiscovered mineral resources use subjective probability and simulation. However, in some assessment projects there are mineral-resource assessment tracts that are not appropriate for application of this method, and other, non-simulation, approaches are used.

Some USGS geoscientists who were involved in earlier, non-quantified assessments of mineral resources do not accept the quantified methods (see A.3.2.4, A.3.2.5). Those earlier assessments used the concept of "high," "medium," "low," and "unknown" potential for the occurrence of undiscovered resources (e.g., Shawe, 1981; Taylor and Steven 1984; Goudarzi, 1984). Proponents of non-quantified assessment suggest that yet other, less subjective, estimation methods might be developed and evaluated.

Research by the USGS and others on alternative assessment methods is a continuing activity. Current studies of oil and gas estimation processes may eventually lead to a new application to mineral resources (L.J. Drew and C.C. Barton, oral communs., 1993). Fuzzy-set-theory-based methods of Chen and Fang (1993) and Gettings and Bultman (1993) may provide alternative ways of dealing with resource assessment, as does research on deposit clustering and deposit density (Drew and Menzie, 1992). The USGS has also funded research on the intrinsic-sample approach to the delineation of assessment tracts (Harris and Pan, 1993). Weighted-factor analysis, similar to that recently applied to environmental problems by Bernknopf and others (1993), is another approach to the delineation of tracts. Most of these research efforts, including the indicator-favorability approach of Pan (1993), the weights-of-evidence method of Agterberg and others (1990), the variance-of-mean-values technique of Agterberg (1993), and the comprehensive-information methodology of Wang and Zhang (1992) focus mainly on tract delineation and/or the estimation of numbers of undiscovered deposits, without the actual estimation of tonnages of undiscovered resources. They also generally require levels of information beyond those commonly available for most tracts. None of them appear to be suitable for general application to our current responsibilities. Research on optional use of analogy should be pursued also; among these are closest analog, weighted-attribute, and discriminating variable methods (e.g., Singer, 1993).

A.3.11 RESEARCH ON NEW ESTIMATION METHODOLOGIES

Comments--Continued:

There is presently no alternative method of using estimated numbers of deposits in combination with grade and tonnage distributions to obtain estimates of grades and tonnages of undiscovered resources, the Mark3 simulator will therefore continue to be part of the quantified assessments.

Recommendations: **The USGS should actively pursue research on new assessment methods, including those mentioned above. By far the weakest link in assessment is the estimation of the number of undiscovered deposits, and it is there that our effort should be focused, as discussed in A.3.4.5.**

Revision or improvement of the actual estimation of tonnages of metals and rock in undiscovered deposits appears daunting because the present compilers of the grade and tonnage models have already identified most of the problems and have pushed our ability to deal with them as far as seems reasonable with the approach being used today. One possible and appropriate line of research would be to examine the use of analogous areas in applying the models; such approaches would be most appropriate for relatively small and well-known assessment tracts. Guidelines are needed for this approach.

A.3.12 ORGANIZATIONAL ATTITUDE, MANAGERIAL SUPPORT, AND PERCEPTIONS

Issue: How important is the assessment of undiscovered mineral resources to the Geological Survey?

Comments: Although the Office of Mineral Resources and the Geologic Division proclaim the importance of the assessment of undiscovered mineral resources, and although OMR currently receives most of its funds for that purpose, and is engaged in such assessments, neither group highlights the activity through project funding and real support, recognition, and reward of the individuals engaged in the projects. Those individuals engaged in assessments perceive that (1) they are providing the efforts that bring the Office its funds, (2) they are carrying others who contribute little, (3) those others are being rewarded with research opportunities and research funding, and (4) the linkages between the others' research and the assessment activities are tenuous at best.

There is also a perception that the present method of doing resource estimations is the only "accepted" way to produce quantified assessments, and that the methodology is being forced onto some unwilling members of the scientific staff.

In addition, OMR may not be facing up to its assessment needs realistically in this time of reduced funds and staff. In particular, although almost everyone accepts the ideas that the Office needs more economic geologists and that assessments are

A.3.12 ORGANIZATIONAL ATTITUDE, MANAGERIAL SUPPORT, AND PERCEPTIONS--CONTINUED

Comments--continued

best done with the full involvement of such geologists, not enough of the staff are actively working to improve their mineral-deposits knowledge and abilities, and management has yet to emphasize training to provide needed mineral-deposit expertise (see A.3.2.4 and A.3.2.5).

Recommendations:

1) Both the inequities and the perception of inequities in the OMR system should be eliminated. This can be accomplished by proper recognition and rewards given to those involved in mineral-resource assessments and in directly supporting research. Showcasing the assessment program and its products to the outside world is one relatively simple type of recognition. An example of such a highlighting effort is the current high visibility British Columbia Province Geological Survey's systematic assessment program for all of the Province (Anonymous, 1993a,b; Kilby and Grunsky, 1994).

The USGS had a large role in the design and plan for that program and it runs with a Mark3 heart; but the Canadians have already given their program visibility well beyond that given to the USGS assessment program.

2) OMR should commit itself to personnel training at several levels: (a) identification of and support for geoscientists who want further (or even new) academic (re-)training in mineral-deposit studies, (b) mandatory short-course training of OMR scientists in the currently used assessment procedures, and (c) one- to two-day mandatory training of entire assessment teams as a prerequisite to estimation. That training should include the alternative, mostly analog approaches, that are appropriate in some estimation situations.

A.3.13 THE REWARD SYSTEM

Issue: Are employees who participate in assessments fairly rewarded for their efforts? Does the system reward excellent performance?

Comments: One common theme throughout the forums was that most OMR scientists do not like to do assessments, although many acknowledge that assessments are a valuable part of our program. Numerous complaints were heard that our reward system (peer-review panels and the Research Grade Evaluation Guide) acts as a disincentive to enthusiastic participation in assessments. Assessment work is not viewed by the panels as being as important as basic research, and it seldom is the basis of a recommendation for promotion. A peer-

A.3.13 THE REWARD SYSTEM

Comments--Continued:

reviewed publication in an outside journal is viewed as a demonstration of "scientific" accomplishment whereas an excellent assessment often is not, even by promotion panels made up of other assessors. These attitudes work to undermine any attempts at programmatic change in the organization.

The committee heard enough to convince us that many of the complaints are valid, and we feel the effect on the assessment program is substantial and deleterious. Related complaints indicate that the whole reward system, particularly as it relates to team efforts, needs attention.

Few assessments deal with such mundane subjects that there are no scientific topics to pursue. The problem for those interested in outside publication is time and official encouragement.

Recommendations: **The existing peer evaluation guidelines and attitudes should be changed to recognize quality assessment work and reward high-quality assessments by judicious use of the awards system to reinforce the idea that assessment is important work**

If peer-evaluation change is desired, then care should be exercised in the appointment of individuals to the panels. In addition, the award system should be considered a tool that the Office can use to raise the prestige and desirability of assessment work. There is a certain degree of cynicism about awards, perhaps because they are used so infrequently. The procedures for various awards have been streamlined recently and, if the Office were to budget a substantial amount of money for awards related to assessment, it could have a significant positive effect. Supervisors should see that opportunities for scientific spin-offs are recognized and supported with modest uncommitted time and, if necessary, funding.

A.3.14 INCREASED SCOPE OF MINERAL-RESOURCE ASSESSMENTS

Issue: Should the scope of assessments be enlarged to include other geological concerns?

Comment: Land managers are greatly concerned about water resources, energy resources, environmental matters, and geologic hazards. These are topics in which we, as earth scientists, have interest and capabilities. Industrial minerals clearly deserve attention in many areas, and, as models are developed, industrial minerals are being added to assessments.

In the USGS, water studies are the prerogative of the Water Resources Division; fossil-fuel expertise is concentrated in the Office of Energy and Marine Geology; and geothermal energy and hazards are studied by the Office of Earthquakes, Volcanoes, and Engineering. However, each of these subjects is of interest to the Office of Mineral Resources because they affect producibility and operating costs of non-fuel mineral deposits, as well as the environmental consequences of mineral production (see section A.3.6.3).

A.3.14 INCREASED SCOPE OF MINERAL-RESOURCE ASSESSMENTS--CONTINUED

Comments--Continued:

Forum participants uniformly supported extension of assessments to these resources, but most expressed reservations about the time, personnel, and other resources needed, as well as about relations with the other Offices and the Water Resources Division.

Recommendation: We support the initiatives of OMR management to participate with other parts of the USGS in comprehensive resource and hazard investigations as integrated packages to meet the needs of clients. OMR should not necessarily try to be the leader, but should concentrate on metallic and industrial minerals and the environmental consequences of their exploration and development. Other topics may be addressed on an *ad hoc* basis, if necessary. As with many other recommendations, additional guidelines, preparation, and training should accompany any broadening of our studies.

A.3.15 ARIZONA REPORT RECOMMENDATIONS REJECTED BY THIS COMMITTEE

The Arizona Report devotes Chapter X to recommendations. These recommendations provided the framework for the discussions at the six forums. Additional recommendations were submitted by individual panel members (Appendix II of the Arizona Report). This section identifies those specific recommendations from both sources that have not been accepted for this present report, and gives a brief explanatory statement. In the preceding sections of this report, most of the recommendations of the Arizona Report have been accepted at least in part, and only those recommendations that have been substantially rejected are listed here.

Either the title and the page number for rejected recommendations from the main part of the Arizona Report or the name of the Panel Member precede each comment.

A.3.15.1 SHORT-RUN RECOMMENDATIONS MADE IN CHAPTER X OF THE ARIZONA REPORT

Replace GIPV [Gross-In-Place-Value] With a Useful Measure of Value (p. 415-416): This recommendation was, in general, accepted, but only conditionally; see the discussion in A.3.6.2. Forum participants agreed with the Arizona committee that GIPV should never be implied to represent societal value.

A.3.15 ARIZONA REPORT RECOMMENDATIONS REJECTED BY THIS COMMITTEE--CONTINUED

A.3.15.1 SHORT-RUN RECOMMENDATIONS MADE IN CHAPTER X OF THE ARIZONA REPORT--CONTINUED

Reporting of Assessments (p. 416-417): The concept of improving reporting was accepted, but not all the specific actions proposed were accepted. The reason is that different approaches may be appropriate for certain assessments.

Consistent Description and Application of Methodology (p. 421-424): This recommendation was for a greater degree of uniformity; consistent description was accepted, but consistent application rejected. That is to say that the process used should be described adequately, but the methodology may vary from the present methods.

Within this recommendation were several subsidiary ones that were essentially rejected *in toto*. They include the concept of centralized responsibility and a select group of assessors; the idea that all tracts have to be delineated with the same procedures; and the idea that regional or economic geologists can always provide an adequate interpretation of geochemical data (p. 388).

Assessment by a Group (Team) (p. 425-426): This recommendation is very specific to how all assessment teams should operate. Some of the suggestions covered items that already are in place, some introduced unnecessary redundancy, and others prescribed overly rigid procedures. One such suggestion was that all individuals' estimates be carried to the point of economically filtered values and that all of those outcomes be presented to the user.

We reject the idea that a single rigid procedure is appropriate for all situations, although it is possible that a given assessment team might choose to operate exactly as recommended. The idea of presenting multiple filtered outcomes engendered a lot of discussion, but was eventually rejected, mainly because detailed analysis of the suggestion indicated that the range in the outcomes that would be represented would be small and the communication difficulties involved would be great. The idea of using the scatter in estimates as a measure of precision and the archiving of the individual estimates has been accepted (see A.3.6.4).

A.3.15.2 LONG-RUN RECOMMENDATIONS MADE IN CHAPTER X OF THE ARIZONA REPORT

Group Assessment Using RCON (Rational Consensus) (p. 429-430): This technique was rejected as costly, cumbersome, and inappropriate for open exchange of information among assessment participants and for effective interaction of diverse personalities ranging from extremely reticent to extremely egotistic.

A.3 ISSUES, COMMENTS, AND RECOMMENDATIONS--CONT.

A.3.15.3 REJECTED RECOMMENDATIONS MADE IN INDIVIDUAL PANEL MEMBERS' REPORTS (APPENDIX II)

Not all members of the Arizona Panel made separate statements; of those that did, the forums and this report generally accepted all of the suggestions by Lawrence D. Meinert, Richard L. Nielsen, John S. Sumner, and Spencer R. Titley.

Recommendations Made by Stuart E. Marsh: Marsh recommended the use of remotely sensed data as part of all assessments, and in his analysis of the Costa Rica, Spotted Owl, and Tongass projects highlighted the non-use and possible utility of such data. Actually, remotely-sensed data were used in several of the 1:250,000-scale assessments that comprise the Tongass study, but Marsh apparently was unaware of that. He also apparently did not know that USGS mineral-assessment programs utilized remote sensing for almost two decades and that the experience showed that remote sensing was not as useful as originally hoped.

Recommendations Made by Donald E. Myers: (1) Myers is concerned that it is uncertain to some that 4,999 runs in Mark3 produces a statistically stable outcome and this should be tested. This test has already been done and the 4,999 runs are judged to produce a stable outcome. (2) "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 number of deposits:" The concept of an exterior, SWAT-type, team approach to the estimation of numbers of deposits received very little support in the forum discussions and this suggestion (which is similar to one in the main Arizona Report) was rejected.

A.3.16 GENERAL COMMENT ON THE ARIZONA REPORT

Issue: Did the Arizona Committee's activity and the Arizona Report fulfill the charge given to that committee?

Comment: Our charge (A.1.1; A.2.1) was to critically examine the contents of the Arizona Report and its recommendations; to obtain reactions to the report and the USGS assessment methodology in the forums and to critically examine that information; and to make recommendations to the Geologic Division for the improvement of USGS methodology. In this section we comment on aspects of the Arizona Report that are not covered elsewhere.

The Arizona Committee report served the important purpose of focusing attention on the USGS method of estimating undiscovered mineral resources. The main part of the report contained much material of value and the appendices prepared by the individual committee members were equally valuable. Nevertheless, we were disappointed in some aspects of the Arizona Committee's activities and report.

According to USGS Solicitation 7881, as quoted on page 4 of the Arizona Report, the purpose of the contract was to: "Provide assistance to the USGS by preparing a report that reviews and analyzes the agency's undiscovered mineral-resource assessment methodology and offer recommendations for future method development and applications. The review should (1) examine the legal and administrative ligations 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

A.3.16 GENERAL COMMENT ON THE ARIZONA REPORT--CONT.

Comment--Continued:

variability of the input data and perceived bias of analytical methods; (4) include a comparison of methods used by USGS with procedures of 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."

Comparison of the points in the above statement with the "Master Table of Contents" and with the actual contents of the Arizona Report suggests that the authors of the report followed their own outline, rather than to respond directly to the charges given them. Point (1) is covered exhaustively, point (2) quite adequately, and the expectation for point (3) was too optimistic; points (4) and (5) are either thinly covered or presented in an almost obscure way. In contrast, the report also contains an abundance of unrequested material; some of it, such as the "Overview of the three-step methodology" is appropriate and pertinent; but much of it repeats information from textbooks that could have been simply referenced. This contributes to a problem in that the sheer volume of verbiage overwhelms potential readers.

