Developments in Mineral Deposit Modeling

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JAMES D. BLISS, Editor

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Introduction and Overview of Mineral Deposit Modeling

By Dan L. Mosier and James D. Bliss

INTRODUCTION

Activities in mineral deposit modeling have continued to develop on several fronts since the publication of "Mineral Deposit Models," edited by Cox and Singer (1986). That bulletin is a collection of 87 descriptive deposit models and 60 grade and tonnage models prepared by many authors both from within and outside of the U.S. Geological Survey. The present bulletin continues that effort with the addition of new or revised models. Before these models are introduced, a review of modeling as used here is provided as well as an overview of mineral deposit modeling since the publication of Cox and Singer (1986).

EXPLANATION OF DESCRIPTIVE AND GRADE AND TONNAGE MODELS

A general definition of a mineral deposit model as found in Cox and Singer (1986, p. 2) is "the systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. The model may be empirical (descriptive), in which instance the various attributes are recognized as essential even though their relationships are unknown; or it may be theoretical (genetic), in which instance the attributes are interrelated through some fundamental concept."

With a descriptive model in hand, member deposits can be recognized and their size and grades can be used to develop a grade and tonnage model. Ideally, the data should be the estimated premining tonnages and grades. Estimates should be for the tonnage at the lowest cutoff grades. The grade and tonnage model is presented in a graphical format in order to make it easy to display the data and to compare this type of deposit with other deposit types (Cox and Singer, 1986). The plots (figs. 2–19, 21, 22, 25–34) show either grade or tonnage on the horizontal axis, whereas the vertical axis is always the cumulative proportion of deposits. The units are all metric, and a logarithmic scale is used for tonnage and most grades. Each dot represents an individual deposit, and the deposits are cumulated in ascending grade or tonnage. Owing to limitations in the plot routine, a point will not be shown on the plot if it has exactly the same value as the vertical axis (for example, the Keystone-Union deposit is not displayed in figure 12). On rare occasions, values less than the value of the vertical axis are not shown as well (for example, Hog Ranch is not displayed in figure 16). Smoothed curves, representing percentiles of a lognormal distribution that has the same mean and standard deviation as the observed data, are plotted through the points. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distributions are constructed.

OVERVIEW OF PAPERS ON DEPOSIT MODELING

A number of papers on deposit modeling and support data have been published in various places since 1986. These papers focus on descriptive deposit models and (or) grade and tonnage models that are useful for resource assessments. Some of the papers document the models originally published in Cox and Singer (1986), others attempt to improve the models' applicability in resource assessments, and still others present new deposit models. The following overview is presented chronologically by type of study. Model numbers shown in parentheses follow the format used in Cox and Singer (1986), with some modifications.

Several papers not cited in Cox and Singer (1986) document the data used in some of the grade and tonnage models. Orris (1985) provided data for 93 bedded barite deposits (No. 31b), of which less than 30 had grade and tonnage information. Additional tabulated data for each deposit include volume of deposit, associated minerals, host formation, host age, host lithology, and references. Orris and Bliss (1985) provided data for 330 gold placers (No. 39a). The data for each deposit include placer type, mining method(s), production history, bedrock source, and

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references. Bagby and Berger (1986) presented data for 31 of the deposits used in the grade and tonnage model for carbonate-hosted Au-Ag (No. 26a) and discussed the geologic characteristics of the deposit type, which (in order to accommodate the noncarbonate host rocks) they called the sediment-hosted, disseminated precious-metal deposits. A number of tables provide information on host rocks, igneous rocks, structure, mineralization age, alteration, ore bodies (form, mineralogy, gold or silver site, veins), trace-element geochemistry, tonnage, grades, and references for selected deposits. Also included are plots of trace-element variations, sulfur isotopic variation in sulfides and barite, gold grade versus tonnage, and cumulative frequency distributions of tonnages and grades. Bliss and Jones (1988) provided data for 357 deposits used to develop the grade and tonnage model for low-sulfide Au-quartz veins (No. 36a). Tabulated data for each deposit include tonnage, grades, mineralogy, and references. This paper also evaluated the frequency of occurrence, order of abundance, and assemblages of ore minerals, and displayed the results in tables and pie diagrams.

Grade and tonnage models can provide insight into geologic processes. A paper by Mosier and others (1986) documented three types of epithermal gold-quartz-adularia deposits, based on the types of basement rocks underlying the host volcanic pile. The Sado type (No. 25d) occurs over an igneous-dominant basement, the Comstock type (No. 25c) over a sedimentary-dominant basement, and the Creede type (No. 25b) over a saline-carbonate-dominant basement. Each type has different tonnages and grades, particularly among the base metals. These models indicate that basement rocks probably influence the character of the ore fluids. Grade and tonnage models are shown for the three deposit types. Tabulated data for each district include tonnage, grades, basement rocks, and references. A study by Page and others (1986) examined the platinum-group element values of 250 deposits used in the grade and tonnage model for minor podiform chromite deposits (No. 8a) to test for homogeneity of platinum-group elements within the deposit type. Analysis of variance of platinum-group element content demonstrated that deposits within terranes were not significantly different. Relatively small but significant differences in the combined medians for Ir, Ru, Rh, and Pt exist (at the 1 percent level) among terranes, but the reasons for these differences are not clear. Also, it was discovered that the platinum-group element abundances of minor podiform chromite deposits are similar to those of major podiform chromite deposits (No. 8b). A part of the analysis of platinum-group elements is tabulated, and grade models for individual platinum-group elements are shown.

There are three new descriptive deposit models based on one or two examples. These new models have not been included in this bulletin because they do not have associated grade and tonnage models. Cox and Rytuba (1987) developed a descriptive model for Lihir Island gold (No. 25), a gold deposit occurring in the root of a volcanic center. This deposit, in Papua New Guinea, is the only known example of its type. Tosdal and Smith (1987) developed two descriptive models for deposits in regionally metamorphosed eugeosynclinal rocks. (The model numbers assigned to these models should have been 36 rather than 37, in that they are not hosted in metasedimentary rocks.) First, the gneiss-hosted gold model (No. 37c) is based on the Tumco mine group and American Girl–Padre y Madre mines in the Cargo Muchaco Mountains, southeastern California. This deposit type either occurs in lenticular bodies of biotite-magnetite-quartz gneiss of volcanic or granitic origin, subparallel to the gneissic foliation, or is associated with low-angle ductile shear zones. Second, the gneiss-hosted epithermal gold model (37d) is based on the Mesquite mine, southern California, which occurs in breccia fillings, fracture fillings, and high-angle veins that cut subhorizontal amphibolite-facies metavolcanic gneiss and plutonic gneiss. The Mesquite deposit is similar to epithermal quartz-adularia-gold vein deposits (Sado type?), except that it is hosted in metaigneous rocks—this raises the question of whether or not it should be treated as another type of deposit.

Attempts to distinguish subtypes within existing deposit models have been carried out in several papers. Heald and others (1987) successfully distinguished two types of volcanic-hosted epithermal precious- and base-metal deposits through a detailed examination of the characteristics of 17 well-documented districts. These characteristics include the ore, gangue, and alteration mineral assemblages; the spatial and temporal distributions of mineral assemblages; the host-rock composition; the age relations between ore deposition and emplacement of the host rock; the size of the district; the temperatures of mineral deposition; the chemical composition and origin of the fluids; the paleodepth estimates; and the regional geologic setting. Differences in many of these characteristics were documented in the two major types designated the acid-sulfate type and the adularia-sericite type. It was found that the two most important factors for distinguishing these types are (1) the vein and alteration mineral assemblages and (2) the age relations between ore deposition and emplacement of the host rock. Bliss and others (1987) examined gold grades and volumes to distinguish among gold placer types but found that they could not distinguish most types of gold placers, except for the alluvial-plain and fan placers. However, when these data were coupled with mining methods, estimates could be made of the amount of gold remaining when a placer mine changes from small-volume mining (such as panning, sluicing, or drift mining) to large-volume mining (such as dredging or hydraulic mining). New descriptive and grade and tonnage models for two subtypes of Au-bearing skarn deposits were designated Au skarn and byproduct Au skarn (Orris and others, 1987; Theodore and others, 1990). Although the two subtypes do not differ in geologic characteristics or tonnages, there are significant differences in the median gold and silver grades. Tabulated data which are largely overlapping can be found in both Orris and others (1987) and Theodore and others (1990). Data tables give name, location (mining district), formation age/name, igneous rocks, age, ore minerals, gangue minerals, ore control, tonnage, gold grade, silver grade, base metal grades, comments and references. Cox and Singer (1988) examined the distribution of gold in three types of porphyry copper deposits designated as porphyry copper-gold (No. 20c), porphyry copper-gold-molybdenum (No. 17), and porphyry copper-molybdenum (No. 21a). This paper defines the three types of porphyry copper deposit models used in Cox and Singer (1986). It was concluded that gold content alone could not define porphyry copper-gold systems, but that the three types differed significantly in Cu-Mo-Au content, magnetite content, deposit morphology, depth of emplacement, and tonnage. Mosier and Page (1988) distinguished among four subtypes of volcanogenic manganese deposits (No. 24c) based on tectonic environments. These subtypes are supported by differences in tonnage, grades, volume, lithology, mineralogy, and deposit morphology. The new models—called Franciscan (No. 24c.1), Cuban (No. 24c.2), Olympic Peninsula (No. 24c.3), and Cyprus (No. 24c.4)—each have individual descriptive and grade and tonnage models and mineral-deposit density values.

Berger and Singer (1987) developed a new grade and tonnage model for hot-spring gold-silver deposits (No. 25a) based on 10 deposits in Nevada and California.

The importance of industrial minerals in economic development has been long recognized in national and international assessments and commonly far exceeds that of fuels and metals. However, they usually receive only a passing reference. This is because, in part, they cannot always be modeled using standard grade-tonnage models. Orris and Bliss (1989) took a step in resolving this impasse by formally defining three new model types for describing industrial mineral deposits. These include (1) the contained-material model applicable to commodities where the material must meet a minimum level of purity (for example, feldspars, travertine); (2) the impurity model for commodities where the distribution of impurities affects utilization (for example, iron or aluminum in glass sand); and (3) the deposit-specific model applicable to commodities that are unique (for example, the distribution of the proportion of gem-quality diamonds, and the average diamond size in diamond kimberlite pipes). Descriptive models of 22 industrial mineral deposit types prepared by 13 contributors can be found in a report edited by Orris and Bliss (1991). Sutphin and Bliss (1990) compared amorphous and disseminated deposit types using graphite grade, tonnage, and contained carbon. While differences are clearly present in the carbon grade and tonnage between the two types, this was not the case for contained carbon.

A graphic method was develop by Bliss and others (1990) to show how tonnage data can be used to guide in the selection among the 71 deposit types (with grade and tonnage models) during the search for deposits amenable to small-scale mining. McKelvey and Bliss (1991) compared the contained copper, lead, zinc, gold, and (or) silver of a median deposit for all deposit types having grade and tonnage models with the 1989 world production of copper, lead, zinc, gold, and silver. This work shows the importance of porphyry deposit types as a source of most of these metals.

NEW DEVELOPMENTS IN DEPOSIT MODELING

This volume will be one of several pertaining to developments in deposit modeling. Future volumes will include studies on predictive resource assessments, exploration modeling, and spatial modeling. Here, we present six new descriptive models, nine new or revised grade and tonnage models, and a numerical method of matching mineral deposits to deposit models. New descriptive models were developed for thorium-rare-earth veins (No. 11d), distal disseminated Ag-Au (No. 19c), solution-collapse breccia pipe uranium deposits (No. 32e), oolitic ironstones (No. 34f), laterite-saprolite Au (No. 38g), and detachment-fault base and precious metals (No. 40a). New grade and tonnage models include thorium-rare-earth veins (No. 11d), distal disseminated Ag-Au (No. 19c), Sierran kuroko (28a.1), solution-collapse breccia pipe uranium deposits (No. 32e), oolitic ironstones (No. 34f), Chugach-type low-sulfide Au-quartz veins (36a.1), and laterite-saprolite Au (No. 38g). Revised existing grade and tonnage models include hot-spring Au-Ag (No. 25a) and sediment-hosted Au (No. 26a). The principal use of grade and tonnage models is for making quantitative mineral resource assessments. A recent example can be found in a paper by Reed and others (1989) for the Seward Peninsula, Alaska. They used grade and tonnage models for Sn skarns (Menzie and Reed, 1986a), replacement Sn (Menzie and Reed, 1986b), Sn veins (Menzie and Reed, 1986c), and Sn greisen (Menzie and Reed, 1986d). These models, together with estimates of the number of undiscovered deposits, allow computer simulations to be made that estimate the amount of Sn in undiscovered deposits of the Seward Peninsula.

A new development by R.B. McCammon is the numerical characterization of deposit models. This method can be used to assign the appropriate deposit type to a target mineral deposit, permitting a quantitative matching of the description of a mineral deposit to one or more descriptive models. To facilitate the scoring used to do this, worksheets are provided for each of the descriptive models found in Cox and Singer (1986).

The descriptive model of thorium-rare-earth veins (No. 11d), by Mortimer Staatz, is based on data from North American deposits. The grade and tonnage model of thorium-rare-earth veins by J.D. Bliss is different from those developed for most other deposit types modeled to date in that none of the thorium-rare-earth deposits have been mined extensively. Instead of using grades and tonnages from production plus reserves plus resources, the model is based on estimates of size of unworked veins and the median values of rock analyses. The grade and tonnage model is based on 28 deposits in the United States and one in Mexico.

The descriptive model of distal disseminated Ag-Au (No. 19c) by D.P. Cox, was developed during the analysis of Nevada's resources project for deposits that (1) are richer in Ag relative to Au, (2) contain Zn, Pb, Cu, and Mn, (3) occur near igneous intrusions, and (4) are distally associated with skarns and polymetallic veins and replacements. Some of these deposits were formerly classified as carbonate-hosted Au-Ag deposits (No. 26a; Berger, 1986a). The grade and tonnage model, by D.P. Cox and D.A. Singer, is based on data for 10 deposits from the United States, Mexico, and Peru.

The grade and tonnage model of hot-spring Au-Ag (No. 25a), by B.R. Berger and D.A. Singer, is a revision of an earlier model by Berger and Singer (1987). It is in response to the availability of grade and tonnage data for more deposits and of revised data for others.

The grade and tonnage model of sediment-hosted Au (No. 26a), by D.L. Mosier, D.A. Singer, W.C. Bagby, and W.D. Menzie, is a revision of an earlier model by Bagby and others (1986). It is in response to the availability of grade and tonnage data for more deposits and to a new definition for a deposit, which combined or separated some deposits. The result of this new descriptive definition is that some deposits included in the earlier model have been reassigned to distal disseminated Ag-Au (No. 19c) by D.P. Cox.

The grade and tonnage model of Sierran kuroko deposits (No. 28a.1), by D.A. Singer, was developed because Triassic or Jurassic deposits of the kuroko massive sulfide (No. 28a) in North America and, perhaps, South America are significantly smaller than the worldwide kuroko group as described by Singer and Mosier (1986).

The descriptive model of solution-collapse breccia pipe uranium deposits (No. 32e), by W.I. Finch, is based on deposits from the Colorado Plateau of Arizona. This deposit type is most likely an important future source of uranium. The grade and tonnage model, by W.I. Finch, C.T. Pierson, and H.B. Sutphin, is developed from data on eight deposits in Arizona. The model is atypical in that the deposit tonnages have a very narrow range and the lognormal distribution was rejected. This is also true for uranium oxide grades.

The descriptive model of oolitic ironstones (No. 34f), by J.B. Maynard and F.B. Van Houton, is an important addition to the two existing descriptive models for iron deposits including Superior Fe (Cannon, 1986b) and Algoma Fe (Cannon, 1986a). The grade and tonnage model of oolitic ironstones, by G.J. Orris, is based on 40 deposits from North and South America, Europe, and China.

The grade and tonnage model of Chugach-type low-sulfide Au-quartz veins (No. 36a.1), by J.D. Bliss, was developed because low-sulfide Au-quartz veins in and adjacent to the Chugach National Forest, Alaska, are significantly smaller and have lower Au grades than the low-sulfide Au-quartz veins (No. 36a) elsewhere in the world (modeled by Bliss, 1986). This model and the previous one developed for kuroko massive sulfide exemplify the flexibility of grade and tonnage models in conforming to a specific geologic criterion that is observed but for which the reasons are not yet clear. These and other identified subtypes represent opportunities to identify either economic and (or) geologic factors causing these differences.

Au placers have been classified using various criteria, including types and modes of transport. Placers are identified as "alluvial" when concentration has occurred in streams and rivers, "colluvial" when Au has been transported with surface material by downhill creep away from the bedrock source, and "eluvial" when a deposit develops in situ over or adjacent to the bedrock sources (Boyle, 1979). The descriptive model of laterite-saprolite Au (No. 38g), by G.E. McKelvey, is of the latter type, but it is a type that develops primarily from chemical rather than physical processes. Because these deposits develop chemically, they have been classified here as a residual rather than a depositional type of deposit. This continuum between the two types is an enigma in classification schemes and should really be represented by both types—hence its inclusion in parentheses in the depositional type of deposit (see app. A). Au is transported in water under near-surface temperature and pressure conditions, and deposition appears to be controlled by ground-water levels in areas that have or have had tropical and subtropical climate conditions. The ubiquitous nature and the hydrogeologic and paleoclimatic constraints of this deposit type could affect the applicability of the model (depending, of course, on the level of information available) in resource assessments. The deposits used in the grade and tonnage model of laterite-saprolite Au, by J.D. Bliss, are based on the model (No. 38g) by G.E. McKelvey. The grade and tonnage model is developed from data on nine, some which are poorly defined, deposits from Guyana, Western Australia, and Surname. Like the thorium-rare-earth model (No. 11d), these deposits have yet to be worked extensively.

The preliminary descriptive model of detachment-fault-related polymetallic deposits (No. 40a), by K.R. Long, is part of the continued effort to effectively describe this emerging deposit type(s). The model is preceded by a paper giving an evaluation of available descriptive and grade-tonnage data, including a list of distinguishing characteristics of detachment-fault-related mineralization. Also given is a list of deposit types commonly confused with detachment-fault-related mineralization. The descriptive model of gold on flat faults (No. 37b) by Bouley (1986) is an earlier model for this deposit type. An important revision of this model, using lithologic-tectonic environment criteria of Cox and Singer (1986, table 1), is its reclassification into the new categories of "Regional Geologic Structures" and "Extended Terranes" (see app. A).

Each of the grade and tonnage models presented in this bulletin is accompanied by a list of the deposits, locations, and, in some cases, the grade and tonnage data. The location is shown by an abbreviated form that identifies either the country or the country plus a state or province. A list of abbreviations is provided in appendix B.

Descriptive and grade and tonnage models are useful in mineral resource assessments, but, as demonstrated in these studies, they may have wider applications. Not only do these models help to define the many deposit types present, but they also help to decipher the complexities of mineral concentrations and provide insight on the genetic or geologic processes responsible for their formation.

Numerical Mineral Deposit Models

By Richard B. McCammon

INTRODUCTION

The numerical mineral deposit models described in this paper are a part of a continuing effort to develop more quantitative approaches to assessing undiscovered mineral resources in graphically defined areas. These models have their origin in the descriptive mineral deposit models of Cox and Singer (1986). As defined by Cox and Singer, descriptive mineral deposit models represent a systematic arrangement of information summarizing the essential attributes (properties) of a class of mineral deposits. Such information is available usually in carrying out regional mineral resource assessments (Shawe, 1981). Descriptive mineral deposit models provide the geologist with a link between deposit types and geologic environments. Establishing links within a given area is the first step of the three-step assessment process described by Singer and Ovenshine (1979). The definition of this step is the delineation of areas according to the types of deposits that the geology will permit.

This decision as to which types of deposits are permitted by the geology of an area is subjective. The decision is dependent almost entirely on the experience of the geologist performing the assessment. The more experienced the geologist, the more likely the models that are selected will be the right ones. Consequently, a team approach involving geologists having knowledge about different deposit models will ensure that a wide range of possibilities will be considered. The best approach is to give the team access to geologists with expert knowledge about the deposit models being considered. The idea of giving the geologist access to experts gave rise to Prospector, an expert system developed during the mid-1970's to aid the geologist in the search for hidden deposits (Duda, 1980). Expert systems are computer programs that achieve competence in performing specialized tasks by reasoning about the task and the task domain (Feigenbaum and others, 1988). During the years of its development, which lasted until 1983, Prospector was regarded as a serious attempt to model the decision-making process involved in the application of deposit models in mineral exploration.

Since 1983, much has changed. Prospector II, the successor to Prospector, has been developed at the U.S. Geological Survey (McCammon, 1989). Two major developments have included (1) the format used to represent deposit models, and (2) the algorithm used to classify mineral occurrences, prospects, and deposits. These developments were necessary in order to (1) acquire a more comprehensive, economical, and adaptable deposit model format, and (2) accommodate changes in the use of descriptive mineral deposit models in regional mineral resource assessments (Singer and Cox, 1988). Numerical mineral deposit models have emerged as a result of these developments.

NUMERICAL MINERAL DEPOSIT MODELS

Numerical models differ from descriptive models in that numerical scores are associated with each model. A maximum score is obtained when the geologist concludes that all of the attributes of a particular model are present. However, maximum scores for different models differ. The reason is that models are made up of different attributes. In particular, two scores—one that is positive, and one that is negative—are associated with each of the attributes. A positive score reflects the degree to which a model is suggested by the presence of a particular attribute. A negative score reflects the degree to which a model is negated when a particular attribute is absent. If, on the other hand, the absence of an attribute is suggestive of a model, a positive score is associated with its absence, and a negative score is associated with its presence. Consequently, the states of presence and absence correspond, respectively, to the conditions of sufficiency and necessity in Prospector (Duda, 1980).

The attributes of numerical models are grouped into headings similar to those of descriptive models. The current headings in the numerical models are the "AgeRange," "RockTypes," "TextureStructure," "Alteration," "Mineralogy," "GeochemicalSignature," "GeophysicalSignature," and "AssociatedDeposits." In an attempt to represent the linkages within these attributes, a taxonomy has been created that facilitates these linkages. For example, under RockTypes, "Granite" is defined as a "kind-of" Felsic-plutonic RockType, which is a "kind-of" Plutonic RockType, which is a "kind-of" Igneous RockType. Thus, numerical models are characterized by generalized attributes as well as by specific attributes. This "kind-of" characterization aids greatly in limiting the number of models considered at any one time. The taxonomy that defines the attributes of the numerical models described in this paper is given in appendix C.

Virtually all of the terms listed in the taxonomy in appendix C appear as attributes in one or more of the descriptive models in Cox and Singer (1986). In creating the numerical models, the decision was made to preserve to the maximum extent possible the terminology used by the authors who contributed the descriptive models. As a result, the taxonomy does not contain terms not found in the descriptive models. Thus, the taxonomy is not a glossary of geology, but rather a glossary of terms used in the descriptive models.

Not all of the headings contained in the descriptive models are included in the numerical models. The reason is that it is not yet possible to define a taxonomy and to assign positive and negative scores for attributes that relate to headings such as "TectonicSetting," "DepositionalEnvironment," and "OreControls". Despite these shortcomings, the numerical models described in this paper offer a further means of quantifying the decision as to which mineral deposit models are permitted by the information collected in regional mineral resource assessments.

WEIGHTING OF THE ATTRIBUTES

The task of assigning positive and negative scores to attributes in the numerical models were aided greatly by the indices prepared by Barton (1986a, b) and Cox (written commm., 1987). The indices contain information on the frequency of occurrence of geochemical anomalies, minerals, and types of alteration according to the descriptive models contained in Cox and Singer (1986). Associated with each attribute was an index number ranging from +5 down through 0 to –5 in a system similar to Prospector (Duda and others, 1977). The numbers represent the commonness or rarity of each attribute. It was the intent to have the numbers 1, 2, 3, 4, and 5 correspond, respectively, to the 0–10, 10–30, 30–70, 70–90, and 90–100 percent frequency relationship between the attribute and the deposits represented by the models. In almost all instances, the numbers assigned were "best" guesses based on experience. In the future, the compilation of such data would make the assignments less subjective. For the numerical models, the attributes were each assigned a positive and negative number for each model according to the levels given in table 1. Negative levels correspond to the frequency of occurrence and express how the absence of an attribute with respect to a particular model is to be weighted. Positive levels express how the presence of an attribute is suggestive of a particular model. For instance, a Leucogranite is highly suggestive (+4) of a Sn-greisen deposit model. The known absence of Felsic-plutonic rocks in an area, however, virtually precludes (–5) the existence of Sn greisen deposits. Generally, the numbers were assigned so that they reflected as near as possible the context in which the attributes were defined by the compilers of each of the models. In the final analysis, however, the assignment is a trial-and-error process.

Table 1. Quantization levels for presence/absence of particular mineral deposit

State	Level	Verbal description
Degree of sufficiency		
	5	Very highly suggestive
	4	Highly suggestive
Presence	3	Moderately suggestive
	2	Mildly suggestive
	1	Weakly suggestive
Degree of necessity		
	−1	Infrequently present
	−2	Occasionally present
Absence	−3	Commonly present
	−4	Most always present
	−5	Virtually always present

In many cases, it was not possible even by trial and error to assign positive and negative numbers to the attributes. A rationale for assigning numbers was simply lacking. In these cases, default numbers of +2 and –2, respectively, were used.

SCORING OF THE ATTRIBUTES

The score that was assigned to an attribute in a numerical model was dependent upon the heading to which it belonged. In reviewing the descriptive models, it was recognized that the number of attributes within a heading varied from one model to the next. Different headings contained a different number of attributes. As a result, it was necessary to devise a weighting scheme that would take this into account. The intent was to balance the scores associated with each heading with the scores assigned to each attribute within each heading. In order to accomplish this, the levels in table 1 were associated with the scores given in table 2. Thus, the score associated with the highest positive (and negative) level for each heading reflects both its relative importance in defining a particular model and the number of attributes it contains. For example, the maximum score for a particular rock type cannot exceed

Table 2. Quantization levels and associated scores for mineral deposit models

[Abbreviations: Age, AgeRange; Rk, RockTypes; Alt, Alteration; Min, Mineralogy; Gx, GeochemicalSignature; Gp, GeophysicalSignature; Dep, AssociatedDeposits. Default levels: 2, presence; –2, absence]

	Presence						Absence				
Level	5	4	3	2	1	0	–1	–2	–3	–4	–5
Age:	100	40	40	40	40	0	–100	–100	–100	–100	–100
Rk:	75	60	45	30	15	0	–5	–10	–45	–60	–75
Alt:	400	300	200	100	50	0	–2	–10	–100	–200	–400
Min:	75	60	45	30	15	0	0	–5	–10	–30	–75
Gx:	75	60	45	30	15	0	0	–5	–10	–30	–75
Gp:	250	150	50	25	10	0	–10	–50	–100	–200	–250
Dep:	400	320	200	150	75	0	–50	–100	–200	–300	–400

75. However, virtually all of the numerical models are characterized by several rock types. Thus, if all types are present, the total score for rock types will be many times 75.

UNCERTAINTY IN THE EVIDENCE

In Prospector, the geologist was asked to state the degree of certainty about the presence or absence of evidence (Duda and others, 1977). The degree of certainty was expressed on a scale from +5 through 0 to –5 for which +5 was taken as absolute certainty about the presence of the evidence and –5 was taken as absolute certainty about the absence of the evidence. A value of 0 was taken to mean indifferent or "don't know." The degree of belief expressed by the geologist was used to adjust the strength of the rules relating to the evidence.

For the numerical models, a simpler method has been devised. For a given model, an attribute is judged as being present, suspected of being present (present?), missing, or absent. Absence is treated as the attribute having been looked for but not found. Missing is treated as the default, meaning that the attribute is neither present or suspected of being present nor known to be absent. If all of the attributes within a heading are missing, a default score of 0 is assigned to the heading. Thus, if no information exists on the known deposits in an area, the heading "AssociatedDeposits" is assigned a 0 score. If only some of the attributes within a heading are missing, the attributes that are missing are assigned the score corresponding to the level of –1. Attributes suspected of being present are assigned the next less positive level than the level associated with their presence. Experience to date indicates that this treatment of uncertainty in the observations is sufficient for taking into account the quality of the information available in regional mineral resource assessments.

The "AgeRange" heading is treated differently from the other headings. A statement that was made for many of the descriptive models in Cox and Singer (1986) was that deposits of the type represented by the model are restricted mainly to one interval of geologic time but may be of any age. In this sense, "AgeRange" is not particularly restrictive for these models. It was decided to assign a single score to the "AgeRange" heading—namely, a score of +100 if any part of the interval specified by the geologist lies within the interval specified by the compiler of the model, a score of –100 if it did not, a score of +40 if the geologist was uncertain about the "AgeRange," and a score of 0 if no information is available. As defined by Singer and Cox (1988), "Age" refers to the age of the event responsible for the formation of the deposit. For many areas, this age is unknown.

"TextureStructure" is not used as a basis for numerical scoring because it describes the morphology of deposits, and morphology is generally not well recognized at the time an assessment is made. If the morphology is known, the geologist tends to focus quickly on those models whose deposits exhibit these characteristics. The attributes within "TextureStructure" serve more as a checklist for identifying the types of deposit models to be considered in any given situation.

WORKSHEETS FOR NUMERICAL MODELS

Worksheets for the numerical mineral deposit models are given in appendix D. The model numbers for the numerical models correspond to the model numbers for the descriptive models in Cox and Singer (1986). The worksheets are designed to be reproduced and used to score geologic descriptions of areas that may contain mineral occurrences, prospects, or deposits. The worksheets can be used to determine numerically the degree to which a given geologic description matches a particular model. If, after scoring, there is doubt about the choice of a particular model, reference can always be made to the original model contained in Cox and Singer (1986).

A WORKED EXAMPLE

To illustrate how a person might fill in a worksheet, the following example is taken from field observations and subsequent thin-section studies and geochemical analyses of a massive, quartz-rich, seriate to porphyritic Tertiary granite that occurs in the White Mountains of east-central Alaska (Weber and others, 1988). An earlier investigation (Dean Warner, written commun., 1984) suggested that the granite might be a host for Sn greisen deposits. With this in mind, the worksheet for the Sn greisen deposit model was filled in using the scores in table 2 based on the information that was available. The worksheet along with the scores of the attributes, is shown in table 3.

In the example, the age of the granite was established to be Tertiary and was considered to be the age of any mineralization that may have occurred. As a Tertiary age falls within the Phanerozoic age interval, a score of 100 is assigned to Phanerozoic on the worksheet.

Muscovite-leucogranite was identified as the major rock type present. On the worksheet, Muscovite-leucogranite is assigned a level of 3 for presence. Referring to table 2, the score that is associated with a level of 3 for RockTypes (Rk) is 45. Therefore, the score for Muscovite-leucogranite is 45. Taking note that Muscovite-leucogranite is a kind-of Leucogranite, Leucogranite is also present therefore. On the worksheet, Leucogranite is assigned a level of 4 for presence. Referring to table 2, the score that is associated with a level of 4 for Rk is 60, and therefore the score assigned to Leucogranite on the worksheet is 60. By similar reasoning, Granite and Felsic-plutonic RockTypes are also present, and by referring to table 2, they are each assigned the score of 75. The remaining RockType (Biotite-leucogranite) was missing—that is, neither its presence nor its absence could be confirmed. On the worksheet, Biotite-leucogranite is assigned a level of –2 for absence. As Biotite-leucogranite is considered missing rather than being absent, referring to table 2, the score associated with one level higher—that is, a level of –1—is –5, and therefore the score assigned to Biotite-leucogranite on the worksheet is –5.

In a similar way, scores were assigned to the remaining attributes under the different headings on the worksheet. Under each heading, the score assigned to each attribute was based on the score associated with the level specified for the attribute depending on whether the attribute was judged to be present, suspected to be present (present?), missing, or absent. Attributes whose presence-absence levels were not specified were assumed to be 2 and –2, respectively. Under headings for which there was no information available, (AssociatedDeposits, for instance, in this example), the score assigned to all of the attributes was 0.

When scores for all of the attributes were assigned, the partial scores—that is, the total scores under each heading—were calculated.

The total score in this example was 1,055 out of a possible maximum score of 2,930. Although this score is relatively low compared with the maximum score, scores for the four next highest scores among all of the other models obtained using Prospector II were 637 out of 2,430 for Sn veins, 576 out of 2,445 for Climax Mo, 559 out of 1,730 for Porphyry Sn, and 466 out of 1,795 for W veins. It should be noted that absolute rather than relative scores are used for ranking purposes. It was concluded that even though this area could not be considered a likely prospect for Sn greisen deposits, if deposits should exist, they most likely would be of this type rather than any other type.

This example brings out a problem that has persisted throughout the development of the models: the continuing confusion between regional and local characteristics. In performing regional mineral resource assessments, the scores obtained in applying the numerical models tend to be low, largely owing to the lack of information. At the same time, application of a particular model in an area in which the information is sufficient to conclude that, in all probability, one or more deposits of the type represented by the model do not exist results in large scores because the model, in detail, is not discriminating enough. Thus, even though such differences in scores that are obtained by application of the models in different areas are probably real and usable, reliance on absolute scores could lead to serious misinterpretation, and for this reason, caution is urged in applying the results indiscriminately.

TEST OF NUMERICAL MODELS

As a test of the numerical models, an experiment was performed that was designed to compare the results of classifying 124 lode deposits in Alaska by a panel of eight geologists using the Cox and Singer (1986) classification with the results obtained by classifying the same deposits using the numerical models. The 124 lode deposits were classified by the panel using the descriptions of the deposits given in Nokleberg and others (1987). Using the same descriptions, the 124 deposits were classified by Prospector II using the numerical models. The results of the experiment are summarized in table 4. The 124 deposits were classified by the panel of geologists into 27 different deposit types using the Cox and Singer classification. The five columns on the right in table 4 record the frequency of the rank order in which each of the 124 deposits was clas-

Table 3. Worksheet for numerical model of Sn greisen deposits

Model 15c

Worksheet for Numerical Model of Sn greisen deposits

Deposit, Prospect, or Occurrence: Cache Mountain
Location: White Mountains, East-Central Alaska
Description: Quartz-rich seriate porphyritic granite with ubiquitious miarolitic cavities and common occurrence of tourmaline.

AgeRange: Precambrian __ Phanerozoic 100
RockTypes: Felsic-plutonic (5 -5) 75 Granite (5 -5) 75 Leucogranite (4 -4) 60 Muscovite-leucogranite (3 -2) 45 Biotite-leucogranite (3 -2) -5
TextureStructure: Greisen ____ Veinlets ✔ Stockwork ____
Alteration: Greisenization (5 -2) -10 Albitization (5 -2) -10 Tourmalinization (3 -2) 200
Mineralogy: Cassiterite (4 -5) 60 Molybdenite (4 -5) -75 Arsenopyrite (3 -5) 30 Topaz (4 -2) 60 Tourmaline (4 -2) 60 Beryl (2 -4) 0 Wolframite (2 -3) -10 Bismuthinite (2 -2) -5 Fluorite (4 -3) 60 Calcite (1 -3) 15 Pyrite (2 -4) 30
GeochemicalSignature: Sn (4 -5) 60 F (5 -5) 75 B (5 -4) 75 Mo (2 -5) 0 Rb (2 -4) 0 Cs (2 -4) 0 Be (2 -3) 30 REE (2 -4) -30 U (2 -4) 30 Th (2 -4) 0 Nb (2 -4) 0 Ta (2 -4) 0 Li (2 -4) 0 W (2 -3) 30 As (2 -4) 0 Bi (2 -3) 30
GeophysicalSignature:
AssociatedDeposits: Sn greisen 0 Sn veins 0 Sn replacement 0
MaxScore: 2,930

Partial Scores

AgeRange: 100 **RockTypes:** 250 **TextureStructure:** 0 **Alteration:** 180
Mineralogy: 225 **GeochemicalSignature:** 300 **GeophysicalSignature:** 0
AssociatedDeposits: 0

Model Score: 1,055

sified using the numerical models. For example, of the six deposits classified by the panel as being a Gabbroic Ni-Cu deposit type, four of these were also classified as being a Gabbroic Ni-Cu deposit type by Prospector II. For the other two deposits, however, a Gabbroic Ni-Cu deposit type was Prospector II's third choice for one and fifth choice for the other. It should be noted that for both of these deposits, the panel had a question mark after their choice.

Table 4. Comparison of classification between Prospector II and panel of geologists using the Cox-Singer deposit classification for 124 metalliferous lode deposits in Alaska (Nokleberg and others, 1987)

[Alphanumeric characters in parentheses refer to model numbers in Cox and Singer (1986)]

Deposit type (classified by panel of geologists)	Frequency of ranking (classified by Prospector II) 1st	2nd	3rd	4th	5th
1. Gabbroic Ni-Cu deposits (7a)	4	0	1	0	1
2. Podiform chromite deposits (8a)	7	1	0	0	0
3. Serpentine-hosted asbestos deposits (8d)	1	0	0	0	0
4. Alaskan-PGE (9)	5	0	0	0	0
5. W skarn deposits (14a)	1	0	0	0	0
6. Sn skarn deposits (14b)	2	0	0	0	0
7. Sn vein deposits (15b)	1	0	1	0	0
8. Sn greisen deposis (15c)	1	0	0	0	0
9. Porphyry Cu deposits (17)	4	1	0	0	0
10. Cu skarn deposits (18b)	2	0	1	0	0
11. Zn-Pb skarn deposits (18c)	2	0	0	0	0
12. Fe skarn deposits (18d)	4	1	0	0	0
13. Porphyry Cu-Mo deposits (21a)	1	0	2	0	0
14. Porphyry Mo, low F deposits (21b)	1	0	0	0	0
15. Polymetallic vein deposits (22c)	14	3	0	0	0
16. Basaltic Cu deposits (23)	0	0	1	0	0
17. Cyprus massive sulfide deposits (24a)	0	0	1	0	0
18. Besshi massive sulfide deposits (24b)	3	0	0	0	0
19. Epithermal vein deposits (25b, 25c, 25d, 25e)	2	0	0	0	0
20. Hot-spring Hg deposits (27a)	3	1	0	0	0
21. Sb-Au vein deposits (27d, 27e)	5	0	0	0	0
22. Kuroko massive sulfide deposits (28a)	9	0	0	0	0
23. Sandstone U deposits (30c)	1	0	0	0	0
24. Sedimentary exhalative Zn-Pb deposits (31a)	2	0	0	0	0
25. Bedded barite deposits (31b)	2	0	0	0	0
26. Kipushi Cu-Pb-Zn deposits (32c)	1	0	0	0	0
27. Low-sulfide Au quartz vein deposits (36a)	25	1	0	0	0
Totals	103	8	7	0	1

Of the 124 deposits classified by the panel, 103 of these were classified the same by Prospector II. This represents an 83 percent agreement between the two sets of classifications. The deposit types for which there was perfect agreement between the two were Serpentine-hosted asbestos, Alaskan-PGE, W skarn, Sn skarn, Sn greisen, Zn-Pb skarn, Porphyry Mo–low F, Besshi massive sulfide, Epithermal vein, Sb-Au vein, Kuroko massive sulfide, Sandstone U, Sedimentary exhalative Zn-Pb, Bedded barite, and Kipushi Cu-Pb-Zn. In almost all cases, the deposit type receiving the highest score was clearly distinguishable from the other deposit types, which received considerably lower scores. There were 8 deposits for which the classification made by the panel was Prospector II's second choice. For 5 of these deposits, the panel either put a question mark after their choice or else suggested that the deposit could be considered one of two different deposit types. Such ambiguity highlights the fact that the classification of a deposit often is largely a matter of judgment. The scores obtained using Prospector II for each of the 9 deposits characteristically were not markedly different for the first and second choices. By combining Prospector II's first and second choices as indicating a match with the classification made by the panel, there was agreement in 111 out of the 119 deposits classified—that is, a 93 percent agreement.

