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Mineral Deposit Modeling using Components for Complex Mineral Deposits: Mixed Base- and Precious-Metal Veins of the Idaho Batholith, Idaho

by

James D. Bliss[1]

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[1] U.S. Geological Survey, Tucson, Arizona

Summary

•Models developed in this study for mixed base- and precious-metal veins of the Idaho batholith (fig. 1) can be used to: (1) characterized the copper, lead, zinc, gold, and silver grades and sizes in deposits yet to be discovered for use in mineral resource assessment.

•Six different types (or components) of mineralization are found in mixed base- and precious-metal vein deposits and are as follows:

(1) **Au veins** with byproduct Ag, Cu, Pb, and (or) Zn;
(2) **Ag veins** with byproduct Au, Cu, Pb, and (or) Zn;
(3) **Ag-Pb veins** with byproduct Cu, Au, and (or) Zn;
(4) **Cu veins** with byproduct Au, Ag, and (or) Zn;
(5) **Cu-Pb-Zn veins** with byproduct Au, and (or) primary Ag;
(6) simple **Sb deposits** with byproduct Au and (or) Ag.

•Deposits contain one to three components; 80 percent of the deposits contain a single component; about 3 out of 4 times it is a Au vein (table 1).

•Fifteen percent of the deposits contain two components and 6 percent contain 3 components; Au veins and Ag veins are more likely in two component deposits and joined by Ag-Pb veins in three component deposits (table 1);

•Deposit size is independent of the type or number of components in the deposit; the geometric mean is 13,000 metric tons (t) (see fig. 10).

•The geometric mean gold grades in gold veins is 13 grams (g)/t; in other components the gold grade is commonly less than 10 g/t (fig. 13).

•Silver grades vary from 1 g/t to 10,000 g/t (fig. 14).

•Data are sufficient for Au veins and Ag veins to be treated as separate mineral deposits models as well as components.

•The size of the area with mines (or target area) has a median of 2.9 square kilometers (fig. 19).

Preface

One use of the models developed here is to characterize deposit sizes and grades for use in quantitative mineral resource assessments. Models provide "reasonable answers" to the question of "how much" of specific resources remain undiscovered in an area under evaluation where the area has not been completely explored. The reviews of methods used in mineral resource assessment are described by Harris and Agterberg (1981) and Singer and Mosier (1981) and they give an idea of the range of techniques and products available. Drew and others (1986) is an example of prediction of resources using one of these forms of assessment (Singer and Cox, 1988).

Defining groups of polymetallic veins sufficiently similar in metal grades to model can be extremely difficult. Vein deposits, particularly smaller-sized ones, are probably among the most difficult deposit types to model. Extraction and recovery details can be equally incomplete because for some, base metals were discarded, not reported, or, as for zinc, possibly avoided in mining. Descriptions are almost always incomplete.

Base and precious metal grades for model development should represent deposits where a single metal (or group of metals) was necessary for the deposits to be worked. Nearly all the data for veins are from mill production which can be inefficient (only part of the metal is recovered). Concentrate production and smelter recovery is biased toward selected metals. Estimating mineral deposit grade of byproduct metals under these condition are likely less than the actual grades of the metals in the veins. Models are difficult to develop for groups of deposits where mixing vein deposits in which a metal is primary commodity may be mixed with those in which the same metal is a byproduct.

Polymetallic and other types of veins have been a favorite target for small-scale miners and can be found in large numbers scattered over a region. Their relative small size also makes them of less interest to scientists studying mineral deposits (and companies looking for big deposits) and fewer data are available about them.

A somewhat different approach to grade and tonnage modeling is described in this report. It was developed to help the USGS assess undiscovered mineral potential of some of the roadless public lands in Idaho, as targeted in the 1989 version of the McClure-Andress Idaho wilderness proposal (Johnson and Worl, 1991). The new approach to modeling may find application in other assessments.

Introduction

Grade and tonnage models (Singer, 1993) describe characteristics of mineral deposits that can help determine their economic viability. Models are presented graphically with grades or tonnages plotted on the horizontal axis and the cumulative proportion of deposits along the vertical axis. Following the procedure of Cox and Singer (1986), "smoothed curves are plotted through arrays of points, and intercepts for the 90th, 50th, and 10th percentiles are constructed." The curve usually represents a lognormal distribution that has a mean and a standard deviation which fit the data. Statistical analysis of data was made using the computer package, StatView512+. The procedures outlined in Gibbons (1976) was used for nonparametric analysis.

Problems in modeling

For many mineral deposits, classifications can be made using descriptive models, that is, the systematical arrangement of essential attributes (Cox and others, 1986). It is not always obvious which attributes are essential and which are not. Deposits that are transitional between existing mineral deposit types are not always readily classifiable (e.g., skarns transitional into replacements) and may be arbitrarily classified or simply not all. Modelers usually avoid deposits with ambiguities given that enough data can be be collected from clearly definable deposits. Those making land assessments may not have the luxury of ignoring these deposits. Under careful inspection, many mineral deposits exhibit several styles of mineralization. Minor mineral styles which depart from the primary mineralization style within the deposit usually can be ignored for classification purposes. Most modelers have a tendency to focus on a targeted deposit type and collect data on that specific deposit type without lumping adjoining mines especially if they appear to be a different style of mineralization and producing different commodities. A particularly good example is hydrothermal systems which produce porphyry copper deposits, skarn deposits, and replacements deposits where each style of mineralization is considered a different deposit type and each with its own grade and tonnage model (D.L. Mosier, written commun., 1992). Mines working extensions of the same deposit type are usually grouped given they have similar geology and commodities. This has been a relatively successful strategy.

Different deposit types can be adjacent but independent (e.g, two different hydrothermal systems spatially close but operating at different times and with different mineral deposit types). More difficult to untangle is where two mineral deposit types are overprinted. Modeling overprinted mineral deposit types can be extremely difficult or impossible.

A similar situation can be found where adjacent mines are of the same style of mineralization (e.g, veins) but produce different commodities. While the type of commodity produced is integral to mineral deposit definition, the modeler can have difficulties in defining deposits in these situations. Failure to sort out the role of commodities during deposit definition can result in unrealistic grades in deposits where mines are lumped together arbitrarily. For example, consider two adjacent mines working mineralized bodies of about the same size. If mine A is worked for Cu, and mine B is worked for Au, the average Au grade will be very low if the computed average consists of the amount of Au produced by mine A divided by the total tonnage of mine A plus mine B; similarly for Cu. This can get very messy given a group of mines producing three or more commodities.

A similar problem has developed for Au because of recent changes in cut-off grades and extraction technology. Some deposit types previously defined as Cu skarns are now being worked for Au and has been redefined as Au skarns. Some descriptions of newly discovered gold mines fail to even report the Cu grade. The situation for skarns clearly highlights a problem of using mineral deposit definitions based only on commodity. Two skarn subtypes are recognized by Theodore and others (1991): (1) Au skarns, and (2) byproduct gold skarns. In the first situation Au is a primary commodity and in the second it is a secondary commodity which was recovered as part of the recovery process for some other commodity. Very low Au grades are possible for byproduct gold skarns where a Au recovery circuit is added to an existing extraction operations for some other metal. For Au skarns, the average Au grade is dependent on the lowest viable cut-off Au grade of material which can be mined and processed under existing extraction technology and Au prices. A similar situation occurs for some mineral deposits with a long history of exploitation where several types of mining methods have been used and under various commodity prices. Deposits once worked for Au in veins may be reworked using open pit methods for Au in disseminated ore.

A strategy to solve the problem of adjacent mines working the same type of mineralization but for different commodities is developed below. Using this strategy, vein deposits found in or adjacent to the Idaho batholith are modeled. Difficulties in modeling these vein deposits were discovered during the preliminary assessment of the Elk City 1° x 2° quadrangle, Idaho and Montana (Lund and others, 1990).