In addition, some errors of fact, such as the contention that the Mark3 mineral-resource simulator calculates gross-in-place values (GIPV), persist throughout the report and indicate less-than-careful attention to some important points. Appendix 1, which purports to examine the grounds for the "controversy" (or critical discussion of the methodology), is particularly unfortunate in that it contains errors of fact, is defensive when no defense was needed or appropriate, and it has exacerbated the already somewhat uncomfortable relations between the USGS critics of the methodology and both their colleagues who created and use the method and the authors of the Arizona Report. (See letter by Force and others in section B.2.6)

In anticipation of a wide variety of questions, the Arizona committee was given what may be perceived as a somewhat unusual group of reports and presentations demonstrating the use of the "three-step," or USGS, methodology. The four presentations included one, by R.F. Sanford of Central Mineral Resources Branch, on the Red Cloud-Handies Peak area, Colorado; it was one of the assessments of relatively small Wilderness Study Areas that led to criticism of the methodology. Another presentation, on Costa Rica, by S. D. Ludington of the Branch of Resource Analysis, did not describe a quantified assessment. Another, by D.A. Brew of the Branch of Alaskan Geology, was on the Tongass National Forest, Alaska, and described essentially an amalgam consisting mostly of previous detailed assessments. The fourth presentation, by S.H. Church of the Branch of Geochemistry, was about an assessment for copper-porphyry deposits only in the Pacific Northwest area inhabited by spotted owls. A fifth report, concerning the East Mojave assessment which was one of the assessments that led to criticism of the methodology, was also given to the committee for review, but it was not the subject of a presentation. Some of these assessments were done with Branch of Resource Analysis participation and some were not. The reports and presentations did not focus on the apparent difficulties that had emerged concerning the methodology, or on their causes, but instead gave either a broad sample of types of assessments or a highlight of those without problems. Thus the selection of reports and presentations may have influenced the Arizona committee's perception of how the methodology has actually been applied. We do question, for example, why

A.3.16 GENERAL COMMENT ON THE ARIZONA REPORT--CONT.

Comment--Continued:

the high-visibility ongoing assessment of the State of Nevada was not presented as an example of how the Branch of Resource Analysis itself does an assessment.

A.4.0 CONCLUDING STATEMENT

The recommendations given in this report support what we consider to be the optimum path for future quantified assessment of undiscovered mineral resources by the USGS. A primary lesson learned is that the introduction and use of any new and potentially controversial methodology must be accompanied by an effective effort to educate the prospective users about the methodology's foundation, its limitations, and the procedures for its use. Use by an experienced cadre of geoscientists will not automatically ensure the appropriately critical evaluation and implementation of such a methodology by others in the organization. We believe that the six forums did an excellent job in educating and inspiring thoughtful discussion by a large number of people in our organization.

Quantified resource assessment differs in two ways from much of the work we have done in the past. First, it has important and direct societal implications. The controversy over land use in this country is growing, and judgments about the value of mineral resources are an important part of that controversy. Second, although subjective judgment and interpretation are inherent in most geologic studies, an assessment involves assigning a subjective value to things whose character, and even existence, are unknown. This is very different from the description, measurement, and geologic interpretation processes with which we are experienced and feel much more comfortable.

Another primary lesson learned is that, because of our organizational and individual freedom of critical inquiry and investigation, we all need to deal openly, rationally, and immediately with contrary points of view on all topics. We do this every day with scientific questions and do so in a remarkably tolerant and pluralistic manner. We should make sure that this attitude pervades all of our endeavors. We hope that the forums and our committee's efforts are an example of how diverse convictions and agendas can be discussed thoroughly for the betterment of the organization and individuals.

Regarding the future, there are three main points:

- First, the USGS must, in support of all the points made above, act to make assessment of mineral resources and the study of assessment methodologies essential parts of its program. These words have been used for years, but the actual record indicates to us that these activities have been given secondary priorities. If the assessment of mineral resources is our main underlying mission, then all of us need to contribute to that task.
- Second, as with all of our endeavors, we need to be simultaneously pursuing several lines of inquiry into assessment methodologies. This will take significant time and resources.
- Third, we and others have put an enormous amount of time and energy into this report. If our recommendations are not taken seriously, then we all would have been better off "doing science," rather than taking up each others' time and

ending up only feeding the circular file with another ignored document. Implementation of our recommendations will take even more time and resources, and will require a reevaluation of priorities and a schedule of actions.

The unrelenting pressure to do more with less will force a continual reappraisal of Office of Mineral Resources priorities. In this report we have taken the stance that, inasmuch as the Office is already committed to assessment of undiscovered mineral resources, we should find a way to accomplish that task. However, the Survey's scientific stature in mineral resources is based, not only on assessments, but on many years investigations of such topics as district studies, ore-forming processes, and geochemical exploration. Improvement in our ability to do future assessments rests on improvement in basic geologic science. If too many resources are allocated for assessment, we may jeopardize the advancement of Survey geoscience, which is the foundation of the Survey's credibility.

Lastly, we thank the forum participants for their essential contributions to our efforts and B.R. Berger and R.M. Tosdal for their thorough technical reviews.

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A.6.0 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS

This glossary contains most of the terms whose meanings were questioned or discussed in the forums, in communications, or in the preparation of this report. Included also are additional terms that may be used during the assessment process. Some of the definitions are incomplete and should therefore be reviewed before inclusion in a comprehensive assessment glossary. Sources for many of the definitions are indicated by footnotes.

accurate *adj:* **1.** Having no errors; correct. **2.** Deviating only slightly or within acceptable limits from a standard.

analogy *n.:* **2.** A form of logical inference, or instance of it, based on the assumption that if two things are known to be alike in some respects, then they must be alike in other respects.

appraise *tr. v.:* **1.** To evaluate, especially in an official capacity. **2.** To estimate the quality, amount, and other features of; to judge.

assess *tr.. v.:* **4.** To evaluate, appraise, estimate.

assessment *n.:* Defined here as both the the process of appraisal of resources within some specified region, and the product of that appraisal. Thus assessment refers to the whole process and the product of that process; whereas estimate is used to note step(s) within the assessment process.

assessment tract *n:* Defined here as a portion of the earth's crust and overlying surficial materials that are permissive for the existence of undiscovered mineral deposits of a specific type or types, for which evidence exists that such deposits are likely to be present and discoverable, and for which an estimate of the numbers of undiscovered deposits may be made.

attribute *n.:* Defined for use here as a characteristic or property of a mineral deposit model, or of the deposit itself.

belief *n:* **2.** Mental acceptance or conviction in the truth or actuality of something.

bias *n:* General: A purposeful or accidental distortion of observations, data or calculations in a nonrandom manner[2]. Statistics: The difference between ... average value [that obtained from many repetitions in an investigation] and ... true value of the characteristic is ... the bias (International Encyclopedia of Statistics, Kruskal and Tanur, 1978, The Free Press, New York).

calculate *tr. v.:* **2.** To make an estimate of; evaluate...

client *n. :* **4.** Loosely, a customer[6].

comfort level *n.:* Defined here to identify the mental response of an individual confronted by an assessment situation.

confirmation *n.:* The support with additional information of a prior position[7].

consensus *n.:* 1. Agreement, especially in opinion.

consistency *n.:* Defined here as agreement with other information.

decision process *n. :* Defined here as a sequence of logical steps leading through relatively simple intermediate decisions to a final conclusion.

demonstrated *adj. :* A collective term, used as a modifier, for the sum of measured plus indicated reserves or resources[3].

deposit *n.:* Earth material of any type...that has accumulated by some natural process or agent[2]; see also "mineral deposit" and "ore deposit".

deposit density *n.:* Used here to refer as the number of mineral deposits (usually of a single type) per unit area.

A.6 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS--CONTINUED

deposit type *n.*, Defined here as a class representing all the recognized mineral deposits that are defined by physical and genetic factors that can be consistently differentiated from those of other classes or deposit types.

discoverable deposit *n.:* Defined here as an undiscovered mineral deposit that could be found using conventional and available mineral-exploration techniques.

documentation *n.:* Defined here as the presentation of all information.

economic *adj.:* Of, or pertaining to, the production, development, and management of material wealth[1]. Applied in the context of this report to identify those mineral deposits that may yield a profit as a result of mining.

economic potential *n.:* Defined here as a quality of a mineral deposit (or other entity) that a reasonable person would interpret to indicate that the eventual income from exploitation would outweigh the costs of discovery, development, and production enough to make investment worthwhile.

elicit, *tr. v.:* Defined here as the obtaining, from an assessor, an estimate of the number of undiscovered deposits in a given tract.

elicitation *n.:* Defined here as the act of eliciting.

endowment *n.:* Defined here with respect to mineral resources as the sum of all mineralized material that is accessible, regardless of economic concerns.

enumerate *tr. v:* To determine the number of; to count[1].

estimate *tr. v.:* **1.** To make a judgement as to the likely or approximate cost, quantity, or extent of; calculate approximately. **2.** To form a tentative opinion about; evaluate[1]. Here estimate and estimation are used to refer to some substeps in an assessment.

evaluate *tr. v.:* **1.** To ascertain or fix the value or worth of... **2.** To examine and judge; appraise; estimate[1].

exhaustive *adj:* Defined here as a modifier for "exploration" where it refers to exploration so intensive that any untested ground would fall under the definition of an extension to known deposit rather than as "undiscovered". An example might be the immediate vicinity of the Viburnum Trend lead deposits of Missouri.

extension [ore] *n.:* Defined here as part of and physically associated with a known mineral deposit, but outside of the identified parts. "Undiscovered hypothetical resources" in the sense of the USGS-USBM classification[3].

favorable area *n. :* Defined here as that portion of a permissive area for which a quantified assessment of undiscovered mineral deposits may be made. See also "assessment tract".

fragile *adj.:* Defined here to describe an estimate the outcome of which is strongly subject to the uncertain aspects of conditions or data used to make the estimate.

guess *tr. v.:* **a.** To predict (a result or event) without sufficient information. **b.** To assume, presume, or assert (a fact) without sufficient information[1].

guideline *n.:* Defined here as a statement of policy or procedure.

habitat *n :* **1.** The region where a plant or animal naturally grows or lives; native environment. **2.** the place where a person or thing is ordinarily found[1]. [This term has been foreign to descriptions of mineral deposits (but has been used for oil and gas); however, as land planners with backgrounds in the biological sciences attempt to use mineral-resource information, they in some cases view mineral-resource-assessment tracts as the "habitat" of mineral deposits and actually use the word in that sense.]

A.6 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS--CONTINUED

heuristic *adj.:* 1. Helping to discover or learn; guiding or furthering investigation[1].

hypothetical resources *n.*: Undiscovered resources that may be reasonably expected to exist in a known mining district under known geologic conditions.

identified resources *n.:* Specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence[3].

indicated [identified/demonstrated] *adj.:* Reserves or resources for which the tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence[3].

inferred [identified] *adj.*: Reserves or resources for which quantitative estimates are based largely on broad knowledge of the geologic characteristics of the deposit and for which there are few, if any, samples or measurements[3].

internal analogy *n.:* Defined here as analogy applied from one area to another within the tract and having the same geologic setting.

judge *tr.v. :* **2.** To determine authoritatively, after deliberation, especially: **a.** To decide... **b.** To appraise discriminatingly, as an expert[1].

Mark3 *n.:* The name of the simulator used by the USGS to combine grade distributions, tonnage distributions, and probability-of-occurrence distributions via a Monte Carlo procedure to produce an estimate of total metal content.

McKelvey diagram *n.:* A graphical classification of mineral resources according to economic viability and certainty of existence.

mean *n.:* The average; the sum of the values of all entries divided by the number of entries.

measured [identified/demonstrated] *adj.*: Reserves or resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling[3].

median *n.:* The value of the 50th percentile.

metallogenic belt (also metallogenic province) *n.:* A geographic region or geologic terrane characteristic of, or containing, a group of related mineral deposits or occurrences.

MILS *n:* Acronym for the Mineral Industry Locator System designed and maintained by the U.S. Bureau of Mines.

mineral deposit *n.*, 1. A mass of naturally occurring mineral material, e.g., metal ores or nonmetallic minerals, usually of economic value, without regard to mode of origin[2]; **2.** a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential[4]; **3.** defined here also as that accumulation of associated mineralized bodies that constitute a single mineralizing event, including subsequent processes (e.g., oxidation and supergene enrichment) affecting part or all of the accumulation.

mineral deposit model *n.:* A systematic arrangement of information describing the essential attributes of a class of mineral deposits.

mineral occurrence *n.:* A concentration of a mineral...that is considered valuable by someone somewhere, or that is of scientific or technical interest[4].

A.6 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS--CONTINUED

model *n.:* Used here following the definition of Cox and others (1986) for a unifying concept that explains or describes a complex phenomenon.

model *tr. v.:* To create or modify a model (of a mineral deposit or a process involving mineral deposits).

Monte Carlo *adj.:* A statistical simulation strategy wherein numerous samples are chosen at random from two or more probability distribution arrays and combined to yield a probabilistic cumulative distribution.

MRDS *n.:* Acronym for Mineral Resource Data System designed and maintained by the U.S. Geological Survey.

negligible (as a modifier for mineral resources of a tract) *adj.:* having less than a 1 in 100,000 to 1 in 1,000,000 chance of the existence of at least one mineral deposit of a specific type of the size and grade as those recorded in the tonnage and grade models for that type[5].

numerical *adj.:* Expressed in, or dealing with, numbers.

ore *n.:* The naturally occurring material from which a mineral or minerals of economic value can be extracted at a profit. In nationalized economies and integrated industries, the definition may not apply to an individual mineral deposit, but instead to an entire national economy or corporation. (See also "economic".)

permissive *adj.:* Defined here as a term identifying a portion of the earth's crust and the accompanying surficial materials as having the geologic and other characteristics that are essentially like those of other places known to contain a specific type of mineral deposit.

permissive tract *n.:* Areas delineated or "...based on geologic criteria derived from deposit models..." and their "...boundaries are defined such that the probability of deposits of the type delineated occurring outside the boundary is negligible, that is, less than 1 in 100,000 to 1,000,000...."[5].

preassessment *n.:* Defined here as the process or result of identification of the state and sources of existing knowledge and human and institutional resources available to investigate an area under consideration for mineral resource assessment.

precision *n.:* Defined here as the degree of agreement between repetitive estimates.

predict *tr. v.:* To state, tell about, or make known in advance, especially on the basis of special knowledge[1].

predictive value *n. :* Introduced here as a working proxy for the term "accuracy" which, in the absence of exhaustive exploration, is impossible to evaluate rigorously.

quantified *adj.:* Expressed in numbers.

quantify *tr. v.:* To determine or express the quantity of...[1].

quantitative *adj.*: **1.a.** Expressed or capable of expression as a quantity. **b**. Of, pertaining to, or susceptible of measurement. c. Of or pertaining to number or quantity[1].

quantity *n.:* **1a.** Number or amount of anything, either specified or indefinite. **b**. A sufficient or considerable amount or number:.. c. The exact amount of anything. **2.** The measurable, countable, or comparable property or aspect of a thing[1].

random *adj.:* b. Statistics[1]: Used here in the sense that the outcome of successive events is independent of preceding events.

A.6 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS--CONTINUED

recreational mining *n.:* Here defined as mining as an avocation rather than as a business.

reserve *n.:* That portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at thetime ot the determination. The term ore is used for reserves for some minerals[3].

resource *n.:* A concentration of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible[3].

robust *adj.:* Here used to describe an estimate that is relatively insensitive to the conditions or data used to make the estimate.

speculative resources *n.:* Undiscovered resources that may occur either in known types of deposits in a favorable geologic setting where no discoveries have been made, or in as yet unknown types of deposits that remain to be recognized[1].

stochastic *adj.:* **1.** Of, denoting, or characterized by conjecture; conjectural. **2.** Statistics: random[1].

strength of belief *n,:* Defined here as the measure of mental acceptance or conviction in the truth or actuality of something.

sufficient *adj.:* As much as is needed; enough, adequate;...[1].

suggest *tr. v.:* To offer for consideration or action; propose...[1].

surmise *tr. v. :* To infer (something) without sufficiently conclusive evidence...[1].

target counting *n.*: Defined here to identify a procedure for estimating the numbers of potential deposits involving enumeration of mineral occurrences and/or geologically, geochemically or geophysically sensed indications of such occurrences.

three-part method *n. :* Defined by Singer (1993) to refer to a procedure in which: 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 using grade and tonnage models; and 3. the number of undiscovered deposits of each type is estimated under the condition that they conform the the grade and tonnage population represented by the models.

three-step method *n.:* See three-part method; the "-step" term is poor because the three parts are not necessarily used successively.

tract *n.:* Defined here an as area defined, usually on geologic grounds, for the purposes of mineral-resource assessment.

unannounced deposit *n.:* Defined for use here to describe a discovery that has not been announced in a publicly available medium.

unconventional mineral deposit *n.:* A mineral deposit of such unusual grade, mineralogy, or geologic setting that experienced mining personnel would not consider it to be similar to any known deposit type.

undiscovered resources *n.:* Unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory[3].