The deposit for which there was the most disagreement between the panel and Prospector II was the Spirit Mountain deposit (Nokleberg and others, 1987, p. 87). The panel classified this deposit as a Gabbroic Ni-Cu deposit type with a question mark, whereas Prospector II classified the deposit unequivocally as a Dunitic Ni-Cu deposit type (Cox and Singer, 1986, p. 24). The deposit is described as disseminations of sulfides in serpentinized peridotite and pyroxenite that are associated with gabbroic sills that have intruded upper Paleozoic limestones. The ore minerals contain Ni and Cu. This description fits closely with the Dunitic Ni-Cu deposit model described as disseminated sulfide mineralization in intrusive dunites and olivine peridotites that exhibit prograde and retrograde serpentinization. Although the description of the Gabbroic Ni-Cu deposit model is similar, what is lacking in the model is any mention of serpentinization. This attribute was critical in this instance. The three other deposit models that Prospector II rated higher than the Gabbroic Ni-Cu deposit model were the Alaskan-PGE, Podiform chromite, and Serpentine-hosted asbestos deposit models. In order to resolve all the differences in the classification of this particular deposit, it would be necessary to review the description again with the panel members and compare it with the descriptions of these five models.

A different situation exists for the Bernard Mountain deposit (Nokleberg and others, 1987, p. 55), in which the panel members classified the deposit as a Podiform chromite deposit type, whereas Prospector II narrowly classified the deposit as a Bushveld-Cr deposit type. The score for the Bushveld-Cr deposit model was 380 out of a possible 1,705, whereas the score for the Podiform chromite deposit model was 360 out of a possible 1,325. Situated in between these two models, were the scores for the Alaskan-PGE and the Merensky-Reef-PGE deposit models, which were 370 out of a possible 1,925 and 365 out of a possible 1,750, respectively. The relatively low scores obtained for all four of the models suggest that it may not be possible with the present information to distinguish among them.

CONCLUSIONS

Numerical mineral deposit models demonstrate the technical feasibility of encoding descriptive mineral deposit models to provide (1) a numerical-based consultant for regional mineral resource assessments, (2) objective evaluations of particular geologic settings as part of regional assessments, and (3) determination of the most likely model or models that best match a particular geologic setting. This approach is potentially valuable for (1) screening data bases of mineral occurrences, (2) providing instruction about the geology of mineral deposits, (3) systematizing the development of mineral deposit models, and (4) introducing objective procedures for evaluating models numerically.

While these numerical deposit models have useful applications in their present form, the extent to which their potential can be realized will depend upon future activities, some of which are already in progress. First, it is clear that the numerical models cannot be better than the descriptive models upon which they are based. The 87 numerical models represent but a sampling of what is ultimately desirable. Moreover, only a few of the numerical models have been completely tested and calibrated for regional mineral resource assessments. Many years will be required to develop numerical models for all types of deposits of economic interest, and refining these models and introducing new models as new deposit types are identified will be a continuing task. Fortunately, the formats that have been developed for the descriptive models will make it easier to carry out this task.

Because the techniques used to develop numerical models are new, few geologists are familiar with them. As the advantages of this numerical approach become more widely appreciated, more geologists will be interested in becoming involved in this activity. Several activities could encourage their participation, including (1) further exposure of these ideas at professional conferences and workshops, (2) acceptance of the publication of such models as a significant professional activity, (3) incorporation of these ideas in a course on economic geology, and (4) provision of ways for geologists in the governmental, academic, and industrial communities to access the models by computer.

DESCRIPTIVE MODEL OF THORIUM-RARE-EARTH VEINS

By Mortimer H. Staatz

BRIEF DESCRIPTION

SYNONYM: Rare-earth-thorium veins.

DESCRIPTION: Various thorium and rare-earth minerals in a quartz-potassium feldspar-iron-oxide gangue in veins 1 to about 1,330 m long and less than 1 cm to about 16 m thick.

TYPICAL DEPOSITS: Last Chance vein, Lemhi Pass district, Montana (Staatz, 1979); Little Johnnie vein, Powderhorn district, Colorado (Olson and Wallace, 1956); vein no. 12, southern Bear Lodge Mountains, Wyoming (Staatz, 1983); Wet Mountains area, Colorado (Armbrustmacher, 1988).

RELATIVE IMPORTANCE: A future thorium resource. Highest grade thorium resource in the United States, second largest total resource of thorium (Staatz and others, 1979). Rare earths important byproduct in some deposits; in others, the principal product.

COMMODITIES: Th, rare earths (mainly light rare earths, but at Laughlin Peak, New Mexico, the heavy rare earths most important).

OTHER COMMODITIES: None.

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): Disseminated rare-earth minerals in both massive carbonatites and carbonatite dikes; example: one of the world's largest rare-earth deposits in a massive carbonatite at Mountain Pass, California (Olson and others, 1954).

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Commonly associated with diverse suites of alkaline rocks and carbonatites. Thorium-rare-earth veins generally occur in an outer ring around alkaline rocks (fig. 1). May be as far as 16 km beyond outer limits of the alkaline rocks. Veins most common in the eastern part of the Cordilleran belt associated with continental crustal rocks (Staatz and Armbrustmacher, 1982).

REGIONAL DEPOSITIONAL ENVIRONMENT: Veins formed along fractures in brittle rocks. Vein fluids commonly traveled many kilometers before deposition. In a few areas, such as the Powderhorn district (Olson and Hedlund, 1981), all related igneous rocks are exposed. From the center, igneous alkaline rock complex surrounds a massive carbonatite and is bordered by fenite. Carbonatite dikes intrude outer part of alkaline rocks and neighboring country rock. Thorium-rare-earth veins intruded into an outer zone (fig. 1).

AGE RANGE: Host rock for veins: mainly Precambrian, but in several areas is Cretaceous and Tertiary. Veins: in Powderhorn and Wet Mountain districts, Colorado, formed between very late Precambrian to Ordovician (Olson and others, 1977); in Lemhi Pass district, Idaho and Montana (Staatz, 1972), Bear Lodge Mountains, Wyoming (Staatz, 1983), and Laughlin Peak area, New Mexico (Staatz, 1985), formed in Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Hard brittle rocks. Rocks include Precambrian quartzite, hornblende schist, gneiss, granite; Upper Cretaceous Dakota Sandstone; Tertiary trachyte, phonolite, and intrusive breccia.

ASSOCIATED ROCKS: Alkalic rocks, carbonatites, fenites.

ORE MINERALOGY: principal ore minerals in most deposits: thorite±monazite. Associated minerals: ±brockite±allanite±bastnaesite. Exceptions: (1) Bear Lodge Mountains, Wyoming, no thorite, principally monazite±brockite±bastnaesite; (2) Laughlin Peak area, New Mexico, neither thorite nor monazite, principally either (a) brockite + xenotime or (b) thorium- and rare-earth-bearing crandallite.

GANGUE MINERALS: Principal minerals: quartz+iron oxides (goethite and (or) hematite)±potassium feldspar. Minor minerals: ±barite±apatite±magnetite ±rutile±anatase±zircon (Staatz, 1974).

STRUCTURE and ZONING: Veins usually fine grained and commonly heavily stained with iron oxides±manganese oxides. Mineral zoning unknown.

ORE CONTROLS: Large alkaline rock body or bodies, whose magma was source of vein fluids within about 20 km of veins (Staatz, 1974). Joints and small faults that served both as conduits for ore fluids and as sites of deposition.

ISOTOPIC SIGNATURES: Unknown.

FLUID INCLUSIONS: Unknown.

STRUCTURAL SETTING: All ore in tabular veins.

ORE DEPOSIT GEOMETRY: Veins of potential economic interest range in length from about 60 to about 1,330 m and in thickness from about 0.3 to about 16 m. Veins may strike in almost any direction. Dips of all veins steep.

ALTERATION: Iron minerals, where present, altered to goethite±lepidocrocite±hematite. Clay minerals not common; thorite often metamict, sometimes narrow zone of fenitization around vein.

EFFECT OF WEATHERING: Probably aided in forming iron-oxide minerals.

EFFECT OF METAMORPHISM: Not applicable.

GEOCHEMICAL SIGNATURES: Some enrichment of Th and rare earths in alkaline igneous rocks. Th tends to disperse rapidly in stream sediments short distances below veins (Staatz and others, 1971). Heavy metals in stream sediments not diagnostic.

GEOPHYSICAL SIGNATURES: Radiation due to thorium used to locate most veins. Generally located by hand-held geiger counter or scintillometer. Most veins too narrow and (or) poorly exposed to locate with airborne radiation counters.

OTHER EXPLORATION GUIDES: Unknown.

OVERBURDEN: Most known veins have some part exposed at surface. Veins have been traced from original exposure under as much as 10 m of overburden.

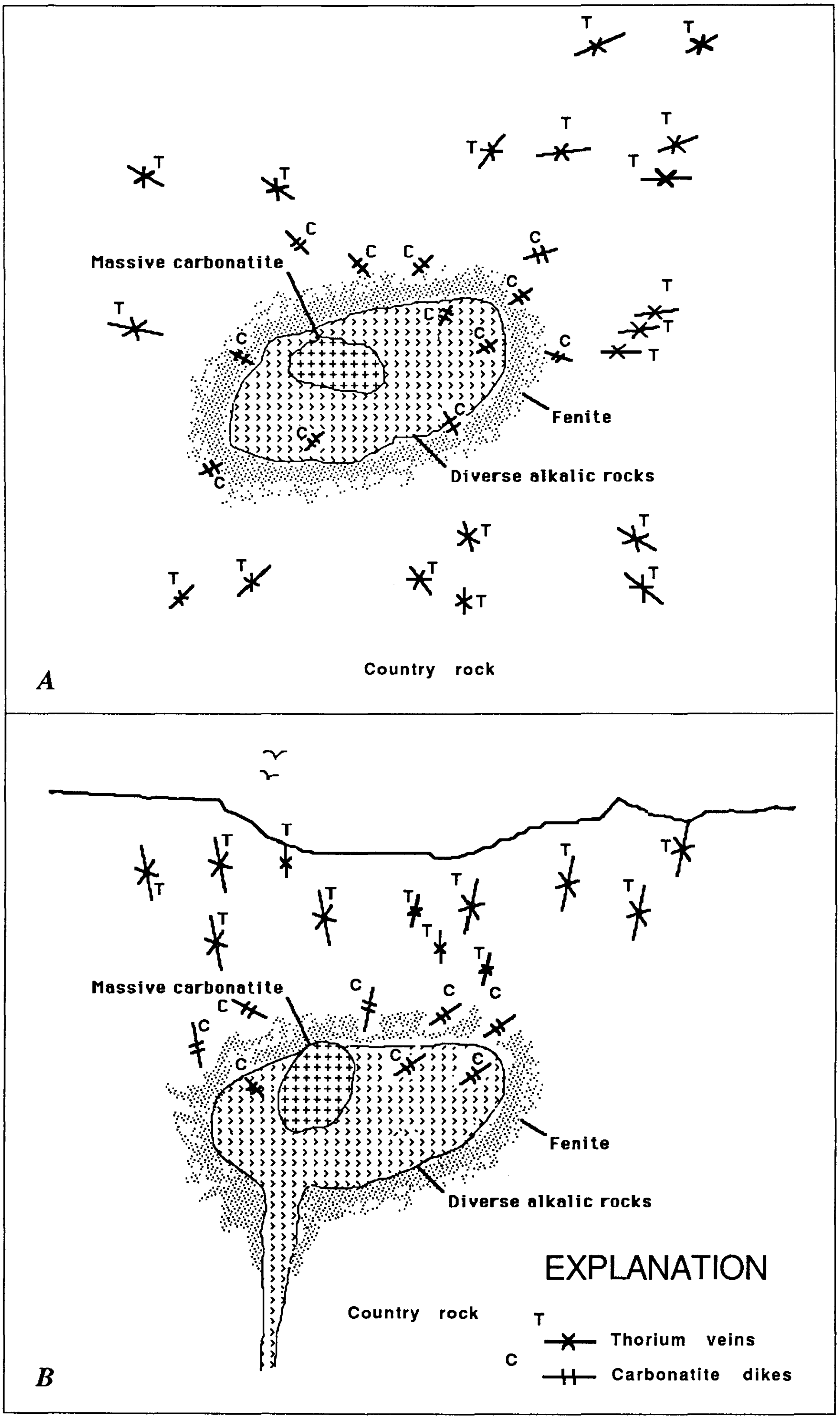

Figure 1. Idealized model showing relationship of thorium-rare-earth veins to alkalic rocks and carbonatites. *A*, Plan view. *B*, Cross-section view.

GRADE AND TONNAGE MODEL OF THORIUM-RARE-EARTH VEINS

By James D. Bliss

COMMENTS Definition of deposits for thorium-rare-earth veins used for this model is subject to several types of complications. Definition of vein-type deposits is never an easy task, since veins and mines exhibit various types of spatial relationships. Reports about thorium-rare-earth veins also show veins and mines using different scales. Some of the veins have been worked by small-scale mining. The majority of the veins are unmined. Production data are usually not available. Data on reserves, if known, are also not available. Production grades are not known. In some cases the distinction between carbonatite veins and thorium-rare-earth veins is unclear, and thus the model may contain carbonatite veins in error. To develop a model, several rules were established: (1) grades were estimated using the median values reported from samples taken from the veins; (2) when possible, veins were treated as a single deposit if they occurred within 1 km of each other; and (3) tonnage was estimated using median vein widths, lengths, and depths (depths estimated as 2.5 times length). Rules were applied when possible; in some cases, deposits were not used, since the rules could not be clearly applied. Thorium-rare-earth veins in the Powderhorn and Mountain Pass districts were considered, but data were found inadequate for estimation of grades and tonnages for veins using the stated rules. Some districts with closely spaced veins are treated as a single deposit. The model is probably biased in ways undefined, since none of the data are from deposits worked to exhaustion. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 2–4.

DEPOSITS

Name	Country
Apex	USID
Beardsley	USCO
Beaverhead	USMT
Black Bear No. 2	USID
Black Bull No. 3	USID
Black Rock	USMT
Black Rock	USID
Buffalo	USID
Cage No. 12	USID
Capitan Mountain	USNM
Contact	USID
Cottonwood	USAZ
Deer Fraction 1A	USID
Elkhorn	USMT
General Ike	USCO
Haputa Ranch	USCO

DEPOSITS

Name	Country
I&L	USAK
Last Chance	USMT
Lone Star No. 2	USID
Lucky Horseshoe	USID
Nellie B	USID
Paystreak	USAK
Quartzite	USAZ
Reactor	USMT
Schwarz Ranch	USCO
Silver Queen 38A	USID
Silver Queen 52B	USID
ThO2	USID
Tuttle Ranch	USCO
Unnamed property	MXCO
Wonder	USID
Wonder No. 18-Little Dandy	USID

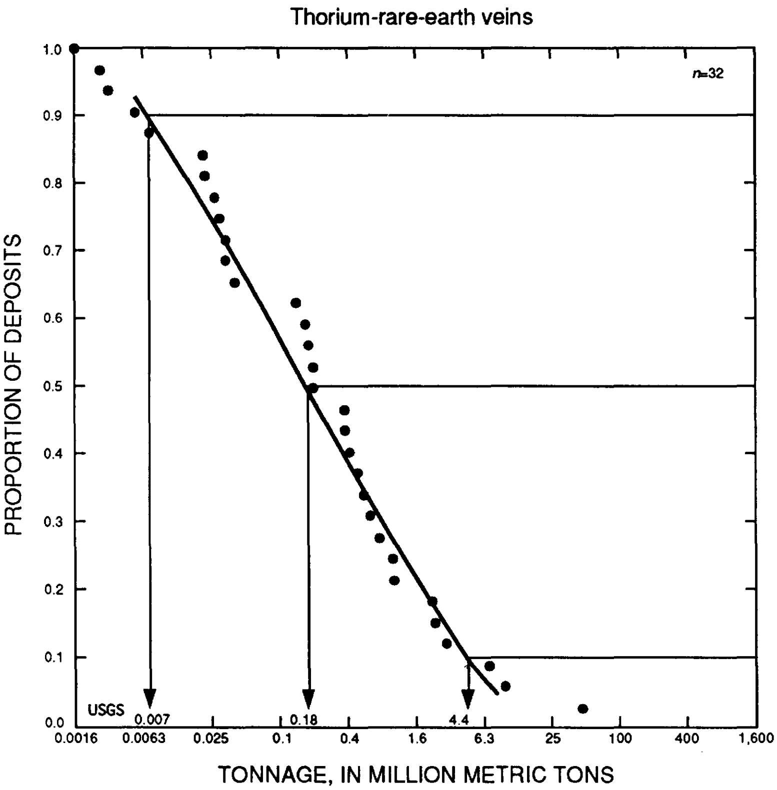

Figure 2. Tonnages of thorium-rare-earth veins.

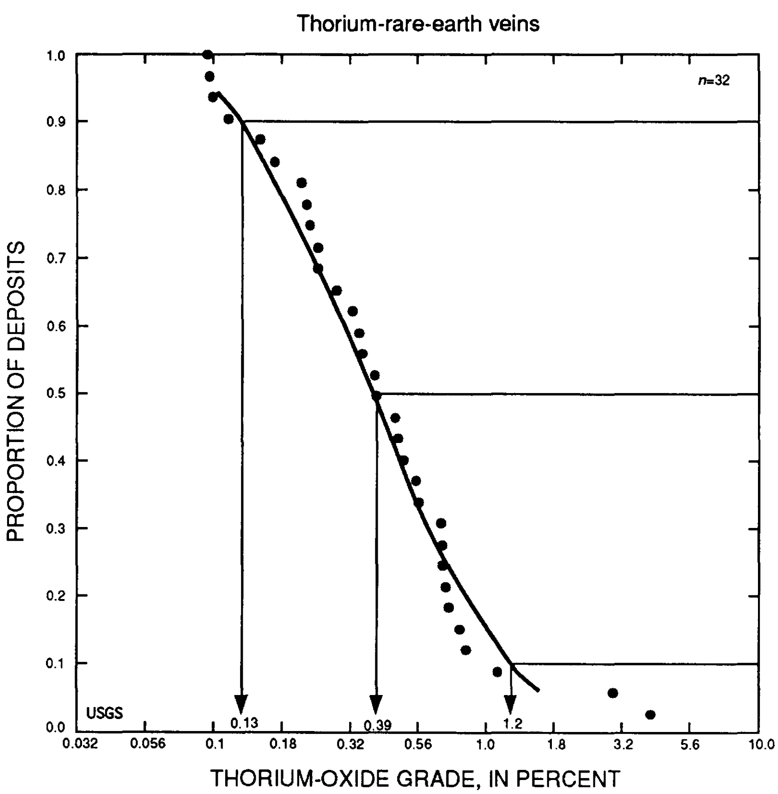

Figure 3. Thorium-oxide grades of thorium-rare-earth veins.

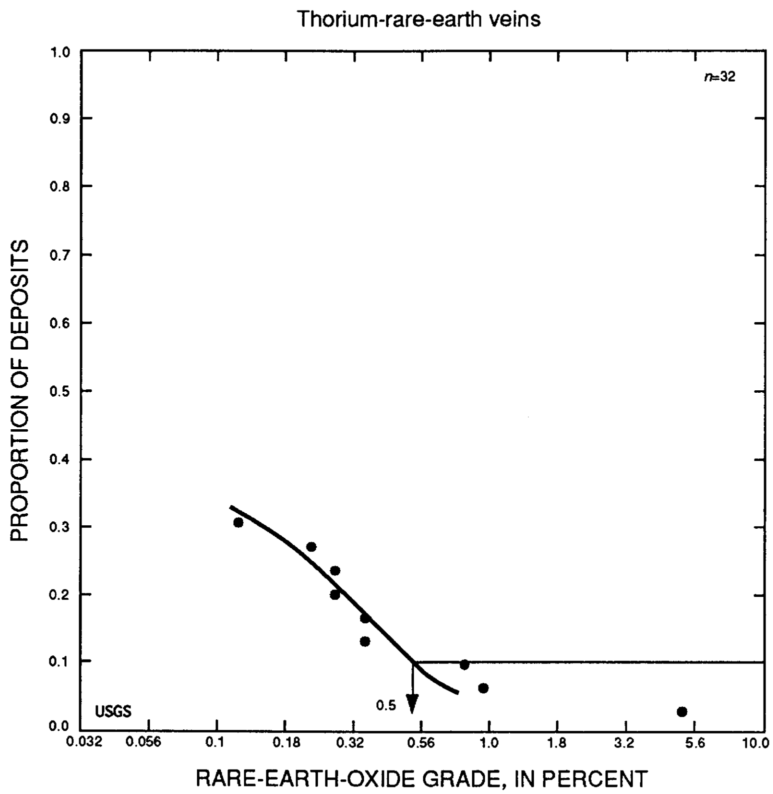

Figure 4. Rare-earth-oxide grades of thorium-rare-earth veins.

DESCRIPTIVE MODEL OF DISTAL DISSEMINATED Ag-Au

By Dennis P. Cox

BRIEF DESCRIPTION

SYNONYM: Sediment-hosted Ag-Au, disseminated Ag

DESCRIPTION: Disseminated Ag and Au mainly in sedimentary rocks distal to porphyry Cu, skarns, and polymetallic veins (Graybeal, 1981).

TYPICAL DEPOSITS: Taylor, Candelaria, Star Pointer, Cove deposits, White Pine district, Nevada; Tecoma, Utah; Vekol, Tombstone, and Hardshell, Arizona.

DISTINGUISHING FEATURES: This model is similar to sediment-hosted Au but has significantly higher Ag grades than that model (see Ag grades in grade and tonnage models for both). It also is characterized by higher geochemical background values

COMMODITIES: Ag, Au

OTHER COMMODITIES: Locally, Sb

ASSOCIATED DEPOSIT TYPES: Porphyry Cu, Cu skarn, Pb-Zn skarn, Au skarn, polymetallic veins, polymetallic replacement and replacement Mn deposits.

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Continental margins.

REGIONAL DEPOSITIONAL ENVIRONMENT: Shelf and basinal sedimentary rocks are folded and faulted and intruded by I-type granitic rocks.

AGE RANGE: Mesozoic-Tertiary in Western United States; may be any age.

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Carbonate and clastic sedimentary rocks.

ASSOCIATED ROCKS: Felsic hypabyssal or subvolcanic intrusions.

ORE MINERALOGY: Native Au, native Ag, electrum, argentite, Ag sulfosalts, tetrahedrite, stibnite, galena, sphalerite, chalcopyrite, pyrite, marcasite, arsenopyrite; at Cove deposits, stannite and canfieldite.

GANGUE MINERALS: Quartz, rhodochrosite, Ag-rich manganocalcite.

STRUCTURE AND ZONING: Ore minerals sparsely disseminated or in stockwork of thin quartz-sulfide veins.

ORE CONTROLS: Deposits commonly occur in skarn and polymetallic vein and replacement districts outboard of all other types of mineralization. Fracture permeability is the most important ore control. Primary rock permeability may be important locally

STRUCTURAL SETTING: Shear zones, axial plane fractures in folded rocks

ORE DEPOSIT GEOMETRY: Irregular bodies, locally conformable to bedding

ALTERATION: Silicification (Taylor, Star Pointer, Cove) and decalcification (Star Pointer) of carbonate rocks; sericite-clay in clastic rocks (Candelaria).

EFFECT OF WEATHERING: Leaching and redeposition of Ag as cerargyrite forms bonanza deposits (White Pine district, Nevada; Vekol, Arizona).

GEOCHEMICAL SIGNATURES: Ag±Au±Pb±Mn±Zn±Cu±Sb±As±Hg±Te; Mn introduced at Cove, Candelaria, and Star Pointer. Ag:Au ratios are highly variable: Candelaria 400:1; Taylor, 143:1; Tecoma, 60:1; Purísima Concepión, 51:1; Hilltop, <2:1.

GRADE AND TONNAGE MODEL OF DISTAL DISSEMINATED Ag-Au

By Dennis P. Cox and Donald A. Singer

COMMENTS Estimated premining tonnages and grades from the deposits listed in table 5 were used to construct the model. Where several different estimates were available for a deposit, the estimated tonnage associated with lowest cutoff grades was used.

No significant correlations between grades and tonnages were observed. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 5–7.

Table 5. Grades and tonnages of distal disseminated Ag-Au deposits

[Tonnages in million metric tons; silver (Ag) and gold (Au) grades in grams per metric ton. Country and state abbreviations explained in app. B]

Deposit	Country	Tonnage	Au grade	Ag grade
Candelaria	USNV	27	0.19	50
Cove	USNV	81	1.8	92.5
Fresnillo	MXCO	19	.22	141.6
Hardshell	USAZ	6	0	245
Hilltop	USNV	10.35	2.5	2
Purísima Concepción	PERU	.2	3.1	7.5
Real de Angeles	MXCO	66	0	66.6
Star Pointer	USNV	1.36	4.8	10.3
Taylor	USNV	7	0	103
Tecoma	USUT	1.5	1.56	93.3

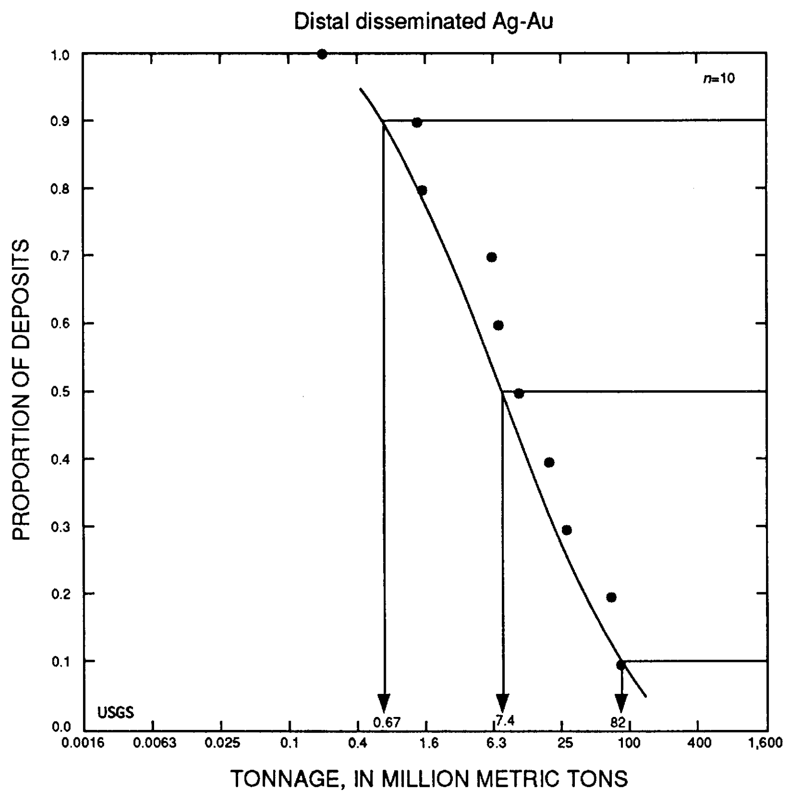

Figure 5. Tonnages of distal disseminated Ag-Au deposits.

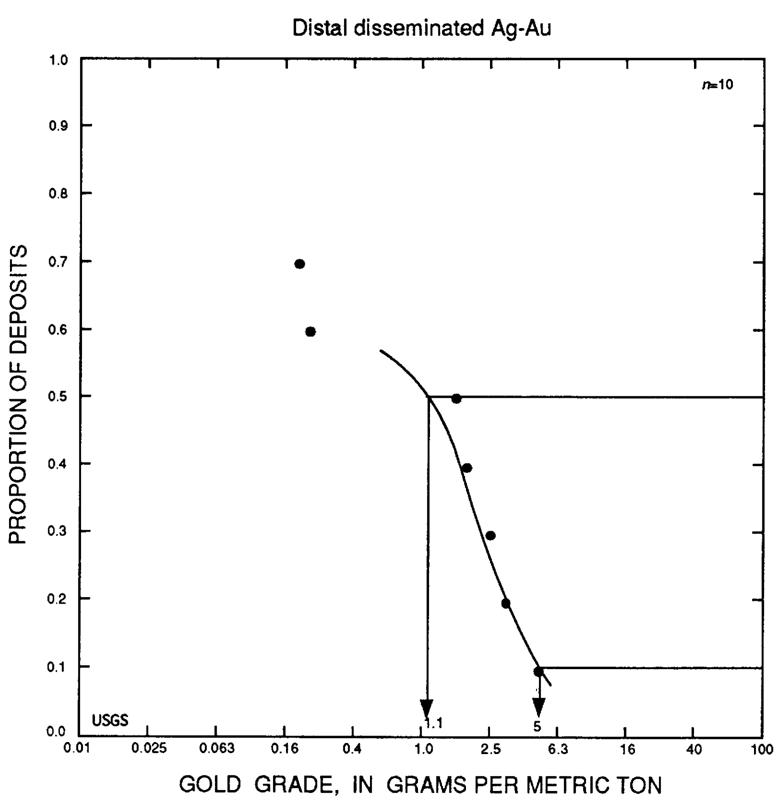

Figure 6. Gold grades of distal disseminated Ag-Au deposits.

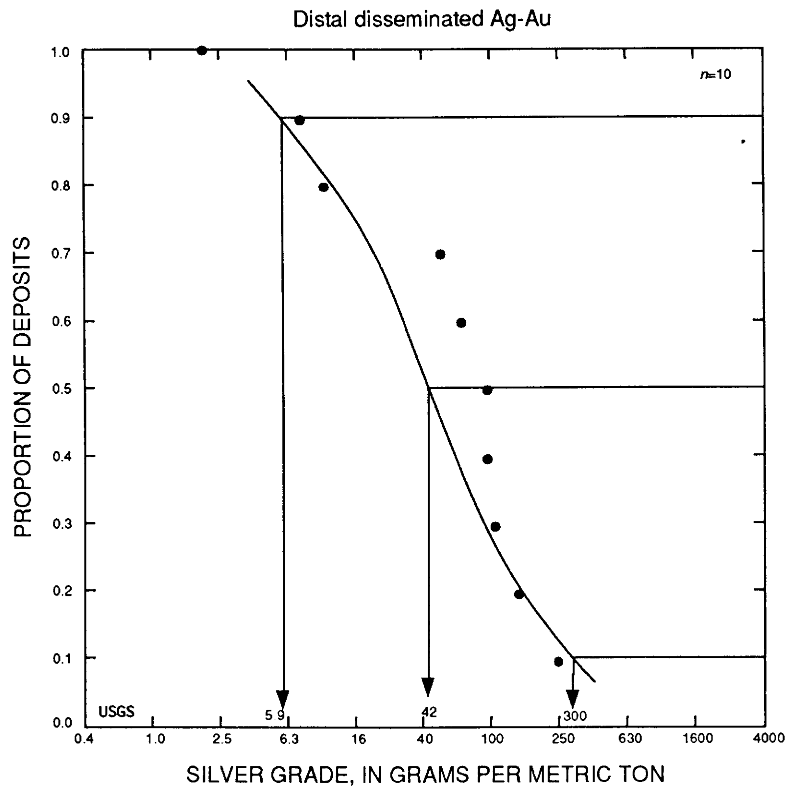

Figure 7. Silver grades of distal disseminated Ag-Au deposits.

GRADE AND TONNAGE MODEL OF HOT-SPRING Au-Ag

By Byron R. Berger and Donald A. Singer

<u>COMMENTS</u> This model applies to the descriptive model for hot-spring Au-Ag (No. 25a) by Berger (1986b). It is a modified version of a previously published report (Berger and Singer, 1987). Estimated premining tonnages and grades from the deposits listed in table 6 were used to construct the model. Where several different estimates were available for a deposit, the estimated tonnage associated with lowest cutoff grades was used.

No significant correlations between grades and tonnages were observed. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 8–10.

Table 6. Grades and tonnages of hot-spring Au-Ag deposits

[Tonnage in million metric tons; gold (Au) and silver (Ag) grades in grams per metric ton. Country and state abbreviations explained in app. B]

Deposit	Country	Tonnage	Au grade	Ag grade
Atlanta	USNV	1.0	2.742	54.8
Borealis	USNV	4.17	2.571	17.14
Buckhorn	USNV	4.54	1.51	20.05
Crowfoot	USNV	22.68	.857	0
Fire Creek	USNV	.3174	2.057	0
Florida Canyon	USNV	35.87	.788	0
Hasbrouck	USNV	11.7	1.0	20.2
Hog Ranch	USNV	30	1.767	.088
Ivanhoe	USNV	75.73	1.166	0
Lewis	USNV	9.07	1.37	0
McLaughlin	USCA	18.1	5.48	0
Mother Lode	USNV	4.44	1.851	0
Paradise Peak	USNV	16.48	2.894	80.18
Rawhide	USNV	35.46	1.135	16.11
Round Mtn.	USNV	243.8	1.136	2.113
Sleeper	USNV	47.41	1.664	5.0
Wind Mtn.	USNV	13.61	.72	14.4

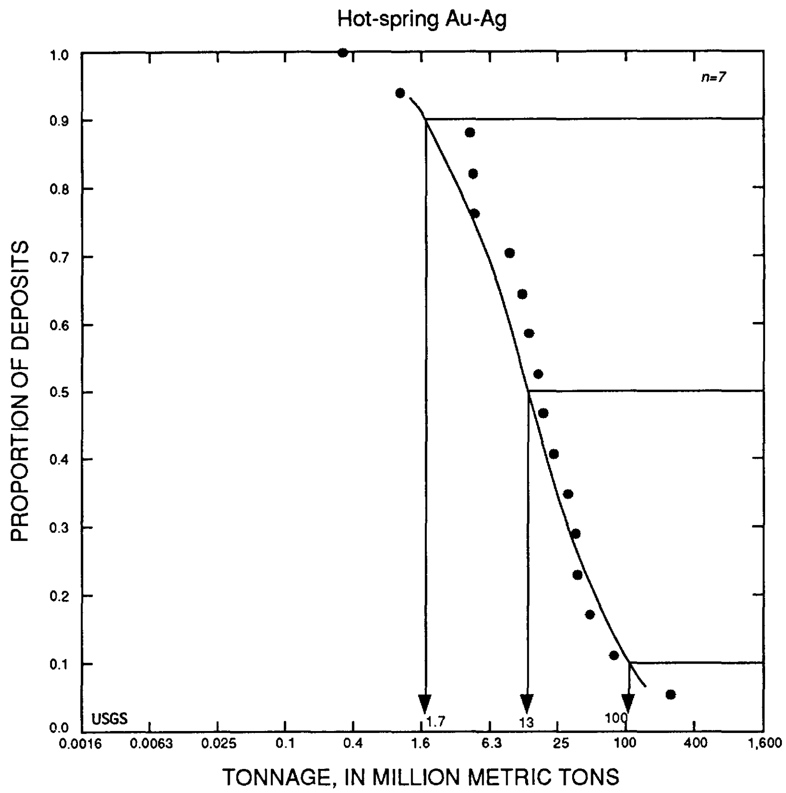

Figure 8. Tonnages of hot-spring Au-Ag deposits.

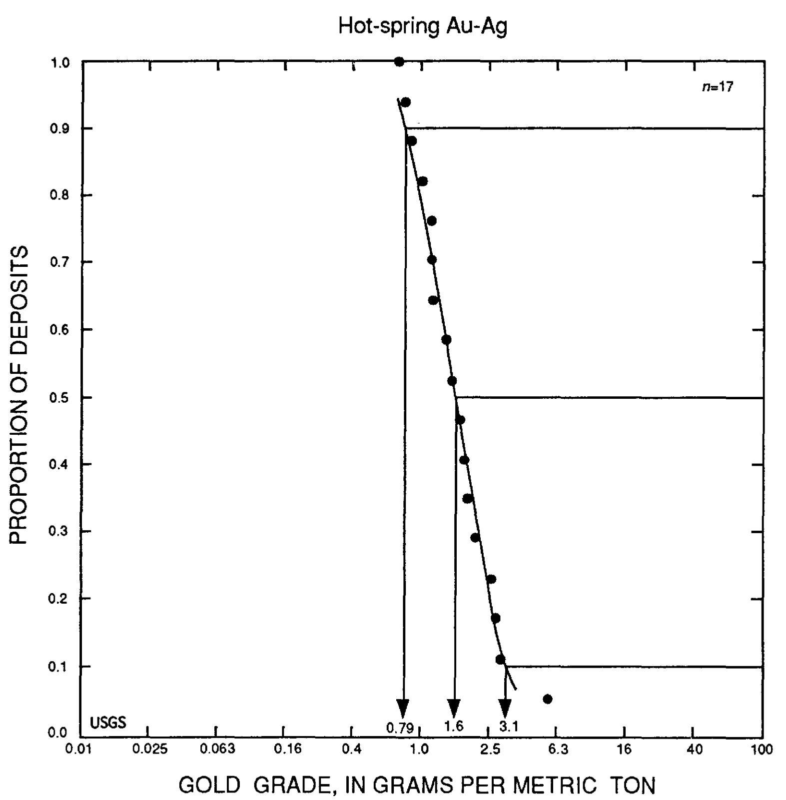

Figure 9. Gold grades of hot-spring Au-Ag deposits.

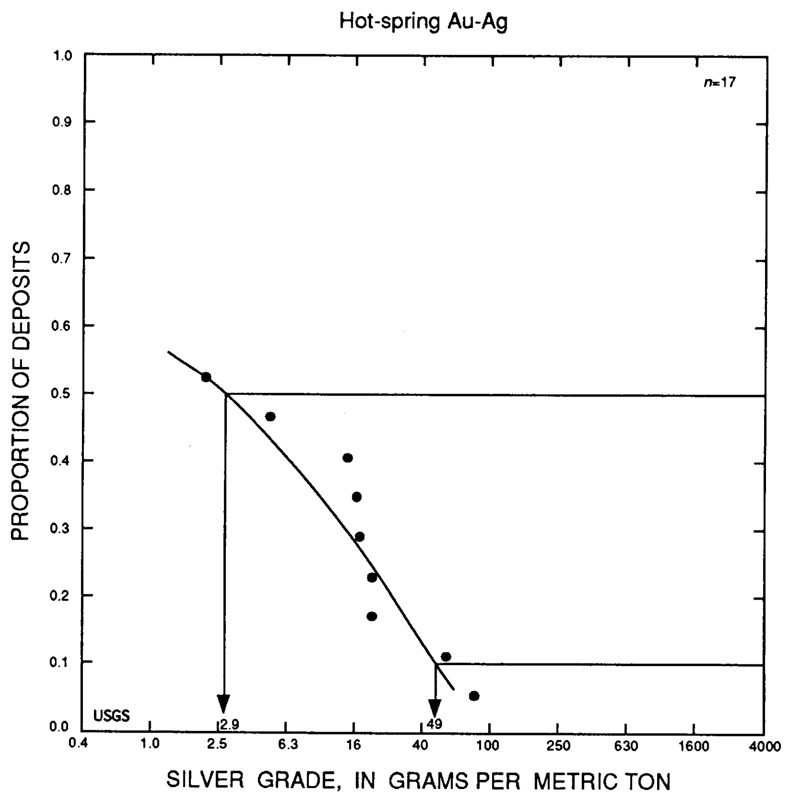

Figure 10. Silver grades of hot-spring Au-Ag deposits. (Silver grade of 0.088 g/mt for Hog Ranch not shown.)