Vein deposits of the Idaho batholith

To build a grade and tonnage model, a descriptive model is needed to help recognize the deposit population. Cookro and others (written commun., Mar. 6, 1991) and Worl and others (written commun., April 10, 1991) prepared such descriptive models. Worl calls these deposits polymetallic quartz veins and lodes. The suggested synonym, mixed base- and precious-metal veins, is used in this paper to emphasis the commodities usually produced from these deposits. Worl suggests that these veins form during the late stage of the formation of the batholiths when the structural environment changed from dominantly compressive to dominantly tensional. The descriptive models are largely based on vein deposits in and (or) adjacent to the Idaho batholith and thus they may be biased. Figure 1 gives a generalized outline of the batholith. The same deposit type is found associated with the Nelson batholith, British Columbia (Cairnes, 1934). In the Idaho batholith, deposits are hosted in all phases of the batholith, roof pendants, and in the country rock on the margins within 600 m (2000 ft) of the batholith contact. Mineralization is a complex mixture of commodities and the descriptive model suggests that the multistage quartz-rich veins were deposited during the "waning stages of batholith formation" in shears and faults. Veins may be epithermal and (or) mesothermal. Comstock epithermal veins occurs in the area of the Idaho batholith and can be confused with mixed base- and precious-metal veins when hosted in the volcanic country rocks.

The descriptive model proposes two end-member types: (1) a quartz-rich end member and (2) a polymetallic end member containing Ag-Pb-siderite. All compositional gradations between the two can be found making a complex family of deposits. Commodities hosted by these veins include Au, Ag, W, Sb, Cu, Pb, and Zn and are grouped by Worl into five dominant members: (1) silver/base metal veins, (2) gold veins, (3) tungsten veins, (4) antimony veins, and (5) silver veins. Two minor vein types are tungsten veins and antimony veins. Bruce Johnson (written commun., April 1, 1991) suggests three vein types are present at the north end of the batholith (fig. 1). These are: (1) precious-metal quartz veins, (2) copper-dominated Au veins, and (3) lead-silver veins. Bruce Johnson suggests that the copper-gold polymetallic veins were more common around the north end of the Idaho batholith while the lead-silver dominated polymetallic are distal to the batholith. The latter type appears to be the same type of deposit characterized by the descriptive model for polymetallic veins defined by Cox (1986).

Some of the deposits are also a product of surface effects--they would likely not have been worked without oxidation. This is true of Cu, Pb, and Zn which was found in secondary enriched surface deposits (R. Worl, written commun., 1992). Some of the complications found in modeling are probably due to including data from secondary deposits with primary ones. This is not an uncommon problem in many small-size deposits found at the surface.

Data for modeling

The mine is the minimum reporting unit used for data collection. Mines must be resolved as points on maps of a scale of 1:250,000. In a few cases, prospects or occurrences of note were used. However, the minimum reporting unit will be referred to as a mine for the balance of this report.

Data collected to prepare these models were extracted primarily from the Mineral Resource Data System (MRDS), a database of mineral resources of deposits and occurrences operated by the USGS and available for public enquiry at Minerals Information Offices located in Tucson, Arizona; Reno, Nevada; Spokane, Washington; and Washington, D.C. Other sources include the U.S. Bureau of Mines, Spokane, Wash. Because some propriety data were used for grade and tonnage modeling, the complete data set can not be released.

As noted in the introduction, byproduct grades can be suspect as they are often computed from concentrate data where concentrates usually consist of minerals with higher value commodities. Other minerals are ignored. When this is done, metals found in minerals not selected are not included in the grade calculation. To determine if metal grades in this study are reasonable, a review was made of deposit metal grades (e.g., Cu, Pb, Zn, Au, Ag) in models for 26 mineral deposit types found in Cox and Singer (1986) and Bliss (1992). Approximate lowest grades used in previous developed grade and tonnage models are as follows: 0.04 percent Cu, 0.01 percent Pb, 0.01 percent Zn, 0.01 g/t Au, and 0.1 g/t Ag. Only Cu grades in this data set is less than the grades used in other mineral deposit models. Cu grades below 0.04 percent are noted as appropriated but not used in modeling.

The geographic distribution of mines was also used to develop spatial models. Mines located near one another are considered to be working the same deposit as resolved at a scale of 1:250,000 and data for them are combined. The locations of mines were taken from Mitchell and others (1981a) for areas in the Idaho portion of the Challis 1^{o} by 2^{o} quadrangle, Mitchell and others (1981b) in the Elk City 1^{o} by 2^{o} quadrangle, Hustedde and others (1981) in the Hailey 1^{o} by 2^{o} quadrangle, and Mitchell and others (1981c) in the Hamilton 1^{o} by 2^{o} quadrangle.

The Mineral Deposit Component Model

Complex mineralized systems like those described here require an explicit recognition that mineral deposits are not necessarily mines nor districts (Bliss and Menzie, in press). Mines which are adjacent but which extracted different metals were treated separately in much of the past grade and tonnage modeling work. The modeling strategy used here is different--deposits are defined using a operational proximity rule and mines are grouped if within a given distance. Only data on mined deposits conforming to the descriptive model are used. The mines <u>within</u> each deposit are then classified according to commodities or combination of commodities.

When inspecting maps showing location of mines, prospects, and occurrences, nearly all sites appear in clusters; some clusters are as large as 41 km^2 in area. As a result, the term deposits, as used in the model, are defined to include all adjacent mines (i.e., within one mile (1.6 km) or less) (fig. 2). A total of 48 mineral deposits were developed using this rule from sites in the Hamilton, Elk City, Challis, and Hailey 1^{o} by 2^{o} quadrangles. Data for over 700 mines were evaluated to develop the model. Ten percent of the deposits are based on data from isolated mines.

If all grade and tonnage data for the mines in the cluster are combined to calculate a single tonnage and a single grade for each commodity, some deposits will have some grades which are unrealistically low since adjacent mines did **not** produce the same commodity. In order to better reflect the grades actually worked, mines have been classified according to the primary commodity produced. A composite tonnage and grade is then calculated by aggregating just those mines in the cluster with the same classification; this is defined as a **mineral deposit component** within the deposit. Figure 2 shows the relation of mines, mineral deposit components, and deposits. Mineral deposit A consists of 20 mines and three mineral deposit components. Each mine in the deposit is classified by mineral deposit component type (type A, B, and C, fig. 2). Note that in mineral deposit A (fig. 2), mineral deposit components may be in several parts (that is, two components for types A, B, and C) but a single grade and tonnage is computed for each component type. Mineral deposit C has 7 mines all classified alike. Therefore the deposit is represented by a single component. Mineral deposit B is an example of a single mine classified by a mineral component type and sufficiently distant from other mines to be a deposit in its own right. Each mineral component type for all deposits is modeled as a separate population. One problem with **mineral deposit component modeling** is the necessity to have multiple models to fully characterize the deposit type.

Each mine has one or more primary commodity and possibly one or more secondary commodity. Most of the mines were worked in the previous century or in the early part of this century. Using metal prices from that period (U.S. Bureau of Mines, 1989), the values of the metals recovered were computed from grade data. This was used to assist in deciding which metals are primary, co-products, or byproducts. In this study, a metal is considered primary if it contributed more than 75 percent of the value of the production based on metal values as of 1900. Metals are co-products when their summed value is greater than 75 percent. If Au is 37 percent of the value and Ag is 40 percent of the value, the summed value is 77 percent making Au and Ag co-products.

Other metals that contribute less are byproduct. The variation of value of a commodity is small when compared to the differences of values between commodities except for base metals. Of the metal considered, Au and Ag usually are found to be the source of most of the value. This is very apparent when comparing the value of Au to Ag, and Ag to the base metals. The base metals are quite similar to each other in value and their contribution to the total value is small. Sb in veins contributes little to value and W in veins almost nothing at all.

Vein deposits were found to contain one to three mineral deposit component types as defined by commodity. Sb veins are compatible with the simple Sb deposit model (Bliss and Orris, 1986). In this situation, Sb veins which were identified previous as deposits are now recast as a mineral component. Based on this criteria, mines were classified according to the following **mineral component types**:

(1) **Au veins** with byproduct Ag, Cu, Pb, and (or) Zn
(2) **Ag veins** with byproduct Au, Cu, Pb, and (or) Zn (also some co-product Au)
(3) **Ag-Pb veins** with byproduct Cu, Au, and (or) Zn
(4) **Cu veins** with byproduct Ag, Pb, and (or) Zn (also some co-product Au)
(5) **Cu-Pb-Zn veins** with byproduct Au; primary Ag, and
(6) **Sb veins** with byproduct Au and (or) Ag.