A.6 GLOSSARY OF COMMON TERMS USED IN MINERAL-RESOURCE ASSESSMENTS--CONTINUED

unreported deposit *n.:* Defined here as a mineral deposit whose character is known to a limited.group, but not generally known to the public at large.
validate *v.:* Defined for this report as consistency with other information.
verify *v.:r.:* To prove true.
well explored *adj.:* Defined here to describe a deposit that has been so intensively explored that no significant additional material with current economic potential remains undiscovered.

Sources of the definitions indicated above:

1 The American Heritage Dictionary of the English Language, Ninth Printing, 1971, *et seq.*
2 The Glossary of Geology, Third Edition, 1987.
3 U.S.G.S. Bulletin 1450-A, 1976, p.A3-4; or Circular 831, 1980, 5 p.
4 U.S.G.S. Bulletin 1693, p. 1., 1986.
5 Singer, 1993, Nonrenewable Resources, v. 2, n. 2, p. 73.
6 Webster's New World Dictionary of the English Language, College Edition, 1966.

A.7.0 **INDEX**

Section numbers, rather than page numbers, are listed below. A "+" is appended to section numbers to indicate that all subsections contain discussions of the same subject.

Subject--Continued | **Section Number**

Subject--Continued **Section Number**

Subject--Continued **Section Number**

A.7.0 INDEX--CONTINUED

Subject--Continued **Section Number**

PART B: WRITTEN CONTRIBUTIONS TO THE FORUM COMMITTEE

B.1.0 INTRODUCTION

Written contributions on the assessment of undiscovered mineral resources were solicited and accepted until February 1994; this was done to maximize the participation of all individuals in the preparation of this report and to insure that dissenting opinions were represented. Final drafts were accepted until late April 1994, following editorial exchange with the chairperson. The only constraints given concerned length and a limitation to scientific and policy topics; because of this, the contributions range beyond the specific charge to the forum committee.

The fourteen written contributions thus received are reproduced in section B.2, with section identifiers added at the bottom of each page.

The opinions and suggestions are those of the individual authors, and not necessarily those of the forum committee or of the Geological Survey.

B.2.0 WRITTEN CONTRIBUTIONS

These are sections B.2.1 through B.2.14 on the following pages.

From: Dave Campbell and Bob Jachens, Branch of Geophysics

Subject: Use of geophysics in the quantitative assessment of undiscovered mineral deposits

The Harris Commission concluded that geophysics was not being used adequately or effectively in many quantitative mineral resource assessments and that the assessments were suffering as a result (executive summary, p. 13 and p. 14; appendices by Sumner, Titley, and Marsh). We strongly agree with those conclusions, especially in light of the fact that OMR assessments now specifically include all deposits down to a predetermined depth (commonly 1 km) and that many areas being assessed contain substantial tracts covered by surficial deposits, ice, water, or tundra. Properly used, geophysics can significantly reduce the uncertainties in the final assessment numbers. Conversely, lack of adequate geophysical input to the assessments may well result in estimates that are unnecessarily flawed. We offer the following suggestions for ways to improve the contributions that geophysics can make in quantitative mineral resource assessments.

Data Acquisition

The Commission correctly points out that geophysical data used by the USGS in quantitative assessments lags far behind industry standard (Sumner appendix). They specifically indicate that electromagnetic data are not being acquired at all (Sumner); that remote sensing data have not been used at all in many assessments (Marsh); and that aeromagnetic data typically lack the density and/or quality that are routinely used in the exploration industry (Sumner). At present many study areas have no data or data that are so inadequate as to be effectively useless in assessments of any sort. We assert that geophysical data are useful everywhere, and are altogether necessary to assess study areas with any significant cover. We believe adequate aeromagnetic and other geophysical data could be obtained for these areas in ways that are within the financial constraints of current and future budgets. Three such ways are as follows:

1) Systematically acquire new airborne surveys—
We propose that the Office of Mineral Resources commit a fixed amount of funding (of the order of $100K) each year for the acquisition of new airborne geophysical data. A cross-Office committee could decide priorities for acquisition based on areas anticipated to require future assessments. Such a program would not only yield the benefits of a systematic approach to filling in coverage, but would provide a predictable and dependably source of survey funds that could be used to leverage other money from other USGS programs with common areal interest (NGM, NHERP, Sed Basins, DCS, etc.)

2) Begin a systematic effort to obtain industry data—
With the troubles in the domestic mining industry and the virtual collapse of the domestic petroleum industry, many formerly proprietary

airborne surveys probably can be acquired by the USGS free or for a nominal cost far below that required to conduct new surveys. This effort should begin immediately and be pursued vigorously because many of these surveys will soon be lost forever as a result of industry upheaval and layoffs. For example, the Branch of Geophysics recently acquired, free of charge from Shell Oil Company, an aeromagnetic survey of the entire southern California Continental Borderland from Point Conception to the Mexican border ($3-400K at today's prices). We were able to acquire this survey simply with an official request, but only after spending more than 6 months to convince Shell that they really had such a survey somewhere in their files. There was no one left in the appropriate Shell divisions who had any knowledge of its existence.

3) Begin a systematic effort to obtain public domain remote sensing data— There are many noncopyrighted, nonproprietary satellite and airborne remote sensing data sets covering the U.S., and some can be acquired at little or no cost. For instance, many Agencies acquired particular TM scenes before they got privatized, and data sets for these scenes can be freely interchanged between Agencies. BGP maintains an informal index of such data that have come to our attention. Similarly, data for TM scenes over 10 years old now cost only a few hundred dollars, as contrasted with $4600 for the newer ones. OMR could begin a systematic (budgeted) effort to acquire such cheap scenes. (It is not clear why OMR should pay for the scenes at all, since USGS already "owns" them, according to the Land Remote Sensing Policy Act of 1992, which places them under the custody of USGS-NMD-Sioux Falls EROS Data Center. It might be worthwhile for OMR to check the wording of the Act to investigate the rationale and legality for such interDivisional charges).

The potential dividends from such efforts could be enormous for assessment studies and for earth science in general. However, it will not happen without a commitment from OMR.

Data Preparation

Certain map products derivable from existing geophysical data have proved useful in quantitative mineral resource assessments. Examples include maps of remote-sense alteration haloes; maps of depth to pre-Tertiary basement (or some other lithologic boundary); maps showing locations, numbers and types of concealed plutons; merged and rationalized 1000 ft drape aeromagnetic maps; pseudogravity maps; and aeroradiometric maps. The time-frames of quantitative assessments, however, are too short to permit these products to be generated routinely in time to contribute to the assessments process. Therefore we recommend a systematic effort to produce these types of data bases for areas where quantitative assessments are anticipated or likely. Some specific suggestions are:

1) complete merging of existing aeromagnetic data from the U.S. Cordillera and all of Alaska, into equivalent 1000 ft drape aeromagnetic data

bases. Once those data are in hand, derivative maps can be produced relatively rapidly, usually within the time frames of quantitative mineral resource assessments.

2) generate data bases containing a suite of standardized maps:
   depth-to-basement
   depth to Tv in western US
   depth to pre-T in rest of western US
   depth to basement in tundra, ice, glacial deposit, sediment, and water covered areas of Alaska

3) complete aeroradiometric data base for U.S., including Alaska

4) push to get modern geophysical survey coverage of the Nation, flown to modern specifications under a multi-Agency consortium. Upgrade survey specifications to industry standards—closer line spacing, especially—for any new USGS surveys. (The Getchell survey, done not for NAMRAP but for research ends, is an example of such a modern survey).

5) continue to support the concept of teams of regional experts. Make sure all teams include both potential fields and remote sensing geophysicists who can be activated on short notice to interpret the prepared geophysical data bases in terms of the structure, lithology, and tectonic history of an area, especially the uppermost 1 km (preferably the regional experts would have been intimately involved in the preparation of those data bases). Initiate actions to assure such members are well trained in the assessment process. This course of action is explicitly recommended by Commission member Lawrence D. Meinert (p. 9 of his Appendix section).

6) provide adequate lead time (at least 6 months) to remote sensing investigators to search for possible public domain remote sensing data sets in anticipation of new mineral resource assessment efforts.

Assessment Technique Research

In select situations, specific geophysical data bases can be used to tailor global grade-tonnage models to local conditions. For example, aeromagnetic surveys can be used to set an upper limit on the size of magnetite deposits within an area, thus possibly truncating the global grade-tonnage model to satisfy local conditions. Such truncation can significantly constrain the magnitude of the estimate of undiscovered resources. Other resource estimates might be similarly constrained by geophysical data bases, such as igneous-related deposits by maps showing numbers and areal extent of magnetic plutons, massive sulfides by airborne electromagnetic surveys, or porphyry copper deposits by ground IP surveys. Specific procedures need to be developed that can be applied uniformly in all quantitative mineral resource assessments. Some recommendations are:

1) expand and complete the formalism of the search-efficiency determinations for aeromagnetic surveys and magnetite deposits (Jachens memo, attached).

2) continue the efforts started in the "geophysical signatures" report (Hoover and others, 1992, OF92-557) so as to generate tables that determine how efficiently and completely a given volume has been searched by specific types of survey:

a) relate survey type to deposit type, since efficiency depends on both. Examples: aeromagnetics and intrusion-related deposits; electromagnetic surveys and deposits of massive conductors; IP for disseminated sulfides; aeroradiometric data, gravity, etc. for other specific deposits.
b) include a range of flightline heights and separations, sensitivities of detecting instruments, and general noise levels in the survey area.
c) include magnitude and extent of geophysical signatures associated with deposits of specific sizes, so as to know how close you can "miss" a specific size deposit but still detect the skirts of its anomaly.

(This would be most useful if we were able to obtain appropriate industry data, but could also be useful if we only knew what surveys industry had conducted and what the survey specifications were, even if we never saw the actual data).

3) explore possibility that other deposit type and search method pairs might be amenable to this type of procedure. For example, knowledge of the size of geochemically detectable haloes around some deposit types, coupled with geochemical survey data of some known quality and density, might be sufficient to make quantitative statements about the size and number of deposits that could have been missed by such a survey. Given the tenuous information that is sometimes used in quantitative assessments, even weak constraints could be a significant gain.

7/13/92

MEMO

To: West Mojave Assessment Team

From: Bob Jachens

Subject: Fe Skarn Search

Since I spent so much time ragging on everyone about not being quantitative in the quantitative mineral resource assessment of the Desert Tortoise Habitat area, I started feeling guilty that I had not been as quantitative as I should. Therefore, I did some modeling last week that carries the estimate at least some distance toward being an actual quantitative estimate. It still has some distance to go as you will see, but here's what I did.

A. Modeling
I took the median grade for Fe Skarns from the model book, converted this to magnetite content, then to magnetic susceptibility. Assuming a compact geometry (in my case it was a cube), I calculated the magnetic anomaly for various sized deposits (3, 7.2, 20, 60, 110 mtonnes) at various depths (exposed at surface, top at .15 km, .3km, and .6km).

B. Search Efficiency
I then examined the various aeromagnetic survey specifications that we have to deal with in the West Mojave assessment (1000' drape- 0.5 mi spacing; 1000' drape-1 mi spacing; 400'drape-3 mi spacing), assumed a cutoff anomaly amplitude based on the actual magnetic map below which I felt I could not distinguish a skarn anomaly from the general background noise, and determined the percentage of a given volume (above 1 km) that a given survey searched successfully for a given size deposit. For example, assuming a survey at 1000' drape, 0.5 mi line spacing, and a 200 nT anomaly cutoff, 60% of the top 1 km was searched successfully for 20 mtonne deposits (I would find every one of them in 60% of this volume).

The results are as follows:
1) 1000' drape-0.5 mi spacing
  a) 200 nT cutoff

110	mtonnes	100%
60	mtonnes	100%
20	mtonnes	60%
7.2	mtonnes	22%
3	mtonnes	8%

  b) 300 nT cutoff

110	mtonnes	100%
60	mtonnes	100%
20	mtonnes	40%
7.2	mtonnes	13%

2) 1000' drape-1 mi spacing
  a) 200 nT cutoff

110	mtonnes	90%
60	mtonnes	70%
20	mtonnes	30%
7.2	mtonnes	11%

  b) 300 nT cutoff

110	mtonnes	75%
60	mtonnes	60%
20	mtonnes	20%
7.2	mtonnes	7%

3) 400' drape-3 mi spacing

B.2.1 attachment

a) 200 nT cutoff

110	mtonnes	30%
60	mtonnes	25%
20	mtonnes	12%
7.2	mtonnes	5%
3	mtonnes	1.5%

b) 300 nT cutoff

110	mtonnes	25%
60	mtonnes	22%
20	mtonnes	8%
7.2	mtonnes	2.5%
3	mtonnes	1%

C) Actual Search

For the entire area I found only 1 probable Fe skarn--about 3 mtonnes. Interestingly, this one was found by both the 1000′ drape-0.5 mi survey and the 400′ drape-3 mi survey.

According to Don Singer, finding one 3 mtonne deposit when 8% of the volume was successfully searched for this size deposit leads to an expected 11 similar deposits in the remaining 92% of the volume (based on a binomial distribution). Unfortunately, he doesn't yet know how to convert the null results (no deposits found in certain percentage volume) into expected numbers of undiscovered deposits. However, he's working on it.

Meanwhile, assuming a random, uniform distribution of skarns, we can compute the probability that we would get the null result assuming a given number of deposits actually exist in the total volume. For example, for 20 mtonne deposits and a search efficiency of 60% (1000′ drape-0.5 mi spacing), if there were 3 deposits in the total volume, the probability is 0.06 that we would find none of them (which is what we found). This doesn't translate directly into numbers of undiscovered deposits, but it may help. I've got some of these types of probabilities computed.

This is where I am. Where do we go from here?

PS--This same type of reasoning could apply no matter how we determine the successful search volume. For example, if we can say that all porphyry copper deposits exposed in areas not covered by Q would have been discovered by now and that the systems are large enough in size (characteristic dimension of about 3 km) that any one in the top 1 km would be exposed, then the successful search volume would be the outcrop area (plus a 3 km wide buffer around all outcrops) times 1 km. The rest would follow as above.

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

In Reply Refer To:
Mail Stop 954

April 7, 1994

From: Sandra Clark
Subject: Comments on the National Mineral Resource Assessment

The process of assessing the nation's mineral resources has been the source of concern and discussion about the validity of the three-part method and the reliability of the estimates. I think the concerns are appropriate and hope that the discussion will clarify and improve the process. My experience with the application of the method is that the iterative process allows numerous opportunities for interaction between the geologic observations and quantitative estimates; this allows for identification and correction of errors, misunderstandings, or unrealistic results. The basis for identifying permissive tracts, discussions of how well models fit, and doubts or uncertainties are addressed in the text. This information will allow a reader to evaluate the reliability of the estimates and provide a basis for improving future estimates.

The pieces that are needed for the assessment have been assembled over the last 20 years. The existence of a well-described assessment method combined with more than a century of geologic and mineral resource studies have led us to a stage where a quantitative assessment of the nation's mineral resources is possible. I believe that the Office of Mineral Resources would be remiss in its obligation to the public if the method and expertise were not used to make a national assessment. The data may not be complete; the process may not be perfect; but waiting until all data are available and the process is perfected is not feasible. I believe that doing the assessment is the best way to identify gaps in knowledge and improve the process. Another by-product will be ideas generated during the assessment meetings and in evaluating Mark3. When preconceived ideas do not match estimates of undiscovered deposits, the result can be development of new ideas or new models. An additional benefit from the process is that increased communication and generation of new ideas are facilitated by the interdisciplinary teamwork required by the assessment process. As with much scientific research, it is possible that by-products may be at least as important as the identified goal.