GRADE AND TONNAGE MODEL OF SEDIMENT-HOSTED Au

By Dan L. Mosier, Donald A. Singer, William C. Bagby, and W. David Menzie

COMMENTS This model applies to the descriptive model for carbonate-hosted Au-Ag (Berger, 1986a) and supersedes the grade and tonnage model for that deposit type (Bagby and others, 1986). The change in the model name reflects the discovery of many deposits in siliceous shale and other noncarbonate host rocks and the reassignment of some silver-rich deposits to the distal disseminated Ag-Au type (that is, Hilltop, Candelaria, and Taylor); the few deposits remaining with reported silver grades are Alligator Ridge, Dee, and Standard. Other deposits in the original set were deemed atypical (Bald Mountain, Windfall, Giltedge, Tolman) or reclassified as other types (Atlanta and Florida Canyon—now considered hot spring Au). This model represents considerable refinement of the data used by Bagby and others (1986). Deposits where mineralization is known to be within 500 m of each other were combined. Most of the names listed in table 7 are property names that contain multiple zones or deposits. Well-known property names containing multiple deposits that are over 500 m apart, such as Jerritt Canyon, are listed individually with corresponding deposit names in parentheses. For some property names with multiple deposits, such as Marigold, only the well-explored deposits were included and are shown in parentheses. This model excludes deposits for which information on distances between discrete orebodies was not available at the time of the compilation (for example, Big Springs, Northumberland, and Tonkin Springs). The distribution of tonnages is significantly skewed toward larger tonnages because of the two very large deposits. No geologic reason has been found to distinguish these large deposits from the other deposits; however, these two deposits appear to be more thoroughly explored, both laterally and vertically, than most of the other deposits, suggesting that many of the other deposits will eventually be found to be much larger than now estimated. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 11–13.

Table 7. Grades and tonnages of sediment-hosted Au deposits

[Tonnages in million metric tons; gold (Au) and silver (Ag) grades in grams per metric ton. Country and state abbreviations explained in app. B]

Name	Country	Tonnage	Au grade	Ag grade
Alligator Ridge	USNV	6.35	3.29	0.72
Austin	USNV	1.59	5.49	0
Bootstrap-Capstone	USNV	22.90	1.46	0
Bullion Monarch–Lantern	USNV	14.90	1.11	0
Carlin	USNV	32.85	4.11	0
Chimney Creek North	USNV	27.60	2.14	0
Chimney Creek South	USNV	53.00	2.4	0
Cortez	USNV	3.18	9.60	0
Dee	USNV	5.13	2.78	2.6
Emigrant Springs 1	USNV	10.44	.82	0
Emigrant Springs 2	USNV	3.60	1.37	0
Felix Canyon	USNV	.32	1.03	0
Getchell	USNV	13.97	6.65	0
Gold Acres	USNV	8.34	3.35	0
Gold Bar	USNV	3.95	2.87	0
Goldstone–Gold Ridge	USNV	6.75	3.4	0
Gold Quarry–Deep West–Maggie Creek	USNV	464.00	1.32	0
Goldstrike–Post-Deep Post–Blue Star–Genesis–Bobcat–North Star	USNV	306.62	2.89	0
Green Springs (C Pit)	USNV	1.1	2.1	0

Table 7. Grades and tonnages of sediment-hosted Au deposits—Continued

Name	Country	Tonnage	Au grade	Ag grade
Horse Canyon	USNV	4.54	3.43	0
Illipah	USNV	1.03	1.13	0
Jerritt Canyon (Bell mine)	USNV	15.40	7.06	0
Jerritt Canyon (Burns Basin)	USNV	3.67	5.11	0
Jerritt Canyon (Mill Creek)	USNV	1.00	5.80	0
Jerritt Canyon (Saval Canyon)	USNV	2.27	4.15	0
Jerritt Canyon (Winters Creek)	USNV	1.27	5.2	0
Jerritt Canyon (Wright Window)	USNV	1.18	3.26	0
Marigold (East Hill Zone)	USNV	6.65	.72	0
Marigold (8 South Zone)	USNV	4.5	2.91	0
Mercur	USUT	29.70	2.07	0
Nighthawk	USNV	4.35	1.2	0
Pete	USNV	14.29	1.03	0
Pinson	USNV	9.80	2.60	0
Preble	USNV	3.00	3.29	0
Rain-Gnome	USNV	22.95	1.76	0
South Bullion	USNV	18.14	.89	0
Southern Mining Zone	USNV	1.44	.65	0
Standard	USNV	.80	1.65	3.43
Tusc	USNV	18.80	1.20	0

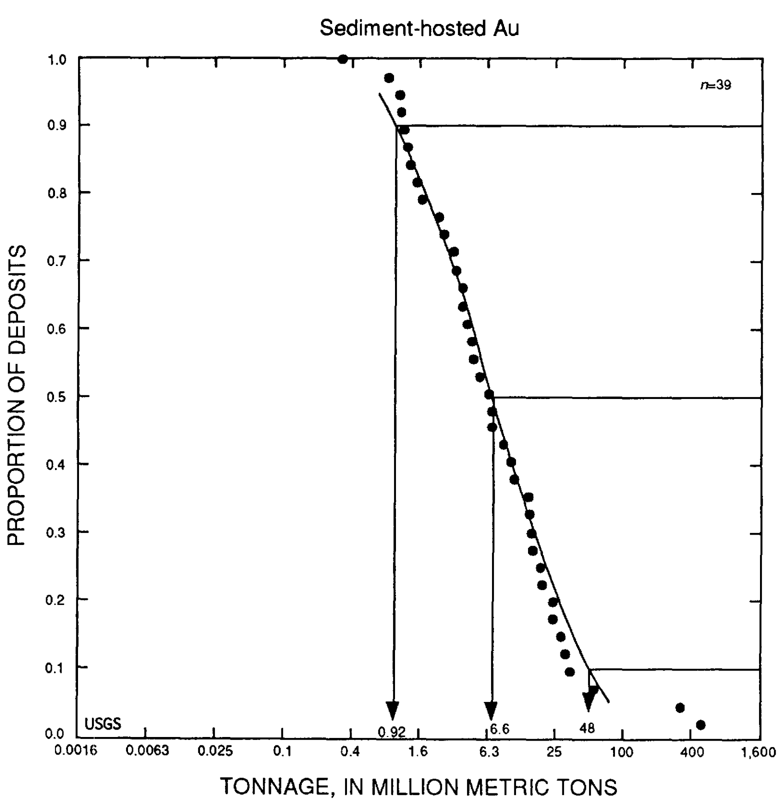

Figure 11. Tonnages of sediment-hosted Au deposits.

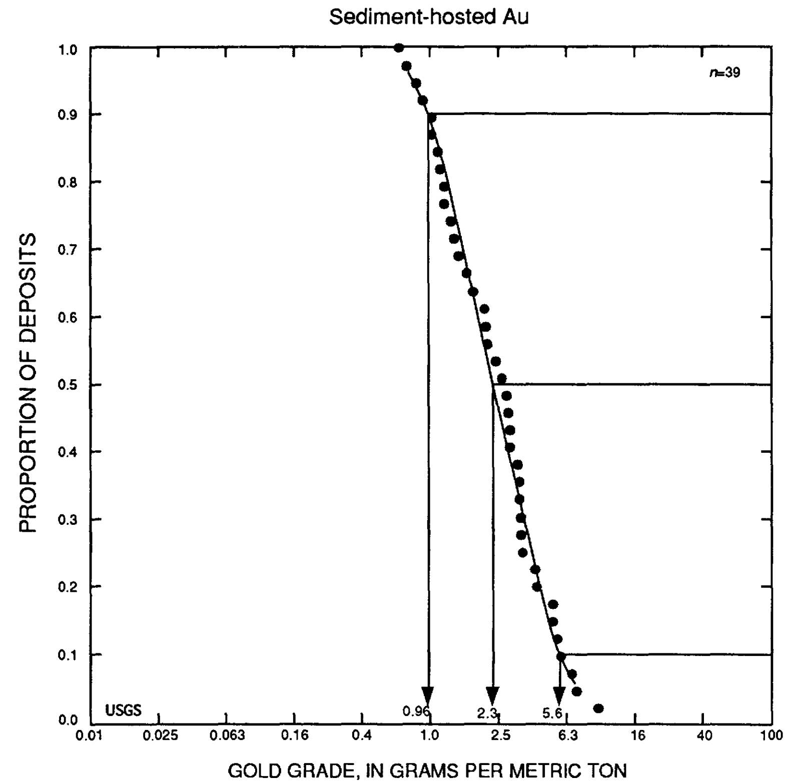

Figure 12. Gold grades of sediment-hosted Au deposits.

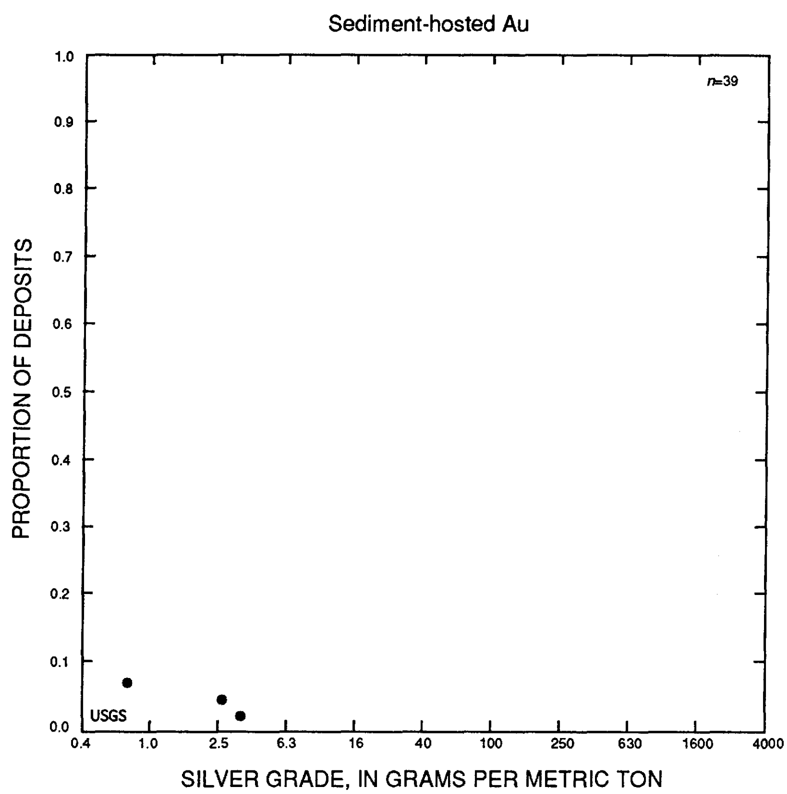

Figure 13. Silver grades of sediment-hosted Au deposits

GRADE AND TONNAGE MODEL OF SIERRAN KUROKO DEPOSITS

By Donald A. Singer

COMMENTS This model applies to the descriptive model for kuroko massive sulfide (No. 28a) by Singer (1986); however, only kuroko deposits of Triassic or Jurassic age in North America were used to construct this subset (table 8). Because many of the deposits lie in the western foothills of the Sierra Nevada in California, the name Sierran kuroko is given to the group. These deposits are significantly smaller in tonnage than the worldwide kuroko group. The reason for this difference is not known. Estimated premining tonnages and grades or total production from the deposits listed below were used to construct the model. Where several different estimates were available for a deposit, the estimated tonnage associated with lowest cutoff grades was used.

The breaks in slopes of the lead, silver, gold, and zinc plots (figs. 16–19) may be related to underreporting of production grades caused by early ore-processing problems. Silver grade is correlated with gold grade (r=0.76, n=16). See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 14–19.

Table 8. Grades and tonnages of Sierran kuroko deposits

[Tonnages in million metric tons; silver (Ag) and gold (Au) grades in grams per metric ton; other grades in percent. Country and state abbreviations explained in app. B]

Deposit	Country	Tonnage	Cu grade	Zn grade	Pb grade	Ag grade	Au grade
Afterthought	USCA	0.151	3.23	16.15	2.17	190	1
Big Bend	USCA	.05	1.14	10.7	.2	41.4	1.54
Blue Ledge	USCA	.18	4.1	2	0	187	4.3
Blue Moon	USCA	.105	.36	12.5	.45	123	2.09
Bully Hill–Rising Star	USCA	.62	3.8	3.1	0	130	1.98
Copper Crown	CNBC	.211	.31	4.25	0	25	0
Copper Hill	USCA	.266	.43	0	0	0	0
Cronin	CNBC	.054	8.12	7.11	0	431	.34
Double Ed	CNBC	3.63	1	.6	0	0	0
Duthie	CNBC	.118	.4	6.5	2.8	106.5	1.27
George Copper	CNBC	.553	2	0	0	17.2	2.06
Gray Eagle	USCA	1.33	3.8	0	0	17.6	6.17
Greens Creek	USAK	3.629	.5	9	2.5	343	3.4
Keystone-Union	USCA	1.2	2.37	0	0	.75	.01
Mamie	CNBC	.055	.7	7.6	0	0	11
Newton	USCA	.15	3.51	.2	0	13.6	.17
North Keystone	USCA	.205	2.2	0	0	1.3	.02
Penn	USCA	.884	4.24	1.14	.06	75	2.38
Red Wing	CNBC	.181	2	0	0	0	0
Silver Queen	CNBC	.363	.76	6	2.1	275	3.1
Spenceville	USCA	.136	5	0	0	0	0
Sunshine	CNBC	.313	.18	4.8	1.69	12.2	0
Tulsequah	CNBC	1.62	1.27	6.9	1.26	140	4.04

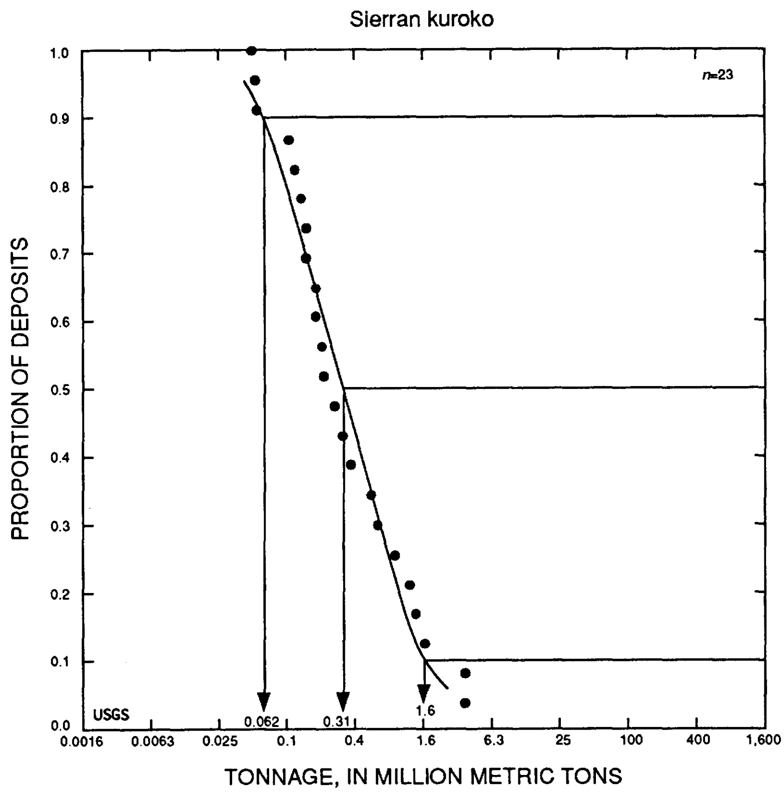

Figure 14. Tonnages of Sierran kuroko deposits.

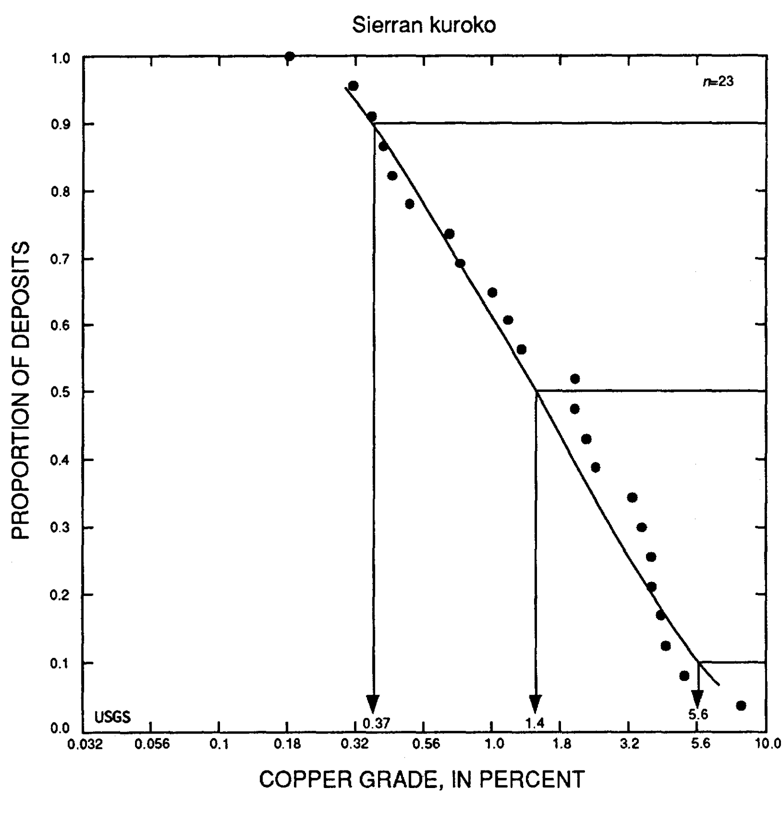

Figure 15. Copper grades of Sierran kuroko deposits.

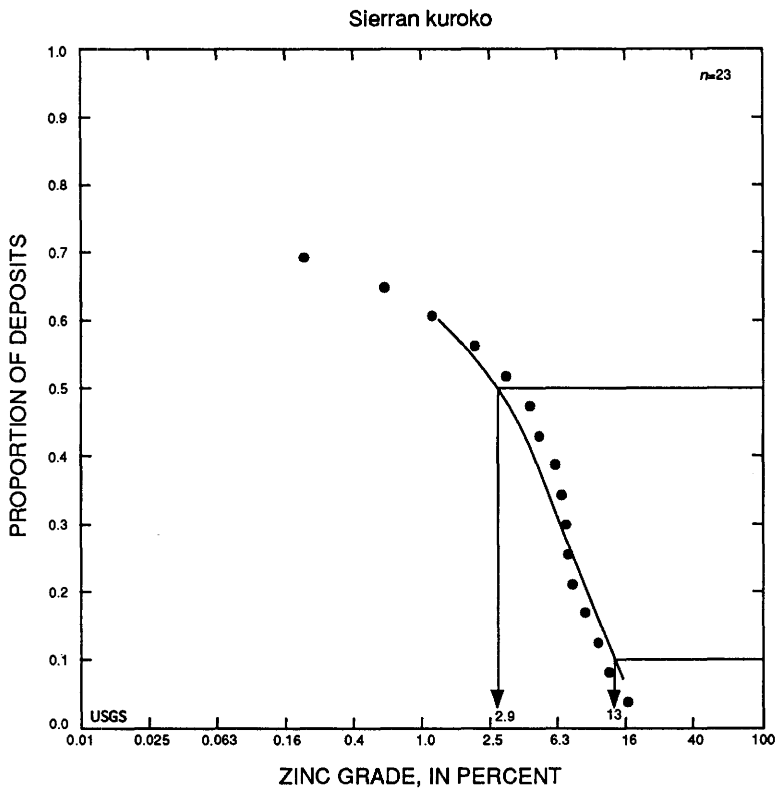

Figure 16. Zinc grades of Sierran kuroko deposits.

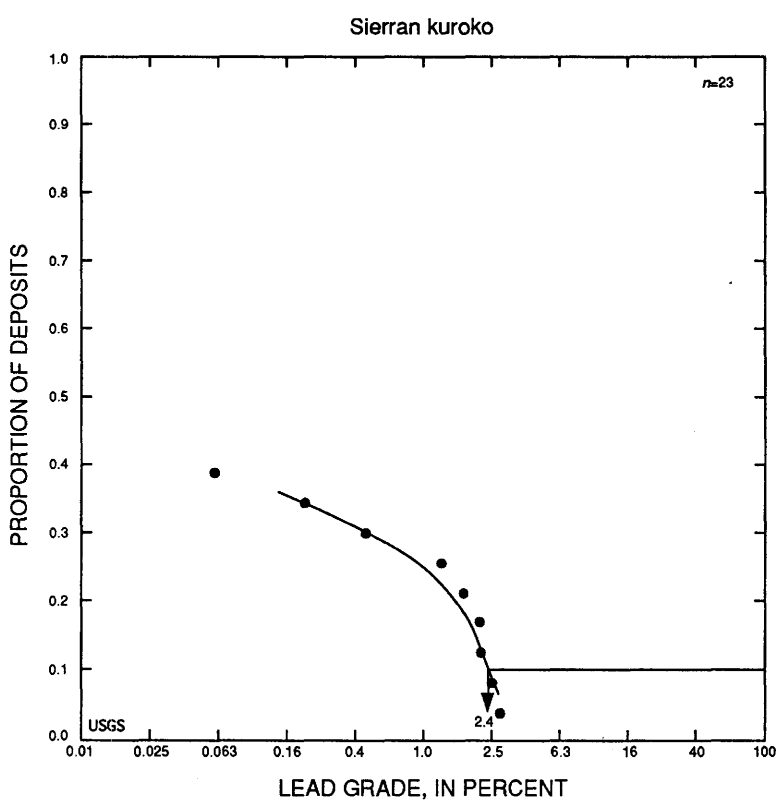

Figure 17. Lead grades of Sierran kuroko deposits.

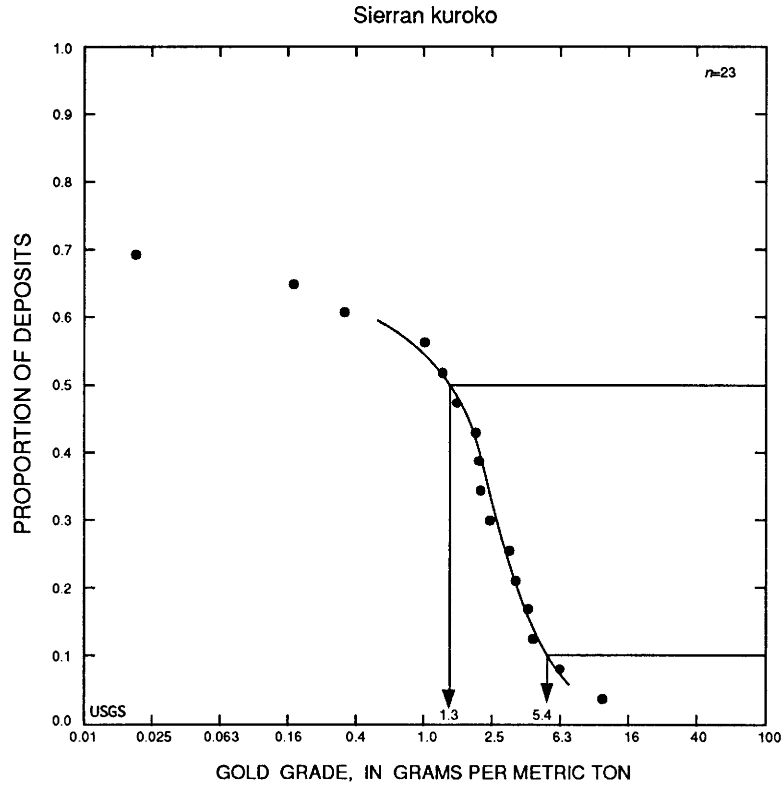

Figure 18. Gold grades of Sierran kuroko deposits. (Gold grade for Keystone-Union not shown.)

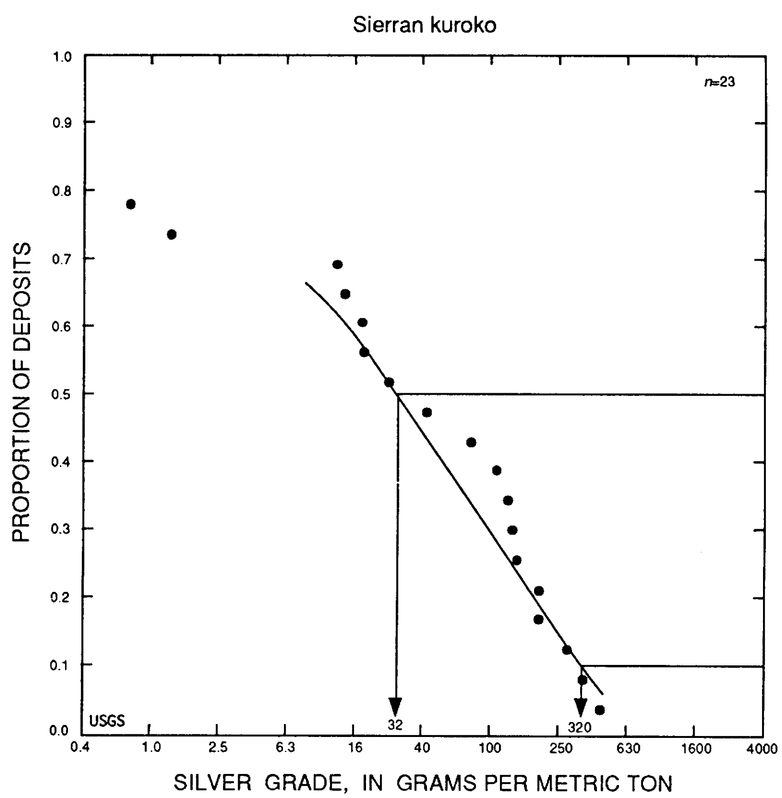

Figure 19. Silver grades of Sierran kuroko deposits.

DESCRIPTIVE MODEL OF SOLUTION-COLLAPSE BRECCIA PIPE URANIUM DEPOSITS

By Warren I. Finch

BRIEF DESCRIPTION

SYNONYM: Collapse breccia pipe deposits, sedimentary breccia pipe deposits, Orphan Lode–type deposit.

DESCRIPTION: Uraninite and associated sulfide, arsenide, sulfate, and arsenic-sulfosalt minerals as disseminated replacements and minor fracture fillings in distinct bodies in near-vertical cylindrical solution-collapse breccia pipes, 30–175 m in diameter and 1,000 m in length. Pipes located in flat-lying upper Paleozoic and Triassic rocks restricted to the Grand Canyon region in the southwestern part of the Colorado Plateau.

TYPICAL DEPOSITS: Orphan Lode (Chenoweth, 1986; Gornitz and others, 1988), EZ-2 (Krewedl and Carisey, 1986), Pigeon (Schafer, 1988), all in Arizona.

RELATIVE IMPORTANCE: One of two dominant high-grade sources of United States uranium production in 1987; expected to be major source of future uranium production within the United States.

COMMODITIES: U

OTHER COMMODITIES: ± Cu± V± Ag± Au

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): *Sandstone uranium; supergene enrichment of Cu and V and depletion of U in deeply eroded and weathered pipes—typical example, Ridenour, Arizona (Chenoweth, 1988); Apex germanium- and gallium-bearing breccia pipe nearby in Basin and Range province (Wenrich and others, 1987).

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Pipes found within and along the southwest margin of the Colorado Plateau, in a stable block existent since the Precambrian and resistant to tectonic forces acting on the western part of the North American plate. Wall rocks of pipes were deposited on a stable marine platform. Pipes apparently originated along and at intersections of N. 50° E.- and N. 45° W.-trending joint or fracture sets (Wenrich and Sutphin, 1989), roughly parallel to orthogonal Colorado River (N. 45° E.), Zuni (N. 45° W), and related lineaments shown by Green (1988, fig. 4) that developed in the Precambrian and rejuvenated in later periods. No igneous rocks are found in the pipes.

REGIONAL DEPOSITIONAL ENVIRONMENT: Breccia pipes developed from solution collapse within the thick Mississippian Redwall Limestone (0–210 m) beginning in the Late Mississippian and propagated upward into overlying strata of carbonate-cemented sandstone, siltstone, limestone, and conglomerate for at least 1,000 m, apparently only where the Redwall is >15 m thick. Stoping was intermittently active and reached the lower members of the Chinle Formation in Late Triassic time.

AGE RANGE: Host wall rocks for pipes: Late Mississippian to Late Triassic. Ores: 260–200 Ma (Ludwig and Simmons, 1988).

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Karst-collapse breccia. Breccia clasts as wide as 10 m across, consisting mainly of sandstone (~90 percent) and siltstone (~10 percent), occur in a matrix of quartz grains that is commonly well cemented with carbonate minerals. Minor claystone and limestone clasts.

ASSOCIATED ROCKS: Unbrecciated flat-lying sandstone, siltstone, and limestone.

ORE MINERALOGY: <u>Principal ore minerals</u>: uraninite±roscoelite± tyuyamunite*±torbernite*±uranophane*±zeunerite* ±chalcopyrite±bornite*±chalcocite*±malachite*±azurite *±brochantite *±volborthite±naumannite. <u>Associated base-metal minerals</u>: ±sphalerite ±galena±bravoite± rammelsbergite±stibnite ±molybdenite±skutterudite. An asterisk indicates sugergene origin. Pre-uraninite mineral assemblages resemble those of Mississippi Valley–type deposits. Unusual complexity of mineralogy shown in appendix E.

GANGUE MINERALS: Pyrite+marcasite+calcite+dolomite+barite+anhydrite±siderite±hematite±limonite±goethite ±pyrobitumen (see app. E).

TEXTURE AND MINERAL ZONING: Orebodies occur as discontinuous pods mainly in the core of the breccia pipe, but some are also found in the annular-ring structure and may occupy as much as a 200-m vertical interval (fig. 20). Mainly replacement and sparse open-space filling. Pyrite/marcasite and base-metal sulfides, locally associated with pyrobitumen, form a discontinuous "massive sulfide cap" above the uranium deposits in many pipes. Uranium, vanadium, and copper roughly zoned within some deposits.

ORE CONTROLS: Fractured, permeable rock within breccia pipe. Nearly all primary ore confined to the breccia pipe: rarely, a little uranium ore is reported in relatively undisturbed beds outside the ring structure. Vertically, most primary ore is below the Coconino Sandstone and at the level of the Hermit Shale and the Esplanade Sandstone of the Supai Group (fig. 20).

ISOTOPIC SIGNATURES: See Age Range above.

FLUID INCLUSIONS: Fluid-inclusion-filling temperatures of 80–173 °C for ore-related sphalerite, dolomite, and calcite. Salinities (in weight percent NaCl equivalent) are for sphalerite, ≥9, for dolomite, ≥17, and for calcite, ≥4 (Wenrich, 1985; Wenrich and Sutphin, 1988).

STRUCTURAL SETTING: All ore associated with solution-collapse breccia pipes.

ORE DEPOSIT GEOMETRY: Orebodies develop in annular-ring structures and in the core (fig. 20). At Orphan Lode, orebodies in core range from 15 to 60 m in diameter and from 30 to 90 m high; annular-ring orebodies are 5–20 m wide and a few tens of meters high, and extend variably part way around ring circumference (Chenoweth, 1988).

ALTERATION: Characteristic bleaching by reduction (some extends locally outward into wall rocks as much as 30 m); common carbonate recrystallization and calcification, local dolomitization and kaolinization, some weak silicification. Calcified rock extends outside boundary shears, completely surrounding the Orphan Lode pipe. Malachite, azurite, goethite, and other secondary minerals on surface outcrops of eroded pipes.

EFFECT OF WEATHERING: Leaching of U and enrichment of Cu and V, particularly in those pipes deeply weathered. "Massive sulfide cap" apparently prevented oxidation prior to erosion and exposure.

EFFECT OF METAMORPHISM: Not applicable.

GEOCHEMICAL SIGNATURES: Enrichment of Ag, As, Ba, Cd, Co, Cr, Cs, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sr, U, V, Y, Zn, Zr, and REE; indicator elements are Ag, As, Co, Cu, Ni, Pb, and Zn (Wenrich, 1985).

GEOPHYSICAL SIGNATURES: Electrical conductivity and magnetic properties of the pipes are significantly greater than for unbrecciated rocks; diagnostic differences in conductivity shown by scalar audiomagnetotelluric (AMT) and E-field telluric profile data for one pipe (Flanigan and others, 1986). Ground magnetometer surveys show subtle low magnetic values over several pipes (Van Gosen and Wenrich, 1989).

SPATIAL EXPLORATION GUIDES: Collapse features recognized by concentrically inward-dipping beds, circular concave topography, circular patches of brecciated and (or) bleached or iron-stained rock (related to "massive sulfide cap"), and differences in vegetation. In well-exposed areas of the Marble Plateau, collapse breccia pipe densities are 0.11 pipes per square kilometer. Marked tendency for pipes to occur in clusters as small as 3 km^2 in diameter. The presence of one pipe indicates a high probability for other pipes nearby.

OTHER EXPLORATION GUIDES: For a new area outside of the Grand Canyon region, a thick (>15 m) flat-lying, karst-forming limestone overlain by a thick sequence of predominantly carbonate-cemented sandstone and siltstone within a perpetually stable cratonic environment and a post-pipe formation volcanic source for uranium. Preexisting Mississippi Valley-type Cu-Co-Ni-Pb-Zn sulfide-rich ore may be required as a reductant for uranium deposition.

OVERBURDEN: Favorable area on Coconino Plateau (fig. 20): depths to mineralized portion of pipes are 150–600 m. Area exposed on Esplanade surface (fig. 20): depths are 0–120 m. Additional cover by basalt, 0–100 m thick, around San Francisco and Mt. Floyd volcanic fields. Quaternary and Tertiary sediments, 0–50 m thick, cover a few areas.

OTHER: Tectonic stability required for preservation. "Massive sulfide cap" prevented and delayed oxidation of some breccia pipe ores. Goethite possible pathfinder mineral for recognition of concealed pipe.

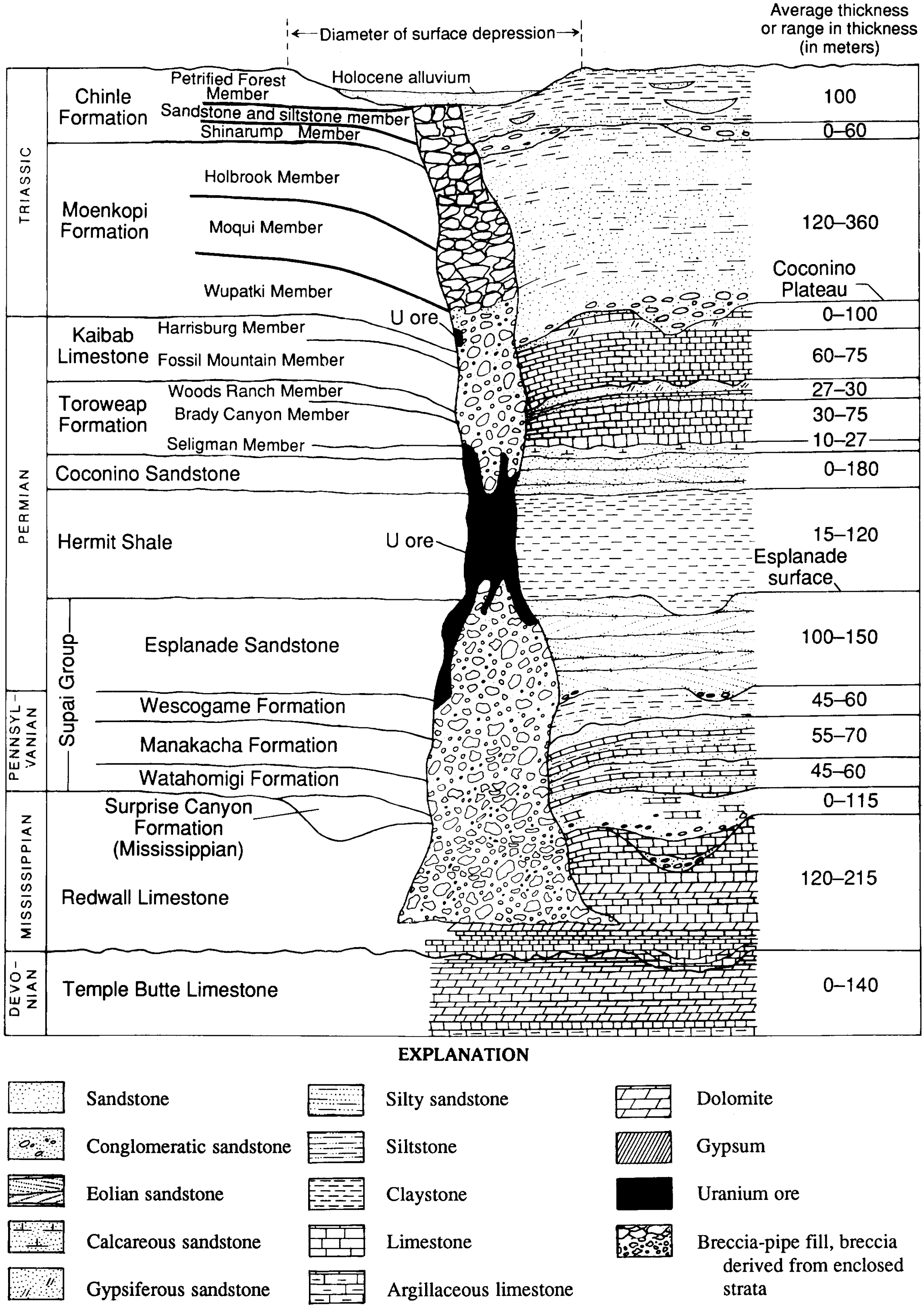

Figure 20. Schematic cross section of a solution-collapse breccia pipe in the Grand Canyon region, showing the general distribution of uranium ore within the pipe (stratigraphic section modified after Van Gosen and Wenrich, 1989).

GRADE AND TONNAGE MODEL OF SOLUTION-COLLAPSE BRECCIA PIPE URANIUM DEPOSITS

By Warren I. Finch, Charles T. Pierson, and Hoyt B. Sutphin

COMMENTS All the deposits in this grade and tonnage compilation are from the Grand Canyon region of northwestern Arizona. From the many mineralized solution-collapse breccia pipes in the region, we have chosen eight deposits that contain mostly primary, unoxidized minerals and have complete, reliable grade and tonnage data. Other mineralized breccia pipes are deeply eroded, strongly weathered, depleted in uranium, and enriched by supergene processes to minable grades of copper, vanadium, and other metals. These remnant deposits are not considered here to be a separate, distinct class of deposits. Furthermore, grade and tonnage data of these remnant deposits (Chenoweth, 1988) are too incomplete to graph meaningfully either separately or combined with the primary deposits.

During the 1950–70 period when the Orphan Lode was mined, the cutoff grades were around 0.10 percent U_3O_8. Few, if any, breccia pipes were mined in the 1970's. In the 1980's, the cutoff grade was 0.20–0.35 percent U_3O_8 for the remaining seven pipes. The average grade of the Orphan Lode ore mined in the early period was 0.43 percent U_3O_8 (Chenoweth, 1986), whereas ores mined from other pipes in the 1980's averaged about 0.65 percent U_3O_8 (Mathisen, 1987). The grade and tonnage data used to plot the graphs in figures 21 and 22 are based on premining reserves calculated at a cutoff grade of 0.05 percent U_3O_8. Energy Fuels Nuclear, Inc., operators of all deposits but the Orphan Lode, kindly permitted the use of data from their properties. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 21 and 22.