A total of 61 mineral components have sufficient data to be modeled. They are distributed among the 48 mineral deposits. Most mineral deposits (79 percent) contain just one mineral component like example mineral deposit B and C (fig. 2). Only 14 percent have two components and 6 percent have three. The classification scheme used incorporates some of the ideas of Worl and of Johnson noted previously.

Au veins are the most common mineral component type found in these deposits. It is found in 73 percent of the deposits. Ag is the most likely byproduct commodity but the base metals are also reported. Other commodities reported in Au veins include two with grades of 0.05 percent and 0.06 percent WO_3, one with a grade of 0.004 percent As, and one with with a grade of 0.002 percent Sb respectively. Au veins are found in five single-mine deposits for example in mineral deposit B (fig. 2); the balance are in clusters of mines. Statistical analysis using the Mann-Whitney U test found that the median size, Au grade, and Ag grade of Au veins in single mine deposits was not significantly different (at the one-percent level of confidence) from those Au veins in deposits with two or more mines. All but one of the other mineral component types have been recognized with Au veins. Cu veins which are rarely identified in these deposits at all are not recognized with Au veins. Given the presence of Au veins in a deposit, the probability is 0.25 that Au placers will be in the vicinity of the deposit.

Ag veins are the second most common mineral deposit component type. Even so, only 19 percent of the deposits contain this style of mineralization. Byproducts include all three base metals. In only one situation, are Ag veins found in deposits without other mineral components. They are found associated with all types of mineral components with the exception of Cu-Pb-Zn veins.

Ag-Pb veins and Cu-Pb-Zn veins tie for third. Twelve percent of the deposits contain these mineral component types. Byproducts of Ag-Pb veins include Au, Cu, and Zn. Half the Ag-Pb are found associated with other mineral components. This includes all type of mineralization components with the exception of Cu-Pb-Zn veins and Cu veins. Of the six mineral component types, the Cu-Pb-Zn veins have the most complex mixture of primary and secondary commodities and will need to be refined when more data are available. Some components contain just one of the base metals as a primary commodity. Au is a byproduct; while Ag is also a byproduct, its grades are best described using the primary model. Four of the six components occur in deposits without other mineral component types. The only other component type found associated with Cu-Pb-Zn veins is the Au veins.

Cu veins are reported in only two deposits. In one deposit, they are associated with Ag veins and in the other, without an association. Pb may be a byproduct. This mineral component type is rare and whether it will continue to be recognized in future modeling efforts concerning mixed base- and precious-metal veins is unclear.

Data to model Sb veins are found in 6 percent of the deposits. In two examples, it was the only mineral component type to be clearly identified. In only one example, the Sb vein is associated with Au veins and Ag veins. As noted previously, the Sb vein components are compatible with the descriptive model for simple Sb deposits (Bliss and Orris, 1986a). The grades and tonnages data are also compatible with the grade and tonnage model for simple Sb deposits (Bliss and Orris, 1986b). Description of the Sb veins and associated rocks in which they occur in the Idaho batholith also suggests that disseminated Sb mineralization may be found which in the models is associated with 15 percent of simple Sb deposits (Bliss and Orris, 1986c).

Analysis of Mineral Deposit Metal Grades by Component Type

The base- and precious-metal grades found in mineral deposit components have a large range of values. This should come as no surprise as a metal may be the primary or co-product in one vein and only a minor byproduct in the next. Precious metals account for much of the monetary value of these deposits and Au accounts for a large part of the value while Ag is the next most important. When Au and Ag are both reported, Au veins forms a separate group as illustrated in the lower right of Figure 3 from those with Ag as the primary commodity or byproduct where base metals are important. Ag-Pb veins together with most of the Ag veins and Cu-Pb-Zn veins make up the group shown in the upper left of Figure 3. Three Ag veins and one Cu-Pb-Zn vein are a transitional between the two groupings. Cu veins are represented by one observation in the Au group and one in Ag group. Ag veins were worked when Ag grades were greater than 18 g/t and Ag-Pb veins were worked when the Ag grades were greater than 130 g/t. Au grades and Ag grades are independent if all mineral components are considered.

Cu veins were worked if the Cu grades were 0.4 percent or greater (fig. 4). Au veins can contained up to one percent Cu, while Ag-Pb, Ag-Au can contained up to about a third of a percent Cu. The same situation for Pb in Au veins is suggested in a scatter plot of Au and Pb grades (fig. 5). Au veins contained up to one percent Pb. Obviously higher Pb grades are present in Ag-Pb veins, Ag veins, and Cu-Pb-Zn veins. With one exception as illustrated in scatter plots (figs. 4, 5), Au generally varies between 0.1 and 10 g/t per metric ton, and increasing Cu or Pb grades have little effect on its variation.

High Cu and Ag grades are characteristic of Cu-Pb-Zn veins, and, to a lesser degree, Ag-Pb veins (fig. 6). The two Cu veins have low Ag grades. Ag veins tend to have decreasing Cu grades with increasing Ag grades. When both Pb and Ag grades are reported, a positive correlation is suggested between the two (fig. 7) for most deposits types. This trend is strong for Ag-Pb veins.

High Pb and Cu grades are characteristic of Cu-Pb-Zn veins, and, to a lesser degree, Ag-Pb veins (fig. 8). The overall trend, though weak, is increasing Pb grades with Cu grades.

Possible correlations between metal grades is examined in detail later. The scatter plots (figs. 3-8) show that most grades are more or less continuous.

A metal is low grade when it is a byproduct in some mineral deposit component types. It is intermediate to high grade when it is a primary or co-product commodity in other mineral deposit component types. This should come as no surprise since mixed base- and precious-metal veins contain a complex mixture of commodities. The mineral deposit components form adjacent or overlapping groupings in these scatter plots.

Grade and Tonnage Models

Introduction

Deposits used for modeling contain between 1 and 66 mines; the median deposit contains 15 mines. There is substantial overlap among commodity grades which suggests models might be shared among the mineral component types. For example, Cu as a byproduct in Au veins has the same range of values as Cu as a byproduct in Ag veins. Therefore commodity grades can be separated in a general way for those grades which represent a primary commodity and for those grades which represent a byproduct commodity. Deposits with commodities as co-products occur infrequently and do not present problems using the two part classification. An additional style of mineralization is simple Sb veins which were modeled previously (Bliss and Orris, 1986a; 1986c) but are included in this classification framework and can also be used for making predictions about undiscovered mixed base- and precious-metal veins. While this vein type has been previously defined as a deposit, it will be used as a mineral deposit component in mixed base- and precious-metal veins. W veins which are recognized in the preliminary descriptive model for mixed base- and precious-metal veins are never sufficiently documented to be modelled.

Percentages in some of the discussion on mineral components can add to more than 100 percent. Correlation between variables is reported for data sets with five or more variable pairs. Because most models are for incomplete data sets, the test to determine whether the data significantly differs from lognormal can not be made using tests of skewness and kurtosis (Rock, 1988).

Modeling deposit tonnage

Mineral components, no matter which type, appear to have the same range of tonnages. The median tonnages among the five mineral component types were not significantly different (at the one-percent level) using the Kruskal-Wallis test. Therefore, the tonnages of all other mineral components can be described using a single tonnage model (fig. 9). This suggests that fissure, faults, etc. which controlled the sizes of these vein deposits were equally suitable repositories regardless of the commodity. Data on several of the mineral component types are represented by only a few examples and may be subject to revision. The component tonnage model applicable to all mineral deposit components is not significantly different from lognormal using the test of skewness and kurtosis (Rock, 1988).