A major concern is potential misuse of the results. Even though doubts and uncertainties are adequately explained, there is no way to prevent data being quoted out of context to serve specific political or economic interests, and our credibility may suffer as a result. This concern is certainly valid, but there is never assurance that any scientific data and interpretations will be understood or used as intended; the risk is less if the topic is of interest to only specialists who fully understand the inherent level of certainty. Similarly, our credibility should not be affected with people who understand the assessment process and the level of uncertainty inherent in estimates of undiscovered mineral resources. However, if we are to address topics of national need in terms that can be understood by non-scientists, we run the risk of misinterpretation, and the misuse of the results. In this context, I recall hearing about Albert Einstein's distress about the application of his theory of relativity to produce weapons capable of mass destruction and realize that it is impossible to anticipate or control the use of scientific work. However, I believe that our responsibility is limited to presenting the material as clearly and accurately as possible with explanations of interpretations, assumptions, doubts, and uncertainties. Thus, responsibility for misinterpretation or misuse of the results belongs to the user.

MEMORANDUM

Date: 15 April 1994 (modified from 12/13/93 communication)

To: Barton Panel

From: Clay M. Conway, Western Mineral Resources, Flagstaff, AZ Clay M. Conway

Subject: Improvement of USGS Mineral Resource Assessments

I endorse the concept of resource assessment, including attempts to estimate the amounts of undiscovered resources, at all scales. It appears this has become the Survey's business so we should all work together to get better at it. Implementation of many of the recommendations in the Harris report will help. In the following paragraphs I emphasize several improvements I consider to be essential; they are discussed largely in the context of broad assessments, with the current national two-year assessment for Au, Ag, Cu, Zn, and Pb as an example.

It seems to me that by far the weakest link in the assessment process is the estimation of numbers of undiscovered ore deposits. Some methodologies have been developed for estimations, but too often the estimates are made only from the collective hunches of assessment teams.

I attended a meeting for the two-year assessment estimations for Arizona; at the meeting were the Arizona team (BWMR staff from Tucson), BORA and BWMR experts from Menlo Park, and a few of us called in as consultants. For each ore deposit type a "vote" (the term that was used at the meeting) was taken on the number of undiscovered deposits. The voting was preceded by discussion of the known ore deposits, permissive terranes, etc., but no method was developed to make the estimates. The votes were simply the best guesses of each person willing to vote. [I declined to vote, even on the Proterozoic massive sulfide deposits, the deposit type most familiar to me. I said I would be willing to make an estimate, but only after developing a systematic methodology.] Thus the first and major problem in estimating is this woefully inadequate "voting" method.

This leads to the next problem in estimating - that the estimators are often not the best qualified people available. Often the geologists who best know metallogenic terranes and their ore deposits are not doing the estimating. This may result from assessment by culturally/politically defined regions rather than by geologic or metallogenic terrane, and by failure of managers to carefully and objectively assess personnel qualifications as teams are constituted.

A few suggestions to remedy these problems:

First, we should simply do away with voting (off-the-cuff guessing) and spend the time, effort, and money to develop sound methods of estimation for each of the deposit types. Certainly no major "quantitative," assessment, such as the two-year assessment now nearly completed, should be based on ore deposit numbers determined by voting.

Second, those with expertise in the metallogeny of a region under consideration should be the ones not only to define and evaluate the permissive terranes but also to make the estimates of undiscovered ore deposits. Estimates of numbers of deposits should be primarily in the hands of these regional experts and estimates of value should be primarily in the hands of BORA.

Third, resource assessments should, when possible, be done by metallogenic terrane and by ore deposit types indigenous to the terrane. This may not be practical for small areas such as wilderness study areas, but it is certainly possible for the current national assessment, and would also be possible for many assessments at intermediate scales. The current approach for the two-year assessment, by states or groups of states, should be abandoned. Why use state boundaries, which have nothing at all to do with the geology or distribution of ore deposits? Such an approach also leads to the formation of teams with uneven and limited expertise.

The following is an example of the application of these remedies. Proterozoic massive sulfide deposits in the southwestern United States lie largely in Colorado, New Mexico, and Arizona. Numbers of undiscovered massive sulfide deposits were recently made for the national assessment by three teams, one for each of these three states. Team members with oversight for the massive sulfide deposits, in come cases, had little prior experience with the terranes containing these deposits. Ideally, a single team should be assembled to compile all data on these deposits, to define permissive terranes, and to estimate numbers of undiscovered deposits for the entire Southwest. Members of this team should be those in the Survey (regardless of Branch), and perhaps some outside the Survey, with the most experience on the metallogeny of massive sulfide deposits in the Southwest. This team would develop a systematic method for the estimation of undiscovered ore deposits. Finally, the team would cooperate with BORA in assessment of value. If necessary, final assessment figures could readily be recast to give assessments by state, or whatever, just by areal proportions, with adjustments for other factors.

From my admittedly limited perspective, it seems we may be headed for trouble using the numbers of ore deposits estimated by the national two-year assessment teams. Thus, using the big computer with the fancy MARK3 program seems silly. The old expression, "garbage in, garbage out." may be particularly apt in this situation. Just as well eyeball a distribution of the number of deposits estimated onto the grade and tonnage curves, then eyeball the grades and tonnages from the plots and add them up by hand; and then realize the error is enormous and impossible to determine, but just as meaningful as the product of a MARK3 run.

Finally, a comment on the philosophy and general direction of OMR work as it pertains to mineral resource assessment: In the past few decades, OMR has shifted emphasis to mineral resource assessment and to development of ore deposit models, but has failed to make what should have been a parallel shift in emphasis to metallogenic studies (regional ore controls). Our mineral resource assessments have been strengthened by the development and application of grade and tonnage models, but they have been weakened, often in disastrous proportion, by failure to develop metallogenic expertise and metallogenic models. Good metallogeny is an essential basis to making any reasonable estimate of numbers of undiscovered ore deposits. Estimates of numbers of ore deposits have sometimes been made on the flimsiest understandings of regional controls, characteristics, and distributions of ore deposits (sometimes because metallogenic expertise does not exist and sometimes because those with expertise were not called upon). The same regional expertise that forms the basis for estimation of numbers of undiscovered ore deposits, can be important to other applications, such as regional assessment of environmental concerns related to mining and mineral deposits.

Memorandum October 15, 1993
From: Leslie Cox, Geologist, OMR, WMR, TFO
To: Barton Panel
Subject: Guidelines for mineral resource assessments

There are several different **reasons** to do mineral assessments, four of those are:

-to further develop a known occurrence
-to judge a property or region's potentiality for containing new deposits
-to conduct a national inventory
-to conduct an international inventory

My study of OFR 93-258 and related materials leads me to believe that once the reason to do an assessment is established, the **objective** must be clarified. Two different assessment objectives (among several) might be:
-to facilitate land-use decisions
-to determine long term resource adequacy

Once the objective is clarified, there is more than one **method** the assessors can utilize. The method is in part constained and determined by the unique situation. Two very different, but not the only, methods include:

-getting a subjective probability distribution that approximates the distribution of objective probabilities (Harris and others, 1993, p. 373)
-obtaining a judgement (qualitative favorability)

I would like the panel to consider the possibility of recommending that OMR management first clearly state the reason for doing the assessment and secondly clearly state the objective so that the appropriate method(s) can be pursued by the appropriate assessment team.

In Reply Refer to:
Mail Stop 954

April 11, 1994

Memorandum

To: Paul Barton

From: Michael P. Foose

Subject: Recommendation for the Barton Committee

These comments were initially prepared for the Barton Committee in October of 1993. This revision has been made in an attempt to clarify some ambiguities.

I believe that the Arizona Report was very effective both in objectively reviewing OMR's mineral assessment activities as well as identifying areas where OMR could improve its assessment process. I would like to highlight one of that report's recommendations and suggest that it is one of the most important and straightforward tasks to which OMR should attend.

Critical to the "three step" assessment process are the models on which the assessment is based. I believe that much of OMR's assessment work is being unduly constrained by the limitations of the "Models Book" (USGS Bulletin 1693). This volume represented an outstanding first effort to systematize mineral deposits and it is a body of work of which the USGS should be proud. However, it is dated (nearly 8 years old), is extremely uneven in its coverage of different ore systems, and contains many statements that are now recognized to be incorrect.

Clearly we have learned a great deal since 1693 was put together. Major advances have been made both in understanding ore deposits and in how models should and can be used in making mineral assessments. I am positive that the contributors and authors of 1693 never envisioned this publication to be the definitive work used in making quantitative assessments. However, it has largely assumed that role.

The Arizona report recommends that the models which we use in mineral assessment work be reexamined and updated. This, in my opinion is essential. I recommend that such work involve at least three activities:

First, selected experts should annually review the data (particularly grade tonnage data) in models to insure accuracy and completeness. For most of those involved, such work should neither be particularly laborious nor time consuming.

Second, some of OMR's ongoing deposit-specific research should be reoriented towards identifying common features shared by diverse ore systems. The goal here would be to develop a more coherent geologic framework in which to place mineral deposit models. I will comment on this further below.

Third, updated models should be compiled and released. Open-filing in digital form might be the most economical way to insure wide distribution.

I believe the second activity mentioned above is the most exciting and potentially the most beneficial. For this reason, I would like to discuss aspects of it further.

It is, for example, common knowledge that convergent margins maybe associated with copper porphyries, a variety of precious metal epithermal systems, and several different types of skarns. To some degree these share a common magmatic connection. However, this environment may also host podiform chromite deposits, a deposit type of completely different magmatic affinity. If one were to take an even larger view, the topographic uplift and thrust stacking present in some convergent margins drive large ground water circulation systems that may form MVT or Central African-type stratabound copper deposits. The common feature shared by these deposits is, of course, their association with a specific tectonic element (convergent margins). As an organization, I believe we need to more consistently and comprehensively relate mineral deposits to these kinds of larger geologic elements.

I believe such work will produce at least two distinct benefits. First it should enable us to look at larger tracts of land more efficiently. In part this will occur by simply having a better understanding of the mineral endowment that is typical for different types of geologic environments. In part, it will also come by making assessments more complete. Commonly, the assessments process focuses almost entirely on deposit types that are known to be represented in an area; little consideration is generally given to deposit types that are unrepresented but which occur in geologically similar areas in other parts of the world. Consideration of these unrepresented deposits will both insure completeness in the assessment process and also highlight important research questions such as the cause of the real or apparent absence of deposit types.

Second, this type of synthesis work is needed to counter what I perceive to be a trend towards increasingly detailed ore deposit research and model development, a tendency I also believe will ultimately restrict the scientific effectiveness of our overall research effort. Several years ago, a Nobel Laureate in biology commented on steps in scientific research. She identified three stages.

Stage One: Identification of the problem and its components.
Stage Two: Study of the individual components.
Stage Three: Integration of the stage two results and restatement of the problem

She further observed that most research activities become stuck in stage two and forfeit the substantial benefits that come from integrating results and once again looking at the "Big Picture."

Obviously there are individuals in OMR that move through all three stages, but organizationally, I believe we are solidly locked in "Stage Two". A focused effort to look at the geologic attributes which connect or are shared by diverse deposits may be the most suitable vehicle to start integrating our excellent deposit-specific studies and identifying new areas for productive research.

Nov. 2, 1993

Memo
To: Barton-committee members
From: Eric Force, Mark Bultman, Mark Gettings, Fred Fisher
Subject: Appendix 1 of Harris-panel report -- for the record

This memo by the authors of the "Bultman et. al." paper (OF 93-23) is a brief response to Appendix 1 of the Harris-panel report (OF 238), separately authored by DeVerle Harris alone (see footnote, his p. 472). Harris questions our motives in this appendix. The purpose of the memo is to set the record straight while keeping this a side issue in the discussions of the committee.

Harris' appendix is in the form of a discussion on evolution of controversies (over USGS evaluation methods). We can find no charge to the committee that includes this topic. Our statements at the Arizona Conference regarding evolution of the controversy were cursory as a result. Harris greatly enlarged on these comments, sometimes incorrectly, with innuendo added. We regard the extended discussion on this topic by Harris as gratuitous.

Our paper criticized the then-current method and made concrete suggestions for its reform. The Harris-panel report itself is an indication that reform was needed; although its wording is very gentle toward current methodologists, its conclusions are a mandate for extensive change. Of the 15 suggestions listed in our report, 11 are recognizable as recommendations somewhere in the Harris-panel report. So why should Harris bother to question our motives?

Our motives are clearly set out in our memo of Oct. 29, 1991 (enclosed) and in the introduction of our paper. To paraphrase our motive again: In view of the aggressive approach that OMR was taking to mandating implementation of an important but unreviewed evaluation procedure, we thought it high time to raise a little hell over the method's inadequacies -- in print to avoid being ignored. We attempted to keep the matter within the USGS to enable our organization to clean up its own act, but this proved impossible due to OMR foot-dragging (acknowledged on p. 486). We therefore submitted our paper for open-file. In other words, our response was the minimum effective response.

Harris alludes to bias on our part. We evaluated both over- and under-estimation of resources in our report; indeed our table 6 is the first tabulation of factors leading to under-estimation. We do conclude (from our *evidence*, rather than our bias) that over-estimation is more likely.

An example of unwarranted suspicious attitude by Harris is the discussion (p. 467-9) of a "previous version of the manuscript". What manuscript does not have a first draft? How often do the authors circulate it? Then Harris (p. 469-70) attempts to paint our revisions of the manuscript after review as a suspicious act. What manuscript is not revised after review? A better question perhaps is why Harris distributed to panel members three versions of our report. Note that we endured two reviews by each of two "hostile" reviewers in addition to a formal "friendly" review and an extensive review by our branch chief for an *open-file* report, for which a single review would normally suffice. Why did Harris not mention a favorable review?

The review history of our manuscript is actually quite typical of USGS manuscript reviews, except for further OMR f[illegible]t-dragging. The "hostile" reviewers both made several cogent suggestions, to which we responded, and several that we thought were poor. Agreement with a substantial percentage of our points was expressed by both of these reviewers, in spite of the fact that we sought the tough reviews from the opposing camp.

Harris is offended that we point out his apparent conflict of interest. This is understandable, but we pointed the situation out to our branch chief, not to him. How did he get a copy?

Harris accuses us of naivety (and worse) in our discussions of statistics. As we perceive these questions, he preferred to misunderstand our points. We cleared some of these up in the Barton-committee meetings.

Harris' appendix contains additional errors that have the effect of creating suspicion. For example:

1. Contrary to Harris' assertion (p. 470), Charles Thorman did not review our manuscript. Harris may have confused this review with one of the Coronado Forest manuscript, as he does on p. 486.

2. Our claim was not that we were unable to obtain information on OMR methodology (Harris, p. 478), but that this documentation was not made public, as Harris himself quotes on p. 468.

3. Harris quotes our statements in support of favorability measures as evidence of our opposition to quantitative assessment. These concepts are not mutually exclusive, and some of these quotes are actually in the context of using *defined* favorability measures to improve the information base for assessment. We have suggested improvements of this type to the committee.

4. Harris interleaves our statements in improper order (p. 484-488), and then uses resulting apparent inconsistency to question our motives. Our fourth paragraph in this memo gives the proper order of events.

We conclude that Harris engaged in unprofessional behavior in the process of vaguely insinuating bias and hidden agendas on our part. His leading statements and innuendo are out of place in a scientific report; our paper may have been hard-hitting but it did not employ tricks. Possibly Harris' unjust treatment of our paper was a result of his frustration with attacks not from us but from Warren Hamilton. However, given the stringent standards OMR set for our paper, there is an apparent double standard in OMR's inclusion of Appendix 1 in the publically released version of the Harris-panel report.

Now, having said all this, is there reason to think that the appendix compromises the entire Harris-panel report for purposes of USGS planning? Generally not. The document has a great deal to recommend it, especially if recommendations of individual panel members are included. Harris' negative attitude toward our paper is reflected in only a few places in the main report.

We have responded to the Harris-panel report in general with other members of the Tucson staff at Barton-committee forum meetings. The matter of the appendix did not belong in these discussions, and for this reason we have addressed it separately.

MEMORANDUM Date: 7 Dec 1993; revised 5 Apr 94

From: Mark E. Gettings

Subject: Requested memo of the three points I spoke of at the Tucson meeting of the Implementation Committee of the Harris Commission Report, 18-19 Oct 1993

The points I emphasized are summarized below.