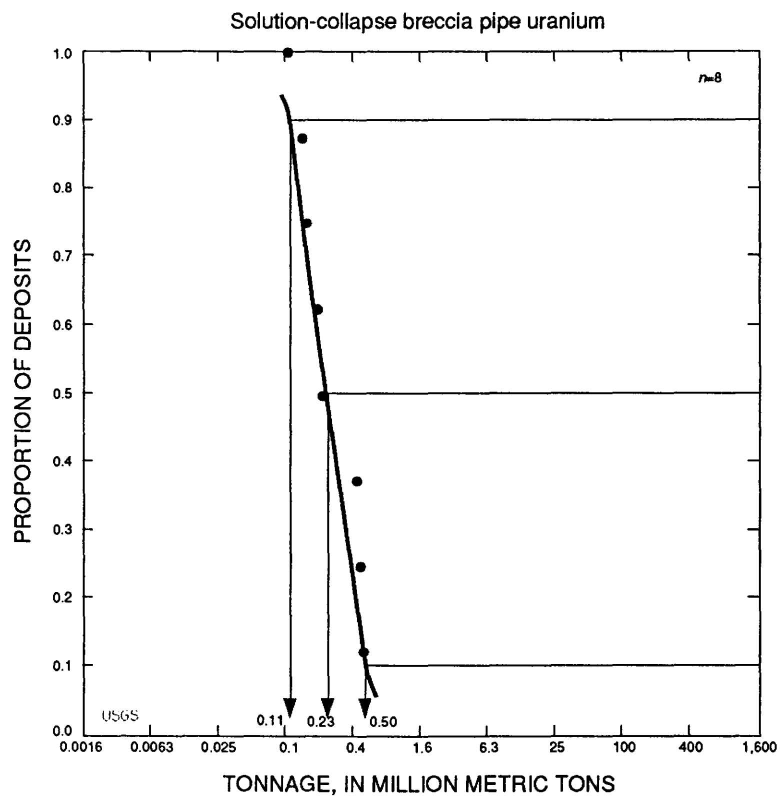

Figure 21. Tonnages of solution-collapse breccia pipe uranium deposits.

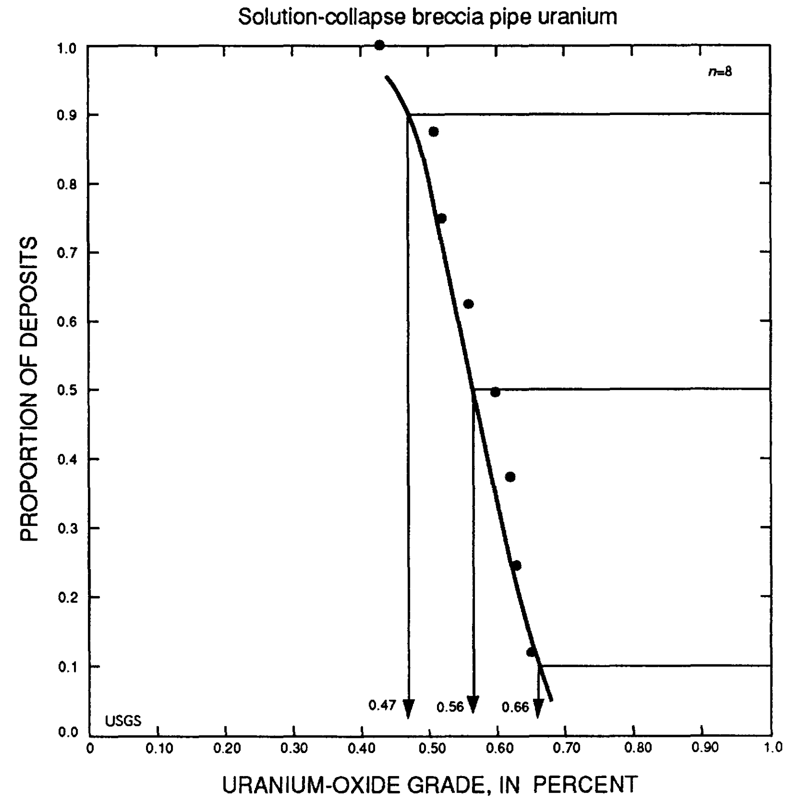

Figure 22. Uranium-oxide grades of solution-collapse breccia pipe uranium deposits.

DEPOSITS

Name	Country	Name	Country
Canyon	USAZ	Kanab North	USAZ
Hack No. 1	USAZ	Orphan Lode	USAZ
Hack No. 2	USAZ	Pigeon	USAZ
Hack No. 3	USAZ	Pinenut	USAZ

The scatter plot of the logarithms (to base 10) of grade and tonnage is shown in figure 23. This plot and the correlation coefficient of –0.122 suggest that the log-tonnage and log-grade are not correlated. Neither probability plots nor histograms of the grade and tonnage data demonstrate either normality or lognormality. Skewness is 0.13 for log-tonnages and –0.90 for log-grades. The mean tonnage and grade are 269,600 metric tons and 0.57 percent U_3O_8, with standard deviations of 157,370 metric tons and 0.07 percent U_3O_8, respectively.

Trace-element contents of five of the eight pipes are shown in table 9. Because the selected samples were high graded, these data do not represent the average grade for a given deposit. Hence, grade curves cannot be constructed from the data. Nevertheless, they do show that the mean value of the elements As, Co, Cu, Ni, Pb, U, and Zn are high locally within breccia pipe primary orebodies. Copper, vanadium, gold, and silver have been produced from some highly oxidized breccia pipe uranium ores (Chenoweth, 1986, 1988).

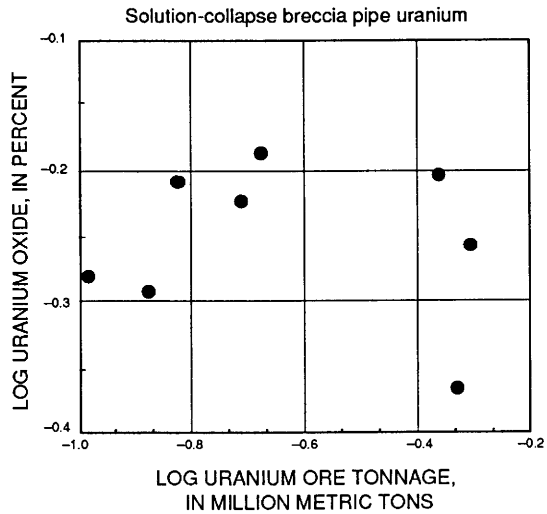

Figure 23. Scatter plot of logarithms of average uranium-oxide grade vs. tonnage of uranium ore.

Table 9. Summary statistics of chemical analyses of one selected sample from each of the five solution-collapse breccia pipe uranium deposits (based on analyses by Wenrich and Sutphin, 1989, and their unpublished data)

Element	Mean (ppm)	Standard deviation (ppm)
Ag	34	22
As	8,340	6,981
Ba	139	109
Cd	31	40
Ce	102	94
Co	2,044	3,795
Cr	51	68
Cu	11,440	9,340
Fe	4.7[1]	3.7[1]
Ga	21	9
La	17	7
Li	20	16
Mo	403	312
Ni	4,760	5,998
Pb	2,978	2,042
Sr	372	494
U	77,400	65,569
V	121	99
Y	124	112
Zn	9,584	11,469

[1]Both the mean and standard deviation for Fe are in percent.

DESCRIPTIVE MODEL OF OOLITIC IRONSTONES

By J.B. Maynard[1] and F.B. Van Houten[2]

BRIEF DESCRIPTION

SYNONYM: Clinton-type deposit, Minette-type deposit.

DESCRIPTION: Beds rich in iron silicate and oxide minerals with distinctive oolitic texture deposited in shallow-shelf to intertidal, clastic-dominated environments.

TYPICAL DEPOSITS: Wabana, Newfoundland (Ranger and others, 1984); Birmingham, Alabama (Simpson and Gray, 1968); Lorraine, France and Luxembourg (Teyssen, 1984); southern Algeria (Guerrak, 1987); Cleveland, northeast England (Hallimond, 1925); Northampton Sand, England (Taylor, 1949).

RELATIVE IMPORTANCE: Important source of Fe from 1850 to 1945. Declining world importance since then because of competition from Precambrian banded-iron formations.

DISTINGUISHING FEATURES: Distinguished from banded-iron formations by absence of chert, presence of oolitic textures, and Al-bearing silicates. Distinguished from blackband ironstones by absence of primary siderite and presence of oolitic textures.

COMMODITIES: Fe.

OTHER COMMODITIES: Ocher.

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): None.

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Craton margins, 40 percent; craton interiors, 25 percent; foreland basins, 20 percent; exotic terranes, 15 percent.

REGIONAL DEPOSITIONAL ENVIRONMENT: Shallow shelf, most typically close to the transition from nonmarine to marine environments.

AGE RANGE: Phanerozoic, concentrated in the Ordovician to Devonian and Jurassic to Paleogene. A few Proterozoic examples.

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Almost always clastic hosted at top of coarsening and shoaling-upward cycles (fig. 24).

ASSOCIATED ROCKS: Standard vertical succession is black shale at base, followed by gray shale and siltstone, then by sandstone with graded bedding and hummocky cross-stratificiation suggesting tempestites, and finally by sandstone or oolitic ironstone with bipolar cross-stratification suggesting intertidal deposition. The association with black shale (Hallam and Bradshaw, 1979) is significant: 75 percent of well-developed Phanerozoic ironstones have an extensive black shale at the base of the shoaling cycle (Van Houten and Arthur, 1989).

ORE MINERALOGY: Younger rocks: goethite + berthierine (7-Å chlorite). Older rocks: hematite + chamosite (14-Å chlorite). Siderite common as a replacement; locally, pyrite found as replacement (Maynard, 1986); occasionally, magnetite.

GANGUE MINERALS: Quartz ± calcite ± dolomite ± clay minerals; apatite (collophane) ubiquitous in small amounts.

STRUCTURE AND ZONING: Rarely reported. Hematite cemented with Fe silicates to magnetite at Sierra Grande, Argentina (Leiding V., 1955).

ORE CONTROLS: Three-quarters of deposits show strong control by position at the top of sedimentary cycle. Many of the larger deposits show features of tidally influenced deposition.

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[1] University of Cincinnati, Cincinnati, Ohio.
[2] Princeton University, Princeton, New Jersey.

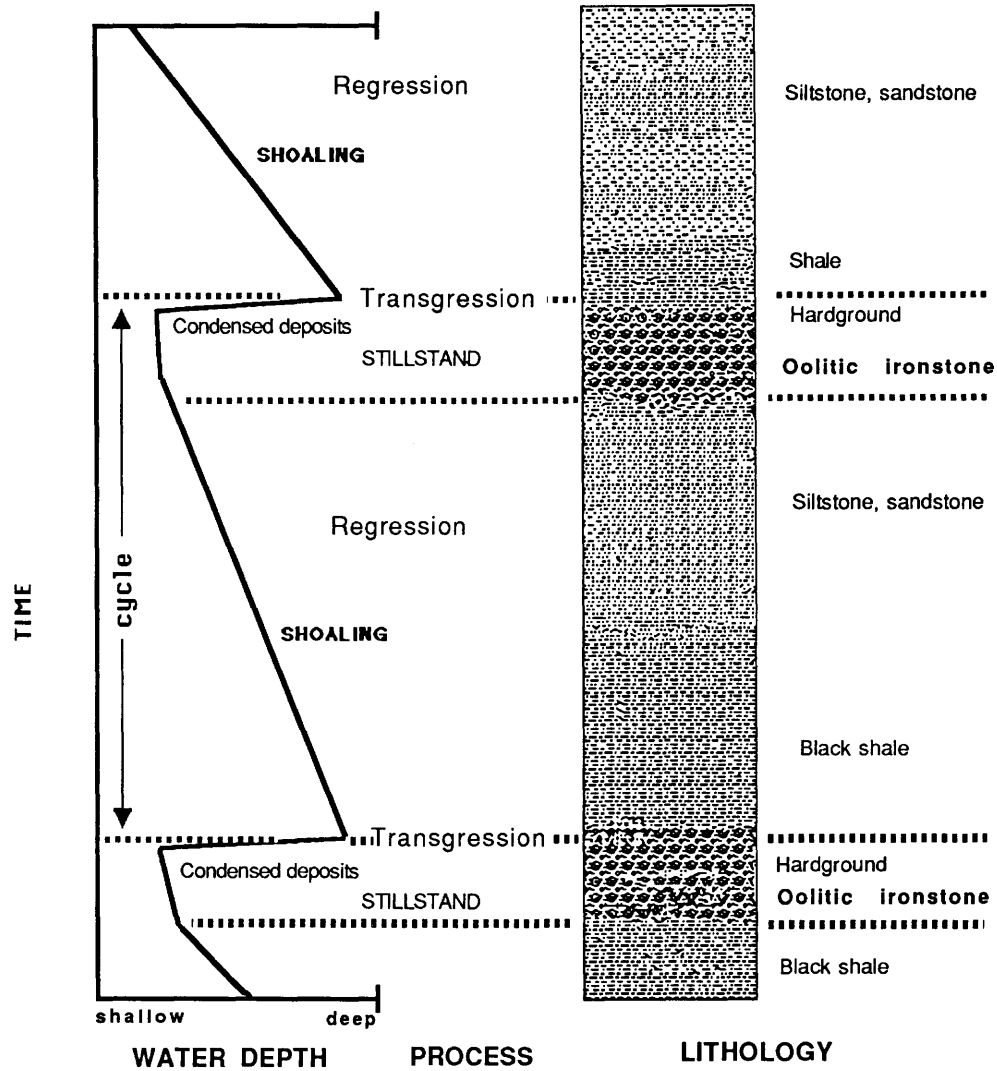


Figure 24. Generalized stratigraphic model for oolitic ironstones. Vertical scale is variable; cycles may range from a few meters to as many as 300 m in thickness (modified after Van Houten and Bhattacharyya, 1982; Maynard, 1983).

ISOTOPIC SIGNATURES: Siderite has light C, about –18 per mil; unknown for other minerals (Maynard, 1983).

STRUCTURAL SETTING: Major deposits in undeformed to simply folded strata. Some Ordovician deposits on blocks complexly deformed by the Armorican (Hercynian) orogeny of Western Europe.

ORE DEPOSIT GEOMETRY: Tabular bodies 2 to 5 m thick and 2 to 10 km across.

ALTERATION: None relevant to mineralization.

EFFECT OF WEATHERING: Removes carbonate gangue and converts ferrous silicates to ferric oxides. Many older mining operations based on weathered ore; typically, workings less than 30 m into outcrops.

EFFECT OF METAMORPHISM: Goethite converts to hematite above 80 °C (Hodych and others, 1984); hematite converts to magnetite under metamorphic conditions, but a few apparently unmetamorphosed deposits have magnetite (Devonian deposits of Libya). Berthierine converts to chamosite at 130–160 °C (Iijima and Matsumoto, 1982). Most deposits unmetamorphosed.

GEOCHEMICAL SIGNATURES: Only Fe.

GEOPHYSICAL SIGNATURES: Marked positive gravity anomaly (1 mgal over 1–5 km) useful in delineating orebodies (Miller, 1983). Magnetite-bearing occurrences detectable by airborne magnetometer.

OVERBURDEN: Most commonly clastic sedimentary rocks, from 0 to 500 m in recently active mines.

GRADE AND TONNAGE MODEL OF OOLITIC IRONSTONES

By Greta J. Orris

COMMENTS As with many deposit models, grade-tonnage information was not available for some of the well-known deposits. In addition, deposit definition (especially with regard to size information) is complicated by (1) the areally extensive bedded nature of the deposits, (2) the presence of multiple mineralized layers interbedded with country rock, and (3) the ambiguity of the reporting with regard to mining district or individual mine- or deposit-level information. Some deposits and (or) mines had tonnages or grades that were so disparate from the tentative grade-tonnage models that they could not be considered. This type of problem is often due to reporting error or deposit definition error. Several tonnages reported for English deposits were orders of magnitude too low and might represent reserves of mines working only parts of larger deposits, and some U.S. and French deposits had tonnages so large that it is likely that several deposits were composited into single grade and tonnage figures. Lastly, it is impossible to claim that all possible sources of information were found and consulted. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 25–28.

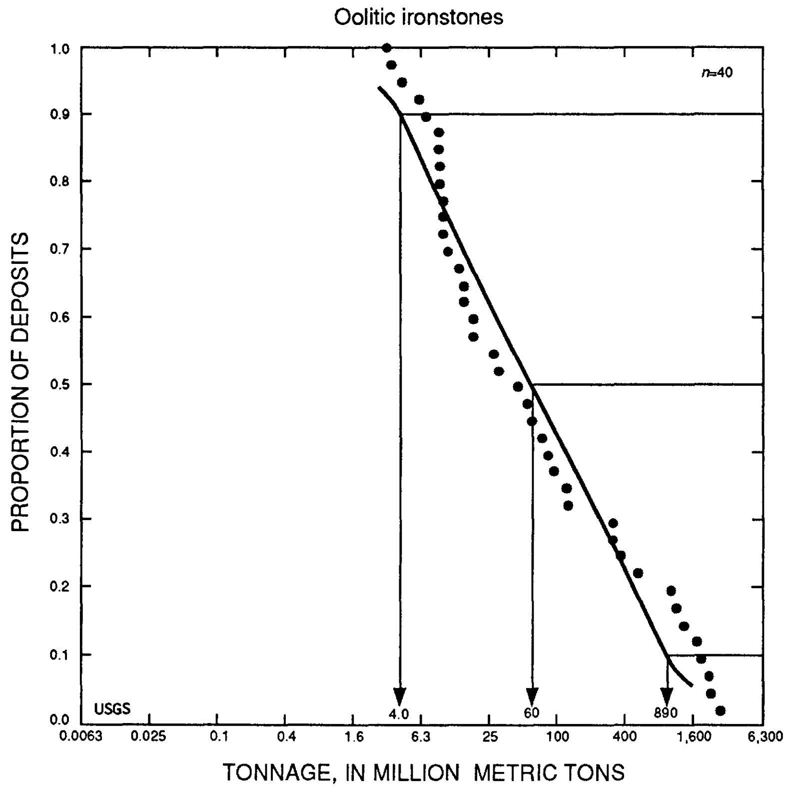


Figure 25. Tonnages of oolitic ironstone deposits.

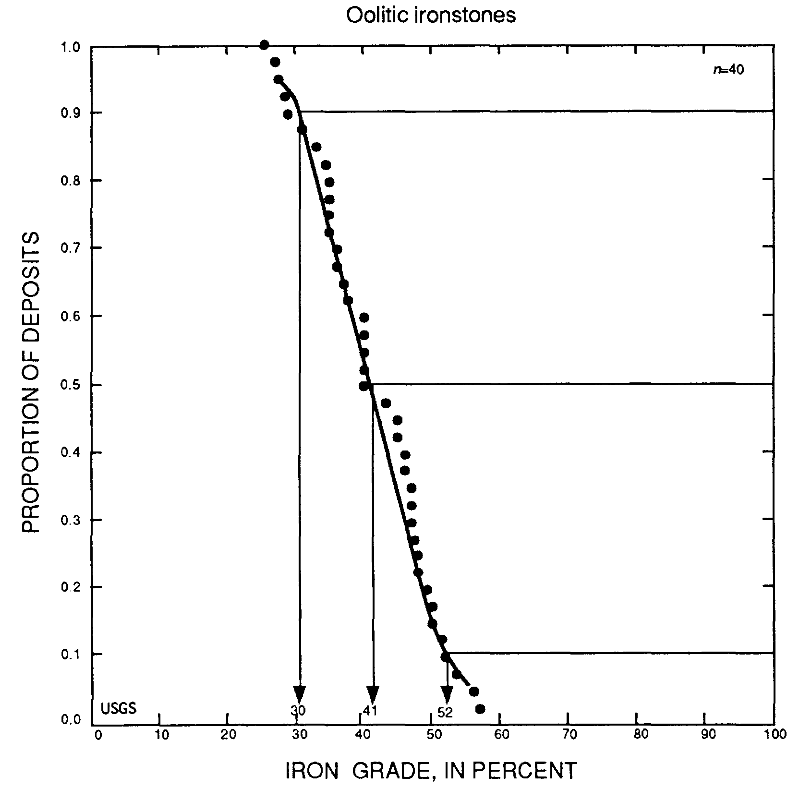


Figure 26. Iron grades of oolitic ironstone deposits.

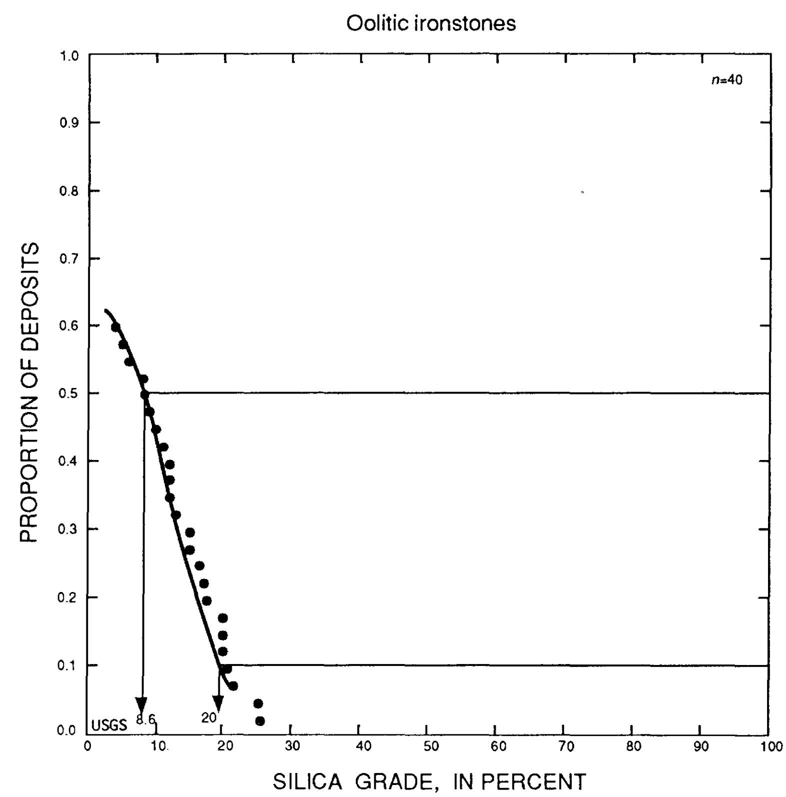


Figure 27. Silica grades of oolitic ironstone deposits.

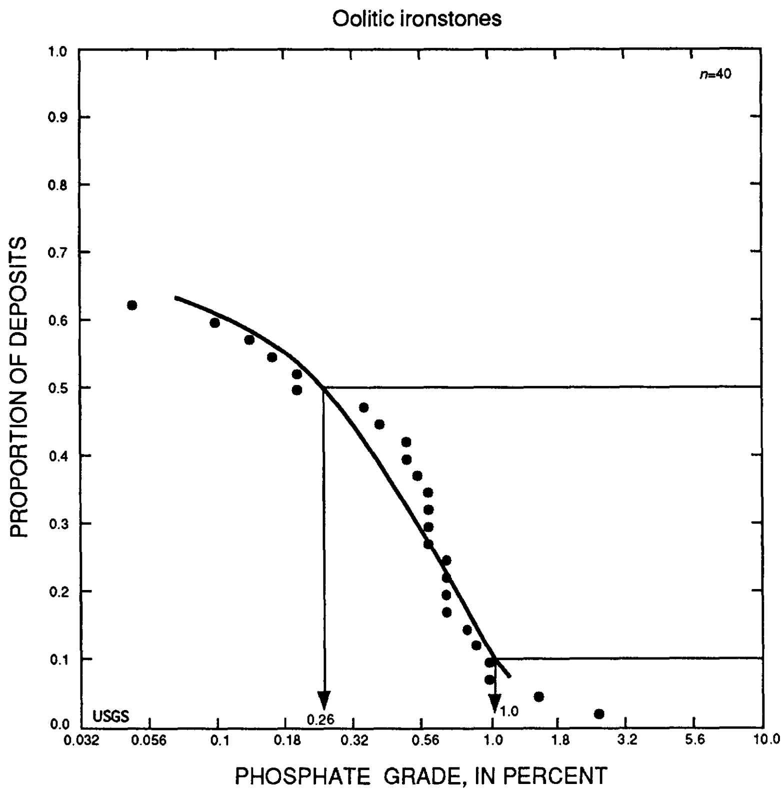


Figure 28. Phosphate grades of oolitic ironstone deposits.

DEPOSITS Name	Country	DEPOSITS Name	Country
Ait Amar	MRCO	Langrial	PKTN
Aswan	EGPT	Ljubija	YUGO
Birmingham	USAL	Ma-yu-kou	CINA
Boulhaut	MRCO	Moncorvo	PORT
Camdag	TRKY	Musson-Halanzy	BLGM
Cho-lu	CINA	Nucice	CZCL
Cleveland	UKEN	Nurra	ITLY
Couthuin	BLGM	Ouarzemine	MRCO
Demir Hisar	YUGO	Pang-chia-pu	CINA
Frodingham-Scunthorpe	UKEN	Paz del Rio	CLBA
Gara Djebilet–Central area	ALGR	Salzgitter	GRMY
Gara Djebilet–East area	ALGR	San-cha-kou	CINA
Gara Djebilet–West area	ALGR	Settat	MRCO
Holoubkha	CZCL	Sierra Grande	AGTN
Hsin-yao	CINA	Sui-Ning	CINA
Imi n'Tourza	MRCO	Sumadija	YUGO
Isle of Raasay	UKSC	Tajmiste	YUGO
Jebel Ank	TUNS	Wabana	CNNF
Kerch	USSR	Yen-tung-shan	CINA
L'Hermitage-Lorge	FRNC	Zditz	CZCL

GRADE AND TONNAGE MODEL OF CHUGACH-TYPE LOW-SULFIDE Au-QUARTZ VEINS

By James D. Bliss

COMMENTS Vein deposits in the Chugach National Forest, Alaska, have gross deposit characteristics that are consistent with the descriptive model for low-sulfide Au-quartz veins (Berger, 1986c). However, grade and tonnage data collected from these deposits during the preparation of the quantitative mineral resource assessment of undiscovered mineral deposits in the Chugach National Forest showed that the typical deposit has about half the tonnages and half the Au grades as those for low-sulfide Au-quartz veins elsewhere (Bliss, 1986). An important regional aspect of these deposits appears be the absence of association with batholithic-scale intrusive bodies, as is commonly found with low-sulfide Au-quartz vein deposits elsewhere. These low-sulfide Au-quartz veins are a subtype, here referred to as "Chugach-type low-sulfide Au-quartz veins." They are located along faults and joints without a "consistent association with igneous activity " (Goldfarb and others, 1986). Major regional faults with mineralization are absent in the Chugach National Forest; such faults are important sites of mineralization for these low-sulfide Au-quartz vein deposits elsewhere. Fluid inclusion data for this area suggest that these deposits were deposited by low-salinity fluids generated by low-grade metamorphism (Goldfarb and others, 1986). The host rocks in the Chugach National Forest are metamorphosed to medium greenschist facies. A distinctive local characteristic of these deposits is that they exhibit much less wall-rock alteration (Goldfarb and others, 1986) than low-sulfide Au-quartz veins elsewhere (Berger, 1986c).

Data for Chugach-type low-sulfide Au-quartz veins are from deposits in or adjacent to the Chugach National Forest and may bias the grade and tonnage model in ways not identified. Deposit definition was made using the same spatial rules concerning proximity of workings as in the model for low-sulfide Au-quartz veins (that is, properties within one mi of each other are aggregated) (Bliss, 1986). Data sources are from Jansons and others (1984) and the U.S. Geological Survey computerized data base on mineralized occurrences, prospects, and mines (the Minerals Resources Data System (MRDS)). In some cases, an estimate of tonnage was made using the technique developed by Bliss (1988). Significant correlation is present between Ag and Au grades (n=21, r=0.77); this is also the case for low-sulfide Au-quartz vein deposits (Bliss, 1986). More Ag grades were found in Chugach-type low sulfide Au-quartz vein deposits (70 percent) than in low sulfide Au-quartz vein deposits (10 percent) (Bliss, 1986). When Ag grades are reported for Chugach-type low-sulfide Au-quartz vein deposits, it is typically from 6 to 40 percent of Au grade compared with 11 to 89 percent for low-sulfide Au-quartz vein deposits. The data giving the ratio of Ag to Au grades between the main deposit type and the subtype are not significantly different at the 5 percent level (Mann-Whitney U Test). See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 29–31.

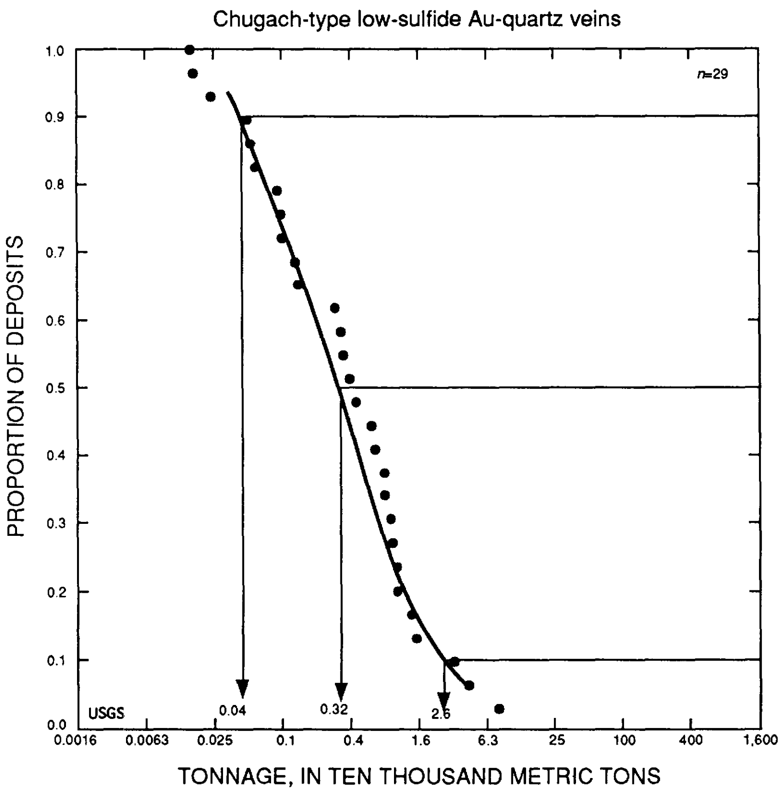


Figure 29. Tonnages of Chugach-type low-sulfide Au-quartz vein deposits.

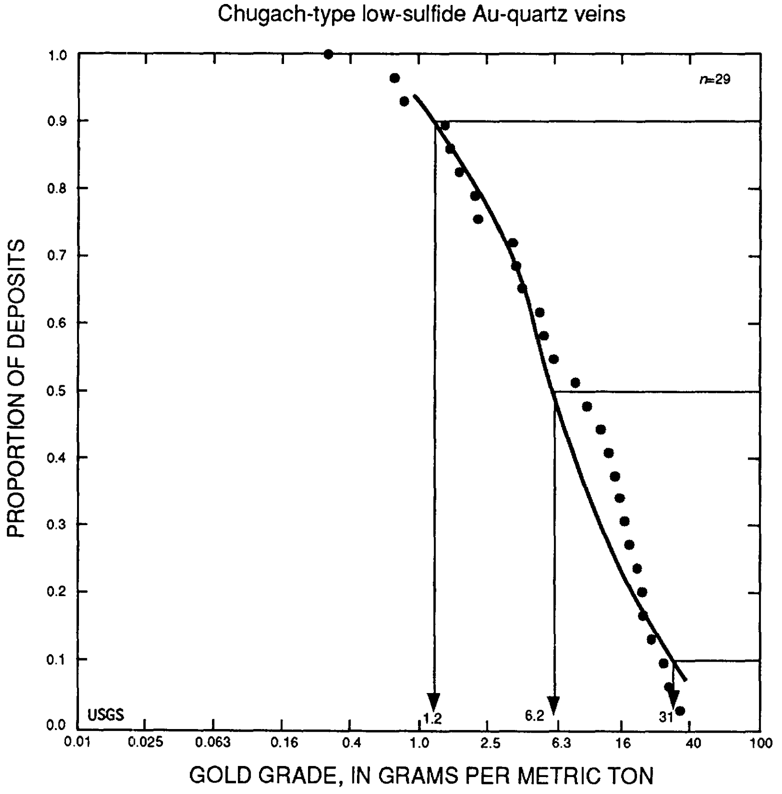


Figure 30. Gold grades of Chugach-type low-sulfide Au-quartz vein deposits.

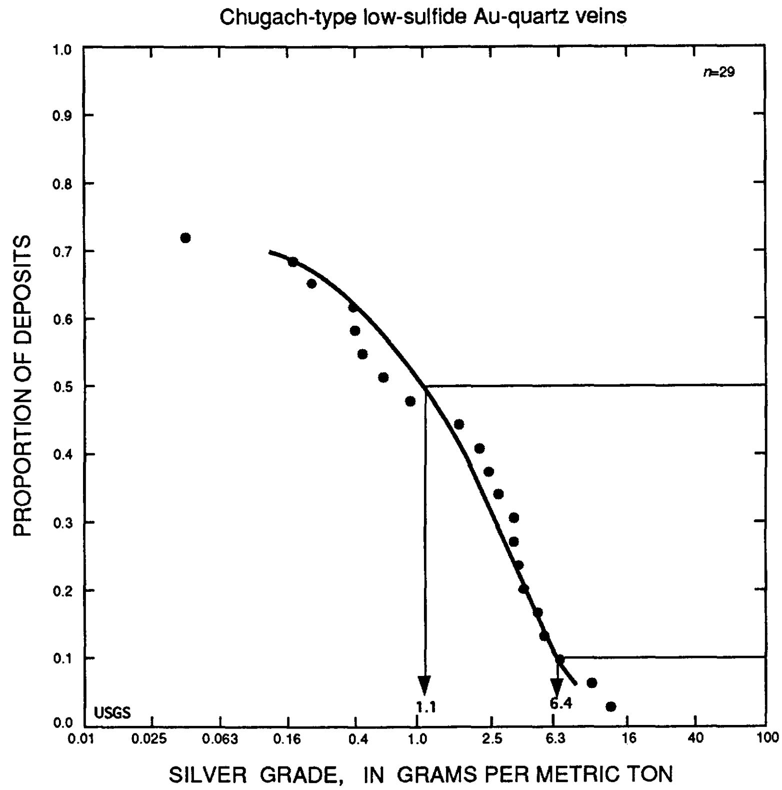


Figure 31. Silver grades of Chugach-type low-sulfide Au-quartz vein deposits.

DEPOSITS

Name	Country	Name	Country
Alaska Homestake	USAK	Imperial	USAK
Cameron-Johnson	USAK	Kana	USAK
Cliff-Sealy	USAK	Kenai Lu	USAK
Crown Point–Fall Creek	USAK	Little Giant	USAK
Cube	USAK	Mayfield	USAK
Donohue	USAK	McMillan	USAK
Downing	USAK	Mineral King	USAK
Gold King	USAK	Monarch-Bahrenburg	USAK
Granite Lake (1)	USAK	Nearhouse	USAK
Granite Lake (2)	USAK	Primrose	USAK
Granite-Snowball	USAK	Ramsay-Rutherford	USAK
Heaston-James	USAK	Rough & Tough	USAK
Hercules-Big Four	USAK	Seward Bonanza	USAK
Hirshey-Carlson	USAK	Tomboy-Lansing	USAK
Hirshey-Lucky	USAK		

DESCRIPTIVE MODEL OF LATERITE-SAPROLITE Au

By Gregory E. McKelvey

BRIEF DESCRIPTION

SYNONYM: Eluvial gold placers (Boyle, 1979), Au-bearing saprolite (Becker, 1895).

DESCRIPTION: Au disseminated in laterite and saprolite that developed under conditions of tropical weathering (fig. 32) over a wide variety of bedrock types but distal to known bedrock gold deposits.

TYPICAL DEPOSITS: Boddington, Mt. Gibson, Edna May, Western Australia; Akaiwang, Arakaka, Guyana; Lumpkin and White Counties, Georgia.

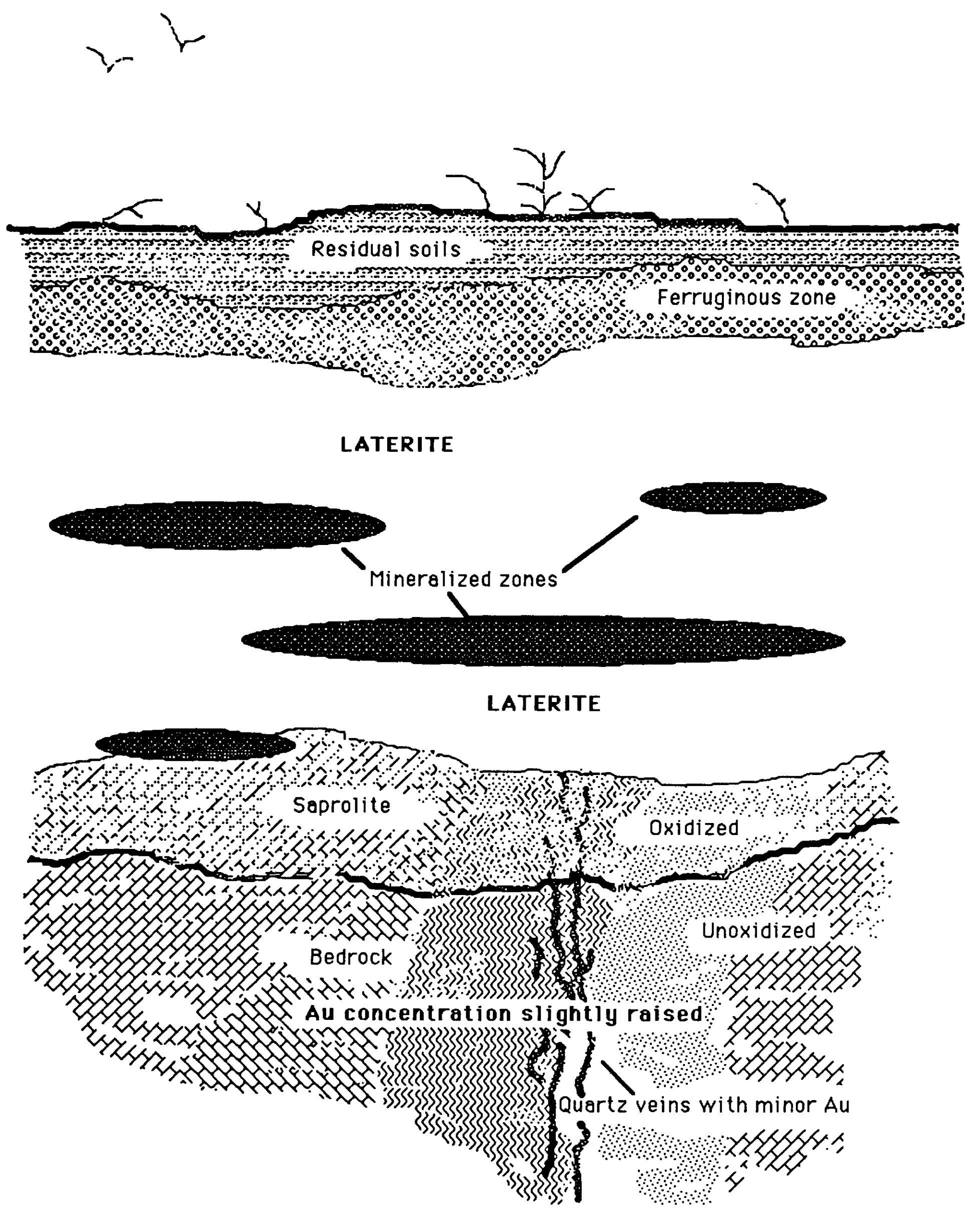


Figure 32. Idealized cross section of laterite-saprolite Au deposit. Vertical scale is in terms of meters; horizontal scale is in terms of kilometers.

DISTINGUISHING FEATURES: Residual and chemical enrichment of gold in tropical areas with laterites and bauxites. Deposit type develops under near-surface conditions of temperature and pressure, and unlike most gold placers it lacks significant detrital gold. Presence of laterite is essential precondition for deposit type.