Tonnage of mineral components are small in comparison with other types of deposits (Cox and Singer, 1986; Mosier and Page, 1988; Bliss, 1992). The median tonnage is 8,000 t. A direct comparison to sizes of other mineral deposit types modeled to date is not quite valid because mineral deposit tonnages represent the whole deposit which is not the situation for mineral components. For comparison, the tonnages of all components within each mineral deposit has been totaled and separately modeled (fig. 10). Deposit tonnages, like component tonnages, were found to be not significantly different from lognormal using the skewness and kurtosis test (Rock, 1988). The high degree of similarity between figure 9 and figure 10 is due to the large number of deposits which contain just one component. In fact, comparison of median tonnages between the two data sets using the Mann-Whitney U test suggests that they are not significantly different at the one-percent level.

When compared to other deposit types, mixed base- and precious-metal veins fall between rank 9 and 10 among 71 mineral deposit types previously ranked by median tonnage (fig. 11). This makes mixed precious- and base-metal veins only slightly larger than polymetallic veins (fig. 8, y-axis no. 9) but smaller than low-sulfide Au quartz veins (no. 14). Blue-Mountain-type Au-Ag polymetallic veins are not found in figure 11 are about 9 times larger (Bliss, in press). Mixed base- and precious-metal veins certainly are much smaller in terms of tonnage when compared to Comstock epithermal veins (no. 28), Creede epithermal veins (no. 32), and related epithermal types which have geometric mean sizes on the order of one or more million tons. No correlation was found between tonnage of mineral components, and Au, Ag, Zn, Cu, or Pb grades.

Modeling Au grade

Au is the most commonly reported commodity and likely the best modeled commodity. Au is reported in 88 percent of the mineral deposit components used for models. Data for three Au grade models was compiled for two component types and a general class: Au in Au veins, Au in Au-Ag veins, and byproduct Au. A histogram showing the distribution of these groups suggest that two groups have differing Au grades (fig. 12). Comparison of median Au grades among the data sets using the Kruskal-Wallis test suggested that significant differences were present at the one-percent level of significance. The results of the multiple comparison method test described by Gibbons (1976, p. 182-183) suggests that median Au grade in Au veins is significantly different (at the 20-percent level), than from Au in Ag veins and byproduct Au. Au in Au veins (fig. 13, curve b) is separately modeled. Au grades for Au veins were found not to be significantly different from lognormal at the one percent level using the skewness and the kurtosis goodness-of-fit tests (Rock, 1988). However, the analysis suggest that median Au grades for Ag veins and byproduct Au have medians which are not significantly different. Therefore, the Au grade data for these two mineral deposit component types have been combined (fig. 13., curve a). The byproduct model also include Au grades for Cu, Ag-Pb, and Cu-Pb-Zn veins.

Few significant (at the one-percent confidence level) correlations were found between commodities in these data sets because the number of pairs was small. Correlations for pairs with less than 5 observations are not reported. Au and Ag are correlated for Au veins (r=0.65, n=14) and Ag and Pb for byproduct Au (r=0.77, n=14).

Modeling Ag grade

Ag is the second most commonly reported commodity. Ag is reported in 67 percent of the mineral components used for models. Two grade models have been developed: Ag as a primary commodity (fig. 14, curve b) for Ag-Au, Ag-Pb, and Cu-Pb-Zn veins and byproduct Ag grades (fig. 14, curve a) for Au veins and Cu veins. The hypothesis that Ag grades as primary and byproduct commodities are the same was rejected at the at the 1 percent level; the alternative hypothesis that the primary Ag grades are larger than byproduct Ag grades was accepted (Mann-Whitney U test). The primary commodity Ag grades were found not significantly different from lognormal (at the 1 percent level) using the skewness and kurtosis goodness-of-fit tests (Rock, 1988). While Ag may or may not be among the primary commodities in Cu-Pb-Zn veins, the primary Ag grade model is best suited to Ag grades found associated with this mineral component type. Two correlations are noted for primary Ag and none for byproduct Ag. Ag is correlated with Cu (r=0.77, n=8) and Zn with Pb (r=0.99, n=5).

Modeling Cu grade

Cu is the second most commonly reported base-metal commodity (after Pb). Cu is reported in 38 percent of the mineral components used for models. Two grade models have been developed: Cu as a primary commodity (fig. 15, curve b) for Cu-Au and Cu-Pb-Zn veins, and byproduct Cu grades (figure 15, curve a) for Au, Ag-Au, and Ag-Pb veins. The hypothesis that Cu grades as primary and byproduct commodities are the same was rejected at the at the 1 percent level; the alternative hypothesis that the primary Cu grades are larger than byproduct Ag grades was accepted (Mann-Whitney U test). As for the previous metals, few correlations are present in these data sets. Cu is correlated with Ag (r=0.83, n=12) for byproduct Cu. Few data are found among many of the variables for primary Cu which precludes correlation determination from being made.

Modeling Pb grade

Pb is the most commonly reported base-metal commodity. Pb is reported in 43 percent of the mineral components used for models. Two grade models have been developed: Pb as a primary commodity (fig. 16, curve b) for Ag-Pb, and Cu-Pb-Zn veins, and byproduct Pb grades (fig. 16, curve a) for Au, Ag-Au, and Cu veins. The hypothesis that Pb grades as primary and byproduct commodities are the same was rejected at the at the 1 percent level; the alternative hypothesis that the primary Pb grades are larger than byproduct Pb grades was accepted (Mann-Whitney U test). Only one correlation was found between Pb and Ag in the Pb primary commodity group (r=.95, n=8)).

Modeling Zn grades

Zn grades are reported in 25 percent of the mineral components used for models. No Cu-Ag veins have reported Zn. Au and Ag veins and base metal veins have about the same level of reporting for Zn. Most Zn is a byproduct and, rarely a co-product. A single composite Zn grade model (fig. 17) was developed for all mineral component types. Only one correlation was found between Zn and Ag (r=0.81, n=16).

Models selection during simulation

Execution of simulations like that described in Drew and others (1986) for predicting the metal endowment from deposits characterized by components will require several additional steps. For mixed base- and precious metal veins, deposits contain one to three mineral deposit components each occurring at different probabilities (Table 1). A flow diagram in fig. 18 also shows some of the paths needed to simulated mixed based- and precious-metal veins. Single-component deposits are common with odds greater than 3 to 1. Simulation of deposits with two and three components requires computer simulations to make two and three iterations, respectively, to portray a whole deposit. The probabilities associated with mineral deposit component types are different depending on the number of components (Table 1). As the number of components increase, component types with Ag and bases metal become more common.

Simple Sb veins (Bliss and Orris, 1986a, 1986c) can be used as a mineral deposit component in mixed base- and precious-metal vein deposits and are found in single component as well as multiple component deposits (Table 1). Given that a simple Sb deposit is predicted among the mineral deposit component types, there is also a probability of 0.15 of associated disseminated Sb deposits with its own grade and tonnage model (Bliss and Orris, 1986b).

Each mineral deposit component type can be described using a grade and tonnage model. As noted earlier, the tonnage model is applicable to all mineral component types (fig. 9) except for simple Sb deposits. Models for mineral component types can share the same grade models because there are no differences in grades among them and are summarized below:

(1) **Au veins**--primary Au (fig. 13, curve b); byproduct Ag (fig. 14, curve a); byproduct Cu (fig. 15, curve a); byproduct Pb, (fig. 16, curve a), primary and byproduct Zn (fig. 17).

(2) **Ag veins**--primary Ag (fig. 14, curve b); byproduct Au (fig 13, curve a); byproduct Cu (fig. 15, curve a); byproduct Pb, (fig. 16, curve a), primary and byproduct Zn (fig. 17).

(3) **Ag-Pb veins**--primary Ag (fig 14, curve b); byproduct Au (fig 13, curve a); byproduct Cu (fig. 15, curve a); primary Pb, (fig. 16, curve b), primary and byproduct Zn (fig. 17)

(4) **Cu veins** --primary Cu (fig. 15, curve b); byproduct Au (fig. 13, curve a); byproduct Ag (fig 14, curve a).

(5) **Cu-Pb-Zn veins**--primary Cu (fig. 15, curve b); primary Pb, (fig. 16, curve b), primary and byproduct Zn (fig. 17); byproduct Au (fig 13, curve a); primary Ag (fig. 14, curve b).