1. Inclusion of error and uncertainty analysis for every deposit type of every assessment. I suggest this should be a part of the meeting of the estimators, because the uncertainties vary a great deal from area to area and deposit type to deposit type due to factors such as availability and quality of data, scale of compilation, applicability of the deposit model to the area being estimated, and local production records. Percentiles of the estimated distribution do not contain these uncertainties since these uncertainties cause large variation in the shape and size of the input distributions of number of deposits, grade, and tonnage. Instead, the final estimate should ~~be based on~~ multiple simulations using many shapes and sizes of distributions for number of deposits, grade, and tonnage, each of which reflects some uncertainty limit; that is, a Monte Carlo technique should be employed where each point is a separate simulation using a particular set of distributions for number of deposits, grade, and tonnage. Final results presented reflect the USGS's credibility and must include an uncertainty so that the estimated variability is always unavoidably clear. There is nothing shameful in this because estimating undiscovered mines is a highly uncertain and untestable process; we just need to insure everyone, including Congresspeople and land planners, understands just how uncertain it is. I urge that error (uncertainty, really) bars be included on all graphs (including bar graphs) and plus/minus values (at +/- one standard deviation, for example) be given in all tables.

2. Use multiple methods. The three-step method is not the only way to estimate undiscovered resources. The uncertainties in the method and those inherent in the estimation problem are so large that the actual numbers probably do not mean much. More insight can be gained by comparing and attempting to explain disparities between estimates from several methods. This can include very low level things like using local production for grade-tonnage as well as world-wide (model book grade-tonnage) and trying different distribution shapes (e.g. exponentially decreasing from zero deposits instead of a centrally peaked distribution) in the three-step method all the way to using different estimation proceedures from the three-step method. By analogy, in geophysics, gravity and magnetic anomalies are routinely interpreted by all the kinds of geological models that are consistent with the known geological and geophysical constraints. Then an attempt is made to rank the possible solutions in terms of their likeliehood according to some criteria such as geologic simplicity, similarity to structures known to occur, or minimum number of structural events necessary.

Using only a single estimate of undiscovered resources is like interpreting a local gravity anomaly maximum to be due to a buried compact mass and not admitting other interpretations. This is possible but can be very damaging to the interpreter's credibility when the anomaly turns out to be due a non-uniform mass distribution in a thin sheet at the surface. Finally, the exercise of evaluating multiple models gives one a much better feel for the influence of the various parameters on the results; these data are essential to the uncertainty analysis referred to above.

There are now several other methods for estimating undiscovered mineral resources besides the three step method; some interesting ones are in a class of data-driven and knowledge-driven methods, for example Bayesian weights of evidence models, regression models, fractal and other non-linear models, and fuzzy logic models. An interesting course on this subject is being taught at the University of Ottawa in May and June of 1994. Perhaps someone from USGS ought to take it.

3. Focus on ways to include more geoscience data into the estimation of number of undiscovered deposits. My experience suggests to me that once the permissive terranes are drawn, it is difficult to visualize the actual spatial and temporal proximities of the geologic factors present in all or part of the terrane during estimation of numbers of undiscovered deposits. This and the tendency to generalize in the drawing of terrane boundaries leads to overoptimistic estimates. Quantifying and in some sense contouring favorableness or necessary conditions within a permissive terrane would be one approach which could help. Such material also provides a basis on which to justify the estimate. USGS Open-File report 93-392 reports a quantification scheme using possibility theory from fuzzy logic. In that case, less than 10% of the study area which would be classified as "permissive" actually had a possibility of 0.5 (out of a maximum of 1.0) or larger for the occurence of a deposit as judged by the occurence of 3 necessary conditions in the correct temporal order. Another significant aspect of this kind of approach is that the quantified material (e.g. degree of fracturing, or, presence of felsic intrusives, etc.) is that it can be used in other unrelated studies and thus contributes additional useful derivative products to the geoscience database. Other methods, for example weights of evidence or fuzzy logic models, give objective means of obtaining these estimates and should always be utilized to help provide a reality check on subjective estimates of number of undiscovered deposits.

M. E. [signature]

March 30, 1994

To: The OMR Quantitative Assessment Committee

From: Donald Grybeck, Branch of Alaskan Geology

Subject: Thoughts on Quantitative Assessment and the Anchorage meeting on the subject.

I found your meeting in Anchorage last Fall heartening, even enjoyable. There was much long-needed discussion about operational methods and details and improvement we should implement. I think the reaction here has been uniformly positive. I have considerable confidence in what your report will say even if I've seen enough Survey committees formed to address problems at least as serious that result in no discernible action by management to question what will happen to your recommendations. However, the very way you have chosen to proceed is itself a positive step in unscrambling the issue you're facing. You have established an honest and open dialogue about mineral resource assessment in OMR that has been sadly missing for a long time. In fact, if I had to make a single recommendation today about what needs to be done to unravel our problems with mineral lands assessment, it would be to establish better dialogue among the participants.

As a preamble to expressing my prejudices, I would like to note that whatever else I might subsequently write here and however it might sound, I believe that numbers are here to stay in science--economic geology included; that a numerical expression of mineral resource potential is a goal toward which we in the USGS should be working; and that the BORA 3-step method of quantitative mineral resource assessment is a significant step forward in mineral assessment. At least until something better comes along, the 3-step method should be used when possible in our mineral resource assessment. Where I differ from some who espouse quantitative mineral assessment is that I do not equate mineral resource assessment or even quantitative mineral resource assessment with the BORA 3-step method. It is an useful tool in some areas maybe even many areas but there are other ways to quantify mineral resources. And qualitative or descriptive measures of mineral resource potential are often an exceedingly useful tool in defining the mineral resource potential of an area. Indeed, in most areas I am familiar with, a full statement of the mineral resource potential <u>requires</u> a qualitative or descriptive measure of the area's mineral potential in addition to whatever can be done in quantitative terms, if anything.

We covered a great deal in the committee meeting in Anchorage and I don't think we need to go over all the issues that were discussed nor the Harris Committee report. But several issues in particular struck me and at the risk of repeating myself (again), my comments on these follow.

o One of the fundamental problems in assessment is that we no longer have the resources in funding and scientists to do all that we aspire to do or have promised. As an example of our lack of people, I'll cite BORA. At the Anchorage meeting I again heard that the BORA mineral economists cannot simultaneously: 1) develop new mineral resource assessment science and techniques, 2) train all those in OMR who need to know the appropriate techniques of quantitative assessment, and 3) furnish BORA staff to each mineral land assessment that is underway. I agree, BORA can't do all this; there are too few of them. Similar problems exist in other Branches.

At numerous places in the Harris Committee report, they proposed standards for the number and composition of an assessment team--standards that in one form or another have been espoused for more than a decade within the Survey.

We ought to face reality. In case after case I know of, we've staffed minerals assessments teams with people who were untrained in quantitative mineral resource assessment--as they themselves attest. In numerous teams, there have been critical holes in the team--in some cases there has been no economic geologist--and commonly now BORA is unable to provide anything more than a minerals economist at the final deliberations of the team and often not that. At least partly because we've spread our scientific talent in OMR so widely across the spectrum of geology, we have nothing like the personnel resources in OMR to staff mineral assessment teams with a minimum of experienced scientists let alone form teams with the number and specialties proposed several places in the Harris Committee report.

o Currently I see a lack of attention to detail in the whole quantitative assessment process. There is insufficient attention to systematically documenting methods and terms. There is not only no feedback mechanism from the project-level scientists to improve mineral assessment techniques, there is often a knee-jerk rejection mechanism that comes into play when they have questions or question how terms are being used. Too much of this "oh yes, we've now defined (something or another) without any indication of who has defined what or when or when we can expect more such words from on high. There is too much fuzziness in the time frame we are considering in the discovery process; how we define "economic", for instance in the tonnage-and-grade curves; the depth to which we are predicting undiscovered deposits; the difference between a deposit and an occurrence and even a district; and many other terms and concepts including how our probabilistic numbers fit into the USGS classification of resources. For so central and complex a task, there is too much unsaid, too much in obscure places, too much undocumented, too much that has to be searched for in someone's mind.

o Although it sounds reasonable enough at first glance I find the recommendation of the Harris Committee that we assign an economic value to undiscovered deposits naive and almost uncertainly unworkable, or at least with the staff we have now or are likely to have. I'm not sure how to begin but:

  * I think it's clear that the existing tonnage and grade curves are based on a mix of deposits, some now economic, some possibly economic in the future, and some that will probably not be economic for decades, if ever.

    It's going to be an interesting philosophical and statistical exercise if we embark on a program to estimate the number and size of undiscovered deposits based on tonnage and grade curves that include uneconomic deposits--as we do now--and then try to establish the economic value of those undiscovered deposits! What kind of system have we set up that even allows of the recommendation in the Harris Committee report that we should be assessing the economic viability of undiscovered deposits? What other kind are there to predict?

  * It is difficult enough to define the economic viability of known deposits <u>at any given time</u> when we know their location, tonnage and grade, and we can make some reasonable predictions of mining methods and the social, environmental, and governmental costs that might have to be borne by the deposit. Can mineral assessment teams of the U. S. Geological Survey do that for undiscovered deposits on any kind of <u>consistent</u>, scientifically defensible basis. I think not. (...but I worry that we'll try to do so with some kind of economic hocus-pocus.) If we go this route, I'd suggest that the first thing that needs to be done is try to define the economic viability of the deposits in the tonnage and grade curve--if we can.

* More pragmatically, look at the problems we've had in trying to predict the number of undiscovered deposits and we've not resolved all our problems by any means. That's why we needed the Harris committee and your committee. Are we really prepared to embrace another level of complexity beyond the training of almost all of us when we haven't even gotten our present quantitative-assessment house in order?

o Perhaps the basic assumption in quantitative mineral assessment is that it serves a purpose. Does it? I question whether an adequate case has been made for quantitative assessment by the USGS. And maybe one of the best examples I can give is the recent paper entitled *A Proposed National Mineral-Resource Assessment* by McCammon and Briskey in the journal *Non-Renewable Resources* (1992, v. 1 p. 259-266). The paper ends with the statement: "Part of the answer to the question (of how the US can compete as land is withdrawn from mineral development) lies in a probabilistic quantitative assessment of the non-fuel mineral resources of the United States and its public lands".

There is not a single example in the whole paper where a quantitative mineral assessment resulted in any decision by a land managing agency nor any action by industry (other than the totally erroneous implication that the discovery of the Pebble Beach deposit in Alaska was based on a Survey quantitative assessment).

I suspect that now and for the foreseeable future there will be a great number of people in the Geological Survey, myself included, who feel that field work, commodity work, and ore genesis studies are not only basic to mineral resource assessment but are essential to the Survey's long term role in mineral resources and indeed to quantitative mineral resource assessment itself. I find it ironic that the authors of this paper are justifying quantitative mineral resource assessment almost entirely with examples of discoveries found with classic field mapping and ore deposit studies!

o Coincidentally, there is another paper in the same issue of *Nonrenewable Resources* by Brew, Drew, and Luddington that nicely describes their quantitative mineral assessment of the Tongass National Forest in Alaska . This is a state-of-the-art assessment by extremely well qualified scientists. Yet in their concluding analyses of results, the authors repeat three times that they have no idea what part their quantitative mineral resource assessment has played in the proposed land use decisions on the Tongass.

For these and whole host of similar examples, I'd submit that we've lost our objectivity on the role of quantitative mineral assessment in the land planning process and we aren't able now to rationally look at what we do, it's utility, and most importantly how much of our resources should be devoted to quantitative assessment relative to other minerals work.

o I'd further submit that minerals will not be adequately represented in the land planning process until knowledgeable minerals people are part of the teams that make the land decisions.

It's patently impossible given our presently limited staff for us to provide a scientist experienced in quantitative minerals assessment to each Federal land planning team in this country. Thus if we want people qualified in quantitative minerals assessment in land planning teams, we are going to have to train people in the land managing agencies. In spite of all the brave, strongly stated words I've heard from some people in our organization I see few people in the land managing agencies that understand our quantitative assessments nor the methods we use to achieve them (and not many in OMR for that matter!).

If nothing else as a reality check , we need to involve several of our people in a few land planning teams. We need to know how our assessments are actually being used in the planning process.

- Mineral land assessment as presently practiced in OMR is a multi-Branch effort and it's a rare team that doesn't include members from 3 or more Branches in OMR alone, all answering to different managers. As we are now organized the lowest-level line manager who has responsibility for individual mineral assessments projects--note projects--is the Office Chief. We need to establish a better chain of responsibility and accountability for mineral assessment projects.

- I've now heard ad nauseam that "they" demand a single number as the measure of the mineral potential of an area. I still don't believe it. In fact, I think the opposite is true. More often than not we look silly in presenting a single number, i.e. GIPV, for the mineral potential of an area and especially to a professional or knowledgeable audience. Not many land managers, members of the Administration, or Congressmen are statisticians but one doesn't have to be a rocket scientist to recognize that there is a range of uncertainty in predicting the mineral resources of the area, especially if the mineral resources are in undiscovered deposits. Our clients may not be sophisticated in the details of mineral assessment but they're not stupid. Not only are we going to be more believable in citing a range of values than a single value but we as scientists owe it to our clients to present them with the honest facts, that our assessments indeed have a wide range in uncertainty in them. Yes, there are people in Congress and the Administration who would like a single mineral-resource-potential number for an area from the Survey--especially if we tell them it's real--but it's our responsibility to educate them to the fact that a single number isn't realistic and keep them from looking foolish..

- One subject I don't recall any discussion on in Anchorage is the presentation of our mineral resource assessments. Our assessments not only have to be scientifically sound, they have to be understandable to those who use them. I think we need more work on this.

- I am somewhat perplexed that there is any doubt that better ore deposit models should be a top priority in improving our mineral resource assessments.

In summary, the Survey's mineral assessment process has been in disarray for some time, witness the need for your committee and the Harris committee. I think your committees have and will made important recommendations on how to remedy our problems. I disagree with some of the recommendations of the Harris committee and I may well disagree with some of yours. Overall, however, the effect of your committees have been positive, above all because you have publicly addressed issues that have been allowed to fester and grow for too long. However, your reports are only words on paper no matter how well grounded in science, well organized, imaginative, and well stated. The next thing that has to happen is for the Survey management to put your recommendations into effect. And that will almost surely require that we prioritize what we do in minerals to make the best use of our limited and decreasing minerals talent.

Don

EVALUATION OF THE BORA METHOD

Warren B. Hamilton

I regard the Branch of Resource Analysis (BORA) methodology for quantitative estimation of undiscovered mineral resources as based on untestable guesses and invalid assumptions and as severely biased toward overstatement. My space limitation here permits only a brief summary of these concerns.

Grade and tonnage models.—The methodology assumes that undiscovered deposits in any study area of appropriate geologic type have grade and tonnage characteristics like those in databases compiled from deposits elsewhere which have been extensively drilled or mined. Those datasets must be heavily biased toward the large and rich deposits most likely to have been both found and thoroughly tested, but this bias cannot be quantified. Perhaps half of the tabulated deposits are subeconomic but the proportion of small and low-grade deposits must be far higher in the total population of actual deposits. All datasets have frequency peaks of both grades and tonnages offset from the smallest values reported. Experience and logic indicate such offsets to be products of economic sampling bias and of the variability of grade cutoffs of "ore." (Grade and tonnage are for ore above those cutoffs, which vary from deposit to deposit within a type and commonly are unknown to the database compilers.) BORA-method theory calls upon deposit estimators to think in terms of numbers of deposits which have the statistical parameters of the datasets, wherein giant deposits drive means and low-probability values, instead of merely of numbers of deposits of which most are small, but analysis of reports shows that this is not effectively done even by BORA theorists themselves. The methodology assumes incorrectly that the proportion of giant to trivial undiscovered deposits is independent of intensity of past exploration in an area—that giant deposits, if indeed present, are not likely to have been found out of proportion to their numbers and are as likely to be completely blind as are trifling deposits.