COMMODITIES: Au±Ag.

OTHER COMMODITIES: Al, PGE, Fe, Sn, W.

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): *Laterite-type bauxite, lateritic Ni, *alluvial Au-PGE placers. All Au-bearing lodes may be found in the bedrock, including low-sulfide Au-quartz veins, Homestake Au, polymetallic replacement and vein deposits, kuroko or Cyprus massive sulfides, porphyry Cu, and rarely lithified placers (Boyle, 1987). By definition, lode mineral deposits should not be present directly under this deposit type.

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Stable weathering zone commonly above greenstone belts and all other gold-bearing terranes.

REGIONAL DEPOSITIONAL ENVIRONMENT: Stable craton, prolonged weathering. If like laterite-type bauxite, deposits should occur commonly along erosional boundaries of old plateau remnants (Patterson, 1986).

AGE RANGE: Cenozoic; late Oligocene to early Miocene in Western Australia (Monti,1987)

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Regoliths, most are lateritic. Others enriched in aluminum (bauxite) (Boyle, 1979). Also, less frequently, deposits found in saprolites, as in the southern Appalachians (Becker, 1895).

ASSOCIATED ROCKS: Greenstones with Au-bearing veins and disseminations. Bedrock may contain various lode deposits and mineralized occurrences typical of stable craton areas (see Associated Deposit Types). Iron-formation or itabirite (Brazil). Other gold-bearing terranes.

ORE MINERALOGY: Finely divided Au. May be splendent, hackle, unworn, rough, and irregular in form. Nuggets are rare. No nuggets are found at Boddington but are identified at Edna May (Monti, 1987). Au as flakes, wire, and specks in canga (see Structure and Zoning). Au is between 1 and 10 μ with an average of 3–5 μ at Boddington (Symons and others, 1988). Ag and other metals usually higher than in alluvial Au placers (however, no Ag was detected in Au grains from Boddington (Monti, 1987), but small amounts of Cu (1.4 to 1.7 percent) and Fe (0.04 to 0.06 percent) were). Saprolitic Au very rough, with masses of wire Au (Becker, 1895). At the Boddington deposit, the following minerals are recognized: malachite, chalcocite, cuprite, chrysocolla, pyrite, chalcopyrite, arsenopyrite, native Cu, and electrum (Monti, 1987).

GANGUE MINERALS: Fe, Al oxides and hydroxides, and Mn oxides. Limonite. Disintegrated bedrock fragments, including iron formation and kaolinite (Boyle, 1979).

STRUCTURE AND ZONING: Mature laterites. Au mineralization may be localized in the laterite or displaced at depth into the underlying saprolite; mineralization in laterites likely to have same texture as that of laterite-type bauxite, which includes pisolitic, massive, nodular, and earthy (Patterson, 1986). Limonite-cemented fragments of iron formation—called apanhoancango or canga in Brazil (Boyle, 1979). At the Boddington deposit, hematitic nodules, clay with Liesegang rings, and ferruginous and bauxitic laterites occur that are locally indurated (Symon and others, 1988). Three broad mineralized levels (average 5 m thick) recognized at this deposit, with individual levels hosted by one or more of the following: (1) a 4- to 12-m-thick ferruginous zone consisting of a hardcap subzone and a B-subzone with nodular and rubbly clay; (2) a 20- to 100-m-thick clay zone; and (3) an up to 5-m-thick saprolite zone. Au found in pisoliths at Edna May but not at Boddington (Monti, 1987).

ORE CONTROLS: Mature laterites. Bauxites and saprolites occur in areas where geomorphology allows sufficient drainage, so that oxidation is both extensive and deep[1] to promote extensive leaching. Develops under conditions of strong chemical weathering with mean annual temperatures greater than approximately 10 °C and rainfall greater than

[1] Observed to 90 m in Nigeria (Thomas, 1965) and to 500 m in Hawaii (S.H. Patterson, written commun., 1978).

approximately 140 cm (Peltier, 1950). Deposition of gold at Boddington believed to be controlled by the position of the water table. Multiple mineralized horizons are products of fluctuations resulting from several climatic regimes (Monti, 1987).

STRUCTURAL SETTING: Bedrocks sufficiently fractured and (or) faulted (or have other types of porosity) so that ground water is below weathered horizon.

ORE DEPOSIT GEOMETRY: Blanketlike on flat terrains or fanlike on gentle slopes (Boyle, 1979). The area of the Boddington, deposit is 4.5 km^2 with an average thickness of 35 m. Deposits are roughly parallel to the land surface and have thicknesses of tens of meters. Pay streaks nonuniform and erratic (Boyle, 1979). Three mineralized zones separated by barren or weakly mineralized zones recognized at Boddington (Monti, 1987). At this deposit, gold is homogeneously distributed when mineralized zones are in laterites and erratic when in saprolites (Symons and others, 1988).

TYPICAL ALTERATION/OTHER HALO DIMENSIONS: Iron oxide and clay mineralogy may indicate chemical enrichment.

EFFECT OF WEATHERING: Main processes of Au concentration include residual enrichment of Au, chemical precipitation of Au, and a combination of both (Boyle, 1987).

EFFECT OF METAMORPHISM: No metamorphic equivalents known.

GEOCHEMICAL SIGNATURES: ±Al±Ga (if contained in a laterite-type bauxite) (Patterson, 1986). Au is signature for some but not all deposits. A study of enrichment/depletion of elements at Boddington shows that Sc is enriched with the Au, and that Fe, Al, Ga, As, Pb, and Sn are enriched as part of the ferruginous zone (Monti, 1987).

GEOPHYSICAL SIGNATURES: Unknown. May be used to identify bedrock features associated with protore. Electrical properties of deposit may prove to be useful. Shallow seismic may be useful in deposit-shape determination.

OTHER EXPLORATION GUIDES: Vegetation may be useful either in identifying areas of poor fertility or in biogeochemical exploration; oxide mineralogy may change systematically from background to adjacent and over the deposits.

OVERBURDEN: Mineralization in saprolite may have a cover of unmineralized laterite or a thin "A" horizon as at Boddington (Symons and others, 1988), which includes loose pisolites (maximum diameter of 2 cm) with gibbsite (45 percent), goethite (20 percent), hematite (20 percent), and maghemite (Monti, 1987).

OTHER: Dissected deposits with very fine gold (several microns) may not have been recognized in the past by placer miners. Some bauxites and laterites have been known to contain Au (Boyle, 1979). Deposit type should not include the weathered horizon of lode deposit types.

GRADE AND TONNAGE MODEL OF LATERITE-SAPROLITE Au

By James D. Bliss

COMMENTS Deposits with data are few and likely subject to revision. Most of the data for laterite-saprolite Au deposits are from one area, and this may bias the model. Deposits are under active investigation and have the following qualifications: (1) data on deposit sizes and grades are for unworked deposits, (2) deposits may be underlain by unrecognized mineral deposits in the bedrocks, and (3) deposits may be placer deposits, not laterite-saprolite Au. One such deposit (Omai, Guyana) has residual mineralization at the surface and mineralization in the bedrock and is excluded in conformance with the descriptive model. The general pattern in the mining of mineral deposits is that the total tonnage (production plus reserves) continues to increase over a portion of the mine life. Therefore, deposit tonnages used in the model are very likely minimum values when compared with tonnages at deposit exhaustion. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 33 and 34.

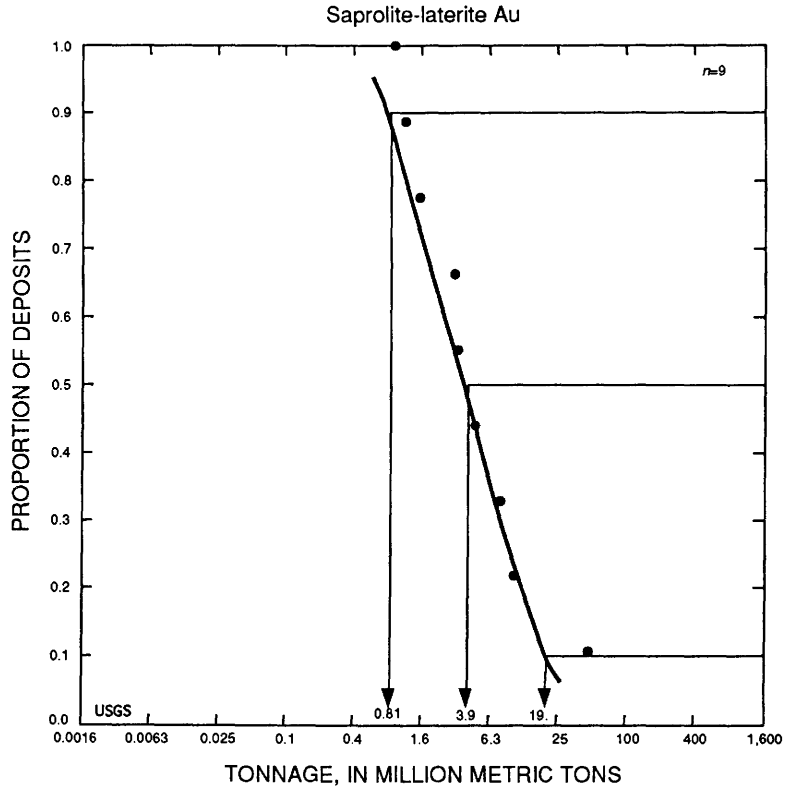


Figure 33. Tonnages of laterite-saprolite Au deposits.

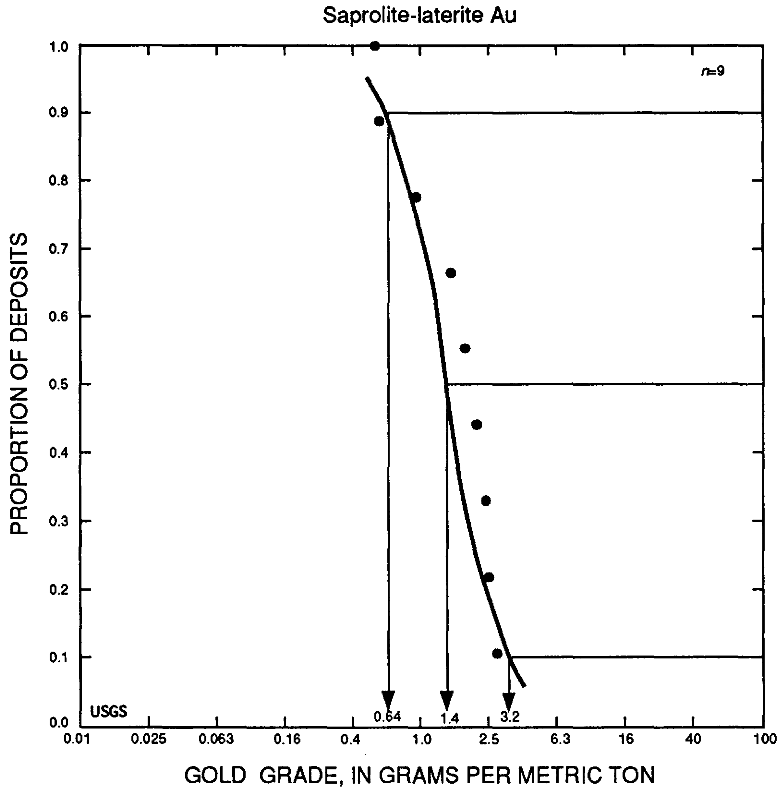


Figure 34. Gold grades of laterite-saprolite Au deposits.

DEPOSITS

Name	Country	Name	Country
Akaiwang	GUYN	Millionaire	GUYN
Arakaka	GUYN	Mt. Gibson	AUWA
Baramita	GUYN	Royal Hill Gold	SRNM
Boddington	AUWA	Tassawine	GUYN
Bullabuling	AUWA		

Preliminary Descriptive Deposit Model for Detachment-Fault-Related Mineralization

By Keith R. Long

INTRODUCTION

Mineralization related to detachment faulting has only recently been recognized as a distinct deposit type, even though such deposits have been mined since the 1860's. These deposits have characteristic mineral assemblages, alteration patterns, ore fluid types, and structural controls that differ considerably from those of other deposit types found in the Basin and Range province of the Western United States. However, detachment-fault-related mineralization is not widely known, having been described but twice in widely circulated journals (Spencer and Welty, 1986; Roddy and others, 1988); most of the detailed studies have appeared as publications of the Arizona Geological Survey and the Arizona Geological Society.

Awareness of the unique character of these deposits has been hampered by confusion with other types of epithermal mineralization that may or may not occur near a low-angle or detachment fault, such as the Cyclopic deposit in northwest Arizona (Myers and Smith, 1986) or the Mesquite deposit in southeastern California (Manske and others, 1988). This discussion sets out the distinguishing characteristics of detachment-fault-related mineralization vis-à-vis other types of epithermal mineralization in the region and provides a justification for the new deposit model presented (K.R. Long, this volume). This deposit model is considered preliminary because this deposit type has yet to be fully investigated and has, thus far, only been recognized in a detachment-faulted terrane encompassing parts of west-central Arizona, southeastern California, and southernmost Nevada (fig. 35).

DETACHMENT-FAULT-RELATED MINERALIZATION

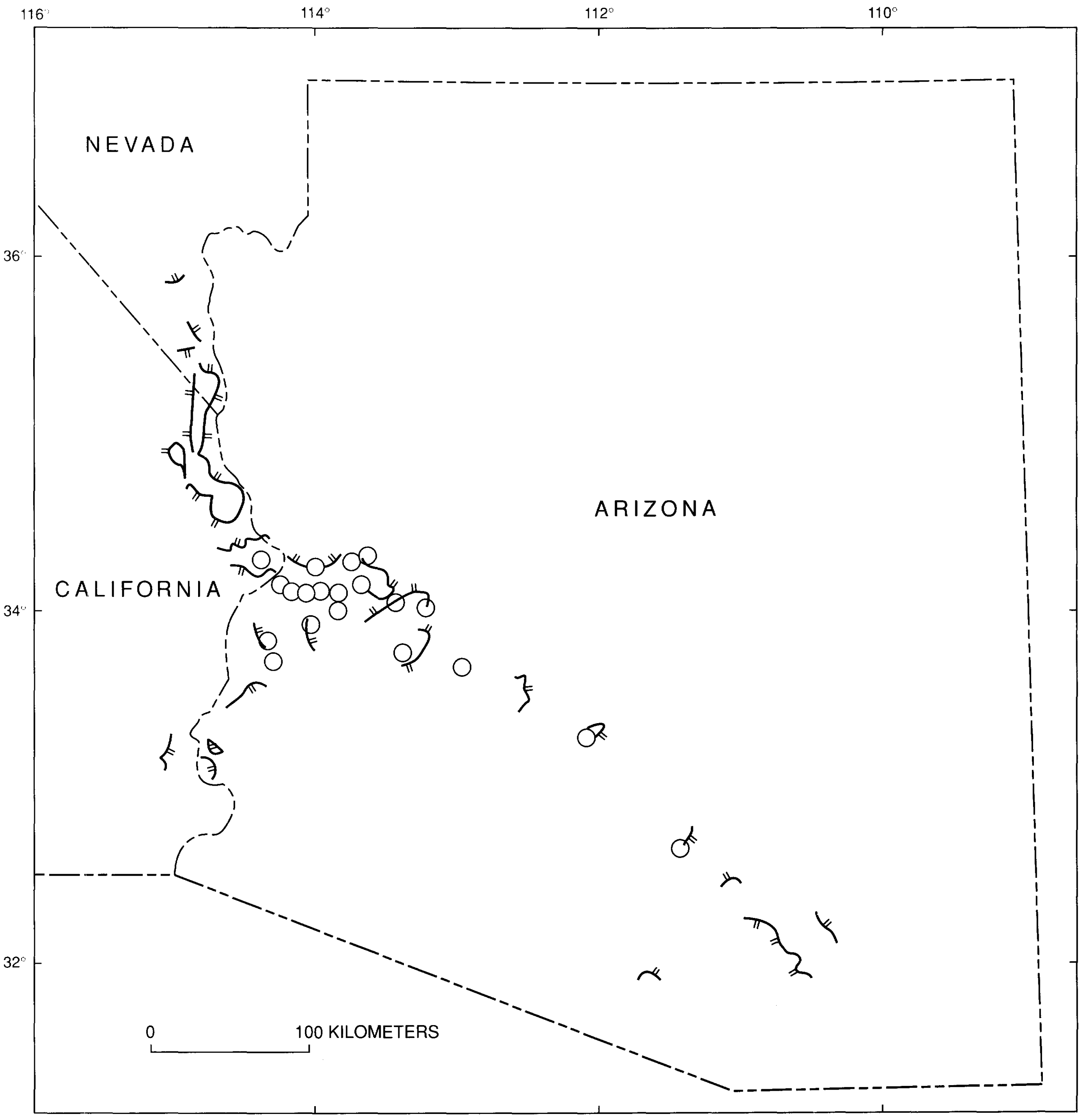
Detachment faults are low-angle (up to 30°) normal faults of regional extent that have accommodated significant regional extension by upward movement of the footwall (lower-plate) producing horizontal displacements on the order of tens of kilometers. Common features of these faults are supracrustal rocks in the upper-plate on top of lower-plate rocks that were once at middle and lower crustal depths, mylonitization in lower-plate rocks that are cut by the brittle detachment fault, and listric and planar normal faults bounding half-graben basins in the upper-plate (Davis and Lister, 1988).

The detachment fault and structurally higher normal faults locally host massive replacements, stockworks, and veins of iron and copper oxides with locally abundant sulfides, veins of barite and (or) fluorite, and veins of manganese oxides (Spencer and Welty, 1986; fig. 36). Bedded manganese oxides occur in sedimentary rocks deposited in the half-graben basins and are generally associated with fault veins of manganese oxides. These bedded manganese deposits should be described separately as another model (lacustrine manganese). Intense chloritic alteration of footwall mylonitic rocks and potassium feldspar replacement of upper-plate rocks are common alteration types that are not always accompanied by mineralization.

This mineralization is termed detachment fault related not simply because it is strongly controlled by detachment-fault structures, but also because it is apparently related to the formation of detachment faults themselves (Roddy and others, 1988). Early chloritic alteration and associated sulfide mineralization appears to result from retrograde metamorphism as hot lower-plate rocks are brought up to shallower depths. Potassium feldspar alteration and oxide mineralization appear to be related to the upward circulation of saline brines derived from syntectonic basins along the detachment fault into more steeply dipping upper-plate normal faults. This fluid movement may have been driven by heat derived either from lower-plate rocks or from syntectonic microdiorite to rhyolite intrusives (Reynolds and Lister, 1987).

DISTINGUISHING CHARACTERISTICS OF DETACHMENT-FAULT-RELATED MINERALIZATION

Features of detachment-fault-related mineralization that distinguish it from other deposit types are listed below. Further details are available in Spencer and Welty



EXPLANATION

Detachment fault

Known detachment-fault-related deposits

Figure 35. Major detachment faults and detachment-fault-related mineral deposits in Arizona, southeastern California, and southernmost Nevada.

(1986), Roddy and others (1988), and Spencer and Reynolds (1989).

1. Deposits are controlled by structures formed during detachment faulting. These include the low-angle, detachment-fault system, high-angle faults in the lower-plate just below the detachment fault, and low- to high-angle normal faults in the upper-plate.
2. Deposits are often brecciated or deformed by movement along or above the detachment fault.
3. Chlorite-epidote-calcite alteration occurs along and below the detachment fault. These altered zones sometimes contain base-metal sulfides and barite.
4. There is massive potassium feldspar replacement of upper-plate rocks. This alteration appears to generally precede ore formation and is not always spatially associated with mineralization.
5. Weak sericite-silica alteration of wall rock is sometimes present around barite-fluorite veins.
6. Most mineralization consists of iron and copper oxides, principally specular to earthy hematite and chrysocolla. Common gangue minerals are chalcedonic to amethystine quartz, ferrous to manganiferous calcite, barite, fluorite and manganese oxides. Distal barite-fluorite veins consist of variable proportions of barite, fluorite, and manganese oxides. Common gangue minerals are quartz and manganiferous calcite.
7. Fluid inclusions have moderate homogenization temperatures (150 to 350 °C) and salinities (10 to 23 equivalent weight percent NaCl), compatible with precipitation from connate brines. Fluid inclusions from barite-fluorite veins have lower homogenization temperatures (90 to 200 °C) and are somewhat less saline (6 to 20 equivalent weight percent NaCl), compatible with precipitation from variably cooled and diluted connate brines.
8. Host rocks are enriched in Cu, Pb, Zn, Au, Ag, and Ba and are depleted in Mn, Sr, Ni, and Rb. Elements characteristic of epithermal environments, such as As, Sb, Hg, and Tl, occur in very low, background-level concentrations.

DEPOSIT TYPES COMMONLY CONFUSED WITH DETACHMENT-FAULT-RELATED MINERALIZATION

Epithermal gold-silver deposits that occur along or near low-angle faults might be mistaken for detachment-fault-related mineralization. Several possible cases can be identified:

1. Epithermal deposits found in metamorphic rocks (for example, Mesquite, California; Manske and others, 1988).
2. Epithermal deposits that are overprinted by younger detachment-fault-related mineralization (for example, Cyclopic, Arizona; Myers and Smith, 1986).

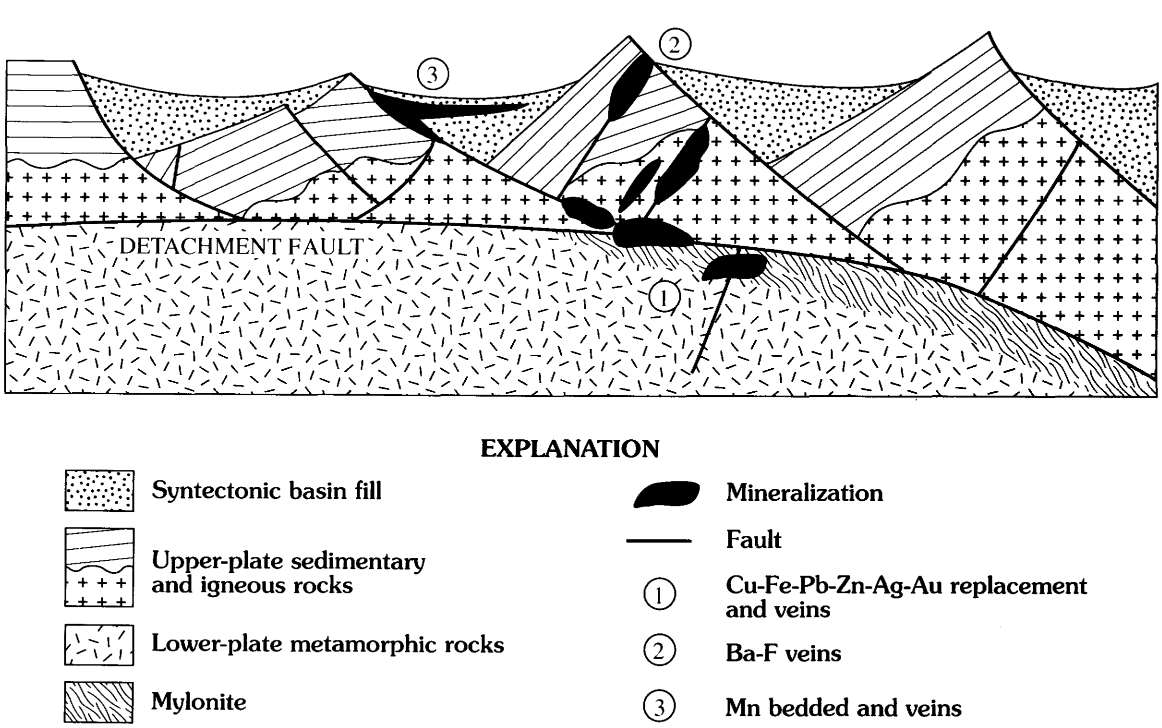


Figure 36. Schematic diagram (not to scale) showing structural position of detachment-fault-related polymetallic mineralization, Ba-F-Mn veins, and lacustrine manganese mineralization in detachment-faulted terranes.

3. Epithermal deposits that overprint detachment-fault-related mineralization or that were emplaced during detachment faulting (for example, Bullfrog, Nevada; Jorgeson and others, 1989).
4. Epithermal deposits that are significantly younger than detachment faulting but are controlled by detachment-fault structures (no known examples in the published literature).

Epithermal deposits can be distinguished from detachment-fault-related deposits by their characteristic ore mineralogy, alteration minerals and patterns, geochemical signatures, and fluid-inclusion compositions, as described in the deposit model for hot spring Au-Ag (Berger, 1986b). Principal distinguishing characteristics are the following:

1. Ore mineralogy consists of base- and precious-metal sulfides with few or no primary oxide minerals. Gangue quartz is not usually amethystine, and gangue calcite is poor in iron and manganese.
2. Extensive propylitic and (or) argillic alteration of upper-plate host rocks is observed with only local potassic alteration.
3. Low-salinity (<6 equivalent weight percent NaCl), moderate homogenization temperature (200 to 300 °C) fluid inclusions are observed.
4. Anomalous concentrations of the elements As, Sb, Hg, and Tl, which are characteristic of epithermal deposits, are present.

SIZES AND GRADES OF DEPOSITS

Available data on sizes and grades of detachment-fault-related mineral deposits consist mostly of production statistics originally collected by the U.S. Bureau of Mines and reported by the Arizona Geological Survey (Keith and others, 1983; Spencer and Welty, 1989). The only reserve data available are for recently explored deposits, such as Copperstone, Arizona (Spencer and others, 1988). Attempts to model tonnages and grades for detachment-fault-related polymetallic deposits using cumulative production data (table 10) were not successful. Few of these deposits produced all of the metals that occur in this deposit type, making it difficult to model deposit grades. In fact, indications are that there may be two subtypes of detachment-fault-related mineralization—a Cu-Au type and a Pb-Zn-Ag type—but further research is required to confirm this.

In any case, grade and tonnage models based on the production data listed in table 10 would not give an accurate indication of the range in sizes and grades of these deposits that could be expected to be encountered in a modern exploration program. Not only were not all metals recovered, but also many of these ores were concentrated in part by hand. In hand sorting, a large quantity of waste is typically rejected prior to sending ore to the concentrator, and these rejects are not always included in recorded production tonnages. Thus, the grades computed from production statistics are not likely representative of the true grade of the ore mined. Further, these were underground mines; thus, in comparison with the tonnages and grades that might be estimated for a modern open-pit operation, these older orebodies were smaller in size and higher in grade.

A better sense of the potential size and grade of these deposits is indicated by recently reported reserves for deposits that have been excluded from table 10 as a result of their lack of production history. These are Copperstone (Spencer and others, 1988), a recent producer with reserves of 4.2 million short tons of 0.077 troy ounce per ton Au ore as of December 31, 1988, having produced 62,800 troy ounces Au prior to that date (Cyprus Gold Co., 1989); and Newsboy, a recent discovery in Arizona, with reserves of 1.5 million short tons of 0.045 troy ounce per ton ore (H. Dummett, oral commun., 1989).

A number of deposits have been excluded from table 10 because their classification as detachment-fault-related deposits is controversial. These include Picacho, California (Van Nort and Harris, 1984), and Silver, Arizona (Bradley, 1986).

Table 10. Grades and tonnages for detachment-fault-related polymetallic deposits

[Tonnages in short tons; copper, lead, and zinc grades in percent; silver and gold grades in troy ounces per short ton. Country and sate abbreviations explained in app. B]

Deposit	Country	Tonnage	Copper grade	Lead grade	Zinc grade	Silver grade	Gold grade	Source[1]
Alamo-Bluebell	USAZ	692	2.80	1.10		.47	0.12	2
ArtilleryPeak	USAZ	500	1.30			1.20		1
Bullard	USAZ	17,000				.35	.21	1
Cienaga	USAZ	19,092	4.50			.08	.63	2
Clara	USAZ	49,728	4.70			.03		2
Cleopatra-Cleopatra	USAZ	14,744	1.50			.23	.11	2
Cleopatra-Kimble	USAZ	4,482	.30			.03	.01	2
Cleopatra-Silverfield	USAZ	863	.90	.03		9.50	.06	2
Harquahala (Eastern)	USAZ	21,000	.14			.35	.13	1
Lead Pill	USAZ	1,451	.96	13.90		1.50	.36	2
Mammon	USAZ	841	5.20			.17	.07	2
Midway–Battleship	USAZ	15	4.00			.07		2
Midway–GreenStreak	USAZ	189	1.30			.11	.20	2
Midway–Mammoth	USAZ	10	16.30			1.30	.80	2
Moon Mountains	USAZ	300				.33	2.70	1
Northern Plomosa	USAZ	7,500	2.30	.16		.93	.67	1
Osborne	USAZ	86,000	.79	4.50		2.30	.15	1
Owens	USAZ	792	.11	3.90		13.00	.13	2
Picacho	USAZ	100	1.20			1.00		1
Planet-Mineral Hill	USAZ	970,756	.68					2
Planet-Planet	USAZ	39,015	8.00			.01	.01	2
Pride	USAZ	38	.03			.16	2.00	2
Rawhide	USAZ	708	.74	18.4	1.60	11.50	.05	2
Salt River Mountains	USAZ	15,000	.09			.33	.47	1
Swansea	USAZ	544,918	2.40			.06		2
Whipple	USCA	5,000	2.30	.01		1.90	.26	3

[1]Sources: 1 (Keith and others, 1983), 2 (Spencer and Reynolds, 1989), and 3 (Spencer and Welty, 1986).

DESCRIPTIVE MODEL OF DETACHMENT-FAULT-RELATED POLYMETALLIC DEPOSITS

By Keith R. Long

BRIEF DESCRIPTION

SYNONYM: Detachment-fault-related gold, flat-fault gold.

DESCRIPTION: Massive replacements, stockworks, and veins of iron and copper oxides and locally sulfides along detachment-fault structures. These deposits sometimes contain economic concentrations of gold and silver. Distal veins of quartz-barite-fluorite-Mn oxides emplaced along high-angle faults in the upper plate of detachment-faulted terranes.

GENERAL REFERENCE: Wilkins and others (1986).

TYPICAL DEPOSITS: Bullard (Roddy and others, 1988), Copperstone (Spencer and others, 1988), Osborne (Allen, 1985), Planet (Lehman and Spencer, 1989), Harris (Roddy and others, 1988), Tiger Wash (Allen, 1985).

COMMODITIES: Cu + Au + Ag ± Pb ± Zn.

OTHER COMMODITIES: Fe-Ba-F-Mn-Mo-V.

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): *Lacustrine Mn.

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Extensional terranes characterized by regional detachment faulting.

REGIONAL DEPOSITIONAL ENVIRONMENT: Half-graben mountain ranges and hydrographically closed basins that formed syntectonically with extensional deformation above detachment faults.

AGE RANGE: Known deposits range from middle to late Tertiary in age.

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: (1) Lower-plate mylonitic rocks, chlorite breccias, and structurally emplaced slivers of upper-plate rocks. (2) Upper-plate Paleozoic to Mesozoic (meta)sedimentary and (meta)volcanic rocks, Mesozoic to early Tertiary felsic intrusive rocks, middle to late Tertiary mafic to intermediate lavas, silicic tuffs, and sedimentary rocks deposited in alluvial fan, fluvial, and saline lake environments.

ASSOCIATED ROCKS: Syn- to posttectonic alkali basalts, microdiorite dikes, and sedimentary rocks deposited in half-graben basins.

ORE MINERALOGY: Specular and earthy hematite, chrysocolla, and gold or electrum. Locally abundant chalcopyrite and other copper sulfides. Rare galena, sphalerite, and tetrahedrite. Sulfides accompany chloritic alteration in early-stage mineralization along and below detachment fault. Quartz-hematite-calcite-chrysocolla mineralization follows along and above detachment fault. Late-stage quartz-barite-fluorite-manganese oxide veins with locally abundant copper oxides, cerargyrite, argentite, gold, and hematite occur above detachment fault.

GANGUE MINERALS: Quartz (sometimes chalcedonic or amethystine), calcite (often ferrous and (or) manganiferous), barite, fluorite, and manganese oxides. Locally abundant pyrite, jasperoid, gypsum, and clays.

ZONING: Intensity of mineralization and alteration decreases away from detachment fault. Many districts zoned from polymetallic deposits outward to Ba-F-Mn veins. Mineralization tends to be base metal–rich and precious metal–poor near the detachment fault but precious metal–rich/base metal–poor away from the detachment fault.

ORE CONTROLS: Deposits commonly located above axis or flanks of synformal structures in underlying detachment surface. Orebodies are localized along high-angle fault zones below the detachment fault, along the detachment fault, and in high-angle, sometimes listric, normal faults in the upper plate. Gold is often associated with local silica flooding and amethystine quartz veins in brittle, fractured upper-plate rocks. Massive specularite replacements and chrysocolla veins occur in reactive calcareous units in both the upper and lower plates.

ISOTOPIC SIGNATURES: Quartz associated with oxide ore minerals has 6 to 8 per mill $\delta^{18}O$, and that associated with sulfide ore minerals has 10 to 12 per mill $\delta^{18}O$. Calcite associated with oxide ore minerals has 4 per mill $\delta^{18}O$ and –4 to –6 per mill $\delta^{13}C$ PDB. K-metasomatized rock has lower $\delta^{18}O$ than unaltered rock by 2 to 4 per mill.

FLUID INCLUSIONS: In quartz, calcite and barite associated with sulfide ore homogenization temperatures are higher (220 to 350 °C) than those associated with oxide ore (150 to 350 °C). Salinities, however, are similar at 10 to 23 equivalent weight percent NaCl. These fluids are thought to be saline brines derived from syntectonic, hydrographically closed, arid basins. Quartz in distal Ba-F-Mn veins have low-temperature (90 to 200 °C) and saline (6 to 20 weight percent equivalent NaCl) fluid inclusions.

STRUCTURAL SETTING: Local flexures of a regional detachment fault with strong development of upper-plate, high-angle, listric and planar normal faults.

ORE DEPOSIT GEOMETRY: (1) Narrow fracture and fault fillings that are 3 cm to 12 m in width with strike lengths of 30 to 2,000 m. (2) Irregular, pod-shaped massive replacements of reactive lithologies up to 900 m long, 100 m wide and 3 to 30 m thick. (4) Pods and anastomosing veins along low-angle faults. (5) Veinlets and breccia clasts in fault breccia.

ALTERATION: Wall rock dependent. Distinct alteration suites are observed: (1) Pre-ore to early chloritic (chlorite-epidote-hematite) alteration of lower-plate mylonites and fault breccias, sometimes with associated quartz-pyrite-chalcopyrite±galena mineralization. (2) Pre-ore to early K-metasomatism of upper-plate volcanic rocks. Mafic rocks are converted into K-feldspar-hematite-calcite-chlorite-epidote rocks, and silicic rocks are converted into K-feldspar-hematite-quartz rocks. (3) Pre-ore to early massive carbonate replacement of carbonate rocks. (4) Propylitic (chlorite-calcite-epidote-sericite-clay) alteration envelopes around veins hosted by mafic rocks. Quartz-chrysocolla veins often have clay selvages. (5) Weak sericite-silica-dolomite envelopes around Ba-F-Mn veins in calcareous rocks.

TYPICAL ALTERATION/OTHER HALO DIMENSIONS: (1) Chloritic alteration may extend from the top of the detachment fault down to 300 m below the detachment fault. (2) K-metasomatism may extend more than 2 km above the detachment fault in zones more than 10 km in extent. (3) Massive carbonate replacements range up to 900 m in length, 100 m wide, and about 30 m thick. (4) Propylitic alteration halos are narrow, up to a few centimeters around veins and fracture fillings.

EFFECT OF WEATHERING: Most ore consists of primary oxides. Locally abundant sulfides may be oxidized.

EFFECT OF METAMORPHISM: Metamorphosed deposits are not known.

GEOCHEMICAL SIGNATURES: Host rocks are enriched in Cu, Pb, Zn, Au, Ag, and Ba and depleted in Mn, Sr, Ni, and Rb. As, Sb, Hg, and Tl are also very low.

GEOPHYSICAL SIGNATURES: There may be a resistivity contrast between oxide ores along and above the detachment fault and the mylonite zone beneath the detachment fault. Silica flooded zones may have high resistivity. Massive hematite orebodies may produce a magnetic dipole anomaly. Shallow reflection seismic might detect detachment-fault structures.

OTHER EXPLORATION GUIDES: Conodont alteration of upper-plate Paleozoic sediments may serve as a guide to regional paleo-heat flow related to fluid movement along and above detachment faults.

OVERBURDEN: Variable, owing to differing degrees of uplift along half-graben structures and regional warps. Polymetallic deposits are thought to have formed at a depth of 1 to 3 km (Spencer and Welty, 1986), and Ba-F-Mn veins at a depth of 0.5 km (Allen, 1985).

REFERENCES CITED

Allen, G.B., 1985, Economic geology of the Big Horn Mountains of west-central Arizona: Arizona Geological Survey Open-File Report 85-17, 140 p.

Alvarez, A.A, and Noble, D.C., 1988, Sedimentary rock-hosted disseminated precious metal mineralization at Purísima Concepción, Yauricocha district, central Peru: Economic Geology, v. 83, no. 7, p. 1368-1378.

Armbustmacher, T.J., 1988, Geology and resources of thorium and associated elements in the Wet Mountains area, Fremont and Custer Counties, Colorado: U.S. Geological Survey Professional Paper 1049-F, 34 p.

Bagby, W.C., and Berger, B.R., 1986, Geologic characteristics of sediment-hosted, disseminated precious-metal deposits in the western United States, *in* Berger, B.R., and Bethke, P.M., eds., Geology and geochemistry of epithermal systems: Society of Economic Geologists Reviews in Economic Geology, v. 2, p. 169-202.

Bagby, W.C., Menzie, W.D., Mosier, D.L., and Singer, D.A., 1986, Grade and tonnage model of carbonate-hosted Au-Ag, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175-177.

Barton, P.B., 1986a, Commodity/geochemical index, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 303-317.

———1986b, Mineralogical index, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 318-348.

Becker, G.F., 1895, Gold fields of the southern Appalachians: U.S. Geological Survey 16th Annual Report, pt. 3, p. 251-331.

Berger, B.R., 1986a, Descriptive model of carbonate-hosted Au-Ag, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175.

———1986b, Descriptive model of hot-spring Au-Ag, *in* Cox, D.P., and Singer, D.A., eds, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 143-144.

———1986c, Descriptive model of low-sulfide Au-quartz veins, *in* Cox, D.P., and Singer, D.A., eds, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 239.

Berger, B.R., and Singer, D.A., 1987, Grade-tonnage model of hot-spring Au-Ag; a supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open-File Report 87-272c, 6 p.

Bliss, J.D., 1986, Grade and tonnage model of low-sulfide Au-quartz veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models, U.S. Geological Survey Bulletin 1693, p. 239-243.

———1988, Predicting gold production from low-sulfide gold-quartz veins: California Geology, v. 41, no. 8, p. 178-180.

———1989, Quantitative estimates of undiscovered metal endowment for selected mineral deposit types in the Chugach National Forest, Alaska: U.S. Geological Survey Open-File Report 89-345, 26 p.

Bliss, J.D., and Jones, G.M., 1988, Mineralogic and grade-tonnage information on low-sulfide Au-quartz veins: U.S. Geological Survey Open-File Report 88-229, 99 p.

Bliss, J.D., McKelvey, G.E., and Allen, M. S., 1990, Application of grade and tonnage deposit models; the search for ore deposits possibly amenable to small-scale mining: U.S. Geological Survey Open-File Report 90-412, 24 p.

Bliss, J.D., Orris, G.J., and Menzie, W.D., 1987, Changes in the grade, volume and contained gold during the mining life-cycle of gold placer deposits: Canadian Mining and Metallurgical Bulletin, v. 80, no. 903, p. 75-80.