(6) **Simple Sb deposits**--tonnage (Bliss and Orris, 1986c, fig. 140); primary Sb (Bliss and Orris, 1986c, fig. 141); byproduct Au and Ag ((Bliss and Orris, 1986c, fig. 142A, B). Also see grade and tonnage for disseminated Sb deposits, associated with simple deposits (Bliss and Orris, 1986b)

One modification is necessary for use of the models in simulation. The model for primary Cu grades suggests that some deposits may be missing Cu. This is true for several component types with primary Cu. The exception is Cu veins where all undiscovered components will contain Cu and simulations using this model need to be modified accordingly.

Using components as mineral deposit models

Those assessing areas where undiscovered mixed base- and precious-metal veins may have additional data which might suggest some components are more likely than others. If this is the situation, probabilities in the simulation network (fig. 18) may be changed. Perhaps only one component may be involved. If this is to be done, only Au veins and Ag veins have sufficiently data to be handled as separate deposit modeled albeit somewhat flawed by the way they were constructed. As seen in the discussion below, the polymetallic vein model by Bliss and Cox (1986) may be somewhat better choice to characterized undiscovered base-metal rich polymetallic veins.

Comparison to other grade and tonnage models

Development of grade and tonnage models of deposits found in just one region (e.g, the deposits in this study) makes the model provincial. However, as modeling development considers new areas, these models may be found to be applicable or they can be modified so that they are applicable to two or more areas. Because models developed here are not for complete deposits, but for components of deposits, making comparisons to other grade and tonnage models might be difficult. However, most deposits (~80 percent) contain only one component (Table 1) and so comparison might be done in a general fashion.

A grade and tonnage model of polymetallic veins as defined by Cox (1986) describes deposits primarily worked for base-metals (Bliss and Cox, 1986). These deposits are comparable to those in this studies. An associated group of deposits worked for precious metals was also recognized (Bliss and Cox, 1986) but could not be modeled. A grade and tonnage model for vein deposits found in east Oregon, the Blue-Mountain-type Au-Ag polymetallic veins represents deposits that may be transitional between low-sulfide Au-quartz veins and polymetallic veins (Bliss, in press). Only Au and Ag were modeled. Therefore, comparison is possible only for precious metals between polymetallic deposits worked for primarily for polymetallic base-metals and the Blue-Mountain-type Au-Ag polymetallic veins which follows.

The grade of Au in Au veins as a primary commodity (fig. 13, curve b) has a distribution different than Au grades in polymetallic veins (Bliss and Cox, 1986, fig. 92). Au grades in Au veins (fig. 13, curve b) are higher and include grades seen in the upper 20 percent of the distribution for polymetallic veins (Bliss and Cox, 1986, fig. 92). About 20 percent of the grades in Au veins (fig. 13, curve b) are higher than the highest Au grade in the polymetallic vein model (Bliss and Cox, 1986, fig. 92). However Au grades in Au veins are comparable to those found in Blue-Mountain-type Au-Ag polymetallic veins (Bliss, in press, fig. 4). Gold grades in Au veins can be somewhat higher--up to several 100 g/t as compared to ~30 g/t in Blue-Mountain-type Au-Ag polymetallic veins.

Byproduct Au grades (fig. 13, curve a) found in Ag veins, Ag-Pb veins, Cu veins, and Cu-Pb-Zn veins has a distribution comparable to those found in polymetallic veins worked for base-metals (Bliss and Cox, 1986, fig. 92). The percent of deposits (or components) with grade data for the two deposits types is comparable as well. Therefore, one might use the distribution of Au grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986, fig. 92) to describe the distribution of Au grades in the four components (Ag veins, Ag-Pb veins, Cu veins, Cu-Pb-Zn veins) where Au is a byproduct commodity.

Ag in Ag veins, and Ag-Pb veins as a primary commodity (fig. 14, curve b) have distributions comparable to Ag grades in polymetallic veins (Bliss and Cox, 1986, fig. 92). Therefore, one might use the distribution of Ag grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986, fig. 92) to describe the distribution of Ag grades in Ag veins, and Ag-Pb veins where Ag is a primary commodity. While Ag in Cu-Pb-Zn veins is a byproduct, the grade distribution is best described using the primary Ag model (fig. 14 curve b). Ag as byproduct in Au veins and Cu veins (fig. 14, curve a) have distributions different than Ag grades in polymetallic veins (Bliss and Cox, 1986, fig. 92). In fact, byproduct Ag grades are not even described by the lowest grades in the polymetallic vein model! The role of Ag is important (as expressed by higher grades) in polymetallic veins used in model development (Bliss and Cox, 1986) which is not necessary found in some of the mineral deposit component models developed here and probably true of some polymetallic veins found elsewhere. The large range seen in Ag grades in Blue-Mountain-type Au-Ag polymetallic veins has a distribution (Bliss, in press, fig. 5) that brackets Ag grades as a primary or byproduct commodity (fig. 14, curve a,b).

Cu in Cu veins and Cu-Pb-Zn veins as a primary commodity (fig. 15, curve b) and have distributions comparable to Cu grades in polymetallic veins (Bliss and Cox, 1986, fig. 94B). Therefore, one might use the distribution of Cu grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986, fig. 92) to describe the distribution of Cu grades in Cu veins and Cu-Pb-Zn veins. However, the percent of components with Cu is twice (~70 percent) that for polymetallic vein deposits (~35 percent). This may be due to the small number of components (n=8) with primary Cu in this study. Byproduct Cu grades (fig. 15, curve a) in Au veins, Ag veins, and Ag-Pb veins are too low to use the distribution of Cu grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986). However, the grades are among the lower Cu grades in the distribution (Bliss and Cox, 1986, fig. 94B). Cu grades in the polymetallic vein model includes both primary and byproduct grade data. The role of Cu is important (as expressed by higher grades) in polymetallic veins of Bliss and Cox (1986) which is not necessary found in some of the mineral deposit component models developed here and probably true of some polymetallic veins found elsewhere.

Pb in Ag-Pb veins and Cu-Pb-Zn veins as a primary commodity (fig. 16, curve b) have distributions comparable to Pb grades in polymetallic veins (Bliss and Cox, 1986, fig. 94B). Therefore, one might use the distribution of Pb grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986, fig. 93) to describe the distribution of Pb grades in Ag-Pb veins and Cu-Pb-Zn veins. However, 80 percent of the components had Pb grades while nearly all of those for polymetallic veins do. Byproduct Pb grades (fig. 16, curve a) in Au veins, and Ag veins are too low to use the distribution of Pb grades in polymetallic veins worked for base-metals (Bliss and Cox, 1986). These Pb grades are less than the lowest grades in polymetallic veins. Pb is not reported at all in Cu veins. The role of Pb is important (as expressed by higher grades) in polymetallic veins used in model development by Bliss and Cox (1986) which is not necessary found in some of the mineral deposit component models developed here and probably true of some polymetallic veins found elsewhere.

Zn in Cu-Pb-Zn veins is either primary or byproduct and described using a single distribution (fig. 17) that is probably lower than Zn grades in polymetallic veins (Bliss and Cox, 1986, fig. 94A). Zn is certainly found in more (~80 percent) of the polymetallic veins modeled by Bliss and Cox (1986) as compared to about 10 percent of the components herein. As noted in the introduction, production of Zn usually is a penalty not a reward for working deposits and so data about it are the poorest. Given that the number of deposits not reporting Zn in the model developed here is not due to reporting problems, etc., the role of Zn is more important (as expressed by higher grades and being reported more frequently) in polymetallic veins of Bliss and Cox (1986) which is not necessary found in the mineral deposit component models developed here and probably true of some polymetallic veins found elsewhere.