BORA models (*e.g.* Cox and Singer 1986) treat grade and tonnage as independent lognormal variates. The empirical case for lognormality is at best unconvincing, and there is no theoretical reason for lognormality above variable and arbitrary cutoffs; I see the cited effects as due to the economically biased offsets of the data from those cutoffs. Bivariate lognormality of grade and tonnage was until recently assumed in BORA calculations even though this produces substantial probabilities for undiscovered deposits in random study areas to be much more valuable than any known in the world. To minimize this unrealistic implication (which however is still expressed in currently compiled grade and tonnage models, as by Menzie and Singer, 1993), most recent calculations deemphasize lognormality and instead model deposit distributions on the basis of piecewise linear curves. These curves eliminate the trouble caused by unbounded upper tails of lognormal distributions but maintain the bias-minimized lower tails (and thus allow the means to be driven by the bias-maximized high values), and still depend completely on grades and tonnages from elsewhere in samples that may be as small as four deposits.

When simulated grades and tonnages are generated independently using either the lognormal or piecewise-linear approach, the mean simulated contained metal (grade times tonnage) often is much higher than the mean metal in the database deposits. To decrease this anomaly, MARK3 now imposes whatever grade-tonnage correlations are required to make mean simulated metal and mean dataset metal the same. (Actual grade-tonnage products are not modeled.) This shifts models arbitrarily away from the data, abandoning both the independence assumption and the fundamental assertion that undiscovered deposit distributions resemble distributions of well-explored deposits elsewhere. Despite the sensitivity of calculations to even small changes in underlying models, MARK3 makes large *ad hoc* changes with little statistical or theoretical justification (Bultman *et al.*, 1993; Hamilton, in press).

These optional MARK3 procedures yield very different results yet are poorly documented in methodological papers. Papers applying the method to study regions are much worse; many wrongly specify procedures used and most do not define them at all. The entire explanation of methodology given by Toth *et al.* (1993): "Using a computer program entitled MARK3, tonnages for undiscovered deposits in the Forest were estimated from known tonnages and grades of deposits worldwide."

Estimates and calculations.—The methodology is critically dependent upon "probabilistic estimates" by BORA teams of numbers of deposits of each type in a study area. These guesses are published only as final-consensus numbers. Estimation teams consist mostly of theorists who lack experience in the region at issue, in ore deposits of the types that might occur there, and in exploration. The MARK3 computer program combines a probability function from the consensus guesses with 4,999 Monte Carlo samplings of grade and tonnage models from the databases, integrated by one of the conventions noted earlier, and orders the calculated samples by metal content. (That these small samplings yield very unstable results [Hamilton, in press] points up the shortage of statistical expertise in the program.) Percentiles represent the values of samples at specific levels; thus, the 1% probability value is the 50th from the largest sample. Because of the positive biases of the grade and tonnage datasets, calculated upper-tail values often are far larger than any deposits known in the world and the arithmetic mean of all 4,999 samples is necessarily driven by these high values. The total in-ground metal in the hypothetical deposits commonly is then assigned the dollar value ("gross in-place value," GIPV) of the current price of refined metal delivered to market.

Exemplifying the minimal constraints on the untestable guesses are the first-round estimates for the East Mojave National Scenic Area (Hodges and Ludington, 1991; unpublished U.S.G.S. documents). The four to six BORA-panel members, none of them knowledgable about the area, were briefed by experts and then estimated the number of deposits, at five probabilities, of each of 10 deposit types in the area of about 6000 square km, the entire procedure taking little more than a day. Initial guesses, recorded by two observers, for the two deposit types that provided most of the calculated value of undiscovered resources ranged from expressions of near certainty to those of little chance:

PROBABILITY, percent	*90*	*50*	*10*	*5*	*1*
CARBONATITE					
High estimate	1	1	2	1*[sic]*	2
Low estimate	0	0	0	0	1
Final consensus	*0*	*0*	*1*	*1*	*2*
SKARN MAGNETITE					
High estimate	1	2	5	-	-
Low estimate	0	0	1	1	3
Final consensus	*0*	*0*	*1*	*3*	*5*

The great variation in the initial guesses, the casual nature of the brief subsequent discussions, and the fact that undiscovered deposits of significant value of these two types are highly unlikely to be present at all mark as misleading the claim (Hodges and Ludington, 1991, p. 6) that the guesses represent "the collective knowledge of 4 to 6 experts, after lengthy discussion of all known relevant factors by those familiar with the geology, geophysics, and geochemistry of the area and (or) the characteristics of the deposit type." The Mountain Pass carbonatite, valuable for its rare earths, is adjacent to the study area, and a small part of the area contains basement rocks old enough to contain more carbonatite although extensive prospecting for easily-seen carbonatite has found only a few small dikes close to Mountain Pass (U.S. Geological Survey, 1991). The Mountain Pass deposit contains no commercial niobium and yet a high-niobium model of grade was used to calculate the value of hypothetical undiscovered East Mojave carbonatite; and the tonnage model was based on deposits of which 80% are larger than Mountain Pass itself, although Mountain Pass is the only deposit of its type in the region (Hodges and Ludington, 1991; D. A. Singer, in Cox and Singer, 1986, p. 52-53; U.S. Geological Survey, 1991). The consensus guess of a 10% probability of one deposit resulted in a GIPV of $41,700,000,000 for niobium alone in undiscovered East Mojave shallow carbonatite at 1% probability. Small magnetite-bearing skarns are developed locally along contacts between Jurassic granitic rocks and carbonate rocks in the area; the largest known deposit, containing about 2,000,000 metric tons of iron, produced the most conspicuous aeromagnetic anomaly in the study area, precluding greatly larger deposits at shallow depths (*cf.* U.S. Geological Survey, 1991). The consensus guess resulted in a calculated iron GIPV of $229,700,000,000, ~1000x that largest deposit, at 1% probability. Impossibly high though these 1% values are for niobium and iron, in each case 49 still-higher calculated values went into the mean. Such values illustrate both the biases in the methodology and the lack of integration of guesses with model parameters; D. A. Singer, compiler of the carbonatite grade and tonnage models, made the high initial guess for carbonatite.

Proponents of the BORA methodology favorably cite the Spotted Owl study (Diggles, 1991) because two of the eight members of the guessing panel were local experts and because the study considered only porphyry copper, relatively easy to evaluate from geologic, geochemical, and geophysical information. Despite thorough exploration, and rejection because of the total lack of known bulk-mineable deposits, by industry, the Cascade Range was guessed to contain 7 undiscovered porphyry coppers at 90% probability, and many more at lower probabilities. The grade and tonnage models allow these hypothetical deposits to include giants, and MARK3 calculated the mean content of copper as 58,000,000 metric tons (GIPV ~$130,000,000,000).

Another BORA-favored study is Tongass (Brew, 1991), where also two local experts were on the estimating panel and local geology was integrated. Sample problem: a default 5% probability of a huge molybdenum porphyry on Forrester Island was assigned because of an unprospected "occurrence" of molybdenite, yielding a mean GIPV of $161,000,000 for that tiny island alone.

Presentation.—BORA-method data are generated primarily for the guidance of legislative and administrative land-use policymakers who are unsophisticated in both science and statistics and who can only be misled by the presentations, which emphasize high values at low probabilities and do not explain adequately the limitations of the methodology or the way its numbers should be interpreted.

All recent BORA-method reports with which I am familiar emphasize arithmetic means of the 4,999 Monte Carlo samples for each commodity. Many reports term the means "expected values" and some, "mean endowment;" the term "at least" is commonly used. Reports seldom if ever emphasize that these means represent values at low probabilities, typically between about 3% and 35%. Medians, which laymen are likely to think of as "expected," are much closer (and often equal) to zero and rarely are mentioned, and that they can be read from tables as 50% probabilities is not explained.

The GIPV concept hugely exaggerates potential value. GIPV makes no allowance for noncommercial deposits and for the costs of exploration, capitalization, development, processing, transportation, and so on. The disparity is exemplified by the factor of 50 between the BORA-method valuation of hypothetical in-ground copper at about $1.00 per pound and the actual price of less than $0.02 per pound paid for proved copper in 70 western-world copper deposits sold from early 1990 to mid 1992 (*Southwestern Pay Dirt*, July 1992).

Many BORA reports display GIPVs in asymmetric tables wherein values, to 4 or 5 significant figures, are presented in columns for probabilities of 90, 50, 10, 5, and 1%, and mean. For example, a small Colorado wilderness study area, which contains traces of molybdenite and no known commercial deposits, has molybdenum GIPVs listed in those respective columns of, in millions of dollars, 219; 2,721; 9,954; 12,608; 19,908; and 4,048 (McCammon *et al.*, 1991, table 6). The visual impact of such asymmetric tables is on the high values at low probabilities. The sophisticated reader, but not the layman for whom it is intended, recognizes in such a display ludicrous overestimation and pseudoprecision. There cannot be a 40% chance that a small noncommercial area contains an unexposed porphyry with about as much molybdenum as the world's largest known deposit. (The report does not mention that most of the trace molybdenite in the study area is in ashflow tuff erupted from a caldera outside the area.) About 50 of the values going into the mean for this small area were for hypothetical deposits more than 5 times as large as the largest known. Other reports (*e.g.* Toth *et al.*, 1993, who stopped with quantities of contained metals, not GIPVs) use symmetric tables, with columns for probabilities only of 90, 50, and 10%, and mean. This avoids emphasis on the lowest-probability values at the cost of decreasing the recognition by knowledgable readers that it is those impossible values which drive means so high.

Mean GIPVs for various commodities commonly are added and their sum emphasized. This procedure is statistically correct but misleading, for the reports never note that there is near-zero likelihood that a number of separate low-probability means will simultaneously be met. Sometimes the statistically incorrect procedure of summing values at percentiles, such as the amount of metal predicted with 10% probability, is performed. Hodges and Ludington (1991, table 15) implied with such a sum

1 chance in 10 that the sum of ten 10%-probability numbers could be met, whereas the actual probability is 0.1^{10}, or 1 chance in 10 billion.

Overview.—The BORA method begins with minimally constrained and commonly highly optimistic guesses as to numbers of ore deposits present at varying probabilities. MARK3 calculation, incorporating the assumption that those undiscovered deposits include giants even where extensive exploration has found nothing of value, renders the guesses into amounts of metal contained in hypothetical deposits. These amounts are converted to dollar values of total contained metal, without regard for costs which cut true values to small fractions of calculated values. Presentations of results emphasize high values at low probabilities and lack or minimize caveats intelligible to lay policymakers. Effective overstatement by factors of more than a thousand is common.

BORA theorists have resisted criticism and the methodology, developed in the mid 1980s, did not receive peer review until 1993. It still is poorly documented but some beneficial changes are at last underway and others are being pushed on BORA. Most of the long-secret databases with which MARK3 operates have recently been released. Several of the assumptions generating overcalculations in MARK3 have been moderated, albeit in *ad hoc* fashion. Both the GIPV concept and the use of world-class deposits as the norm for calculating sizes of undiscovered deposits may be modified. It is to be hoped that exploration expertise and realism will be introduced, the statistical parameters of models considered, and MARK3 used interactively and its products evaluated objectively, at the number-guessing stage.

Such changes could much reduce the overstatement of resources that has characterized past BORA reports—but results would still be but elaborations of untestable guesses and dubious assumptions.

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December 6, 1993

To: Paul Barton, and others

Quantitative Assessment Review Committee

From: J. T. Nash Tom Nash

Subject: Suggestions for improved resource assessments

I'm impressed by the contradictions that managers, and we scientists, face as we attempt to improve the quality of our resource assessments. The program needs uniformity for National standards but also flexibility for local models and style of reporting for various customers. Projects need more and better data at a time of declining budgets. More research, applications, and teaching must be done by fewer economic geologists. Scientific critics call for more detail while non-technical users complain that our reports are too complex. We know we can not accomplish all that we would want to undertake because of the current facts of budget and staffing, but your improved definition of priorities and goals will make our efforts more effective.

From my experience on ten assessments, I consider the weakest parts of the quantitative assessment method to be the early steps. My concerns are chiefly our poor databases, inadequate first-hand knowledge of area geology and ores, and ineffective psychometrics in the elicitation process. Let me describe some problems as I see them, essentially in the sequence that they are encountered in a typical assessment.

1). **Databases.** We generally make assessments with nondiagnostic data collected by other programs for other purposes. Geophysical, geochemical, and rock alteration databases are generally inadequate. I've seen very little relevant geophysical data or interpretation, partly because our usual magnetic and gravity data are not diagnostic in most ore models. The character and scale of available geophysical data are generally inappropriate to resolve the assessment problem. The best assistance has been gravity models of post-ore cover. State of the art electromagnetic data would help define alteration and sulfide mineralization; we have the expertise in OMR, but new surveys of this type generally are too expensive for the program.

Geochemistry also is a weak component in most assessments and generally is a weak criterion in deposit models. I have worked with regional stream-sediment geochemistry on several projects and find that it adds very little new insight; the problems seem to be chiefly matters of scale and chemical determinations. Improved analyses to lower detection levels on our archived NURE samples may help somewhat, but I suspect the samples are spaced too broadly to be effective. I'm the oddball in Branch of Geochemistry who does not endorse stream-sediment geochemistry for assessments. In my experience, geology and petrology are most effective for defining types and extent of mineralization. Stream-sediment geochemistry is most useful for defining zones of favorability around prospective mineralization centers. More research is needed on sampling, and chemical and computational methods for effective spatial analysis.

Data on alteration mineralogy and distribution are sorely needed, in my opinion, in all of our assessments. This information is expensive to obtain, but at least some is required to characterize the more important prospects. New remote sensing techniques provide high spatial resolution narrowband spectral imagery that is effective for mapping specific alteration minerals. This promising technology is of special interest to assessments because it provides continuous spatial data rather than just single point data. The bandwidth on conventional Landsat photos is not effective, and I do not trust the resulting iron oxide maps. It is essential that trained geologists look at the rocks in the field to determine at least the alteration at obvious visible anomalies--both for ore assessment and for environmental implications.

The Mineral Resource Data Systems (MRDS) database is very useful. I use it routinely on my PC to define locations of mines and prospects and to estimate likely types of deposits in a new study area. Sure it is inconsistent, but it is a good starting point in the office, and the commodities field is provides pretty good geochemical information. I'm pleased that MRDS is getting friendlier with much improved platforms for generalists like me.

2). **Deposit models and concepts.** Ore deposit types known or likely in a study area must be defined at an early stage and the concepts refined as work progresses. MRDS provides useful guiding information, despite the general lack of systematic class coding. An assessment team should not have much difficulty deciding which *known* deposit types should be considered in the assessment, but limitations of experience and knowledge hamper our estimates of the kinds of *unconventional* deposits possibly present in an area. (Unconventional meaning those deposits well known in other parts of the world but not in the study area, or historically unrecognized types such as Olympic Dam prior to 1975 or Carlin in 1960). Our assessments must be more than hindsite--some effort should be given to anticipating new systems of potential value even if a quantitative estimate can not be made for them. When we do our work with care and imagination, we are capable of identifying unconventional deposits such Olympic Dam type in Missouri or bedded barite in Nevada.

Regarding selection or modification of grade and tonnage models (grade and tonnage are just two attributes!), I think considerable discussion is warranted. I've encountered firm resistance to any modification of global models. I've also criticized the Idaho group for use of overly local models, requesting discussion of relations to well known examples outside of Idaho. I can see a value in consistent use of a standard or global model so that estimates can be compared across the Nation, but I think this approach tends to introduce error on the high side because unrealistic giant deposits are included in the model. For most assessments a compromise position is needed: tune the model to fit local geology, but include enough well known deposits to provide standards for the analogy.

Modifying or restricting models probably will not mean a great deal to most customers, and detailed explanations would certainly confuse them, but the process would be meaningful to the team and to experts in the USGS and elsewhere. A flexible policy on model modification would challenge the team to better understand the geology and statistics of a model and the impact of restricting geologic criteria, grade, and tonnage on their estimates. Some in BORA say that model statistics are so complex as to involve major research for modification, but others suggest the models can be adjusted in a few hours. Better documentation of data on a deposit by deposit basis (as in some 1992 models) would allow even amateurs like me to better understand the curve or reconstruct a subset and new curve.