Bouley, B.A., 1986, Descriptive model of gold on flat faults, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 251.

Boyle, R.W., 1979, The geochemistry of gold and its deposits: Geological Survey of Canada Bulletin 280, 584 p.

———1987, Gold—history and genesis of deposits: New York, Van Nostrand Reinhold Company, 676 p.

Bradley, M.A., 1986, Vein mineralogy, paragenesis, and fluid inclusion study of the Silver District, La Paz County, Arizona: Arizona Geological Society Digest, v. 16, p. 457-459.

Cannon, W.F., 1986a, Descriptive model of Algoma Fe, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 198.

———1986b, Descriptive model of Superior Fe, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 228.

Chenoweth, W.L., 1986, The Orphan Lode, Grand Canyon, Arizona — A case history of a mineralized, collapse-breccia pipe: U.S. Geological Survey Open-File Report 86-510, 125 p. Appendix.

———1988, The production history and geology of the Hacks, Ridenour, Riverview, and Chapel breccia pipes, northwestern Arizona: U.S. Geological Survey Open-File Report 88-0648, 60 p.

Cox, D.P., and Rytuba, J.J., 1987, Lihir Island gold; a supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open-File Report 87-272a, 5 p.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

———1988, Distribution of gold in porphyry copper deposits: U.S. Geological Survey Open-File Report 88-46, 10 p.

Cyprus Gold Co., 1989, Securities and Exchange Commision Form 10-K for 1989.

Davis, G.A., and Lister, G.S., 1988, Detachment faulting in continental extension; perspectives from the southwestern U.S. Cordillera, *in* Clark, S.P., Jr., Burchfiel, B.C., and Suppe, J., eds., Processes in continental lithosphere deformation: Geological Society of America Special Paper 218, p. 133-159.

Duda, R.O., Hart, P.E., Nilsson, N.J., Reboh, R., Slocum, J., and Sutherland, G.L., 1977, Development of a computer-based consultant for mineral exploration: Stanford Research Institute Annual Report, Project 5821 and 6415, 202 p.

Duda, R.O., 1980, The Prospector system for mineral exploration: Menlo Park, Calif., Stanford Research Institute Final Report, Project 8172, 120 p.

Feigenbaum, E., McCorduck, P., and Nii, H.P., 1988, The rise of the expert company: New York, Times Books, Inc., 322 p.

Flanigan, V.J., Tippens, C.L., Senterfit, M.R., and Mohr, P.J., 1986, Geophysical exploration criteria for collapse breccia pipes, northern Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 5, p. 355.

Goldfarb, R.J., Leach, D.L., Miller, M.L., and Pickthorn, W.J., 1986, Geology, metamorphic setting, and genetic constraints of epigenetic lode-gold mineralization within the Cretaceous Valdez Group, south-central Alaska, *in* Keppie, J.D., Boyle, R.W., and Haynes, S.J., eds., Turbidite-hosted gold deposits: Geological Association of Canada Special Paper 32, p. 87-105.

Gornitz, V., Wenrich, K.J., Sutphin, H.B., and Vidale-Buden, R., 1988, Origin of the Orphan mine breccia pipe uranium deposit, Grand Canyon, Arizona, *in* Vassiliou, A.H., Hausen, D.M., and Carson, D.J., eds., Process mineralogy VII - as applied to separation technology, 1988: Warrendale, Pa.,The Metallurgical Society, p. 281-301.

Graybeal, F.T., 1981, Characteristics of disseminated silver deposits in the western United States, *in* Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 271-282.

Green, M.W., 1988, Tectonic evolution, *in* Granger, H.C., Finch, W.I., and others, The Colorado Plateau Uranium Province, U.S.A., Proceedings of a technical committee meeting on recognition of uranium provinces, London, England, 18-20 September 1985: Vienna, Austria, International Atomic Energy Agency, p. 169-172.

Guerrak, S., 1987, Paleozoic oolitic ironstones of the Algerian Sahara: a review: Journal of African Earth Sciences, v. 5, p. 1-8.

Hallam, A., and Bradshaw, M.G., 1979, Bituminous shales and oolitic ironstones as indicators of transgressions and regressions: Journal of the Geological Society of London, v. 136, p. 157-164.

Hallimond, A.F., 1925, Iron ores: bedded ore of England and Wales, *in* Special reports on the mineral resources of Great Britain, v. 29: Nottingham, Geological Survey of Great Britain Memoir, 139 p.

Heald, Pamela, Foley, N.K., and Hayba, D.O., 1987, Comparative anatomy of volcanic-hosted epithermal deposits: acid-sulfate and adularia-sericite types: Economic Geology, v. 82, no. 1, p. 1-26.

Hodych, J.P., Patzold, R.R., and Buchan, K.L., 1984, Paleomagnetic dating of the transformation of oolitic goethite to hematite in iron ore: Canadian Journal of Earth Science, v. 21, p. 127-130.

Iijima, A., and Matsumoto, R., 1982, Berthierine and chamosite in coal measures of Japan: Clays and Clay Minerals, v. 30, p. 264-274.

Jansons, Uldis, Hoekzema, R.B., Kurtak, J.M., and Fechner, S.A., 1984, Mineral occurrences in the Chugach National Forest, south-central Alaska: U.S. Bureau of Mines Open-File Report MLA 5-84, unpaginated.

Jorgeson, D.K., Rankin, J.W., and Wilkins, J., Jr., 1989, The geology, alteration and mineralogy of the Bullfrog gold deposit, Nye County, Nevada: Society of Mining Engineers Preprint 89-135, 13 p.

Keith, S.B., Gest, D.E., DeWitt, E., Woode Toll, N., and Everson, B., 1983, Metallic mineral districts and production in Arizona: Arizona Bureau of Mines Bulletin 194, 58 p.

Krewedl, D.A., and Carisey, Jean-Claude, 1986, Contributions to the geology of uranium mineralized breccia pipes in northern Arizona, *in* Beatty, B., and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the southwest: Arizona Geological Society Digest, v. 16, p. 179-186.

Lehman, N.E., and Spencer, J.E., 1989, Mineralization in the central part of the Planet mineral district, northwestern Buckskin Mountains, *in* Spencer, J.E., and Reynolds, S.J., 1989, Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, 279 p.

Leiding, V., Benjamin, 1955, Iron ore deposits of South America, *in* Survey of world iron ore reserves: occurrence, appraisal and use: New York, United Nations Department of Economic and Social Affairs, p. 209-223.

Lovering, T.G. and Heyl, A.V., 1974, Jasperoid as a guide to mineralization in the Taylor mining district and vicinity near Ely, Nevada: Economic Geology, v. 69, no. 1, p. 46-58.

Ludwig, K.R., and Simmons, K.R., 1988, Progress in U/Pb isotope studies of collapse-breccia pipes in the Grand Canyon region, northern Arizona [abs]: Geological Society of America 1988 Centennial Celebration Abstracts with Programs, v. 20, no. 7, p. A139.

Manske, S.L., Matlack, W.F., Springett, M.W., Strakele, A.E., Jr., Watowich, S.N., Yeomans, B., and Yeomans, E., 1988, Geology of the Mesquite deposit, Imperial County, California: Mining Engineering, v. 40, p. 439-444.

Mathisen, I.W., Jr., 1987, Arizona strip breccia pipe program—Exploration, development, and production [abs.]: American Association of Petroleum Geologists Bulletin, v. 71, no. 5, p. 590-591.

Maynard, J.B., 1983, Geochemistry of sedimentary ore deposits: New York, Springer-Verlag, 305 p.

———1986, Geochemistry of oolitic iron ores, an electron microprobe study: Economic Geology, v. 81, p. 1473-1483.

McCammon, R.B., 1989, Prospector II, *in* Antonisse, H.J., Benoit, J.W., and Silverman, B.G., eds., The Annual AI systems in Government Conference, Proceedings, Washington, D.C., March, 1989, p. 88-92.

McKelvey, G.E., and Bliss, J. D., 1991, Application of grade and tonnage models to the development of strategies for mineral deposit exploration [abs.], *in* Good, E.E., Slack, J.F. and Kotra, R.K., eds., USGS research on mineral resources—1990: U.S. Geological Survey Circular 1062, p. 53-54.

Menzie, W.D., and Reed, B.L., 1986a, Grade and tonnage model of Sn skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 58-60.

———1986b, Grade and tonnage model of replacement Sn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 62-63.

———1986c, Grade and tonnage model of Sn veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 67-69.

———1986d, Grade and tonnage model of Sn greisen deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 71-72.

Miller, H.G., 1983, Geophysical constraints on the size and extent of the Wabana hematite deposit: Economic Geology, v. 78, p. 1017-1021.

Moeller, S.A., 1987, Geology and mineralization in the Candelaria district, Mineral Coutny, Nevada, *in* Schafer, R.W., Cooper, J.J., and Vickre, P.G., eds., Bulk mineable precious metal deposit of the western United States: Reno, Geological Society of Nevada, p. 135-158.

Monti, Richard, 1987, The Boddington lateritic gold deposit, Western Australia: a product of sugergene enrichment processes, *in* Ho, S.E., and Groves, D.I., eds., Recent advances in understanding Precambrian gold deposits: Nedlands, University of Western Australia Publication Number 11, p. 355-368.

Mosier, D.L., and Page, N.J, 1988, Descriptive and grade-tonnage models of volcanogenic manganese deposits in oceanic environments—a modification: U.S. Geological Survey Bulletin 1811, 28 p.

Mosier, D.L., Singer, D.A., Sato, Takeo, and Page, N.J, 1986, Relationship of grade, tonnage, and basement lithology in volcanic-hosted epithermal precious- and base-metal quartz-adularia-type districts: Tokyo, Japan, Mining Geology, v. 36, no. 4, p. 245-264.

Myers, I.A., and Smith, E.I., 1986, Control of gold mineralization at the Cyclopic mine, Gold Basin district, Mohave county, Arizona: Economic Geology, v. 81, p. 1553-1557.

Nokleberg, W.J., Bundtzen, T.K., Berg, H.C., Brew, D.A., Grybeck, Donald, Robinson, M.S., Smith, T.E., and Yeend, Warren, 1987, Significant metalliferous lode deposits and placer districts of Alaska: U.S. Geological Survey Bulletin 1786, 104 p.

Olson, J.C., and Hedlund, D.C., 1981, Alkalic rocks and resources of thorium and associated elements in the Powder district, Gunnison County, Colorado: U.S. Geological Survey Professional Paper 1049-C, 34 p.

Olson, J.C., Marvin, R.F., Park, R.L., and Mehnert, H.H., 1977, Age and tectonic setting of lower palezoic alkalic and mafic rocks, carbonatites, and thorium veins in south-central Colorado: U.S. Geological Survey Journal of Research, v. 5, no. 6, p. 673-687.

Olson, J.C., Shawe, D.R., Pray, L.C., and Sharp, W.N., 1954, Rare-earth mineral deposits of the Mountain Pass district, San Bernardino County, California: U.S. Geological Survey Professional Paper 261, 75 p.

Olson, J.C., and Wallace, S.R., 1956, Thorium and rare-earth minerals in Powderhorn district, Gunnison County, Colorado: U.S. Geological Survey Bulletin 1027-O, p. 693-721.

Orris, G.J., 1985, Bedded/stratiform barite deposits: geologic and grade-tonnage data including a partial bibliography: U.S. Geological Survey Open-File Report 85-447, 32 p.

Orris, G.J., and Bliss, J.D., 1985, Geologic and grade-volume data on 330 gold placer deposits: U.S. Geological Survey Open-File Report 85-213, 172 p.

———1989, Industrial-rock and mineral-resource-occurrence models, *in* Tooker, E.W., ed., Arizona's industrial rock and mineral resources of Arizona—workshop proceedings: U.S. Geological Survey Bulletin 1905, p 39-44.

———1991, Some industrial mineral deposit models; descriptive deposits models: U.S. Geological Survey Open-File Report 91-11A, 73 p.

Orris, G.J., Bliss, J.D., Hammarstrom, J.M., and Theodore, T.G., 1987, Description and grade and tonnages of gold-bearing skarns: U.S. Geological Survey Open-File Report 87-273, 50 p.

Page, N.J, Singer, D.A., Moring, B.C., Carlson, C.A., McDade, J.M., and Wilson, S.A., 1986, Platinum-group element resources in podiform chromitites from California and Oregon: Economic Geology, v. 81, p. 1261-1271.

Patterson, S.H., 1986, Descriptive model of laterite type bauxite deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 255.

Peltier, Louis Cook, 1950, The geographic cycle periglacial region as it is related to climatic geomorphology: Annuals of the Association of American Geographers, v. 40, no. 3, p. 214-236.

Ranger, M.J., Pickerill, R.K., and Fillion, P., 1984, Lithostratigraphy of the Cambrian - Ordovician Bell Island and Wabana Groups of Bell, Little Bell, and Kelly's Island, Conception Bay, eastern Newfoundland: Canadian Journal of Earth Sciences, v. 21, p. 1245-1261.

Reed, B.L., Menzie, W.D., McDermott, M., Root, D.H., Scott, W., and Drew, L.J., 1989, Undiscovered lode tin resources of the Seward Peninsula, Alaska: Economic Geology, v. 84, no. 7, p. 1936-1947.

Reynolds, S.J., and Lister, G.S., 1987, Structural aspects of fluid-rock interactions in detachment zones: Geology, v. 15, p. 362-366.

Roddy, M.S., Reynolds, S.J., Smith, B.M., and Ruiz, J., 1988, K-metasomatism and detachment-related mineralization, Harcuvar Mountains, Arizona: Geological Society of America Bulletin, v. 100, p. 1627-1639.

Schafer, R.N., 1988, An example of a northern Arizona solution-collapse breccia pipe - geology of the Pigeon pipe [abs.]: Geological Society of America 1988 Centennial Celebration, Abstracts with Programs, v. 20, no. 7, p. A139.

Shawe, D.R., compiler, 1981, U.S. Geological Survey workshop on nonfuel mineral-resource appraisal of wilderness and CUSMAP areas: U.S. Geological Survey Circular 845, 18 p.

Simpson, T.A., and Gray, T.R., 1968, The Birmingham red-ore district, Alabama, *in* Ridge, John, ed., Ore deposits of the United States,1933-1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 1, p. 187-206.

Singer, D. A. 1986, Descriptive model of kuroko massive sulfide, *in* Cox, D. P. and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 189-190.

Singer, D.A., and Cox, D.P., 1988, Applications of mineral deposit models to resource assessments: U.S. Geological Survey Yearbook Fiscal Year 1987, p. 55-57.

Singer, D.A., and Mosier, D.L., 1986, Grade and tonnage model of kuroko massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 190-197.

Singer, D.A., and Ovenshine, A.T., 1979, Assessing metallic resources in Alaska: American Scientist, v. 67, no. 5, p. 582-589.

Spencer, J.E., Duncan, J.T., and Burton, W.D., 1988, The Copperstone mine: Arizona's new gold producer: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 18, no. 2, p. 1-3.

Spencer, J.E., and Reynolds, S.J., eds., 1989, Geology and mineral resources of the Buckskin and Rawhide mountains, west-central Arizona: Arizona Geological Survey Bulletin 198 (Shackelford Volume), 279 p.

Spencer, J.E., and Welty, J.W., 1986, Possible controls of base- and precious-metal mineralization associated with Tertiary detachment faults in the lower Colorado River trough, Arizona and California: Geology, v. 14, p.195-198.

———1989, Geology of mineral deposits in the Buckskin and Rawhide Mountains, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arziona: Arizona Geological Survey Bulletin 223-254.

Staatz, M.H., 1972, Geology and description of the thorium-bearing veins, Lemhi Pass quadrangle, Idaho and Montana: U.S. Geological Survey Bulletin 1351, 94 p.

———1974, Thorium veins in the United States: Economic Geology, v. 69, p. 494-507.

———1979, Geology and mineral resources of the Lemhi Pass thorium district, Idaho and Montana: U.S. Geological Survey Professional Paper 1049-A, 90 p.

———1983, Geology and description of thorium and rare-earth deposits in the southern Bear Lodge Mountains, northern Wyoming: U.S. Geological Survey Professional Paper 1049-D, 52 p.

———1985, Geology and description of the thorium and rare-earth veins in the Laughlin Peak area, Colfax County, New Mexico: U.S. Geological Survey Professional Paper 1049-E, 32 p.

Staatz, M.H., and Armbrustmacher, T.J., 1982, Preliminary map of the thorium provinces in the conterminous United States: U.S. Geological Survey Open-File Report 79-576U, scale 1:5,000,000.

Staatz, M.H., Armbrustmacher, T.J., Olson, J.C., Brownfield, I.K., Brock, M.R., Lemons, J.F., Coppa, L.V., and Clingan, B.V., 1979, Principal thorium resources in the United States: U.S. Geological Survey Circular 805, 42 p.

Staatz, M.H., Bunker, C.M., and Bush, C.A., 1971, Geochemical prospecting for thorium veins by stream-sediment sampling, Lemhi Pass quadrangle, Idaho and Montana: U.S. Geological Survey Professional Paper 750-C, p. C136-C140.

Sutphin, D.M., and Bliss, J.D., 1990, Disseminated flake graphite and amorphous graphite deposit types: an analysis using grade and tonnage models: Canadian Mining and Metallurgical Bulletin, v. 83, no. 940, p. 85-89.

Symons, P.M., Anderson, G., Beard, T.J., Hamilton, L.M., Reynolds, G.D., Robinson, J.M., and Staley, R.W., 1988, The Boddington gold deposits [extended abs.], *in* Goode, A.D.T., and Bosma, L.T., compilers, Bicentennial gold 88: Geological Society of Australia Abstract Series Number 22, p. 56-61.

Taylor, J.H., 1949, The Mesozoic ironstones of England, petrology of the Northampton sand ironstone formation: Nottingham, Geological Survey of Great Britain Memoir, 111 p.

Teyssen, T.A.L., 1984, Sedimentology of the Minette oolitic ironstones of Luxembourg and Lorraine: a Jurassic subtidal sandwave complex: Sedimentology, v. 31, p. 195-211.

Theodore, T.G., Orris, G.J., Hammarstrom, J.M., and Bliss, J.D., 1991, Gold-bearing skarns: U.S. Geological Survey Bulletin 1930, 90 p.

Thomas, M.F.,1965, Some aspects of the geomorphology of tors and domes in Nigeria: Zeitung für Geomorphologie, v. 9, p. 63-81.

Tosdal, R.M., and Smith, D.B., 1987, Gneiss-hosted kyanite gold and gneiss-hosted epithermal gold; a supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open-File Report 87-272b, 8 p.

Van Gosen, B.S., and Wenrich, K.J., 1989, Ground magnetometer surveys over known and suspected breccia pipes on the Coconino Plateau, northwestern Arizona: U.S. Geological Survey Bulletin 1683-C, 31 p.

Van Houten, F.B., and Arthur, M.A., 1989, Temporal patterns among Phanerozoic oolitic ironstones and oceanic anoxia, *in* T.P. Young and W.E.F. Taylor, eds., Phanerozoic ironstones: London, Geological Society Special Publication 46, p. 33-49.

Van Houten, F.B., and Bhattacharyya, D.P., 1982, Phanerozoic oolitic ironstones - geologic record and facies model: Annual Review of Earth and Planetary Sciences, v. 10, p. 441-457.

Van Nort, S.D., and Harris, M., 1984, Geology and mineralization of the Picacho Gold prospect, Imperial County, California: Arizona Geological Society Digest, v. 15, p. 175-183.

Weber, F.R., McCammon, R.B., Rinehart, C.D., Light, T.D., and Wheeler, K.L., 1988, Geology and mineral resources of the White Mountains National Recreation Area, east-central Alaska: U.S. Geological Survey Open-File Report 88-284, 120 p.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Economic Geology, v. 80, p. 1722-1735.

Wenrich, K.J., and Sutphin, H.B., 1988, Recognition of breccia pipes in northern Arizona: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 18, no. 1, p. 1-8, 11.

———1989, Lithotectonic setting necessary for formation of a uranium-rich solution-collapse breccia-pipe province, Grand Canyon region, Arizona: U.S. Geological Survey Open-File Report 89-0173, 33 p.

Wenrich, K.J., Verbeek, E.R., Sutphin, H.B., Van Gosen, B.S., and Modreski P.J., 1987, The Apex mine, Utah—A Colorado Plateau-type solution-collapse breccia pipe [abs.], *in* USGS research on mineral resources—1987 program and abstracts: U.S. Geological Survey Circular 995, p. 73-74.

Wilkins, Joe, Jr., Beane, R.E., and Heidrick, T.L., 1986, Mineralization related to detachment faults: A model, *in* Beatty, Barbara, and Wilkinson, P.A.K. eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest, v. 16, p. 108–117.

Appendix A. Classification of deposit models by lithologic-tectonic environment

[Partal list of table 1 of Cox and Singer (1986); only applicable parts and modifications given. Some deposit-type numbers have been previously assigned for industrial mineral deposit types (G.J. Orris, written commun., May 1990), which has affected the numbers given here. *, indicates that model is not included in this bulletin]

Deposit environment	Model No.
Mafic and ultramafic intrusions	
C. Alakaline intrusions in stable areas	
Carbonatite	10
(Thorium-rare-earth veins)	(11d)
Alkaline complexes	11
Thorium-rare-earth veins	11d
Felsic intrusions	
E. Porphyroaphanitic intrusions present	
Other felsic and mafic rocks including alkalic	
Wallrocks are calcareous	
Deposits far from contact	
Distal disseminated Ag-Au	19c
Extrusive rocks	
G. Felsic-mafic extrusive rocks	
Subaerial	
Deposits mainly within volcanic rocks	
Hot-spring Au-Ag	25a
Deposits in older calcareous rocks	
Sedimentary-hosted Au[1]	26a
Marine	
Sierran kuroko massive sulfide	28a.1
Sedimentary rocks	
I. Carbonate rocks	
No associated igneous rocks	
Solution-collapse breccia pipe U	32e
J. Chemical sediments	
Shelf	
Oolitic ironstones	34f
Regionally metamorphosed rocks	
K. Derived mainly from eugeosynclinal rocks	
Chugach-type low-sulfide Au-quartz vein	36a.1
Surficial and unconformity related	
M. Residual	
Laterite-saprolite Au	38g
N. Depositional	
(Laterite-saprolite Au)	(38g)
Regional geologic structures	
O. Extended terranes	
Detachment fault-related polymetallic deposits	40a
Lacustrine Mn	40b*

[1]Note name change from "Carbonate-hosted Au-Ag" found in Cox and Singer (1986); other changes described in model text.

Appendix B. Locality abbreviations

[Some abbreviations are from Singer and Cox (1986, app. A); some are new]

AGTN	Argentina
ALGR	Algeria
AUWA	Australia, Western Australia
CINA	China
BLGM	Belgium
CZCL	Czechoslovakia
CLBA	Colombia
CNBC	Canada, British Columbia
CNNF	Canada, Newfoundland
EGPT	Egypt
FRNC	France
GRMY	Germany
GUYN	Guyana
ITLY	Italy
MRCO	Morocco
MXCO	Mexico
PERU	Peru
PORT	Portugal
PKTN	Pakistan
SRNM	Suriname
TRKY	Turkey
TUNS	Tunisia
YUGO	Yugoslavia
UKEN	United Kingdom, England
UKSC	United Kingdom, Scotland
USAL	United States, Alabama
USAK	United States, Alaska
USAZ	United States, Arizona
USCA	United States, California
USCO	United States, Colorado
USID	United States, Idaho
USMT	United States, Montana
USNM	United States, New Mexico
USNV	United States, Nevada
USSR	Union of Soviet Socialist Republics
USUT	United States, Utah
USWY	United States, Wyoming

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models

- Findings
  - Geologic-Ages
    - Precambrian
      - Archean
      - Proterozoic
    - Phanerozoic
      - Paleozoic
        - Cambrian
        - Ordovician
        - Silurian
        - Devonian
        - Carboniferous
          - Mississippian
          - Pennsylvanian
        - Permian
      - Mesozoic
        - Triassic
        - Jurassic
        - Cretaceous
      - Cenozoic
        - Tertiary
          - Paleogene
            - Paleocene
            - Eocene
            - Oligocene
          - Neogene
            - Miocene
            - Pliocene
        - Quaternary
          - Holocene
          - Pleistocene

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Rock-Types
  - Igneous
    - Plutonic
      - Felsic-plutonic
        - Granite
          - Alaskite
          - Leucogranite
            - Muscovite-leucogranite
            - Biotite-leucogranite
            - Granulite
          - Plagiogranite
            - Trondhjemite
          - Alkali-granite
            - Alkali-feldspar-granite
          - Charnockite
          - Monzogranite
        - Granodiorite
        - Tonalite
        - Alkali-quartz-syenite
        - Quartz-syenite
        - Quartz-monzonite
        - Monzonite
        - Syenite
          - Syenite-porphyry
          - Nepheline-syenite
          - Larvikite
          - Naujaite
          - Nordmarkite
          - Shonkinite
        - Nephelinite
      - Intermediate-plutonic
        - Quartz-monzodiorite
        - Quartz-monzogabbro
        - Quartz-diorite
        - Diorite
          - Ferrodiorite
        - Ijolite
        - Diabase
      - Mafic-plutonic
        - Gabbro
          - Ferrogabbro
          - Eucrite
          - Essexite
          - Troctolite
          - Olivine-gabbro
          - Gabbro-norite
            - Norite
          - Hornblende-gabbro
          - Jutunite
          - Picritic-gabbro
        - Jacupirangite
      - Ultramafic-plutonic
        - Dunite
        - Pyroxenite
          - Websterite
          - Hornblende-clinopyroxenite
          - Hornblende-magnetite-clinopyroxenite
          - Magnetite-hornblende-pyroxenite

- Rock-Types—Continued
  - Igneous—Continued
    - Plutonic—Continued
      - Ultramafic-plutonic—Continued
        - Peridotite
          - Lherzolite
          - Harzburgite
          - Kimberlite
          - Wehrlite
        - Chromitite
        - Zoned-ultramafic
      - Other-plutonic
        - Anorthosite
          - Andesine-anorthosite
    - Volcanic
      - Volcanic-rocks
        - Felsic-volcanic-rocks
          - Alkali-rhyolite
            - Alkali-feldspar-rhyolite
          - Quartz-trachyte
          - Quartz-latite
          - Rhyolite
            - Rhyodacite
          - Dacite
            - Rhyodacite
        - Mafic-volcanic-rocks
          - Andesite
          - Tholeiitic-basalt
          - Trachyte
          - Latite
            - Quartz-latite
          - Basalt
            - Shoshonite
          - Phonolite
        - Alkaline-volcanic-rocks
        - Other-volcanic
          - Ignimbrite
          - Komatiite
          - Tephra
          - Tuff
            - Andesitic-tuff
            - Tuff-breccia
            - Tholeiitic-tuff
          - Tuffite
          - Volcanic-breccia
            - Vent-breccia
          - Volcaniclastic-rocks
          - Calc-alkaline-pyroclastics
          - Flows
          - Siliceous-sinter
          - Agglomerate
    - Hypabyssal
      - Lamprophyre
        - Monchiquite
        - Vogesite
      - Leucite-lamproite
      - Olivine-lamproite
      - Diabase

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Rock-Types—Continued
  - Igneous—Continued
    - Hypabyssal—Continued
      - Picrite
        - Picrite-porphyrites
      - Felsic-hypabyssal
        - Aplite
        - Granophyre
        - Felsic-dikes
        - Quartz-porphyry
        - Granite-porphyry
    - Other-igneous-rocks
      - Carbonatite
        - Anierite-carbonatite
        - Sovite
      - Melilite
      - Diabase
      - Pegmatite
      - Migmatite
      - Ophiolite
  - Sedimentary
    - Pelites
      - Mudstone
      - Shale
        - Calcareous-shale
        - Siliceous-shale
        - Carbonaceous-shale
        - Black-shale
        - Gray-shale
        - Green-shale
        - Pyritic-shale
      - Clay
        - Claystone
      - Carbonaceous-pelites
    - Siltites
      - Siltite
      - Siltstone
    - Arenites
      - Sand
      - Sandstone
        - Graywacke
        - Quartzite
        - Grit
        - Red-beds
          - Arkose
        - Feldspathic-sandstone
          - Arkose
        - Phosphatic-sandstone
        - Tuffaceous-sandstone
        - Turbidites
    - Calcareous-rocks
      - Carbonate-rocks
        - Calcarenite
        - Marl
        - Limestone
          - Carbonaceous-limestone
          - Phosphatic-limestone
          - Cherty-limestone
          - Siliceous-limestone

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Rock-Types—Continued
  - Sedimentary—Continued
    - Calcareous-rocks—Continued
      - Carbonate-rocks—Continued
        - Quartz-carbonate-rocks
        - Dolomite
          - Carbonaceous-dolomite
          - Cherty-dolomite
      - Calcareous-shale
      - Calcareous-graywacke
      - Calcareous-phyllite
      - Calcareous-slate
      - Marble
      - Calc-silicates
    - Other-sedimentary-rocks
      - Conglomerate
      - Phosphorite
      - Chert
      - Agglomerate
      - Evaporites
        - Anhydrite
        - Gypsum
      - Gravel
      - Iron-formation
      - Shell-rocks
      - Jasper
  - Metamorphic
    - Regional-metamorphic
      - Gneisses
        - Gneiss
        - Biotite-gneiss
        - Biotite-hornblende-gneiss
        - Diorite-gneiss
        - Garnet-gneiss
        - Granite-gneiss
        - Hornblende-gneiss
        - Granodiorite-gneiss
        - Graphite-gneiss
        - Microcline-gneiss
        - Oligoclase-gneiss
        - Pyroxene-gneiss
        - Quartz-biotite-gneiss
        - Syenite-gneiss
        - Alkalic-fenitized-gneiss
      - Schists
        - Schist
        - Amphibole-schist
        - Biotite-schist
        - Biotite-sillimanite-schist
        - Calcite-biotite-schist
        - Graphitic-schist
        - Chlorite-schist
        - Garnet-biotite-schist
        - Hornblende-schist
        - Mica-schist
        - Staurolite-schist
        - Talc-schist
        - Tremolite-phlogopite-schist
        - Quartz-mica-schist

- Rock-Types—Continued
  - Metamorphic—Continued
    - Regional-metamorphic—Continued
      - Amphibolites
        - Amphibolite
        - Epidote-amphibolite
      - Meta-gabbro
      - Serpentinite
      - Metasedimentary-rocks
        - Marble
        - Fine-grained-metasedimentary-rocks
          - Phyllites
            - Phyllite
            - Calcarous-phyllite
            - Sericitic-phyllite
          - Argillite
          - Slates
            - Slate
            - Calcareous-slate
            - Quartzose-slate
        - Coarse-grained-metasedimentary-rocks
          - Quartzite
      - Metavolcanic-rocks
        - Felsic-metavolcanic-rocks
        - Mafic-metavolcanic-rocks
          - Mafic-metatuff
    - Contact-metamorphic-rocks
      - Hornfels
      - Quartzite
      - Siliceous-dolomite
      - Marble
      - Fenite
    - Other-metamorphic-rocks
      - Breccia
      - Greenstone
      - Mylonite
      - Ophiolite
  - Other rock-types
    - Aluminous-silicate-rocks
    - Apatite-magnetite-rocks
    - Breccia
- Form-Structure
  - Vein
    - Lode
    - Greisen
    - Pegmatite
    - Shear-zone
  - Fissure
    - Fissures
    - Fissure-filling
  - Fracture
    - Fractures
  - Veins
    - Veinlets
  - Porphyry
    - Stockwork
      - Veinlets
    - Stock
    - Zoned-complex

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Form-Structure—Continued
  - Stratiform
    - Zoned-complex
    - Layered-complex
    - Massive
    - Bedded
    - Banded
    - Lenses
    - Disseminated
      - Fine-grained
    - Pellets
    - Nodules
    - Oolites
    - Pisolites
    - Fossil-fragments
    - Gash-filling
    - Ribbon-veins
  - Replacement
    - Contact-metasomatic
      - Skarn
    - Massive-replacement
    - Open-space-filling
    - Breccia
      - Pipe
      - Collapse-breccia
      - Breccia-filling
      - Diatreme
  - Surficial
    - Gossan
    - Laterite
    - Placer
- Alteration
  - Type
    - Spilitic
    - Zoned
    - Potassic
    - Phyllic
      - Sericitization
        - Sericite
    - Propylitic
    - Argillic
      - Sericitization
        - Sericite
      - Kaolinization
        - Kaolin
    - Sodic-calcic
      - (Zeolites)
    - Supergene
  - Process
    - Leaching
    - Sericitization
      - Sericite
    - Dolomitization
      - Dolomite
    - Albitization
      - Albite
    - Kaolinization
      - Kaolin

- Alteration—Continued
  - Process—Continued
    - Oxidation
      - Gossan
    - Hematization
      - Hematite
    - Serpentinization
      - Serpentine
    - Silicification
      - (Silicates)
    - Tourmalinization
      - Tourmaline
    - Feldspar-destruction
    - Chloritization
      - Chlorite
    - Pyritization
      - Pyrite
    - Fenitization
      - Fenite
    - Greisenization
      - Greisen
    - Carbonation
      - (Carbonates)
      - Amorphous-carbon
    - Recrystallization
    - Reduction
    - Replacement
      - Calc-silicates
        - Endoskarn
        - Exoskarn
  - (Oxides)
  - Jarosite
  - Alunite
- Geochemical-Elements
  - (all-elements-in-periodic-table)
  - REE
    - (Y La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu)
  - PGE
    - (Ru Rh Pd Os Ir Pt)
  - NH3
- Minerals
  - Hydrocarbons
  - Native-elements
    - Metals
      - Gold
      - Silver
      - Copper
      - Platinum
      - Iron
      - Mercury
      - Amalgam
    - Semimetals
      - Arsenic
      - Bismuth
    - Nonmetals
      - Sulfur
      - Diamond
        - Carbonado

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Minerals—Continued
  - Native-elements—Continued
    - Nonmetals—Continued
      - Diamond—Continued
        - Ballas
        - Bort
      - Graphite
  - Sulfides
    - Iron-sulfides
      - Pyrite
      - Pyrrhotite
      - Marcasite
      - Arsenopyrite
      - Chalcopyrite
        - Stannite
      - Bornite
      - Cubanite
      - Pentlandite
      - Mackinawite
    - Lead-sulfides
      - Galena
    - Zinc-sulfides
      - Sphalerite
  - Sulfides-other-than.Fe.Pb.Zn
    - Silver-sulfides
      - Argentite
    - Copper-sulfides
      - Chalcopyrite
        - Stannite
      - Bornite
        - Carrollite
      - Covellite
      - Chalcocite
      - Cubanite
      - Digenite
    - Nickel-sulfides
      - Pentlandite
      - Millerite
      - Mackinawite
    - Cobalt-sulfides
      - Cobaltite
        - Gersdorffite
    - Cinnabar
    - Cooperite
    - Laurite
    - Molybdenite
    - Greenockite
    - Realgar
    - Orpiment
    - Stibnite
    - Bismuthinite
  - Selenides-Tellurides-Arsenides-Antimonides
    - Selenides
      - Naumannite
    - Tellurides
      - Hessite
      - Coloradoite
      - Calaverite
      - Sylvanite

- Minerals—Continued
    - Selenides-Tellurides-Arsenides-Antimonides—Continued
        - Arsenides
            - Pararammelsbergite
            - Maucherite
            - Skutterudite
            - Sperrylite
            - Loellingite
            - Arsenopyrite
            - Niccolite
        - Antimonides
        - Polarite
    - Sulfosalts
        - Jamesonite
        - Silver-sulfosalts
            - Pyrargyrite
            - Proustite
        - Copper-sulfosalts
            - Tetrahedrite
            - Tennantite
            - Enargite
                - Luzonite
            - Bournonite
    - Oxides
        - Cuprite
        - Zincite
        - Cassiterite
        - Spinel
            - Chromite
                - Ferrichromite
            - Gahnite
        - Hydroxides
            - Brucite
            - Manganite
            - Valleriite
            - Goethites
                - Limonite
                - Goethite
            - Bauxite-minerals
                - Gibbsite
                - Boehmite
                - Diaspore
        - Columbite
        - Chrysoberyl
        - Mn-oxides
            - Pyrolusite
            - Todorokite
            - Braunite
            - Cryptomelane
            - Coronadite
            - Hausmannite
            - Hollandite
            - Psilomelane
        - Iron-oxides
            - Hematite
            - Magnetite
            - Ilmenite
                - Leucoxene

- Minerals—Continued
  - Oxides—Continued
    - Titanium-oxides
      - Rutile
      - Anatase
      - Ilmenite
        - Leucoxene
    - Uranium-oxides
      - Uraninite
      - Pitchblende
      - Coffinite
      - Carnotite
  - Halides
    - Chlorides
      - Halite
      - Sylvite
      - Cerargyrite
      - Atacamite
      - Carnallite
    - Fluorides
      - Cryolite
      - Fluorite
      - Parisite
      - Bastnaesite
  - Carbonates
    - Hydrous
      - Malachite
      - Azurite
      - Trona
    - Anhydrous
      - Calcite
      - Dolomite
      - Ankerite
      - Siderite
      - Smithsonite
      - Aragonite
      - Witherite
      - Strontianite
      - Cerussite
      - Bastnaesite
      - Breunnerite
      - Mn-carbonates
        - Rhodochrosite
          - Manganocalcite
      - Magnesite
      - Parisite
  - Nitrates-Borates-Phosphates-Arsenates
    - Nitrates
    - Borates
    - Phosphates
      - Apatite
        - Fluorapatite
      - Monazite
    - Arsenates
      - Beudantite
      - Durangite
      - Mimetite

- Minerals—Continued
  - Sulfates
    - Anhydrous-sulfates
      - Barite
      - Celestite
      - Anglesite
      - Anhydrite
    - Hydrous-sulfates
      - Gypsum
      - Chalcanthite
      - Epsomite
      - Antlerite
      - Alunite
      - Beudantite
  - Tungstates
    - Wolframite
    - Huebnerite
    - Scheelite
  - Silicates
    - Titano-silicates
      - Sphene
    - Ortho-silicates
      - Phenacites
        - Phenacite
        - Willemite
      - Olivines
        - Forsterite
        - Fayalite
      - Datolite
      - Sphene
      - Garnets
        - Garnet
        - Andradite
        - Grossularite
        - Pyrope
        - Spessartine
        - Uvarovite
      - Chondrodites
        - Alleghanyite
      - Aluminum-silicates
        - Staurolite
        - Topaz
        - Andalusite
        - Kyanite
        - Sillimanite
      - Zircon
      - Allanite
    - Di-silicates
      - Hemimorphite
      - Lawsonite
      - Niocalite
      - Epidotes
        - Zoisite
        - Clinzoisite
        - Epidote
      - Vesuvianite

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Minerals—Continued
  - Silicates—Continued
    - Cyclosilicates
      - Axinite
      - Beryls
        - Beryl
          - Emerald
        - Cordierite
      - Tourmaline
    - Chain-silicates
      - Pyroxenes
        - Clino-pyroxenes
          - Hedenbergite
          - Augite
          - Jadeite
          - Aegirine
          - Diopside
          - Spodumene
        - Ortho-pyroxenes
          - Enstatite
          - Hypersthene
      - Pyroxenoids
        - Wollastonite
        - Pectolite
        - Rhodonite
      - Amphiboles
        - Amphibole
        - Anthophyllite
        - Tremolites
          - Tremolite
          - Actinolite
          - Cummingtonite
        - Hornblende
        - Riebeckites
          - Glaucophane
          - Riebeckite
    - Sheet-silicates
      - Apophyllite
      - Clay-minerals
        - Illite
        - Attapulgite
        - Bementite
        - Neotocite
        - Montmorillonites
          - Montmorillonite
          - Beidellite
          - Nontronite
          - Hectorite
          - Saponite
        - Kaolin
          - Kaolinite
          - Dickite
          - Halloysite-7Å
          - Halloysite-10Å
          - Allophane
      - Serpentine
        - Garnierite
      - Pyrophyllite

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Minerals—Continued
  - Silicates—Continued
    - Sheet-silicates—Continued
      - Talc
      - Asbestos
        - Chrysotile
      - Micas
        - Mica
        - Muscovite
        - Sericite
        - Magnesia-mica
          - Phlogopite
          - Biotite
        - Glauconite
        - Lepidolite
        - Margarite
      - Chlorites
      - Prehnite
      - Chrysocolla
    - Framework-silicates
      - Silicas
        - Silica
        - Quartz
        - Chalcedony
        - Jasper
        - Chert
        - Opal
        - Cristobalite
        - Tridymite
      - Feldspars
        - Feldspar
        - Plagioclase-feldspars
          - Plagioclase
          - Albite
          - Oligoclase
          - Andesine
          - Labradorite
          - Bytownite
          - Anorthite
        - Barium-feldspar
        - K-feldspar
          - Microcline
          - Adularia
          - Orthoclase
          - Sanidine
          - Anorthoclase
      - Feldspathoids
        - Leucite
        - Nepheline
        - Sodalite
        - Lazurite
        - Petalite
      - Scapolites
      - Zeolites
        - Zeolite
        - Analcime
        - Natrolite
        - Chabazite

Appendix C. Taxonomy used to define the attributes of numerical mineral deposit models—Continued

- Minerals—Continued
    - Silicates—Continued
        - Framework-silicates—Continued
            - Zeolites—Continued
                - Heulandite
                - Stilbite
    - Titanites-Niobates-Tantalates
        - Titanites
            - Perovskite
            - Brannerite
        - Niobates
            - Pyrochlore
        - Tantalates
    - Alteration-products
        - Carbonates
        - Silicates
            - Calc-silicates
                - Skarn
                    - Endoskarn
                    - Exoskarn
        - Zeolites
        - Oxides
        - Alunite
        - Chlorite
        - Greisen
        - Jaresite
        - Amorphous-carbon
- Geophysics
    - Geophysical-anomalies
        - Magnetic-anomaly
            - Magnetic-high
            - Magnetic-low
        - Gravity-anomaly
            - Gravity-high
            - Gravity-low
        - Radioactive-anomaly
        - Electromagnetic-anomaly
        - Induced-polarization-anomaly

Appendix D. Worksheets for numerical mineral deposit models

The model number for each numerical model refers to the model number of the corresponding descriptive model described in Cox and Singer (1986). The worksheets are designed so that the worksheet for each model can be reproduced and used to score a particular mineral occurrence, prospect, or deposit. Space is provided for entering the scores of individual attributes, partial scores of headings, and the total model score. The explanations of the pair of numbers that follows some of the attributes and of the rules for scoring attributes are described in the text.