Modeling base- and precious-metal grades in polymetallic veins developed up to now have some similarities. In summary, most of the differences in grades in mixed base- and precious-metal vein deposit components are related to dominance metals values of (1) precious metals in the component--Au with or with Ag, or (2) one or more base metals. Of the commodities, the importance of Au is new and most distinctive of Au veins considered in this study and of Blue-Mountain-type Au-Ag polymetallic veins (Bliss, in press). The importance of Au as a subdivision of polymetallic veins was also recognized by Bliss and Cox (1986). Otherwise, in polymetallic veins and all other components of mixed base- and precious-metal veins, it is a byproduct. Ag grades in three components of mixed base- and precious-metal vein component--Ag veins, Ag-Pb veins and Cu-Pb-Zn veins--are comparable to that for polymetallic veins. Very low byproduct Ag grades are reported for the first time where Au is important in Au veins and Cu veins. Separation of Cu grades into primary and byproduct commodity in this study may account for the difference in grades when compared to those for polymetallic veins. This distinction was not made in modeling Cu grades in polymetallic veins and polymetallic Cu grades bracket both primary and byproduct grades found in this study. For Pb grades, this is not the situation. Lower Pb grades in this study for byproduct Pb are not comparable to polymetallic veins and represent some of the lowest grades reported and are found in Au veins and Ag veins.

Target-Area Model

Mixed base- and precious-metal vein deposits have areas between 0.25 and 41 square kilometers (Table 2). Deposits contain between 1 to 66 mines. The median deposit contains 15 mines. The procedure for assigning components to a deposit was highly dependent on the level of reporting and is highly variable based locations of mines on the source maps. The area of 49 deposits can be modeled in the same way as grade and tonnage data (fig. 19). These areas are used to develop a **target area model** which can be use as a guide in estimating numbers of undiscovered deposits in areas being assessed. The area defined for these deposits is certainly not a projection of mineralization to the surface or outcrop area because the aggregate area also includes some areas without mineralization. When a single mine is treated as a deposit (i.e., the mine is isolated), a default target area of 0.25 km^2 is assigned to the deposit (fig. 2, Mineral deposit B). The target area model is partly an artifact of the procedure used, but it still gives an idea of representative regional target areas for mixed base- and precious-metal vein deposits. See Bliss (in press) for a more formalized procedure for estimating target areas.

The target area model was found to be significantly different from lognormal (at the one-percent level of confidence) for the kurtosis goodness-of-fit test (Rock, 1988). One problem in the data set is the default area assignment made for single mines. There are 6 such single mine deposits and they are shown as as open-circles in the model (fig. 19). While the model is flawed, it still can be used as one guide in making subjective predictions about numbers of undiscovered deposits during mineral resource assessments.

Can target areas be used to make predictions about deposit tonnage? Previous work with Au-Ag-Te veins suggest not (Bliss and others, 1992); however, the tonnage of mixed base- and precious-metal vein deposits can be predicted from the deposit target area using the the following regression equation (fig. 20):

$$\log [\text{size (t)}] = 3.9 + 0.56 \log [\text{target area (km}^2)]. \qquad (1)$$

About 36 percent of the variation (at the one-percent level of significance) in deposit size can be explained by differences in mineral deposit target area for the 44 deposits used. One deposit, Ramey Ridge North, was a prominent outlier in the initial data set and was excluded from the data set used for the regression. Deposits with Sb veins were not used.

A prediction of tonnage using equation (1) will give a better estimate of tonnage size in a given target area than one can make using the mineral deposit tonnage model (fig. 9). Since there is no significant difference between the mineral component tonnage model and mineral deposit tonnage model (see the previous section on **Modeling deposit tonnage**), equation (1) can be used with the probabilities of number of mineral deposits components and the probability of a component type (table 1) in computer simulation (see fig. 18).

The median deposit target area of 2.9 km^2 is comparable to the median deposit target area of 2.5 km^2 for Au-Ag-Te veins (Bliss and others, 1992, fig. 4). The geometric mean tonnage of mix base- and precious-metal veins (fig. 10) is 13,000 t as compared to 2,000,000 t for Au-Ag-Te veins (Bliss and others, 1992, fig. 1). In both deposit types, mines were aggregated into deposits if within 1.6 km. Low-sulfide Au-quartz veins with a median tonnage of 30,000 t (Bliss, 1986, fig. 182) have a median mineral deposit target area of 0.6 km^2 where mines were also aggregated into deposits if within 1.6 km. While the median mineral deposit target area for low-sulfide Au-quartz veins is 4.8 times smaller its tonnage is 2.5 times larger.

Spatial Mineral-Deposit Models

Spatial mineral-deposit models describe the pattern of mineral deposits within some control area (Bliss and Menzie, in press). They have two parts--the measures of deposits per unit area (i.e., mineral-deposit density) and discrete distributions. These models can be helpful in making estimates of the numbers of undiscovered deposits in mineral resource assessment. Mineral-deposit density is the probability that a deposit of a given type will occur within a square kilometer in a control area. The computation is simply one of dividing the number of deposits by the area. Deposit definition is made in the exact same fashion as for the target-area model and is compatible with a deposit (or component) grade and tonnage model.

No attempt was made in this study to fit discrete distributions to the mineral deposits. However, mineral deposit densities calculated for mix base- and precious-metal vein deposits were from data in the preliminary mineral resource assessment of the Elk City 1° x 2° quadrangle (Lund and others, 1990) and from data compiled in this study related to most of the Idaho batholith in Idaho (fig. 1). The control area for the Elk City study used the identified and suspected outcrops of the late, two mica granite phase of the Idaho batholith (Lund and others, 1990, fig. E1). The number of deposits found in Elk City 1° x 2° quadrangle is 25. The calculated mineral-deposit density is 2.0×10^{-3} deposits/km^2. Another 4 deposits in addition to the those in the preliminary study were found to fit the deposit type but data were lacking so they could not be used in previous models. Thus the mineral deposit density is 2.3×10^{-3} deposits/km^2.

The second computation uses a control area based on 90 percent of all the outcrop of the Idaho batholith in Idaho (Bennett and Knowles, 1985; fig. F1) which includes all phases of the Cretaceous intrusive rocks as part of the control area. A total of 48 deposits occur in Challis, Elk City, Hailey, and Hamilton 1° by 2° quadrangles. The calculated mineral-deposit density is 1.9×10^{-3} deposits/km^2. Given that 16 percent of the deposits will be excluded from the deposit count as was done in the Elk City study, an additional 10 deposits are likely. This gives a total of 58 deposit and a mineral-deposit density of 2.3×10^{-3} deposits/km^2.

Estimates of numbers of undiscovered deposits at the 50 percent confidence level for National Forest Roadless Areas in Idaho (Johnson and Worl, 1991) were made in only one of the four study areas with an undiscovered mixed base- and precious-metal deposit. The addition of one more deposit to the calculations results in the same mineral-deposit density value to two significant figures. Mineral-deposit densities converge at 2.3×10^{-3} deposits/km^2 from both studies even through different delineation criteria.

Bulk-Minable Deposits

Recently modern mining, exploration, and development has focused on possible extensions of known vein deposits but the majority of activity is concerned with locating bulk minable mineralization which may consist of dispersed mineralized veinlets in a body of otherwise barren country rock and (or) disseminated mineralization. These deposits may or may not be associated with the veins previously worked. Preliminary estimates suggest that these disseminated deposits may have sizes on the order of several million metric tons and Au grades on the order of 0.6 to 2.5 g/t Au. These deposits need to be modeled as soon as sufficient data becomes available.

Future Research

One problem with using mineral deposits components is the need for a large number of values. This is not an insignificant problem. In this study, the need to group adjacent mines (i.e., separated by less than or equal to 1.6 km) to form deposits/components grouped hundreds of properties into 60 deposits which in turn are subdivided into components. This has resulted in too few values in some of the models. This is particularly true for primary Cu, Pb, and Zn. Addition data and work are needed. Target area data also need to be handle more consistently as describeed in Bliss (in press).

Confusion between what is a component and what is deposit can occur. Even in this study, I have used simple Sb deposits as a component. It also makes the grades of the deposits as a whole less visible (Mosier, D.L., written commun., 1992).