Some of our precious funds should be allocated to revising and extending models. Ongoing research is required to improve our assessments. I would like to see a team of model builders investigate new perspectives in assessment that are based on spatial geologic attributes. In my opinion, the current methodology is fundamentally a point by point analysis, akin to *Prospector* of SRI, that suffers when translated to space (maps). Also, I'm concerned that undo emphasis has been placed on grade and tonnage statistics as the basis for a model, as opposed to geologic definition. Distinctive geologic attributes, especially empirical (not genetic) ones that can be gleaned from geologic maps, are a more important basis in assessment than statistical ones relating to engineering or economic aspect. In the National assessment, we've found distinctions among the epithermal polymetallic types (Creede, Sado, Comstock) difficult or impossible to apply, and I think that the several varieties of "porphyry type" Cu-Mo-Au ± skarn deposits are unrealistic when one has very little information on an area. Gaps in model coverage must also be filled, such as one or several types of veins in basement rocks such as Central City, Colorado.

3). **Elicitations.** The Review Committee needs to look closely at the impact of this step in the assessment process on the final product. Social conditions at this step can overwhelm science. I suspect that the skills and personalities of elicitators have been a factor in the numbers generated in some assessments. Huge errors, multiple orders of magnitude, may have been made in this step because of human dynamics. Some elicitators squelch discussion and differences of opinion. Others are not knowledgeable enough about the system, especially the quirks of models. One person stands head and shoulders above all others, because he has the rare combination of geologic experience, ore deposit knowledge, familiarity with models and statistics, and personality to make people contribute effectively. This style and knowledge needs to be imparted to others. Elicitators seem to do better if they are well grounded in geology; common sense and instincts in geology and ore deposits are harder to train (I think) than statistics of the Mark3 system. Some of our questionable assessments have resulted from the elicitator's lack of knowledge of ore deposit geology.

The elicitation would benefit from real time runs through Mark3, but that is not essential. The use of tables of simplified conversions from quantiles to estimated mean deposits gives a pretty clear indication of magnitude. More important than feedback from the Mark3 computer is the dialog between elicitator and team regarding the implications of estimates. If the team is very inexperienced, for example, the elicitator should discuss with the team what a number at 90th percentile means relative to numbers at lower quantiles, etc. Discussion relative to other assessments, other deposit types, or to exploration experience certainly is appropriate. I prefer multiple passes on estimates, especially at middle and end of project, using a variety of model conditions; the results should then be discussed by the team and evaluated by national experts. We probably can report only one "best" estimate to our customers, but results for other model conditions should be documented for future internal use.

It is **essential** that the team have a chance to review and comment on the final numbers before publication. The team also should be asked to review a simplified briefing table. Clearly, some of our biggest problems have been caused by poor planning, review, and communication. The human errors can be minimized by better planning, and in some cases by refusal to rush the process to meet a capricious political deadline.

OMR has few qualified elicitators and the situation will be getting worse in the future as some experts move on and demands rise. I disagree with those who say that the three step system is proven and now can be applied by nearly anyone. I'm impressed that some new people have quickly learned the methods and picked up the skills to be effective elicitators. As many as a dozen more are needed. Training of new elicitators will require travel for field experience with known ore deposits.

4). **Presentation and Publication of results.** Traditional writing styles are not effective for our assessment reports. I have seen a lot of confusion and time lost in report reviews because the publication organization and style were not clearly defined for multiple writers. Because of vast differences in background, no single style is effective for all readers. Harris et al call for more documentation and assessment of errors, but I hear the users saying our reports are too complex. Even mineral specialists in the USFS and BLM do not understand most of what we say, and are not given the time to learn from us. To most users, more detail is not better. Our Bulletins are getting longer and longer, and will be huge when new chapters on environmental topics are added. The minimum product should be a concise, readable (nontechnical), and well illustrated report in the Bulletin series. In addition, we also need to get the facts and the discussion of methods and errors to those few scientists who can comprehend them, and are interested. I vote for separate release of scientific data and discussion as open-file reports, MF maps, digital diskettes or CD-ROMs, and papers in peer-reviewed journals.

Development and use of improved graphical methods should be encouraged. Geographic information system (GIS) is one approach, but I am not convinced that many projects are faster or better with a GIS. Digitizing geology may be more costly and time consuming than it is worth to the analysis. If the project has very little data, as is common these days, GIS will not make up for a lack of appropriate data or poor understanding of ore deposits. The Paducah assessment made excellent use of GIS, but it certainly is not a typical project in terms of time, science, and manpower. We'd all prefer to work at that high level. The recent experiment with digital products and display by Ron Tidball and Susan Winkler for Roswell BLM results, or of multimedia methods, may be examples of how computer-aided displays can explain our results more effectively than traditional paper products.

Detailed descriptions of how we placed lines on maps and produced estimates are very dry reading and also make us look pretty naked. When it comes to justifying some of our lines or estimates, the data commonly are very weak. In essence we must say "trust our judgment" and that is neither convincing nor scientific. If we go through a few cases, picking some good examples of placing lines or polling "experts" we could make a case for reliable our work is.

The way we present our estimates can influence the way our customers use and understand the numbers. Summary tables tend to encourage abuse and misunderstanding because caveats from the text are ignored. I favor use of a range of values because they are less likely to be abused than single values such as a mean. Scientific notation such log scales and cumulative curves are likely to cause confusion.

5). **GPIV.** I do not favor converting tonnage estimates to dollars. I groaned when GPIV was introduced a few years ago and hoped it would go away. Nope. The intent of the Harris recommendation for RGIV may be appropriate, but I fear that this can open us to a new level of errors and criticism. I favor trying to emphasize amounts of metal, as that is based in geology. If we must use some other unit, then we must stress that the value unit is a derivative. The "restricted value" of Harris probably would confuse everyone. I'm impressed that mineral economic factors are highly variable in time and space, and rarely related to geology. Errors in our economic modeling or adjusting of resources could dwarf the magnitude of the original estimate and add an additional uncertainty. It seems to me that the more we manipulate our estimate with statistics and economics, the farther we get from the strength or weakness of the original estimate.

16 Sept. 1993
Modified 4/6/94

MEMORANDUM

To: Dave Brew

From: Steve Nelson

Subj: Mineral resource assessments

We have been recently reminded of the visit by you and several others regarding the quantitative mineral resource assessment methodology workshops. I have read the Arizona report and find it useful in understanding the process. However there seems to be more effort on trying to make the process statistically valid rather than making it geologically realistic; for example there are no proposals for field validation of the quantitative assessment . I do however understand the importance of being consistent in the work we present and the fact that we should be doing resource assessments.

My greater concern is are we providing a useful or useable product for land managers regardless of the format or statistics. I have been involved in three resource assessment projects. The first two, the Talkeetna and Survey Pass AMRAPS, involved large areas subsequently added to the National Park System. In both quads park boundaries were drawn on the basis of existing active mining claims not on the basis of resource areas determined by the USGS. The third resource assessment that I worked on was the Chugach National Forest RARE II Wilderness Project. During the final team meeting (1982) forest service staff appreciated what we were doing but specifically wanted to know "where will the mining activity take place". We tried to tailor our assessment to address that issue. In 1989 Jim Bliss published a quantitative assessment of the CNF (OF 89-345) in response to a court settlement agreement that wanted answers to several issues (see attachment) similar to the 1982 question. In 1992 I completed 30 days of fieldwork in a special study area funded by the CNF. At a progress briefing held for the CNF in March 1993, I asked for clarification of what type of resource information they wanted. The answer was the same as before (see attachment).

There are two conclusions that I have made from these experiences. One conclusion is that our resource assessments aren't utilized (Talkeetna and Survey Pass), the second conclusion is that we aren't providing what is wanted or they don't know how to use the information (Forest Service). In the case of the CNF I discussed with them how to address their concerns using the existing assessment both before OF 89-345 was published and again at the 1993 progress briefing.

In July 1993 I met with several people trying to determine how best to spend some of the EXXON Valdez settlement money. They were interested in specific areas in Prince William Sound. These areas were the shoreline parts of larger resource areas defined during the RARE II project. I found the question of the resource value for these secific areas difficult to answer since our methodology is not flexible enough to allow evaluation of parts of resource areas. This is clear if you compare the assessments values by commodity and planning area with the total for the CNF in OF 89-345 (p. 4).

I note that one of the goals of the upcoming workshops is to make recommendations for ensuring that the next generation of mineral-resource assessments will continue to be state-of-the-art. With this idea in mind maybe we need to start concerning ourselves with what it is the customers really need. In some cases this may be a quantitative assessment and in others something different. I would appreciate your thoughts on this and hope that this issue can be addressed at the upcoming meeting.

cc
OMR Chief
BAG Chief
Gamble

bcc
Goldfarb 9/22
Schmidt 9/24
Barton 10/7

126

Submitted October 27, 1993, revised April 19, 1994

FROM: Gary Raines GLR

CONCERNING: USGS Mineral Assessment Method

Concerning training:
I think it is of critical importance that more people be trained to carry out a quantitative mineral assessment. This will include general training on the concepts and methods for all participants and specific training to develop a larger group of assessors. It was very apparent to me at the meeting that those most opposed to the current method have no foundation in probability theory, statistics, or economic decision theory. I recommend that the assessors need a solid grounding in these three subjects and that all participants be given at least an overview of these three areas. The Geologic Division is very negligent in any sort of technical training, and this meeting clearly demonstrated that professionals will not necessarily obtain the required training on their own. There needs to be a Geologic Division commitment to technical training.

Concerning development of a group of assessors:
From discussion with many people, I have the strong impression that many people believe that taking an active part in mineral assessment will hurt their career. It is still very common to bad-mouth mineral assessment and contribute the minimum. The management of OMR has to develop an atmosphere in the organization that mineral-resource assessment is an honorable activity and reward those that do this work.

Concerning the time-frame for mineral assessments:
It is often said that there is not enough time to do a given assessment. I believe this problem exists in large part because we in OMR have treated mineral assessment as a distraction from our science, e.g. something that will go away. Therefore, we have not prepared. Consequently when an assessment starts we consume our research time and dollars compiling the known information in a form we can use for the assessment. I recommend the following: 1. We use the national assessment to define what research is critical and give such research priority. 2. We compile all the necessary data in a GIS to support the current national assessment and enter new data to refine such an assessment. 3. We establish a policy to review and upgrade the national assessment on a regular basis; so we are prepared at any time to present an assessment for any piece or all of the country. 4. Then we should use the upgraded assessments to refine our research focus and revise the funding priorities to reflect this new research focus.

In making these four connected recommendations, I am emphasizing that GIS is a tool to help us analyze, display, organize, and store map data. Research has to be done to provide the data and concepts to analyze, display, organize, and store. My concern is that we reduce the funds and time to do research by not properly managing how we respond to current questions. If we implement these recommendations, we will be able to use whatever time is allowed for an assessment to improve the existing assessment. The function then of a multi-year resource-assessment project will be to improve the assessment for that place starting from the existing assessment and to incorporate the new data into the national mineral assessment data base.

Concerning alternative methods:
To implement the above recommendations we must develop a GIS to support mineral and environmental assessment and methods to use these data to do assessments. The methods are formal methods to integrate multidisciplinary data. The long-term objective is to better understand the process used to integrate multidisciplinary data to make a prediction and hopefully improve our predictions. Also GIS techniques provide a method to make decisions consistently and to fully document the process and decisions. The lack of consistency and documentation is an important criticism that the Harris

Committee raised about mineral assessments.

As an example of what and how to compile data for mineral assessment, Don Sawatzky, Kathy Connors, and I have developed a regional GIS for the Great Basin including over 60 different data sets. These data include base map data, geology, geochemistry, geophysics, MRDS data, mineral assessments, and various thematic data including, for example, age dates, hydrothermal alteration, extensional terranes, young faults, and pluvial lakes . These data are described in a 250 page catalogue, which is the documentation about the sources, quality, and characteristics of the data in the GIS. These data will be released in 1994 in the USGS Digital Data Series (a CDROM). The catalogue and the GIS data are a beginning to the data compilation necessary to support mineral assessment, and incidently many other predictive activities of the USGS, such as landslides, volcanic hazards, earthquakes, water quality, water quantity, and environmental assessments. This data compilation represent approximately 4 man-years of effort.

Then once you have this data, it is necessary to develop some method to analyze digital data. These methods could be all digital, all graphical to support expert decisions, or some combination. For the near future a combination of all digital and graphical support of expert decision are probably best. There are several alternative methods for aspects of our current methodology. Most of the alternatives were favorably referenced in the Harris report. I have attached the abstract of a chapter of a USGS Bulletin concerning the weights of evidence method for defining terranes. This Bulletin is currently in WTRU.

This Bulletin Chapter only begins to address the issues of estimating numbers of undiscovered deposits based on the weights of evidence method; but I am pursuing this problem with some interesting preliminary results. I will send you some results of predicting numbers of deposits in comparison to the expert estimates soon. I should point out that this paper addresses an alternative way of doing Steps 1 and 2 of the current 3-Step Method. It does not replace the current method; but maybe it offers some opportunities to improve the current method.

A MAJOR issue in digital data compilation is standards. Basically, if you intend to develop national data sets, you have to have everyone following the same standards or you will not be able to put the data together. This is a very complex issue that will require a lot of discussion and more structure than the Geologic Division has previously demonstrated. The use of guidelines and the lack of standards has lead to the problems that now exist with, for example, MRDS and RASS. The Geologic Division needs to look at the standards that NMD uses for digital topographic maps. Then develop a set of standards for digitizing geologic, geochemical, and geophysical maps. These are not guidelines; these are standards so when a customer gets a geologic, geochemical, or geophysical data set, the data will be in a format the same as the last data set. That customer includes an OMR scientist making a mineral assessment.

For an example of standards, the line attributes such as solid, dashed, or dotted will all be coded the same way. The formations will have map unit names that are consistent and usable in a computer, for example is Ov an Oligocene volcanic or an Ordovician volcanic map unit. This is different than the question of how it is symbolized on a piece of paper. The difference is, if I want to use a computer to find all the Oligocene units, how can I select the Oligocene units. The GIS really offers some new ways to deal with maps; but the data structure in the GIS defines what questions can be asked of the map.

Attachment:

CHAPTER IV

EVALUATION OF CENOZOIC BASINS AND RANGES FOR SELECTED MINERAL DEPOSIT TYPES WITH WEIGHTS-OF-EVIDENCE METHOD

by
G.L. Raines[1] and D.L. Sawatzky[1]
1992

ABSTRACT

Mineral occurrences in the rocks of the Triassic and Jurassic magmatic arc of western Nevada and eastern California were analyzed by the weights-of-evidence method implemented in a geographical information system. The portion of the arc studied lies in an area from Walker Lake northwestward through Lake Tahoe to the northern Sierra Nevada mountains. Metavolcanic and metasedimentary rocks and plutons of the arc crop out over a large region of western Nevada and eastern California. Geologic relationships of the arc have been complicated by intrusion of a variety of younger Jurassic plutons as well as Cretaceous plutons of the Sierra Nevada batholith, concealment beneath Cenozoic volcanic rocks, fragmentation by Cenozoic extension and strike-slip faulting, and burial under Neogene basin fill. The most significant ore deposits associated with this arc are the Yerington porphyry copper system and related skarn deposits. Many other types of base metal deposits, including Cu and Fe skarns, polymetallic replacement, polymetallic veins, and Mo-W porphyry and associated skarn deposits also occur within this arc. Various geologic characteristics of exposed (known) mineral deposits were used to predict the potential for undiscovered deposits in covered areas.

This study is an evaluation and practical application of pattern analysis and the weights-of-evidence method to the analysis of three groups of mineral deposits, occurrences, and prospects referred to as sites: 1) all sites hosted by Triassic and Jurassic rocks, 2) Cu-Fe skarn mineral sites, and 3) polymetallic vein sites. Pattern analysis consists of the assignment and summation of weights as predictors of mineral sites to map patterns associated with known mineral occurrences and deposits. In this study, weights are calculated by the weights-of-evidence method, based on Bayesian probability theory. Weights are developed from patterns showing digital geologic, geophysical, remote sensing, geochemical, and mineral occurrences data assisted by a computer-based geographic information system.