Worksheet for Numerical Model of Stillwater Ni-Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Gabbro (4 -2)____ Dunite (3 -1)____ Peridotite (3 -1)____

Pyroxenite (3 -1)____ Anorthosite(3 -1)____

TextureStructure: Stratiform____ Massive____

Alteration:

Mineralogy: Pyrrhotite (2 -5)____ Chalcopyrite (2 -5)____ Pentlandite (2 -5)____

Cobalt-sulfides (2 -5)____

GeochemicalSignature: Cu (4 -5)____ Ni (4 -5)____ PGE (4 -5)____ Mg (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Stillwater-Ni-Cu____ Bushveld-Cr____ Merensky-Reef-PGE____

Bushveld-Fe-Ti-U____ Placer-Au-PGE____ Placer-PGE-Au____

MaxScore: 1645

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Bushveld Cr

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Gabbro (4 -2)____ Dunite (3 -1)____

Peridotite (3 -1)____ Pyroxenite (3 -1)____ Anorthosite (3 -1)____

TextureStructure: Massive____ Disseminated____ Bedded____

Alteration:

Mineralogy: Chromite (4 -5)____ Ilmenite (2 -4)____ Magnetite (2 -4)____Pyrrhotite (2 -5)____

Pentlandite (4 -4)____ Chalcopyrite (2 -5)____

GeochemicalSignature: Cr (4 -5)____ PGE (4 -5)____ Mg (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Bushveld-Cr____ Stillwater-Ni-Cu____Merensky-Reef-PGE____

Bushveld-Fe-Ti-V____ Placer-PGE-Au____Placer-Au-PGE____

MaxScore: 1705

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Merensky Reef PGE

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Gabbro (4 -3)____ Dunite (3 -1)____ Peridotite (3 -1)____

Pyroxenite (3 -1)____ Anorthosite (3 -1)____

TextureStructure: Massive____ Disseminated____

Alteration:

Mineralogy: Pyrrhotite (2 -5)____ Chalcopyrite (2 -5)____ Pentlandite (3 -5)____ Chromite (4 -3)____

Graphite (2 -3)____

GeochemicalSignature: PGE (4 -5)____ Cu (2 -5)____ Ni (3 -5)____ Cr (3 -5)____ Ti (2 -4)____

Mg (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Merensky-Reef-PGE____ Stillwater-Ni-Cu____ Bushveld-Cr____

Bushveld-Fe-Ti-V____ Placer-PGE-Au____ Placer-Au-PGE____

MaxScore: 1750

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Bushveld Fe-Ti-V

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Gabbro (4 -2)____ Anorthosite (4 -2)____

TextureStructure: Massive____

Alteration:

Mineralogy: Magnetite (2 -5)____ Ilmenite (2 -5)____ Sulfides (2 -5)____

GeochemicalSignature: Fe (3 -5)____ Ti (3 -5)____ V (3 -5)____

GeophysicalSignature:

AssociatedDeposits: Bushveld-Fe-Ti-V____ Bushveld-Cr____ Stillwater-Ni-Cu____

Merensky-Reef-PGE____ Placer-PGE-Au____ Placer-Au-PGE____

MaxScore: 1420

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Duluth Cu-Ni-PGE

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Peridotite (4 -2)____ Pyroxenite (4 -2)____

Anorthosite (3 -2)____ Evaporites (2 -1)____

TextureStructure: Massive____ Disseminated____

Alteration:

Mineralogy: Pyrrhotite (2 -3)____ Pentlandite (3 -5)____ Chalcopyrite (2 -5)____

Cubanite (3 -4)____ Graphite (2 -3)____

GeochemicalSignature: Ni (4 -5)____ Cu (4 -5)____ PGE (2 -5)____ Co (2 -4)____

Ti (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Duluth-Cu-Ni-PGE____

MaxScore: 910

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Noril'sk Cu-Ni-PGE

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____

RockTypes: Basalt (5 -5)____ Ultramafic-plutonic (5 -5)____ Gabbro (4 -2)____

Volcanic-breccia (3 -1)____ Evaporites (2 -1)____

TextureStructure: Lenses____ Massive____ Disseminated____

Alteration:

Mineralogy: Pyrrhotite (2 -3)____ Pentlandite (3 -5)____ Chalcopyrite (2 -5)____

Cubanite (3 -4)____ Millerite (2 -3)____ Valleriite (2 -3)____ Pyrite (2 -4)____

Bornite (2 -3)____ Gersdorffite (3 -2)____Sperrylite (3 -2)____ Polarite (2 -2)____

Arsenides (2 -3)____ Antimonides (2 -3)____

GeochemicalSignature: Ni (4 -5)____ Cu (4 -5)____ Co (2 -5)____ Pt (2 -5)____

Pd (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Noril'sk-Cu-Ni-PGE____

MaxScore: 1195

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Komatiitic Ni-Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Cretaceous____ Tertiary____

RockTypes: Ultramafic-plutonic (5 -5)____ Komatiite (5 -5)____

TextureStructure: Lenses____ Massive____ Disseminated____

Alteration:

Mineralogy: Pyrite (2 -4)____ Pyrrhotite (2 -5)____ Chalcopyrite (2 -5)____Pentlandite (4 -5)____

GeochemicalSignature: Mg (2 -5)____ Ni (4 -5)____ Cu (4 -5)____ PGE (2 -4)____ Pd (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Komatiitic-Ni-Cu____

MaxScore: 760

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Dunitic Ni-Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____

RockTypes: Ultramafic-plutonic (5 -5)____ Dunite (4 -2)____ Peridotite (4 -2)____

TextureStructure: Massive____ Lenses____

Alteration: Serpentinization (5 -2)____

Mineralogy: Pyrrhotite (2 -5)____ Pentlandite (3 -5)____ Magnetite (2 -5)____ Pyrite (2 -4)____
Chalcopyrite (2 -5)____ Chromite (3 -5)____

GeochemicalSignature: Ni (4 -5)____ Cu (4 -4)____ PGE (2 -5)____ Cr (2 -5)____ Co (2 -5)____
Mg (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Dunitic-Ni-Cu____ Komatiitic-Ni____Synorogenic-synvolcanic-Ni____
Talc-carbonate-Ni-Au____Layered-sedimentary-Ni____

MaxScore: 1895

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Synorogenic-synvolcanic Ni-Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Mafic-plutonic (5 -5)____ Gabbro (4 -2)____ Ultramafic-plutonic (4 -4)____

Anorthosite (3 -1)____

TextureStructure: Disseminated____

Alteration:

Mineralogy: Pyrrhotite (2 -5)____ Pentlandite (4 -5)____ Chalcopyrite (2 -5)____ Pyrite (2 -3)____

Magnetite (2 -4)____ Graphite (2 -3)____

GeochemicalSignature: Ni (4 -5)____ Cu (4 -5)____ Co (2 -5)____ PGE (3 -5)____

GeophysicalSignature:

AssociatedDeposits: Synorogenic-synvolcanic-Ni-Cu____ Komatiitic-Ni-Cu____ Dunitic-Ni-Cu____

Talc-carbonate-Ni-Au____

MaxScore: 1345

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Anorthosite Ti

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____

RockTypes: Anorthosite (5 -5)____ Ferrodiorite (4 -2)____ Gabbro (3 -1)____ Charnockite (2 -1)____

Jutunite (2 -1)____

TextureStructure: Massive-replacement____ Contact-metasomatic____

Alteration:

Mineralogy: Ilmenite (3 -5)____ Rutile (3 -2)____ Apatite (2 -3)____

GeochemicalSignature: Ti (4 -5)____ P (2 -5)____ Zr (2 -4)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Anorthosite-Ti____

MaxScore: 755

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Podiform chromite

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Phanerozoic____

RockTypes: Ultramafic-plutonic (5 -5)____ Dunite (4 -2)____ Peridotite (4 -2)____ Ophiolite (4 -2)____

TextureStructure: Massive____ Disseminated____

Alteration: Serpentinization (5 -2)____

Mineralogy: Chromite (4 -5)____ Ferrichromite (4 -5)____ Magnetite (2 -3)____ Laurite (3 -2)____

GeochemicalSignature: Cr (5 -5)____

GeophysicalSignature:

AssociatedDeposits: Podiform-chromite____Limassol-Forest-Co-Ni____

MaxScore: 1325

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Limassol Forest Co-Ni

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____

RockTypes: Serpentinite (5 -5)____ Ultramafic-plutonic (5 -4)____

TextureStructure: Veins____

Alteration: Serpentinization (5 -2)____ Silicification____ Carbonation____

Mineralogy: Pyrrhotite (2 -5)____ Pyrite (2 -4)____ Pentlandite (3 -3)____ Chalcopyrite (2 -4)____

Valleriite (3 -4)____ Loellingite (3 -2)____ Niccolite (3 -2)____ Maucherite (2 -2)____

Skutterudite (2 -2)____ Gersdorffite (2 -2)____ Cobaltite (2 -4)____ Magnetite (2 -4)____

Chromite (3 -3)____ Mackinawite (2 -2)____ Pararammelsbergite (2 -2)____

GeochemicalSignature: As (2 -5)____ Co (4 -5)____ Ni (4 -5)____

GeophysicalSignature:

AssociatedDeposits: Limassol-Forest-Co-Ni____ Podiform-chromite____

Ni-laterite____ Co-Ni-Cu-ophiolite-sulfide____

MaxScore: 2125

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Serpentine-hosted asbestos

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Serpentinite (5 -5)____ Ultramafic-plutonic (5 -5)____

TextureStructure: Gash-filling____ Ribbon-veins____

Alteration: Silicification (5 -2)____ Carbonation (5 -2)____ Serpentinization (5 -5)____

Mineralogy: Chrysotile (3 -5)____ Asbestos (5 -5)____ Magnetite (2 -4)____

Brucite (2 -3)____ Talc (3 -3)____ Tremolite (2 -2)____ Actinolite (2 -2)____

GeochemicalSignature: Mg (2 -5)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Serpentine-hosted-asbestos____ Podiform-chromite____

MaxScore: 2090

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Alaskan PGE

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____

RockTypes: Ultramafic-plutonic (5 -5)____ Zoned-ultramafic (5 -5)____ Dunite (3 -1)____

Peridotite (3 -1)____ Pyroxenite (3 -1)____ Gabbro (2 -1)____ Felsic-plutonic (2 -1)____

Intermediate-plutonic (2 -1)____

TextureStructure: Zoned-complex____

Alteration: Serpentinization (5 -2)____

Mineralogy: Chromite (4 -5)____ Pentlandite (2 -2)____ Pyrrhotite (2 -3)____ Gold (2 -3)____

Arsenides (2 -4)____ Magnetite (2 -4)____ Cooperite (2 -3)____ Bornite (2 -3)____

Chalcopyrite (2 -3)____

GeochemicalSignature: Cr (4 -5)____ PGE (4 -5)____ Ti (2 -4)____ V (2 -4)____ Cu (2 -5)____

Ni (2 -5)____ S (2 -5)____ As (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Alaskan-PGE____ Placer-PGE-Au____ Placer-Au-PGE____

MaxScore: 1925

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Carbonatite deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Apatite-magnetite-rocks (4 -2)____ Sovite (3 -1)____ Ankerite-carbonatite (3 -1)____

Fenite (2 -1)____ Ijolite (2 -1)____ Dunite (2 -1)____ Picrite-porphyrites (2 -1)____

Alkalic-fenitized-gneiss (2 -1)____

TextureStructure: Zoned-complex____

Alteration: Fenitization (5 -2)____ Chloritization____

Mineralogy: Apatite (3 -4)____ Magnetite (2 -4)____ Pyrochlore (2 -4)____ Columbite (2 -4)____

Perovskite (2 -4)____ Niocalite (2 -4)____ Barite (2 -4)____ Strontianite (2 -3)____ Siderite (2 -3)____

Rhodochrosite (2 -2)____ Ankerite (2 -3)____ Bastnaesite (2 -4)____ Chlorite (2 -2)____

Parisite (2 -2)____ Monazite (2 -3)____ Breunnerite (2 -3)____ Calcite (2 -4)____ Dolomite (2 -4)____

Fluorite (2 -4)____ Pyrrhotite (2 -4)____ Ilmenite (2 -2)____ Molybdenite (2 -4)____

Chalcopyrite (2 -5)____ Pyrite (2 -4)____ Sphalerite (2 -4)____

GeochemicalSignature: REE (4 -5)____ Th (2 -5)____ U (2 -5)____ Ti (2 -4)____ Zn (2 -4)____

Nb (2 -4)____ Y (3 -5)____ Ce (3 -5)____ Mo (2 -4)____ Cu (2 -3)____ V (2 -5)____ P (2 -5)____

Mn (2 -3)____ S (2 -5)____ La (3 -5)____ Sm (3 -5)____ Pb (2 -3)____ Zr (2 -4)____ Ba (2 -4)____

Eu (3 -5)____

GeophysicalSignature: Radioactive-anomaly____ Magnetic-high____

AssociatedDeposits: Carbonatite____

MaxScore: 2570

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Diamond pipes

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Kimberlite (5 -4)____ Olivine-lamproite (3 -1)____ Leucite-lamproite (3 -1)____

TextureStructure: Diatreme____ Pipe____ Breccia____

Alteration: Serpentinization (5 -2)____

Mineralogy: Diamond (5 -5)____ Bort (5 -5)____ Carbonado (5 -5)____

GeochemicalSignature: Cr (2 -5)____ Ti (2 -5)____ Mn (2 -4)____ Ni (2 -5)____

Co (2 -4)____ PGE (3 -4)____ Ba (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Diamond-pipes____ Diamond-placers____

MaxScore: 1415

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of W skarn deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Felsic-plutonic (5 -5)____

TextureStructure: Skarn____

Alteration: Diopside____ Hedenbergite____ Andradite____ Spessartine____

Mineralogy: Scheelite (4 -5)____ Molybdenite (2 -2)____ Pyrrhotite (2 -2)____ Sphalerite (2 -2)____

Chalcopyrite (2 -2)____ Bornite (2 -2)____ Arsenopyrite (2 -2)____ Pyrite (2 -4)____

Magnetite (2 -3)____

GeochemicalSignature: W (4 -5)____ Mo (2 -5)____ Zn (2 -4)____ Cu (2 -4)____ Sn (2 -5)____

Bi (2 -4)____ Be (2 -5)____ As (2 -4)____

GeophysicalSignature:

AssociatedDeposits: W-skarn____ Zn-skarn____ Sn-W-skarn____

MaxScore: 1670

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sn skarn deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Granite (5 -5)____ Biotite-leucogranite (4 -2)____ Muscovite-leucogranite (4 -2)____

Felsic-dikes (2 -1)____ Calcareous-Rocks (5 -5)____

TextureStructure: Skarn____ Breccia____

Alteration: Greisenization (5 -2)____

Mineralogy: Cassiterite (4 -5)____ Scheelite (4 -4)____ Sphalerite (2 -4)____ Chalcopyrite (2 -4)____

Pyrrhotite (2 -4)____ Magnetite (2 -3)____ Pyrite (2 -3)____ Arsenopyrite (2 -3)____ Fluorite (4 -4)____

GeochemicalSignature: Sn (4 -5)____ W (4 -5)____ F (4 -4)____ Be (2 -4)____ Zn (2 -4)____

Pb (2 -3)____ Cu (2 -4)____ Ag (2 -3)____ Li (2 -4)____ Rb (2 -5)____ Cs (2 -4)____ Re (2 -4)____

B (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Sn-skarn____ W-skarn____ Sn-greisen____ Sn-veins____Sn-replacement____

MaxScore: 2390

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Replacement Sn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Felsic-plutonic (5 -5)____

TextureStructure: Massive-replacement____

Alteration: Greisenization (5 -2)____

Mineralogy: Pyrrhotite (2 -4)____ Arsenopyrite (2 -4)____ Cassiterite (4 -5)____ Chalcopyrite (2 -4)____

Ilmenite (2 -3)____ Fluorite (4 -5)____

GeochemicalSignature: Sn (4 -5)____ As (2 -5)____ Cu (2 -5)____ B (2 -4)____ W (4 -4)____ F (4 -5)____

Li (2 -5)____ Pb (2 -4)____ Zn (2 -4)____ Rb (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Replacement-Sn____ Sn-greisen____ Quartz-tourmaline-cassiterite-veins____

W-skarn____ Sn-skarn____

MaxScore: 2030

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of W veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Felsic-plutonic (5 -5)____ Sandstone (3 -1)____ Shale (3 -1)____

TextureStructure: Veins____

Alteration: Albitization____ Sericitization____ Chloritization____

Mineralogy: Wolframite (4 -5)____ Molybdenite (2 -5)____ Bismuthinite (4 -4)____ Pyrite (2 -4)____

Pyrrhotite (2 -3)____ Arsenopyrite (2 -5)____ Bornite (2 -3)____ Chalcopyrite (2 -5)____

Scheelite (4 -4)____ Cassiterite (4 -5)____ Beryl (2 -3)____ Fluorite (4 -4)____

GeochemicalSignature: W (4 -5)____ Mo (2 -5)____ Sn (4 -5)____ Bi (2 -5)____ As (2 -3)____

Cu (2 -3)____ Pb (2 -3)____ Zn (2 -3)____ Be (4 -3)____ F (4 -4)____

GeophysicalSignature:

AssociatedDeposits: W-veins____ Sn-veins____

MaxScore: 1795

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sn veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -5)____ Granite (5 -5)____ Biotite-leucogranite (3 -2)____

Muscovite-leucogranite (3 -2)____ Pelitic-rocks (2 -1)____

TextureStructure: Veinlets____ Open-space-filling____

Alteration: Sericitization____ Tourmalinization____ Silicification____ Chloritization____

Hematization____

Mineralogy: Cassiterite (4 -5)____ Wolframite (3 -4)____ Arsenopyrite (2 -4)____ Molybdenite (2 -4)____

Hematite (2 -4)____ Scheelite (3 -3)____ Beryl (2 -3)____ Galena (2 -3)____ Chalcopyrite (2 -4)____

Sphalerite (2 -3)____ Stannite (3 -4)____ Bismuthinite (3 -3)____

GeochemicalSignature: Sn (4 -5)____ As (3 -4)____ W (3 -5)____ B (3 -4)____ Li (2 -4)____

Rb (2 -4)____ Cs (2 -4)____ Be (2 -4)____ REE (2 -4)____ U (2 -4)____ Th (2 -4)____ Nb (2 -4)____

Bi (2 -3)____ F (3 -5)____

GeophysicalSignature:

AssociatedDeposits: Sn-veins____ Sn-greisen____ Sn-skarn____ Sn-replacement____

MaxScore: 2430

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sn greisen deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -5)____ Granite (5 -5)____ Leucogranite (4 -4)____

Muscovite-leucogranite (3 -2)____ Biotite-leucogranite (3 -2)____

TextureStructure: Greisen____ Veinlets____ Stockwork____

Alteration: Greisenization (5 -2)____ Albitization (5 -2)____ Tourmalinization (3 -2)____

Mineralogy: Cassiterite (4 -5)____ Molybdenite (4 -5)____ Arsenopyrite (3 -5)____ Topaz (4 -2)____

Tourmaline (4 -2)____ Beryl (2 -4)____ Wolframite (2 -3)____ Bismuthinite (2 -2)____

Fluorite (4 -3)____ Calcite (1 -3)____ Pyrite (2 -4)____

GeochemicalSignature: Sn (4 -5)____ F (5 -5)____ B (5 -4)____ Mo (2 -5)____ Rb (2 -4)____

Cs (2 -4)____ Be (2 -3)____ REE (2 -4)____ U (2 -4)____ Th (2 -4)____ Nb (2 -4)____ Ta (2 -4)____

Li (2 -4)____ W (2 -3)____ As (2 -4)____ Bi (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Sn-greisen____ Sn-veins____ Sn-replacement____

MaxScore: 2930

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Climax Mo deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Felsic-plutonic (5 -5)____ Granite (4 -5)____ Rhyolite (4 -3)____

TextureStructure: Stockwork____ Veinlets____

Alteration: Silicification (5 -2)____ Potassic (5 -2)____

Mineralogy: Molybdenite (4 -5)____ Fluorite (4 -5)____ K-feldspar (2 -5)____ Pyrite (2 -4)____

Wolframite (2 -3)____ Cassiterite (4 -3)____ Topaz (4 -3)____

GeochemicalSignature: Mo (4 -5)____ Sn (4 -3)____ W (4 -5)____ Rb (3 -5)____ Pb (2 -4)____

Zn (2 -3)____ F (3 -5)____ Th (2 -3)____ K (2 -2)____ Cs (2 -4)____ Li (2 -4)____ Nb (2 -3)____

Ta (2 -3)____ Mn (2 -4)____ Re (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Climax-Mo____ Ag-base-metal-veins____ Fluorspar____

MaxScore: 2445

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -5)____ Tonalite (4 -1)____ Monzogranite (4 -1)____ Syenite (4 -1)____

TextureStructure: Stockwork____ Veinlets____

Alteration: Sodic-calcic____ Potassic (5 -2)____ Phyllic (5 -2)____ Argillic (5 -2)____

Propylitic (5 -2)____

Mineralogy: Chalcopyrite (3 -5)____ Pyrite (2 -5)____ Molybdenite (3 -4)____ Magnetite (2 -3)____

Bornite (3 -2)____ Gold (3 -4)____

GeochemicalSignature: Cu (4 -5)____ Mo (3 -5)____ Au (2 -3)____ Ag (2 -4)____ W (2 -3)____

B (2 -3)____ Pb (2 -4)____ Zn (2 -4)____ As (2 -3)____ Sb (2 -3)____ Se (2 -3)____ Te (2 -4)____

Mn (2 -4)____ Rb (2 -3)____ Bi (2 -2)____ Sn (2 -3)____ K (1 -2)____ Fe (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Porphyry-Cu____ Base-metal-skarn____ Epithermal-veins____

Polymetallic-replacement____ Volcanic-hosted-massive-replacement____

MaxScore: 3600

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Cu, skarn-related deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -3)____ Calcareous-Rocks (5 -5)____

TextureStructure: Skarn____ Veinlets____

Alteration: Potassic (5 -2)____ Marble____ Phyllic (5 -2)____

Mineralogy: Chalcopyrite (3 -5)____ Pyrite (2 -4)____ Magnetite (3 -3)____ Sphalerite (2 -3)____

Tennantite (3 -3)____ Scheelite (2 -2)____

GeochemicalSignature: Cu (3 -5)____ Mo (3 -5)____ Pb (2 -3)____ Zn (2 -3)____ Au (2 -4)____

Ag (2 -5)____ W (2 -2)____ Bi (2 -2)____ Sn (2 -3)____ As (2 -3)____ Sb (2 -3)____ Se (1 -3)____

GeophysicalSignature:

AssociatedDeposits: Porphyry-Cu-skarn-related____ Cu-skarn____ Replacement-Pb-Zn-Ag____

MaxScore: 2200

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Cu skarn deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (4 -2)____ Calcareous-Rocks (5 -5)____ Hornfels (2 -1)____

TextureStructure: Skarn____

Alteration: Calc-silicates____

Mineralogy: Chalcopyrite (4 -5)____ Bornite (4 -5)____ Pyrite (2 -5)____ Magnetite (2 -4)____

Hematite (2 -3)____ Pyrrhotite (2 -3)____

GeochemicalSignature: Cu (3 -5)____ Au (2 -4)____ Ag (2 -5)____ Pb (2 -4)____ Zn (2 -4)____

B (2 -2)____ Co (2 -2)____ Mo (2 -4)____ W (2 -2)____ As (1 -2)____ Sb (1 -2)____

Bi (1 -2)____ S (2 -3)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Cu-skarn____ Porphyry-Cu____ Zn-skarn____ Polymetallic-replacement____

Fe-skarn____

MaxScore: 1740

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Zn-Pb skarn deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (4 -3)____ Calcareous-Rocks (5 -5)____

TextureStructure: Skarn____

Alteration: Calc-silicates____

Mineralogy: Sphalerite (3 -5)____ Galena (3 -5)____ Pyrrhotite (2 -4)____ Pyrite (2 -4)____

Magnetite (2 -3)____ Chalcopyrite (3 -4)____ Bornite (3 -3)____ Arsenopyrite (2 -3)____

Scheelite (2 -3)____ Bismuthinite (2 -3)____ Stannite (2 -2)____ Fluorite (2 -5)____ Gold (2 -2)____

Silver (2 -2)____

GeochemicalSignature: Zn (3 -5)____ Pb (3 -5)____ Mn (2 -5)____ Cu (2 -5)____ Au (2 -4)____

Ag (2 -5)____ As (2 -4)____ W (2 -3)____ Sn (2 -3)____ F (2 -3)____ Be (1 -2)____ Co (2 -3)____

S (1 -3)____

GeophysicalSignature:

AssociatedDeposits: Zn-Pb-skarn____ Cu-skarn____

MaxScore: 1505

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Fe skarn deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Felsic-plutonic (5 -3)____ Diabase (2 -1)____

TextureStructure: Skarn____

Alteration: Calc-silicates____

Mineralogy: Magnetite (4 -5)____ Chalcopyrite (2 -4)____ Pyrite (2 -4)____ Pyrrhotite (2 -4)____

GeochemicalSignature: Fe (4 -5)____ Cu (2 -4)____ Co (2 -2)____ Au (2 -5)____ Be (2 -2)____

B (2 -2)____ Zn (2 -2)____ Sn (1 -1)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Fe-skarn____

MaxScore: 960

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Carbonate-hosted asbestos

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Serpentinite (5 -5)____ Diabase (2 -2)____ Siliceous-limestone (2 -1)____

Cherty-dolomite (2 -1)____

TextureStructure: Gash-filling____ Ribbon-veins____

Alteration: Calc-silicates____

Mineralogy: Chrysotile (4 -5)____ Asbestos (4 -5)____ Serpentine (3 -5)____ Magnetite (2 -5)____

Calcite (2 -5)____

GeochemicalSignature: Mg (3 -5)____

GeophysicalSignature:

AssociatedDeposits: Carbonate-hosted-asbestos____ Contact-metamorphic-magnetite____ Talc____

MaxScore: 1085

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Polymetallic replacement deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Shale (3 -2)____

TextureStructure: Replacement____ Massive____

Alteration: Dolomitization____ Silicification____ Chloritization____ Pyritization____

Mineralogy: Enargite (2 -3)____ Sphalerite (2 -5)____ Argentite (2 -3)____ Tetrahedrite (2 -4)____

Digenite (2 -2)____ Chalcopyrite (2 -4)____ Galena (2 -4)____ Proustite (2 -4)____

Pyargyrite (2 -4)____ Pyrite (2 -5)____ Marcasite (2 -4)____ Barite (2 -4)____

GeochemicalSignature: Cu (2 -5)____ Pb (2 -5)____ Ag (2 -4)____ Zn (2 -5)____ Mn (2 -4)____

Au (2 -4)____ As (2 -3)____ Sb (2 -3)____ Bi (2 -3)____ Ba (2 -3)____ Ge (1 -2)____ Te (2 -3)____

S (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Polymetallic-replacement____ Zn-Pb-skarn____ Porphyry-Cu____

MaxScore: 1805

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Replacement Mn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Felsic-plutonic (5 -5)____

TextureStructure: Veins____ Open-space-filling____

Alteration:

Mineralogy: Rhodochrosite (4 -5)____ Rhodonite (4 -3)____ Calcite (2 -4)____ Barite (2 -3)____

Fluorite (2 -3)____ Pyrite (2 -4)____ Chalcopyrite (2 -3)____ Galena (2 -2)____ Sphalerite (2 -3)____

GeochemicalSignature: Mn (4 -5)____ Cu (2 -4)____ Ag (2 -4)____ Au (2 -4)____ Pb (2 -4)____

Zn (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Replacement-Mn____ Polymetallic-veins____ Polymetallic-replacement____

Cu-skarn____ Zn-skarn____ Porphyry-Cu____

MaxScore: 1690

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Sn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -5)____ Felsic-volcanic-rocks (5 -5)____

Calc-alkaline-pyroclastics (3 -1)____

TextureStructure: Disseminated____ Veinlets____

Alteration: Tourmalinization____ Sericitization____ Propylitic____ Argillic____

Mineralogy: Cassiterite (4 -5)____ Pyrite (2 -5)____ Pyrrhotite (2 -3)____ Stannite (4 -4)____

Chalcopyrite (2 -4)____ Sphalerite (2 -4)____ Arsenopyrite (2 -3)____

GeochemicalSignature: Sn (4 -5)____ B (2 -4)____ Ag (2 -4)____ Pb (2 -4)____ Zn (2 -4)____

As (2 -4)____ Sb (2 -4)____ Cu (2 -4)____ Ba (2 -4)____ F (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Porphyry-Sn____ Sn-vein____ Sn-polymetallic____

MaxScore: 1730

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sn-polymetallic veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Rhyolite (5 -5)____ Tuff-breccia (3 -2)____ Basalt (2 -1)____ Chert (2 -1)____

Slate (2 -1)____

TextureStructure: Veins____

Alteration:

Mineralogy: Cassiterite (4 -5)____ Chalcopyrite (3 -5)____ Sphalerite (3 -5)____ Pyrrhotite (2 -5)____

Pyrite (2 -5)____ Galena (2 -4)____ Scheelite (3 -3)____ Wolframite (2 -4)____

Arsenopyrite (2 -4)____ Bismuthinite (2 -4)____ Argentite (2 -3)____ Gold (2 -4)____

Magnetite (2 -3)____ Molybdenite (2 -3)____

GeochemicalSignature: Sn (4 -5)____ Zn (2 -5)____ Pb (2 -5)____ W (3 -4)____ Ag (2 -5)____

Bi (3 -3)____ As (2 -4)____ Sb (2 -4)____ B (2 -4)____ F (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Sn-polymetallic-veins____ Polymetallic-replacement____ Epithermal-Ag-veins____

Porphyry-Sn____

MaxScore: 1750

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Cu-Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cretaceous____ Cenozoic____

RockTypes: Felsic-plutonic (5 -5)____ Felsic-volcanic-rocks (4 -4)____ Mafic-volcanic-rocks (4 -3)____

Shoshonite (3 -1)____

TextureStructure: Stockwork____ Veinlets____

Alteration: Chloritization____ Propylitic____

Mineralogy: Chalcopyrite (4 -5)____ Bornite (4 -4)____ Gold (4 -5)____

GeochemicalSignature: Cu (4 -5)____ Au (4 -5)____ Ag (2 -5)____ Mo (2 -4)____ Pb (2 -4)____

Zn (2 -4)____ Mn (2 -4)____ K (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Porphyry-Cu-Au____ Porphyry-Cu-Mo____ Placer-Au____

MaxScore: 1455

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Cu-Mo

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-plutonic (5 -5)____ Tonalite (3 -2)____ Monzogranite (3 -2)____

TextureStructure: Stockwork____ Veinlets____

Alteration: Chloritization (5 -2)____ Potassic (5 -2)____ Propylitic (5 -2)____ Phyllic (5 -2)____

Mineralogy: Chalcopyrite (4 -5)____ Pyrite (2 -5)____ Molybdenite (4 -5)____

GeochemicalSignature: Cu (5 -5)____ Mo (5 -5)____ Ag (2 -5)____ W (2 -4)____ Pb (2 -4)____

Zn (2 -4)____ Au (2 -5)____ As (2 -5)____ Sb (2 -4)____ Te (2 -4)____ Mn (2 -4)____ Rb (2 -3)____

K (1 -2)____ Re (2 -4)____

GeophysicalSignature: Magnetic-low____

AssociatedDeposits: Porphyry-Cu-Mo____ Cu-skarn____ Zn-skarn____ Fe-skarn____ Placer-Au____

Polymetallic-replacement____ Volcanic-hosted-massive-replacement____

MaxScore: 3585

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Porphyry Mo, low-F

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Mesozoic____ Tertiary____

RockTypes: Felsic-plutonic (5 -5)____ Felsic-hypabyssal (5 -2)____ Tonalite (3 -1)____

Granodiorite (3 -1)____ Monzogranite (3 -1)____ Quartz-monzonite (3 -1)____

TextureStructure: Stockwork____ Veinlets____

Alteration: Potassic (5 -2)____ Propylitic (5 -2)____ Phyllic (5 -2)____ Argillic (5 -2)____

Silicification (5 -2)____

Mineralogy: Molybdenite (4 -5)____ Pyrite (2 -5)____ Scheelite (2 -4)____ Chalcopyrite (3 -5)____

Tetrahedrite (2 -4)____

GeochemicalSignature: Mo (2 -5)____ Cu (2 -4)____ W (2 -4)____ Re (2 -2)____ Zn (2 -2)____

Pb (2 -2)____ Au (2 -2)____ Ag (2 -2)____ K (1 -2)____ F (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Porphyry-Mo-low-F____ Porphyry-Cu-Mo____ Cu-skarn____

Volcanic-hosted-Cu-As-Sb____

MaxScore: 3495

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Volcanic-hosted Cu-As-Sb

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Andesite (3 -3)____ Dacite (3 -3)____ Flows (3 -3)____ Breccia (2 -2)____ Tuff (2 -2)____

TextureStructure: Massive____ Breccia-filling____

Alteration: Silicification____

Mineralogy: Pyrite (2 -5)____ Enargite (3 -5)____ Luzonite (2 -5)____ Tennantite (3 -4)____

Covellite (3 -3)____ Chalcocite (3 -3)____ Bornite (3 -3)____ Tetrahedrite (3 -4)____

Sphalerite (3 -3)____

GeochemicalSignature: As (3 -5)____ Sb (3 -3)____ Bi (2 -3)____ Cu (3 -5)____ Zn (2 -4)____

Au (2 -4)____ Ag (2 -5)____ B (1 -2)____ Sn (1 -2)____ S (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Volcanic-hosted-Cu-As-Sb____ Porphyry-Cu-Mo____ Porphyry-Mo-low-F____

MaxScore: 1535

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Au-Ag-Te veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Hypabyssal (5 -5)____ Basalt (4 -4)____ Mafic-volcanic-rocks (4 -4)____

Shoshonite (5 -1)____

TextureStructure: Veins____

Alteration: Propylitic____

Mineralogy: Tellurides (4 -5)____ Calaverite (3 -5)____ Sylvanite (3 -5)____ Hessite (3 -5)____

Coloradoite (3 -5)____ Pyrite (2 -5)____ Galena (2 -4)____ Sphalerite (2 -3)____ Tetrahedrite (2 -4)____

Stibnite (2 -3)____

GeochemicalSignature: Au (3 -5)____ Ag (3 -5)____ Te (3 -5)____ Cu (2 -4)____ Pb (2 -4)____

Zn (2 -3)____ Sb (2 -4)____ Hg (2 -4)____ F (2 -4)____ Ba (2 -3)____ Sr (2 -3)____ PGE (2 -2)____

Tl (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Au-Ag-Te-veins____Polymetallic-veins____Polymetallic-replacement____

MaxScore: 1730

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Polymetallic veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Regional-Metamorphic (5 -1)____ Felsic-plutonic (4 -2)____

Felsic-volcanic-rocks (4 -2)____ Mafic-volcanic-rocks (3 -2)____

TextureStructure: Veins____

Alteration: Propylitic____

Mineralogy: Gold (2 -5)____ Carbonates (5 -4)____ Pyrite (2 -5)____ Sphalerite (2 -5)____

Chalcopyrite (2 -4)____ Galena (2 -4)____ Arsenopyrite (2 -3)____ Tetrahedrite (2 -4)____

Tennantite (2 -4)____ Argentite (2 -3)____ Hematite (2 -3)____

GeochemicalSignature: Zn (2 -5)____ Cu (2 -5)____ Pb (2 -5)____ As (2 -4)____ Sb (2 -5)____

Au (2 -5)____ Ag (2 -5)____ Mn (2 -5)____ Ba (2 -4)____ B (1 -2)____ Ge (1 -2)____ Bi (1 -2)____

Te (1 -2)____ F (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Polymetallic-veins____ Porphyry-Cu-Mo____ Porphyry-Mo-low-F____

Polymetallic-replacement____ Placer-Au____

MaxScore: 1910

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Basaltic Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Triassic____ Jurassic____ Tertiary____

RockTypes: Mafic-volcanic-rocks (4 -1)____ Basalt (4 -1)____Calcareous-Rocks (4 -1)____

Breccia (3 -1)____ Tuff (2 -1)____ Red-beds (3 -1)____

Tuffaceous-sandstone (2 -1)____

TextureStructure: Breccia____ Open-space-filling____

Alteration: Carbonates____

Mineralogy: Copper (4 -5)____ Silver (2 -5)____ Chalcocite (3 -4)____ Bornite (2 -3)____

Chalcopyrite (2 -4)____ Pyrite (2 -3)____

GeochemicalSignature: Cu (4 -5)____ Ag (2 -4)____ Zn (2 -3)____ B (1 -2)____ Co (1 -1)____

GeophysicalSignature:

AssociatedDeposits: Basaltic-Cu____ Sediment-hosted-Cu____ Volcanogenic-Mn____

MaxScore: 1355

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Cyprus massive sulfide

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Ophiolite (4 -1)____ Ultramafic-plutonic (4 -2)____ Basalt (4 -1)____ Diabase (2 -1)____

Fine-grained-metasedimentary-rocks (2 -1)____ Chert (2 -1)____

TextureStructure: Massive____

Alteration: Feldspar-destruction (5 -2)____ Silicification____ Chlorite____

Mineralogy: Pyrite (2 -5)____ Chalcopyrite (3 -5)____ Sphalerite (3 -4)____ Marcasite (2 -2)____

Pyrrhotite (2 -3)____

GeochemicalSignature: Mn (2 -4)____ Fe (2 -5)____ Cu (3 -5)____ Zn (3 -5)____ S (3 -5)____

Ag (2 -4)____ Au (2 -4)____ Co (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Cyprus-massive-sulfide____

MaxScore: 1585

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Besshi massive sulfide

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Tuff (5 -2)____ Shale (4 -1)____ Breccia (3 -1)____ Iron-formation (3 -1)____

Chert (3 -1)____ Sandstone (5 -1)____

TextureStructure: Fine-grained____ Massive____

Alteration: Chloritization____

Mineralogy: Pyrite (3 -5)____ Pyrrhotite (3 -4)____ Chalcopyrite (3 -5)____ Sphalerite (3 -5)____

Magnetite (2 -4)____ Valleriite (2 -2)____ Galena (2 -3)____ Bornite (2 -3)____ Tetrahedrite (3 -3)____

Cobaltite (2 -2)____ Cubanite (2 -3)____ Stannite (2 -2)____ Molybdenite (2 -2)____

GeochemicalSignature: Cu (3 -5)____ Zn (3 -5)____ Co (2 -4)____ Ag (2 -5)____ Ni (2 -3)____

Cr (2 -3)____ Au (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Besshi-massive-sulfide____

MaxScore: 1400

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Volcanogenic Mn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Chert (2 -1)____ Tuff (3 -2)____ Volcaniclastic-rocks (5 -5)____

Felsic-volcanic-rocks (2 -2)____ Mafic-volcanic-rocks (2 -2)____

TextureStructure: Massive____

Alteration: Spilitic (5 -2)____

Mineralogy: Rhodochrosite (4 -4)____ Braunite (4 -2)____ Hausmannite (4 -2)____ Bementite (4 -2)____

Neotocite (2 -2)____ Alleghanyite (2 -2)____ Spessartine (2 -3)____ Rhodonite (4 -4)____

Maganite (4 -2)____ Pyrolusite (2 -2)____ Coronadite (2 -2)____ Cryptomelane (2 -2)____

Hollandite (2 -2)____ Todorokite (2 -2)____

GeochemicalSignature: Mn (4 -5)____ Zn (2 -3)____ Pb (2 -3)____ Cu (2 -3)____ Ba (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Volcanogenic-Mn____ Kuroko-massive-sulfide____

MaxScore: 1790

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Blackbird Co-Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Metasedimentary-rocks (5 -5)____ Fine-grained-metasedimentary-rocks (4 -4)____

Mafic-metavolcanic-rocks (3 -3)____ Iron-formation (2 -1)____

TextureStructure: Massive____ Disseminated____

Alteration: Silicification____ Chloritization____

Mineralogy: Cobaltite (4 -5)____ Chalcopyrite (5 -5)____ Pyrite (2 -5)____ Pyrrhotite (2 -5)____

Arsenopyrite (2 -5)____ Magnetite (2 -5)____ Gold (2 -3)____ Silver (2 -3)____

GeochemicalSignature: Fe (2 -5)____ As (3 -5)____ B (2 -3)____ Co (4 -5)____ Cu (2 -5)____

Au (2 -3)____ Ag (2 -3)____ Mn (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Blackbird-Co-Cu____ Besshi-massive-sulfide____

MaxScore: 1410

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Hot-spring Au-Ag

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____ Quaternary____

RockTypes: Rhyolite (5 -5)____

TextureStructure: Veins____ Stockwork____ Breccia____

Alteration: Silicification (5 -2)____

Mineralogy: Gold (3 -5)____ Pyrite (2 -5)____ Stibnite (3 -3)____ Realgar (3 -4)____

Arsenopyrite (2 -3)____ Sphalerite (2 -4)____ Chalcopyrite (2 -3)____ Fluorite (2 -3)____

GeochemicalSignature: Au (3 -5)____ As (3 -5)____ Sb (3 -4)____ Hg (2 -4)____ Tl (2 -4)____

Ag (3 -5)____

GeophysicalSignature:

AssociatedDeposits: Hot-spring-Au-Ag____ Epithermal-quartz-veins____ Hot-spring-Hg____

Placer-Au____

MaxScore: 1700

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Creede epithermal veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Felsic-volcanic-rocks (5 -5)____ Mafic-volcanic-rocks (5 -5)____

TextureStructure: Veins____

Alteration: Zoned (5 -2)____

Mineralogy: Galena (2 -5)____ Sphalerite (2 -5)____ Chalcopyrite (2 -5)____

Copper-sulfosalts (3 -5)____ Silver-sulfosalts (3 -5)____ Gold (3 -4)____ Tellurides (3 -3)____

Bornite (2 -2)____ Arsenopyrite (2 -2)____

GeochemicalSignature: Au (3 -4)____ As (3 -4)____ Sb (3 -4)____ Hg (2 -2)____ Pb (2 -5)____

Zn (2 -5)____ Cu (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Creede-epithermal-veins____ Placer-Au____ Epithermal-quartz-alunite-Au____

Polymetallic-replacement____

MaxScore: 1835

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Comstock epithermal veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Felsic-volcanic-rocks (5 -5)____

TextureStructure: Veins____

Alteration: Zoned (5 -2)____

Mineralogy: Argentite (3 -5)____ Gold (3 -5)____ Silver-sulfosalts (3 -4)____ Naumannite (2 -4)____

Galena (2 -4)____ Sphalerite (2 -4)____ Chalcopyrite (2 -4)____ Tellurides (3 -3)____

Hematite (2 -3)____ Arsenopyrite (2 -2)____

GeochemicalSignature: Au (3 -5)____ As (3 -4)____ Sb (3 -4)____ Hg (3 -3)____ Cu (2 -5)____

Ag (2 -5)____ Pb (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Comstock-epithermal-veins____ Placer-Au____ Epithermal-quartz-alunite-Au____

MaxScore: 1655

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sado epithermal veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Felsic-volcanic-rocks (5 -5)____

TextureStructure: Veins____

Alteration: Silicification____

Mineralogy: Gold (3 -5)____ Argentite (3 -4)____ Chalcopyrite (2 -5)____ Sulfosalts (3 -5)____

Tellurides (3 -4)____ Galena (2 -4)____ Sphalerite (2 -4)____

GeochemicalSignature: Au (3 -5)____ Ag (2 -5)____ Cu (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Sado-epithermal-veins____ Placer-Au____ Quartz-alunite-Au____

MaxScore: 1100

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Epithermal quartz-alunite Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Felsic-volcanic-rocks (5 -5)____

TextureStructure: Veins____ Pipe____

Alteration: Zoned (5 -2)____

Mineralogy: Gold (3 -5)____ Enargite (3 -5)____ Pyrite (2 -5)____ Silver-sulfosalts (3 -5)____

Chalcopyrite (2 -4)____ Bornite (2 -3)____ Tellurides (3 -3)____ Galena (2 -4)____ Sphalerite (2 -4)____

Huebnerite (2 -2)____

GeochemicalSignature: Au (3 -5)____ As (3 -5)____ Cu (2 -5)____ Te (3 -3)____ W (2 -1)____

GeophysicalSignature:

AssociatedDeposits: Epithermal-quartz-alunite-Au____ Porphyry-Cu____ Polymetallic-replacement____

Volcanic-hosted-Cu-As-Sb____

MaxScore: 1730

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Volcanogenic U

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Archean____ Proterozic____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Felsic-volcanic-rocks (5 -5)____ Mafic-volcanic-rocks (5 -5)____ Alkali-rhyolite (3 -2)____

Trachyte (3 -2)____

TextureStructure: Breccia____ Open-space-filling____

Alteration: Kaolinite____ Montmorillonite____ Alunite____ Silicification (4 -1)____ Adularia (4 -1)____

Mineralogy: Coffinite (4 -5)____ Uraninite (4 -5)____ Brannerite (4 -5)____ Pyrite (2 -5)____

Realgar (2 -3)____ Orpiment (2 -3)____ Leucoxene (2 -3)____ Molybdenite (2 -4)____

Fluorite (2 -4)____ Quartz (1 -4)____ Adularia (2 -4)____ Barite (1 -3)____

GeochemicalSignature: U (4 -5)____ Hg (3 -4)____ As (3 -4)____ Sb (3 -4)____ F (3 -5)____ Mo (3 -5)____

W (2 -2)____ REE (2 -3)____ Li (3 -4)____ Ba (1 -1)____

GeophysicalSignature:

AssociatedDeposits: Volcanogenic-U____ Sandstone-U____ Fluorspar____

MaxScore: 2515

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Epithermal Mn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Tuff (4 -3)____ Breccia (3 -2)____ Agglomerate (2 -1)____ Rhyolite (3 -2)____

TextureStructure: Veins____

Alteration: Kaolin____

Mineralogy: Rhodochrosite (4 -5)____ Manganocalcite (4 -5)____ Barite (2 -5)____ Zeolite (2 -5)____

GeochemicalSignature: Mn (4 -5)____ Fe (2 -5)____ P (3 -4)____ W (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Epithermal-Mn____ Epithermal-Au-Ag____

MaxScore: 1025

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Rhyolite-hosted Sn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Alkali-rhyolite (4 -3)____ Rhyolite (5 -3)____

TextureStructure: Veinlets____

Alteration:

Mineralogy: Cassiterite (4 -5)____ Hematite (2 -5)____ Cristobalite (3 -5)____ Fluorite (4 -3)____

Tridymite (3 -5)____ Opal (2 -5)____ Chalcedony (2 -5)____ Beudantite (3 -2)____

Mimetite (3 -2)____ Adularia (3 -4)____ Durangite (2 -2)____ Topaz (4 -3)____

GeochemicalSignature: Sn (4 -5)____

GeophysicalSignature:

AssociatedDeposits: Rhyolite-hosted-Sn____ Climax-Mo____

MaxScore: 1120

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Volcanic-hosted magnetite

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Mesozoic____ Cenozoic____

RockTypes: Alkaline-volcanic-rocks (5 -3)____ Mafic-volcanic-rocks (4 -4)____ Felsic-plutonic (2 -1)____

TextureStructure: Massive-replacement____

Alteration: Calc-silicates____

Mineralogy: Magnetite (4 -5)____ Apatite (2 -5)____

GeochemicalSignature: Fe (4 -5)____ P (4 -5)____ V (4 -4)____ Ba (2 -3)____ F (2 -3)____ Bi (2 -3)____

Cu (2 -3)____ Co (2 -5)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Volcanic-hosted-magnetite____ Sedimentary-Fe____

MaxScore: 1110

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Carbonate-hosted Au-Ag

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Carbonaceous-limestone (4 -2)____ Carbonaceous-dolomite (4 -2)____

Carbonaceous-shale (4 -2)____

TextureStructure: Replacement____

Alteration: Amorphous-carbon____

Mineralogy: Gold (4 -5)____ Pyrite (2 -5)____ Realgar (2 -5)____ Orpiment (2 -5)____

Arsenopyrite (2 -3)____ Cinnabar (2 -3)____ Fluorite (2 -3)____ Barite (2 -3)____ Stibnite (2 -3)____

GeochemicalSignature: Au (4 -5)____ Ag (2 -5)____ As (3 -5)____ Hg (2 -4)____ W (2 -4)____

Mo (2 -2)____ Sb (2 -4)____ Tl (2 -4)____ F (2 -2)____ NH3 (2 -3)____ C (2 -5)____ Ba (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Carbonate-hosted-Au-Ag____ W-Mo-skarn____ Porphyry-Mo____ Placer-Au____

Stibnite-barite-veins____

MaxScore: 1835

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Hot-spring Hg

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____ Cretaceous____

RockTypes: Siliceous-sinter (5 -5)____ Mafic-volcanic-rocks (3 -1)____ Tuff (3 -1)____

Tuff-breccia (2 -1)____

TextureStructure: Vein____ Disseminated____

Alteration: Kaolinization____

Mineralogy: Cinnabar (5 -5)____ Mercury (5 -3)____ Marcasite (2 -2)____ Stibnite (2 -1)____

GeochemicalSignature: Hg (4 -5)____ As (3 -5)____ Sb (3 -5)____ Au (2 -3)____ B (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Hot-spring-Hg____ Hot-spring-Au____

MaxScore: 1115

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Almaden Hg

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Volcaniclastic-rocks (5 -5)____ Tuff (3 -2)____ Vent-breccia (3 -2)____

TextureStructure: Disseminated____

Alteration:

Mineralogy: Cinnabar (4 -5)____ Mercury (5 -5)____ Pyrite (2 -3)____

GeochemicalSignature: Hg (4 -5)____ As (3 -4)____ Sb (3 -4)____ B (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Almaden-Hg____ Stibnite-veins____

MaxScore: 910

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Silica-carbonate Hg

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Tertiary____

RockTypes: Serpentinite (4 -4)____ Siltstone (3 -2)____ Graywacke (3 -2)____

TextureStructure: Replacement____

Alteration: Silicification (5 -2)____

Mineralogy: Cinnabar (4 -5)____ Mercury (5 -5)____ Pyrite (2 -5)____ Stibnite (3 -4)____

Chalcopyrite (2 -4)____ Sphalerite (2 -4)____ Galena (2 -4)____ Bornite (2 -3)____

GeochemicalSignature: Hg (4 -5)____ Sb (3 -4)____ Cu (2 -3)____ Zn (2 -3)____ B (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Silica-carbonate-Hg____ Stibnite-veins____

MaxScore: 1475

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Simple Sb deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Rock-Types (5 -5)____

TextureStructure: Vein____ Massive____

Alteration: Silicification____ Sericitization____ Argillic____

Mineralogy: Stibnite (4 -5)____ Pyrite (2 -3)____

GeochemicalSignature: Sb (2 -5)____ Fe (2 -4)____ As (2 -4)____ Au (2 -4)____ Ag (2 -4)____

Hg (2 -3)____ W (2 -3)____ Pb (2 -3)____ Zn (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Simple-Sb____ Low-sulfide-Au-quartz-veins____ Hot-spring-Au-Ag____

Carbonate-hosted-Au-Ag____ Placer-Au____

MaxScore: 1585

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Disseminated Sb deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Rock-Types (5 -5)____

TextureStructure: Vein____ Disseminated____

Alteration: Silicification____ Sericitization____ Argillic____

Mineralogy: Stibnite (2 -5)____ Pyrite (2 -4)____

GeochemicalSignature: Sb (4 -5)____ Fe (2 -3)____ As (3 -5)____ Au (2 -5)____ Hg (2 -3)____

W (2 -3)____ Pb (2 -3)____ Zn (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Disseminated-Sb____ Simple-Sb____ Low-sulfide-Au-quartz-veins____

Hot-spring-Au-Ag____ Carbonate-hosted-Au-Ag____ Placer-Au____

MaxScore: 1720

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Kuroko massive sulfide

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Archean____ Proterozoic____ Phanerozoic____

RockTypes: Felsic-volcanic-rocks (5 -5)____ Mafic-volcanic-rocks (5 -5)____

Volcaniclastic-rocks (4 -1)____ Pelites (3 -1)____ Shale (2 -1)____

TextureStructure: Massive____ Stockwork____ Breccia____

Alteration: Zeolites____ Montmorillonite____ Silicification____

Mineralogy: Pyrite (2 -5)____ Sphalerite (3 -5)____ Chalcopyrite (3 -5)____ Pyrrhotite (2 -3)____

Galena (2 -4)____ Barite (2 -2)____ Tetrahedrite (2 -4)____ Tennantite (2 -4)____ Bornite (2 -3)____

Magnetite (1 -3)____ Gahnite (2 -3)____ Gypsum (1 -2)____ Anhydrite (1 -2)____

GeochemicalSignature: Pb (4 -5)____ Au (3 -3)____ Mg (2 -3)____ Zn (4 -5)____ Cu (3 -5)____

Ba (2 -2)____ As (2 -4)____ Ag (4 -5)____ Se (2 -2)____ Sn (2 -4)____ Fe (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Kuroko-massive-sulfide____ Epithermal-quartz-adularia-veins____

Volcanogenic.Mn____ Algoma.Fe____

MaxScore: 2110

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Algoma Fe

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Archean____

RockTypes: Iron-formation (5 -5)____ Mafic-volcanic-rocks (3 -2)____ Felsic-volcanic-rocks (3 -2)____

Volcaniclastic-rocks (4 -4)____

TextureStructure: Banded____

Alteration:

Mineralogy: Magnetite (4 -5)____ Hematite (4 -5)____ Siderite (2 -3)____

GeochemicalSignature: Fe (2 -5)____ Mn (2 -3)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Algoma-Fe____ Kuroko-massive-sulfide____ Homestake-Au____

MaxScore: 1010

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Quartz pebble conglomerate Au-U

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____

RockTypes: Conglomerate (5 -5)____ Sandstone (3 -1)____

TextureStructure: Replacement____

Alteration:

Mineralogy: Gold (3 -5)____ Pyrite (2 -4)____ Uraninite (3 -5)____ Brannerite (3 -5)____

Zircon (2 -3)____ Chromite (2 -3)____ Monazite (2 -3)____ Leucoxene (2 -3)____

GeochemicalSignature: Au (3 -5)____ U (3 -4)____ PGE (2 -4)____ REE (2 -3)____ Zr (2 -3)____

As (2 -2)____ C (2 -4)____

GeophysicalSignature: Radioactive-anomaly____

AssociatedDeposits: Quartz-pebble-conglomerate-Au-U____ Placer-Au____

Low-sulfide-Au-quartz-veins____ Homestake-Au____ Superior-Fe____

MaxScore: 1520

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Olympic Dam Cu-U-Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____

RockTypes: Alkali-granite (5 -2)____ Breccia (5 -3)____ Felsic-volcanic-rocks (3 -2)____ Tuff (2 -1)____

TextureStructure: Breccia____ Veins____

Alteration: Hematite____ Chlorite____ Sericite____ Quartz____

Mineralogy: Hematite (2 -5)____ Bornite (2 -3)____ Chalcopyrite (2 -5)____ Chalcocite (2 -5)____

Fluorite (2 -4)____ Barite (2 -4)____

GeochemicalSignature: Cu (4 -5)____ U (4 -4)____ Co (2 -3)____ Au (3 -5)____ Ag (2 -5)____

REE (2 -3)____ F (2 -3)____ Ba (2 -3)____ Fe (2 -5)____

GeophysicalSignature: Radioactive-anomaly____

AssociatedDeposits: Olympic-Dam-Cu-U-Au____

MaxScore: 1425

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sandstone-hosted Pb-Zn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Sandstone (5 -5)____ Conglomerate (3 -1)____ Siltstone (3 -1)____

TextureStructure: Stratiform____

Alteration: Recrystallization____

Mineralogy: Galena (4 -5)____ Sphalerite (4 -5)____ Pyrite (2 -4)____ Barite (2 -3)____

Fluorite (2 -3)____

GeochemicalSignature: Pb (4 -5)____ Zn (4 -5)____ Ba (3 -3)____ C (2 -3)____ F (2 -3)____

Ag (2 -4)____ Ni (1 -1)____ As (1 -2)____ Sb (1 -2)____ Bi (1 -1)____

GeophysicalSignature:

AssociatedDeposits: Sandstone-hosted-Pb-Zn____ Sediment-hosted-Cu____

MaxScore: 1190

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sediment-hosted Cu

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Phanerozoic____

RockTypes: Red-beds (5 -5)____ Green-shale (3 -1)____ Sandstone (5 -5)____ Shale (3 -2)____

TextureStructure: Stratiform____

Alteration: Reduction (5 -3)____

Mineralogy: Chalcocite (4 -4)____ Pyrite (2 -4)____ Bornite (3 -4)____ Silver (2 -4)____

GeochemicalSignature: Cu (4 -5)____ Ag (3 -5)____ Pb (2 -3)____ Zn (2 -3)____ U (2 -4)____

Ga (1 -2)____ V (2 -2)____ Co (1 -2)____ Mo (2 -3)____ C (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Sediment-hosted-Cu____ Sandstone-U____ Basalt-Cu____ Kipushi-Cu-Pb-Zn____

MaxScore: 1820

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sandstone U

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Devonian____ Carboniferous____ Permian____ Mesozoic____ Tertiary____

RockTypes: Sandstone (5 -5)____ Feldspathic-sandstone (4 -4)____ Tuffaceous-sandstone (3 -3)____

Mudstone (3 -1)____

TextureStructure: Stratiform____

Alteration: Reduction____ Leaching____ Oxidation____

Mineralogy: Uraninite (4 -5)____ Coffinite (4 -5)____ Pyrite (2 -5)____

GeochemicalSignature: U (4 -5)____ V (2 -5)____ C (3 -5)____ Mo (2 -4)____ Se (2 -5)____

Cu (2 -4)____ Ag (2 -5)____

GeophysicalSignature: Radioactive-anomaly____

AssociatedDeposits: Sandstone-U____ Sediment-hosted-V____ Sediment-hosted-Cu____

MaxScore: 1505

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sedimentary exhalative Zn-Pb

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Phanerozoic____

RockTypes: Shale (5 -5)____ Black-shale (4 -4)____ Chert (2 -1)____ Calcareous-Rocks (4 -2)____

Turbidites (2 -1)____ Tuffites (2 -1)____

TextureStructure: Disseminated____

Alteration: Tourmalinization____ Leaching____ Albitization____ Chloritization____

Mineralogy: Pyrite (2 -4)____ Pyrrhotite (2 -3)____ Sphalerite (4 -5)____ Galena (4 -5)____

Barite (2 -3)____ Chalcopyrite (3 -4)____ Marcasite (2 -4)____ Arsenopyrite (2 -3)____

Bismuthinite (2 -2)____ Molybdenite (1 -2)____ Enargite (1 -1)____

GeochemicalSignature: Zn (4 -5)____ Ag (3 -5)____ Pb (4 -5)____ Mn (2 -4)____ B (2 -3)____

Ba (2 -4)____ Co (1 -2)____ Cu (3 -5)____ Mo (2 -2)____ Sn (1 -2)____ As (2 -3)____

Sb (1 -2)____ Bi (1 -1)____ S (2 -5)____ C (2 -4)____ NH3 (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Sedimentary-exhalative-Zn-Pb____ Bedded-barite____

MaxScore: 1970

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Bedded barite

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Phanerozoic____

RockTypes: Shale (5 -2)____ Chert (4 -2)____ Calcareous-Rocks (3 -2)____ Argillite (2 -1)____
Greenstone (2 -1)____ Sandstone (2 -1)____

TextureStructure: Stratiform____

Alteration: Barite____

Mineralogy: Barite (5 -5)____ Witherite (2 -3)____ Pyrite (2 -3)____ Galena (2 -3)____
Sphalerite (2 -3)____

GeochemicalSignature: Ba (5 -5)____ S (2 -5)____ C (2 -4)____ Zn (2 -3)____

GeophysicalSignature: Gravity-high____

AssociatedDeposits: Bedded-barite____ Sedimentary-exhalative-Zn-Pb____

MaxScore: 1155

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Emerald veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cretaceous____ Tertiary____

RockTypes: Black-shale (4 -4)____ Calcareous-Rocks (2 -2)____ Evaporites (2 -2)____

TextureStructure: Banded____ Veins____

Alteration: Hornfels____

Mineralogy: Emerald (5 -5)____ Beryl (3 -5)____ Pyrite (2 -5)____ Fluorite (2 -5)____ Rutile (2 -5)____

GeochemicalSignature: Be (3 -5)____ Na (2 -5)____ Mg (2 -4)____ REE (2 -2)____ Cs (2 -3)____

F (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Emerald-veins____

MaxScore: 875

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Southeast Missouri Pb-Zn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cambrian____ Ordovician____

RockTypes: Dolomite (5 -5)____

TextureStructure: Open-space-filling____

Alteration: Dolomitization____

Mineralogy: Galena (3 -5)____ Sphalerite (3 -5)____ Chalcopyrite (3 -4)____ Pyrite (2 -5)____

Marcasite (2 -4)____

GeochemicalSignature: Pb (3 -5)____ Zn (3 -5)____ Cu (2 -5)____ Mo (2 -4)____ Ag (2 -4)____

Co (2 -4)____ Ni (2 -4)____ Cd (2 -4)____ As (1 -2)____ Sb (1 -1)____ F (1 -2)____

Br (1 -3)____ C (1 -3)____

GeophysicalSignature:

AssociatedDeposits: Southeast-Missouri-Pb-Zn____ Volcanic-hosted-magnetite____

MaxScore: 1115

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Appalachian Zn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____ Paleozoic____ Triassic____

RockTypes: Carbonate-rocks (5 -5)____

TextureStructure: Open-space-filling____

Alteration: Silicification____

Mineralogy: Sphalerite (4 -5)____ Pyrite (2 -4)____ Marcasite (2 -4)____

GeochemicalSignature: Zn (4 -5)____ Pb (4 -3)____ Mg (2 -5)____ Ba (2 -3)____ Cd (2 -4)____
F (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Appalachian-Zn____

MaxScore: 785

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Kipushi Cu-Pb-Zn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Dolomite (5 -5)____ Breccia (4 -4)____ Shale (3 -2)____

TextureStructure: Massive-replacement____

Alteration: Dolomitization (4 -2)____ Siderite____ Silicification____

Mineralogy: Pyrite (2 -5)____ Bornite (2 -5)____ Chalcocite (2 -4)____ Chalcopyrite (2 -4)____

Carrollite (2 -4)____ Sphalerite (2 -4)____ Tennantite (2 -5)____ Galena (2 -3)____ Enargite (2 -2)____

GeochemicalSignature: Cu (2 -5)____ Zn (2 -5)____ Pb (2 -5)____ As (2 -5)____ Co (2 -3)____

Ag (2 -5)____ Ge (2 -3)____ Mo (2 -3)____ W (2 -3)____ Sn (2 -3)____ Bi (2 -3)____ U (2 -4)____

V (2 -3)____ Mg (2 -5)____ Ga (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Kipushi-Cu-Pb-Zn____ Sedimentary-Cu____ U-veins____

Sedimentary-exhalative-Zn-Pb____

MaxScore: 2175

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Superior Fe

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____

RockTypes: Iron-formation (5 -5)____ Sandstone (2 -2)____ Shale (2 -2)____ Dolomite (2 -2)____

TextureStructure: Banded____

Alteration:

Mineralogy: Hematite (2 -5)____ Magnetite (2 -5)____ Siderite (2 -3)____

GeochemicalSignature: Fe (2 -5)____ Mn (2 -3)____

GeophysicalSignature: Magnetic-high____

AssociatedDeposits: Superior-Fe____ Sedimentary-Mn____

MaxScore: 740

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Sedimentary Mn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Calcareous-Rocks (5 -5)____ Clay (3 -2)____ Shell-rocks (2 -2)____

TextureStructure: Oolites____ Pisolites____

Alteration: Supergene____

Mineralogy: Mn-carbonates (4 -5)____ Mn-oxides (4 -5)____ Glauconite (2 -3)____

GeochemicalSignature: Mn (4 -5)____ V (2 -4)____

GeophysicalSignature:

AssociatedDeposits: Sedimentary-Mn____ Sediment-hosted-Cu____

MaxScore: 890

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Upwelling-type phosphate deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Paleozoic____ Mesozoic____ Tertiary____

RockTypes: Phosphorite (5 -5)____ Calcareous-Rocks (3 -2)____ Pelites (2 -1)____ Chert (2 -1)____

TextureStructure: Pellets____ Nodules____

Alteration:

Mineralogy: Apatite (3 -5)____ Fluorapatite (3 -5)____ Siderite (2 -4)____ Carnotite (2 -4)____

GeochemicalSignature: P (4 -5)____ N (4 -3)____ F (2 -5)____ C (2 -4)____ U (2 -5)____

GeophysicalSignature: Radioactive-anomaly____

AssociatedDeposits: Upwelling-type-phosphate____ Sedimentary-Mn____

MaxScore: 965

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Warm-current-type phosphate deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cretaceous____ Tertiary____

RockTypes: Phosphatic-limestone (5 -2)____ Phosphative-sandstone (5 -2)____

Diatomaceous-material (2 -2)____ Chert (2 -2)____

TextureStructure: Pellets____ Fossil-fragments____

Alteration:

Mineralogy: Fluorapatite (4 -5)____

GeochemicalSignature: P (4 -5)____ C (2 -3)____ U (2 -5)____ N (4 -3)____ F (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Warm-current-type-phosphate____

MaxScore: 730

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Low-sulfide Au-quartz veins

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Greenstone (5 -5)____ Metasedimentary-rocks (5 -2)____

Mafic-metavolcanic-rocks (4 -2)____ Graywacke (4 -2)____ Chert (2 -1)____

TextureStructure: Veins____ Shear-zone____

Alteration: Silicification (5 -2)____ Siderite____ Ankerite____ Albite____ Carbonates____

Mineralogy: Gold (5 -5)____ Pyrite (4 -5)____ Galena (3 -3)____ Chalcopyrite (3 -3)____

Arsenopyrite (3 -3)____ Pyrrhotite (2 -1)____

GeochemicalSignature: Au (4 -5)____ As (4 -5)____ Ag (4 -5)____ Pb (3 -4)____ Zn (2 -3)____

Te (1 -2)____

GeophysicalSignature:

AssociatedDeposits: Low-sulfide-Au-quartz-veins____ Placer-Au-PGE____ Kuroko-massive-sulfide____

Homestake-Au____

MaxScore: 2370

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Homestake Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Archean____

RockTypes: Metavolcanic-rocks (5 -5)____ Komatiite (2 -2)____ Volcaniclastic-rocks (2 -2)____

Iron-formation (5 -5)____ Felsic-plutonic (3 -3)____

TextureStructure: Bedded____ Veins____ Lenses____

Alteration: Zoned (5 -2)____

Mineralogy: Gold (4 -5)____ Pyrite (2 -5)____ Pyrrhotite (2 -4)____ Arsenopyrite (3 -4)____

Magnetite (2 -4)____ Sphalerite (2 -3)____ Chalcopyrite (2 -3)____

GeochemicalSignature: Au (4 -5)____ Fe (2 -3)____ As (3 -4)____ B (2 -4)____ Sb (3 -4)____

PGE (2 -3)____ Bi (3 -3)____ Hg (3 -3)____

GeophysicalSignature:

AssociatedDeposits: Homestake-Au____ Kuroko-massive-sulfide____ Algoma-Fe____

Low-sulfide-Au-quartz-veins____

MaxScore: 1940

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Unconformity U-Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Proterozoic____

RockTypes: Fine-grained-metasedimentary-rocks (4 -4)____ Carbonaceous-pelites (4 -4)____

Carbonate-rocks (2 -1)____

TextureStructure: Breccia-filling____ Veins____ Disseminated____

Alteration: Chloritization____

Mineralogy: Pitchblende (4 -5)____ Uraninite (4 -5)____ Coffinite (4 -5)____ Pyrite (2 -3)____

Chalcopyrite (2 -4)____ Galena (2 -4)____ Sphalerite (2 -3)____ Arsenopyrite (2 -3)____

Niccolite (2 -3)____

GeochemicalSignature: U (4 -5)____ Mg (2 -4)____ P (2 -4)____

GeophysicalSignature: Radioactive-anomaly____ Electromagnetic-anomaly____

Associated Deposits: Unconformity-U-Au____

MaxScore: 1030

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Gold on flat faults

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Breccia (5 -5)____ Mylonite (3 -3)____ Igneous (2 -4)____

TextureStructure: Stockwork____ Veins____ Breccia____

Alteration: Iron-oxides____ Silicification____ Carbonate-rocks____

Mineralogy: Gold (4 -5)____ Hematite (2 -5)____ Chalcopyrite (2 -4)____

GeochemicalSignature: Au (4 -5)____ Cu (2 -5)____ Fe (2 -4)____ F (3 -4)____ Ba (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Gold-on-flat-faults____

MaxScore: 1015

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Lateritic Ni

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Ultramafic-plutonic (5 -5)____ Serpentinite (3 -2)____

TextureStructure: Pisolites____

Alteration:

Mineralogy: Garnierite (4 -5)____ Goethite (3 -5)____

GeochemicalSignature: Ni (2 -5)____ Co (2 -5)____ Cr (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Lateritic-Ni____ Podiform-chromite____ Serpentine-hosted-asbestos____

Placer-PGE-Au____ Placer-Au-PGE____

MaxScore: 1165

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Laterite-type bauxite deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cretaceous____ Cenozoic____

RockTypes: Aluminous-silicate-rocks (5 -5)____

TextureStructure: Pisolites____ Massive____ Nodules____

Alteration: Bauxite (5 -5)____

Mineralogy: Gibbsite (4 -5)____ Boehmite (4 -4)____ Hematite (2 -4)____ Goethite (3 -4)____

Anatase (2 -4)____

GeochemicalSignature: Al (4 -5)____ Ga (3 -3)____

GeophysicalSignature:

AssociatedDeposits: Laterite-type-bauxite____

MaxScore: 1055

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Karst-type bauxite deposits

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Paleozoic____ Mesozoic____ Cenozoic____

RockTypes: Felsic-volcanic-rocks (2 -2)____ Aluminous-silicate-rocks (4 -2)____

TextureStructure: Pisolites____ Massive____ Nodules____

Alteration: Bauxite (5 -5)____

Mineralogy: Gibbsite (4 -5)____ Boehmite (4 -4)____ Hematite (2 -4)____ Goethite (3 -4)____

Anatase (2 -4)____

GeochemicalSignature: Al (4 -5)____ Ga (4 -3)____

GeophysicalSignature:

AssociatedDeposits: Karst-type-bauxite____

MaxScore: 1085

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Placer Au-PGE

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cenozoic____

RockTypes: Gravel (5 -5)____ Conglomerate (5 -1)____

TextureStructure: Placer____

Alteration:

Mineralogy: Gold (4 -5)____ Magnetite (2 -5)____ Ilmenite (2 -4)____

GeochemicalSignature: Au (4 -5)____ Ag (2 -5)____ As (2 -4)____ Hg (2 -3)____ Sb (2 -2)____

Cu (2 -3)____ Fe (2 -4)____ S (2 -2)____

GeophysicalSignature:

AssociatedDeposits: Placer-Au-PGE____ Porphyry-Cu____ Cu-skarn____ Polymetallic-replacement____

Low-sulfide-Au-quartz-veins____

MaxScore: 1390

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Placer PGE-Au

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cenozoic____

RockTypes: Gravel (5 -5)____ Conglomerate (5 -1)____

TextureStructure: Placer____

Alteration:

Mineralogy: PGE (4 -5)____ Gold (4 -5)____ Magnetite (2 -5)____ Chromite (2 -4)____ Ilmenite (2 -4)____

GeochemicalSignature: Au (4 -4)____ PGE (4 -5)____ Ag (2 -4)____ As (2 -4)____ Hg (2 -3)____ Sb (2 -2)____

Cu (2 -3)____ Fe (2 -4)____ S (2 -2)____ Cr (2 -5)____

GeophysicalSignature:

AssociatedDeposits: Placer-PGE-Au____ Alaska-PGE____

MaxScore: 1120

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Shoreline placer Ti

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Sand (5 -5)____

TextureStructure: Placer____

Alteration:

Mineralogy: Ilmenite (4 -5)____ Rutile (3 -5)____ Zircon (2 -4)____

GeochemicalSignature: Ti (4 -5)____ Zr (2 -5)____ REE (2 -5)____ Th (2 -5)____ U (2 -5)____ Fe (2 -4)____

GeophysicalSignature: Radioactive-anomaly____ Induced-polarization-anomaly____

AssociatedDeposits: Shoreline-placer-Ti____

MaxScore: 720

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Diamond placers

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Cenozoic____

RockTypes: Gravel (5 -5)____ Conglomerate (2 -1)____

TextureStructure: Placer____

Alteration:

Mineralogy: Diamond (5 -5)____ Bort (5 -5)____ Ballas (5 -5)____

GeochemicalSignature: Cr (2 -3)____ Ti (2 -5)____ Mn (2 -4)____ Ni (2 -4)____ Co (2 -3)____

PGE (2 -4)____ Ba (2 -3)____ Nb (2 -4)____ Mg (2 -3)____

GeophysicalSignature:

AssociatedDeposits: Diamond-placers____ Diamond-pipes____

MaxScore: 1000

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Model Score:_____

Worksheet for Numerical Model of Alluvial placer Sn

Deposit,Prospect,or Occurrence:

Location:

Description:

AgeRange: Precambrian____ Phanerozoic____

RockTypes: Gravel (5 -5)____ Conglomerate (2 -1)____

TextureStructure: Placer____

Alteration:

Mineralogy: Cassiterite (4 -5)____ Magnetite (3 -5)____ Ilmenite (2 -5)____ Zircon (2 -5)____

Monazite (3 -5)____ Allanite (2 -5)____

GeochemicalSignature: Sn (4 -5)____ As (2 -5)____ B (3 -5)____ F (3 -5)____ W (3 -4)____ Zn (2 -5)____

Be (2 -5)____ Zr (1 -1)____ Nb (1 -3)____ Ta (1 -3)____

GeophysicalSignature:

AssociatedDeposits: Alluvial-placer-Sn____

MaxScore: 925

Partial Scores

AgeRange:_____ RockTypes:_____ TextureStructure:_____ Alteration:_____

Mineralogy:_____ GeochemicalSignature:_____ GeophysicalSignature:_____

AssociatedDeposits:_____

Appendix E. Minerals identified in solution-collapse breccia pipe uranium deposits

[Primary ore and gangue minerals marked by *; others oxidized or supergene (modified after Wenrich and Sutphin, 1988, table 1)]

A. ORE MINERALS

URANIUM
uraninite*
coffinite
tyuyamunite
metatyuyamunite
metazippeite
zeunerite
metazeunerite
metatorbernite
uranophane
bayleyite
uranospinite

VANADIUM
hewettite
vesigneite
volborthite
calciovolborthite
roscoelite*

SILVER
acanthite
naumannite
proustite

GOLD
Native(?)

COPPER
chalcocite
djurleite
digenite
covellite
enargite*
chalcopyrite*
lautite*
bornite
tennantite*
tetrahedrite*
cuprite
tenorite
chrysocolla
azurite
malachite
olivenite
chalcanthite
brochantite
cyanotrichite
chalcoalumite
langite
antlerite
devilline
conichalcite

B. BASE-METAL MINERALS

LEAD
galena*
anglesite
cerussite
wulfenite

ZINC
adamite
sphalerite*
smithsonite
aurichalcite
hemimorphite

COBALT
skutterudite*
Co-gersdorffite*
erythrite
linnaeite*
bieberite

NICKEL
nickeline*
rammelsbergite*
pararammelsbergite*
gersdorffite*
bravoite*
siegenite*
vaesite*
millerite*

MOLYBDENUM
molybdenite*
ilsemannite
jordisite

IRON
pyrite*
marcasite*
arsenopyrite*
siderite*
scorodite
melanterite
limonite
hematite
goethite
jarosite
siderotil
coquimbite

MANGANESE
rhodochrosite

ANTIMONY
stibnite*

C. NON-METALLIC MINERALS

quartz*
chalcedony*
pyrobitumen*
celadonite
illite
kaolinite*
chlorite
fluorite*

calcite*
barite*
dolomite*
ankerite*
anhydrite*
gypsum
hexahydrite
leonhardtite

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