Some specific questions about other deposits in this study area also need to be resolved. For example, should the Vienna district which differs from the siderite-Ag-Pb veins characteristic of some mixed base- and base-metal deposits be included (Worl, R., written commun., 1992)? Distinction between weathered (oxidized) and unweathered mineralization was not made. Worl (written commun., 1992) suggests that nearly all of the production of Cu, Pb, and Zn is from oxidized deposits except where black shale terranes are present. No distinction was made in this study of local host rock types nor oxidation condition of the mineral deposits and needs to be considered in future work.

Several models concerning mine workings could also be developed for use in environmental assessment and have been done successfully for Blue-Mountain-type Au-Ag polymetallic veins (Bliss, in press). This includes models describing maximum deposit depths and mine working lengths. Models of maximum mine depths and overall mine lengths together with data on depths of weathering and hydrological conditions can be used to evaluate environmental effects that worked deposits may have had in surface and ground water. Model of mine working lengths can suggest possible magnitude of potential surface subsidence hazard.

Closing Remarks

Mineral deposits are "a body of mineral matter in or on the earth's surface which may be utilized for its industrial mineral or metal content" (Thrush, 1968, p. 710). Explorationists hope that the mineral or metal content is of sufficient concentration and of sufficient economic value that the deposit can be exploited at a profit. Mineral deposits are recognized because they contain something of value as defined by economics. One need only consider how different mineral deposit types would be if the value of Au and Ag were reversed!

Descriptive models plus associated genetic models for mineral deposit types often allow one to make confident classifications of mineral deposits. In most situations, commodities are key to the mineral deposit type definition. However, those developing grade and tonnage models often find the picture concerning commodity definition not so clear cut when evaluating commodity grade data. These departures have been important in the recognition of new mineral deposit types and refinement of old. Development of deposits types without careful evaluation of grade and tonnage data inevitable leads to a grouping of deposits with data found to be badly flawed for modeling purposes.

Mineral deposit component models add another strategy to those already in use. It will be of particular use when a mineral deposit type can be well defined in term of a descriptive model and genetic models but the type of commodities it contains are either heterogeneously distributed so adjoining mines extract different commodities or the commodities change between deposits in ways which can not be predicted. Development of grade and tonnage models in these circumstances is otherwise difficult.

Given an undiscovered mixed base- and precious-metal vein deposit, the models developed here using this new strategy suggest that some of the following features can be expected: (1) a probability of 0.5 the deposit has a target size of 2.9 km^2 or larger, (2) 6 different types of components are possible (fig. 21); no more than three components are found in a given deposit (table 1); (3) a probability of 0.79 the deposit has a single mineral deposit component, (4) given a single component deposit, a probability of 0.71 that the mineral component is Au vein, and (5) given a Au vein component, the probability is 0.5 the component size is 8,000 t or greater and the Au grade is 13 g/t or greater.

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Table 1. The number of mineral deposit components and the probability of each, and the mineral deposit component type and the probability of each in mix base- and precious-metal veins.

Number of mineral components	Probability	Mineral deposit	Probability component type
One	0.792	Au veins	0.71
		Ag veins	0.026
		Cu veins	0.026
		Ag-Pb veins	0.079
		Cu-Pb-Zn veins	0.10
		Simple Sb deposit	0.053
Two	0.146	Au veins	0.36
		Ag veins	0.36
		Cu veins	0.071
		Ag-Pb veins	0.071
		Cu-Pb-Zn veins	0.14
		Simple Sb deposit	---
Three	0.062	Au veins	0.33
		Ag veins	0.33
		Cu veins	---
		Ag-Pb veins	0.23
		Cu-Pb-Zn veins	---
		Simple Sb deposit	0.11

Table 2. Mineral deposit names, quadrangles, and deposit target areas in square kilometers.

Deposit name	Quadrangle name	Area (km^2)	Deposit name	Quadrangle name	Area (km^2)
Ann	Elk City	0.5	Monumental	Elk City	10
Atlanta	Hailey	7.2	Moscow	Elk City	1
Big Creek	Elk City	13	Mule Creek	Hailey	0.25
Black Warrier	Hailey	2.5	Nay-Aug	Challis	0.25
Bonaparte	Hailey	0.57	Orogrande	Elk City	9.5
Bond-Wild Rose	Hamilton	1.2	Orogrande North	Elk City	11
Buffalo Hump	Elk City	10	Orogrande West	Elk City	2.1
Burdorf	Elk City	13	Overlook	Hailey	0.23
Croesus stock	Hailey	38.6	Oxford	Hamilton	.25
Cougar-Kelly	Wallace	0.82	Ozark	Hamilton	1.6
Deadwood	Challis	0.5	Ramey Ridge	Elk City	21
East Black Warrier	Hailey	2.5	Ramey Ridge North	Elk City	22
Edwardburg	Elk City	41	Revenue	Hailey	0.25
Elk City	Elk City	33	Rocky Bar	Hailey	7.4
Elk City Southeast	Elk City	3.7	Salmon Canyon	Elk City	0.5
Elk City West	Elk City	0.52	Sawtooth	Hailey	4
Florence South	Elk City	2.6	Sawtooth-Vienna	Hailey	36
Greater Monolith	Elk City	2.7	Slaughterhouse	Hailey	3.6
Hailey Gold Belt	Hailey	14	South Vienna	Hailey	2
Hermada	Hailey	2.1	Tenmile	Elk City	36
Hollister-Hillside	Elk City	1.3	Tenmile East	Elk City	2
Iron Crown	Elk City	0.5	War Eagle	Elk City	0.3
Liberty Gem	Hailey	0.65	Warren	Elk City	39
Mineral Hill-			West Camas	Hailey	1.2
Mackinaw	Elk City	20	West Yellow Pine	Challis	4