A posteriori probability maps and predicted numbers of mineral sites are produced from the summation of weighted patterns for the three groups of mineral sites. An _a posteriori_ probability is the areal or _a priori_ probability adjusted by the weights due to the patterns. A prediction of the number of mineral sites in the unexplored areas is calculated from _a posteriori_ probabilities.

Proximity to mapped faults and certain rock types, particularly Triassic limestone and Jurassic Yerington granite, have the strongest correlation with mineral sites for all sites and for Cu-Fe skarn sites. For polymetallic vein sites, Thematic Mapper-derived clay anomalies have greater correlation than faults and lithology. The strong spatial association between assumed Cenozoic-age faults and Mesozoic-age mineral occurrences contradicts known evidence of ages of mineralization and assumed ages of faults.

Skarn mineral sites have a strong association with proximity-to-plutons and with limestone lithologies as expected. However, no strong association with plutons was found for the group of all mineral sites or for polymetallic vein sites. It was also found that the pattern of available stream-sediment geochemistry contributes little, compared to other geologic patterns, to predicting mineralization in Triassic and Jurassic-hosted mineral sites. Altered areas are only moderately correlated with the mineral sites, except

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alteration defined by Thematic Mapper data which has a strong correlation with polymetallic vein sites.

The number of known mineral sites for each group is as follows: all sites: 397, Cu-Fe skarn: 32 sites, and polymetallic veins: 157 sites. Based on a posterior probabilities, the predicted number of mineral sites for each group is: all sites: 1505, Cu-Fe skarn: 162 sites, and polymetallic vein: 332 sites.

As anticipated, some geologic patterns in these analyses improved the prediction of the number of mineral sites and highlighted areas important for further study. Pattern analysis and the weights-of-evidence method was used as an analytical tool to define new patterns useful in predicting mineralization. Such analyses help focus on new associations of map patterns and predicted mineral sites that need further study.

From: Ted G. Theodore, Western Mineral Resources Branch; October 14, 1993

Subject: Thoughts concerning Harris and others report

First of all, I want to commend the BORA individuals most involved with initial development, implementation, and continued upgrading of the USGS three-part method of resource estimation for the dedication and scientific thought that they have put into the method over the last ten years or more. I especially want to commend them for the progress that has resulted in the current style of final presentation of results, and also for their attempts to show graphically some of the uncertainties that are inherently involved in this entire process. I nonetheless still wish to express certain reservations about the method in general. I must confess at the outset, however, that I do not have any suitable substitute, but hope that some my thoughts might be considered worthwhile by the panel. With regards to the Harris and others report, I am somewhat disappointed that many suggestions and questions raised in the individually authored appendices did not find their way into the final recommendations. I am not sure that my comments to follow are entirely appropriate, given the charge to your panel, but here they are. The comments below probably are best considered under the "Subjective Probability" part and the "Change Reporting of Assessments" part of the "Short-term Recommendations" section of the Harris and others report.

I would like initially to concentrate my comments on the question of uncertainties that I believe are inherently present in the numerical estimates of undiscovered deposits that are made for a tract of land in any given assessment. This aspect of the method, to date, is at the very crux of my concerns with the method. I believe that there are still some uncertainties present in this part of the method that are not fully conveyed to users of USGS assessment reports, and such uncertainties **must** be conveyed to these users. To this end, I agree totally with the comments made by Rob Zierenberg in another submittal to the workshop panel. As Rob points out,

Every step of the quantitative estimation process is dependent on the initial input of the estimation of undiscovered deposits. If this process is flawed, arbitrary, or untestable, then the results of the entire process are flawed, arbitrary, or untestable. I see no way around this conclusion and therefore feel that discussion of weaknesses in later parts of the process are of secondary importance.

I remain totally unconvinced that estimation of undiscovered mineral deposits, either independently by individuals in a group or through group consensus, has any validity. These estimates are not testable and are not, in any scientific sense of the word, quantitative.

Zierenberg, October, 1993

It seems to me that subjectively derived numerical estimates in any part of the entire assessment method renders the entire method subjective, and the term "quantitative" to me suggests "pertaining to or susceptible of measurement", the second offered definition in my dictionary. I believe that many others not fully cognizant of the many nuances involved in our assessments would also infer the same definition. As suggested, during one of the discussion periods, the terms "numerical" or "quantified" seems more appropriate. This needs to be addressed by your panel. Please refer to that part of the appendix authored by Titley in the Harris and others report for a discussion of "guesses". Furthermore, I still do not understand how someone who purports to be able to predict undiscovered resources can stand on a mineralized system for which grade and tonnage are unavailable, and not be able to tell us the grade and tonnage of that system. Yet, by some magic supposedly inherent in statistics, he proceeds to tell us the metal content of vast tracts of surrounding land. It has not been demonstrated to me that these estimates are reproducible (see appendix authored by Myers in the Harris and others report: "results presented to substantiate the claim that the "test" shows that panels can adequately estimate the number of deposits were simply not adequate"). Some of this land may even be buried under gravels far beyond the system itself. If there is a method of estimating grade and tonnage of a mineralized system without drilling, I would like to read about it.

I have followed closely development of mineral resources in the Battle Mountain Mining District for over 25 years and at no point in that time span could I have predicted accurately the number and the type of deposits still to be discovered. As an additional example of the "uncertainty" in the art of making geologic prediction, a number of years ago I came across a report by Reno Sales wherein he "assessed" the Copper Canyon area of the mining district as having no additional metal resources available for exploitation. Since that time, at least 3.5 million ounces of gold have been blocked out in a large number of ore bodies there, certainly many of them resulting from an advance in mineral extraction technologies over the years. Nonetheless, the point I am trying to make is that there is a huge uncertainty in any attempt to predict or assess whenever we use geology.

In addition, my hesitation concerning numerical estimates probably derives from scale-dependent uncertainties in the geology of an area instilled by my being primarily a field-oriented geologist over the last thirty years. For example, many geologic maps used even at the working scale of regional assessments in the northern Basin and Range do not adequately portray geology in the detail needed to make substantive predictions about undiscovered resources. On the one hand, this is certainly understandable because of the large areas involved in many of the assessments and the short time frames required of the accompanying reports. On the other hand, the area of the surface projection of most deposits of present concern in the Basin and Range is roughly equivalent in size to areal dimensions that I feel uneasy about "predicting" its geology when mapping at 7-1/2-quad scale. How many times have I incorrectly assumed the geology on a ridgeline prior to walking the ridge? The answer is almost always. If I cannot predict the geology at a scale relevent to the presence or absence of a particular type of deposit, how can I make a valid estimate of the presence of that deposit in a permissive tract? If the panel would like to discuss some examples of this in more detail, I would be happy to meet with one of your representatives.

I would like to cite another instance during the West Mojave study that bears on the problem of uncertainty in our estimates. I had responsibility for the writeup of the Jurassic porphyry copper part of the report. Early in the study I remembered that at one time I had visited the Red Hill Porphrry copper system in the Ord Mountains for which there is nothing in the published literature. However, I had sketched the location of the system, the concentration and number of drill holes, and made some brief notes about the extent of the alteration, its copper staining, and geochemistry based on a limited number of select rock samples. We would have assigned a 90 percent probability for the presence of a porphyry system if we were not able to obtain any additional information. I do not think I have to tell you what that would have meant in terms of a Mark3-inferred copper endowment for the tract, even with a reasonable truncation at the high end. We were leaning towards a system being no larger than Yerington, roughly 180 million tons. However, it turned out that I was able to obtain from Placer Amex data on the Red Hill system that allowed us then to move it into the discovered category. The system was approximately 10 million tons, if I remember correctly.

What is it in the prior training of those who feel that they can make such estimates of undiscovered deposits that allows them to be so confident about their estimates, especially when in the past many of the estimators have not even set foot in areas that they are evaluating? I have even less confidence in some of those individuals' estimates made for certain recently completed assessments than my own had I been involved in the process. And, I might add, I have zero confidence in my own ability to estimate the presence of undiscovered resources in a permissive tract even for those types of deposits that I am most familiar.

I would like to paraphrase the following statement which is, I believe, quite appropriate:

Not all things that can be counted count, and some things that cannot be counted count.

Albert Einstein

Therefore, because it appears that mineral resource assessments will continue to play a significant role in future OMR doctrine and strategic plans (see the memo from Chief and Deputy Chief OMR to Steve Ludington dated October 6, 1993 and other recent communications from OMR), suggestions made by the panel that *only attempt to improve* but do not abolish the currently employed method of mineral resource assessments will likely be accepted by OMR managemant. These suggestions below might go a long way toward alleviating many concerns that many scientists in OMR have. I suggest that the panel seriously consider the following:

(1) Convince us that numerical estimates are reproducible.

(2) If you cannot, then recognize that the method is not quantitative and use the appropriate language to describe it as such.

(3) Accept the suggestion of Harris and others that the USGS not present the consensus of the estimating panels but instead report all of the estimates. Perhaps these could be shown as an uncertainty band on the probability distributions of metal contents for each of the types of deposit estimated in a report. Such a procedure of reporting would at least signify that there can be a difference of opinion, which translates into uncertainty, in the method.

(4) Accept the recommendation of the Harris and others report that panels of estimators be somehow pre-qualified by some type of training. In addition, who decides the makeup of the panel that will be making the estimates? What type of prior training qualifies a person to be part of such a panel? Do you need to have an undergraduate course in economic geology? A graduate course in economic geology? Should some or all of the enumerating panel members have published extensively on the type(s) of deposit that he or she will be providing estimates of their numbers of undiscovered occurrences?

Thank you for bearing with me while I expressed some of my concerns.

From: Robert Zierenberg 10/8/93, revised 4/6/94

Subject: Response to W. White's memo dated 10/6/93 re queries for the Barton committee

The University of Arizona report on the USGS procedures for quantitative mineral resource assessment raises many areas for concern. The overriding areas of concern for many of the earth scientists working on mineral resource assessments are the validity of USGS quantitative resource assessments and the policy decision that the USGS will use the method of quantitative assessments of undiscovered resources for advising land-use planning agencies. The University of Arizona report starts with the premise that "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" (Harris et al., 1993). The instructions to the committee that produced the preceding report, as reported in the introduction, state "Whether or not a quantitative assessment should be made is not an issue, it is our responsibility to make such assessments." I can not agree with the above premise and statement. One of the responsibilities of the USGS is to use our expertise to ensure that land-use decisions will be unbiased and based on the best available scientific information. I do not feel that USGS quantitative assessments are scientifically valid, nor do I feel they serve the public interest.

I restrict my comments on the quantitative assessment procedure to the single issue of estimation of undiscovered deposits because this step is critical to the entire process. Every step of the quantitative estimation process is dependent on the initial input of the estimation of undiscovered deposits. If this input is flawed, arbitrary, or untestable, then results of the entire process are flawed, arbitrary, or untestable. The discussion of weaknesses in later parts of the process is therefore of secondary importance.

I remain completely unconvinced that estimation of undiscovered mineral deposits, either independently by individuals in a group or through group consensus, has any validity. Because these estimates are not testable, they are not, in any scientific sense of the word, quantitative. They are subjective estimates and attaching numbers to a subjective estimate of mineral deposits gives a false sense of credibility to the estimates. The more sophisticated and opaque the statistical treatment applied to the subjective estimates, the more "real" they appear to the end user, even thought the validity of the subjective estimates is unchanged. The interviews with users of our mineral information summarized in the University of Arizona report convince me that quantitative estimates are both misunderstood and misused. It is apparent that land use planners do not appreciate the subjectivity and uncertainty of these estimates.

All concerned with the mineral assessment process express a desirability of including error limits in the quantitative assessments. However, the numbers of undiscovered deposits, whether expressed as an estimated cumulate probability function or an estimated probability density distribution, is a non-quantifiable, subjective estimate, so the concept of realistic error limits becomes meaningless. Estimation of the errors that accumulate in the statistical manipulation that follows serves to further disguise the subjective basis on which the process is founded.

I have observed the process of estimation of undiscovered deposits and believe that it is completely arbitrary. The numbers produced are more influenced by the makeup of the evaluation committee, their personalities, and their personal knowledge of the area in question rather than by the geologic constraints of the area. In practice, the driving principle seems to be to choose a non-astonishing number of deposits. Mineral deposits are quite astonishing for their lack of occurrence in some "favorable" terrains and their anomalous abundance in other areas. I believe that it is preferable to do something as simple as measuring the area of a map defined as favorable and multiplying that area by a fixed factor for discovered mineral deposits per km^2 derived from a well-explored, geologically similar area. This method is clearly flawed, but at least it is quantifiable and repeatable, not arbitrary and capricious.

Although the University of Arizona report indicates many reasons why short term weather forecasting of precipitation is not a valid analog for estimation of mineral deposits, the success of precipitation forecasting is repeatedly used to justify the application of subjective probability for mineral resource assessment. A better analogy would be to compare our estimates to the Farmer's Almanac day-by-day prediction of weather. The predictions of daily weather in the Farmer's Almanac are based on a knowledge of the general seasonal weather patterns, just as our estimates of undiscovered mineral deposits are based on geological analogy to favorable terrains. However, any educated person knows that specific daily forecasts in the Farmer's Almanac have no validity, even though they conform to long-term weather patterns. No advantage is gained by the specific prediction of rain on a given date, but if the uninitiated individual uses that prediction for planning, much can be lost. If the National Weather Service (NWS) were to adopt this approach and publish specific predictions of weather for each day of the year one year in advance, there would be considerable criticism and the reputation and effectiveness of the NWS would be compromised. I contend that this is precisely the position in which the USGS now finds itself with regard to our quantitative assessments. We gain nothing by using subjective probability estimates to calculate gross inplace value of metal beyond the information contained in a qualitative assessment of mineral potential. However, we risk losing our credibility, losing our objectivity, and we are contributing to poor-land use planning.

I believe that multidisciplinary mineral resource evaluation is one of the services that the USGS should provide to the nation. I feel that the nation is better served by realistic qualitative estimates of undiscovered mineral potential that include explicit statements addressing the subjectivity and uncertainty of the estimates. It is clear that land-use planners and decision makers want dollar values of mineral potential that can be compared directly to dollar values for alternative uses. It is not our role to make the life of a land-use planner easy by providing oversimplified choices between the largest estimated dollar values in different use categories. It is our role to provide them with the best information available so they can perform their job well. Land-use planners and decision makers need to critically evaluate all available data and make some hard choices.

It is clear that many of our mineral information customers who were interviewed for the University of Arizona report have not been adequately served by the mineral information they received from the USGS. Two reasons for this are that our mineral resource appraisals are not written in a manner appropriate for their end use and that the land-use planners are not adequately equipped to understand the realities of geological uncertainty. It is, therefore, incumbent on the Survey to (1) tailor our mineral assessments to meet the needs of the users and (2) involve our scientists in education of the customers so that our data will be a useful contribution to the decision making process. I think there is an important distinction to be made here. We are not obligated to give our customers what they want (commonly simple numbers, easy choices, or justification for politically motivated decisions). Instead, we are obligated to give them what they need to make good land-use decisions (that is, an objective appraisal of the best geological information available combined with a realistic appraisal of our uncertainties presented in terms they can understand).

I am well aware that the motivation for doing quantitative mineral resource assessment is, in part, a direct response to request from Congress. We scientists, however, have an obligation to follow our conscience. It is time for the USGS to take the honest approach and inform Congress that the goal of quantitative assessment of the Nation's undiscovered resources is not attainable now or in the near future. We are making progress toward that goal, and we still have much of value to offer the nation in terms of mineral and land use policy. We, as an agency or as individuals, should never lose sight of our goal of "Earth Science in the Public Service," or ignore our responsibilities for the sake of political expediency or continued funding for our programs. Most importantly, we should not promise what we can not deliver.