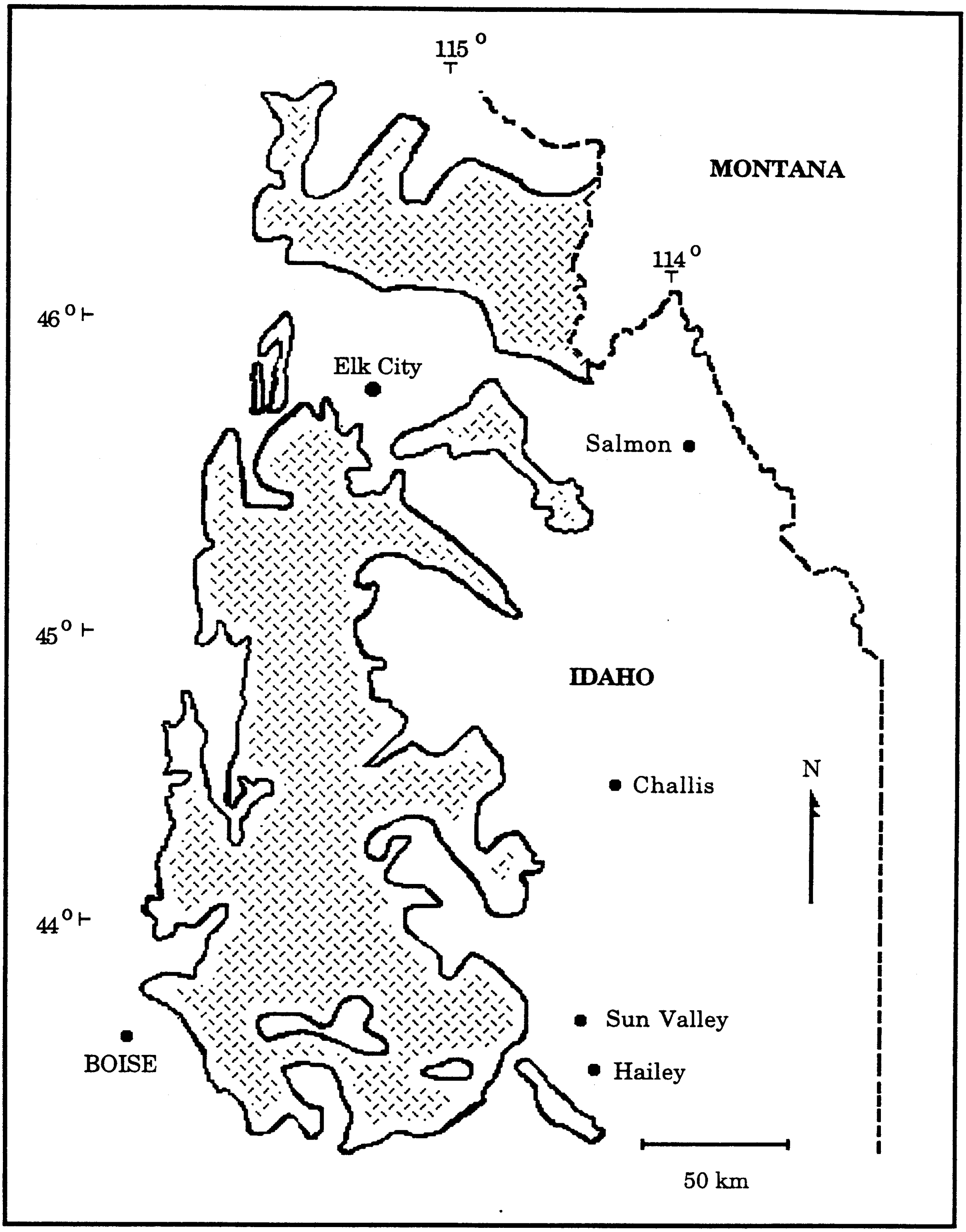

Figure 1. Sketch showing general location of the Idaho Batholith in Idaho. Modified from Bennet and Knowles (1985).

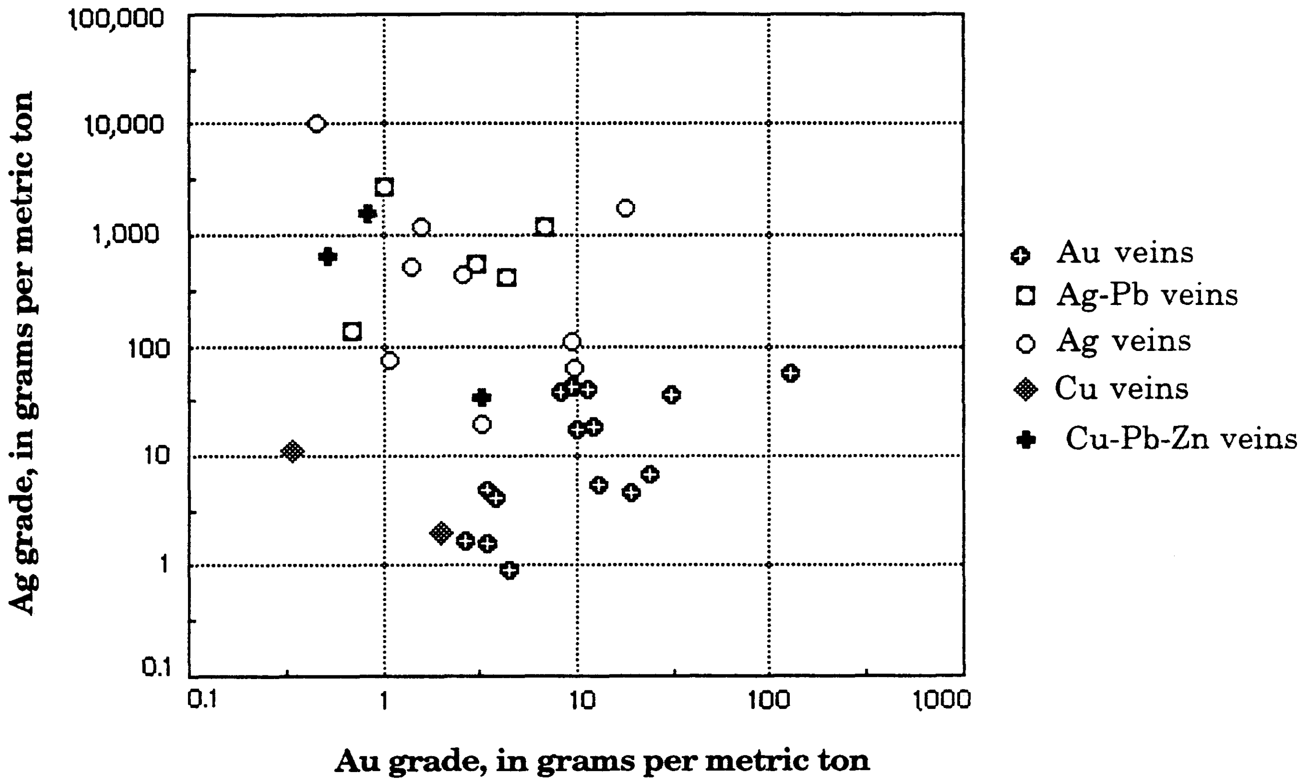

Figure 3. Scatter plot of Ag grade and Au grade of mineral component types.

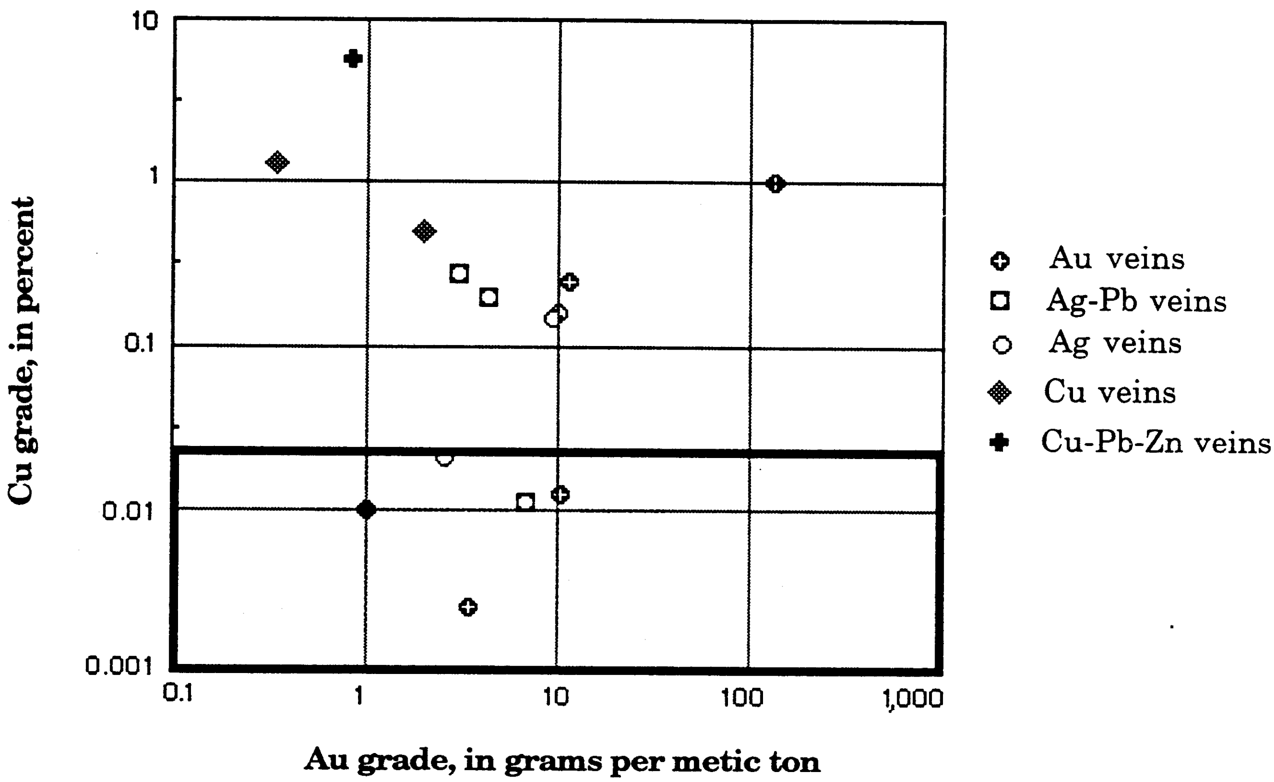

Figure 4. Scatter plot of Cu grade and Au grade of mineral component types. Cu grades are suspect in area outlined in bold area (see text).

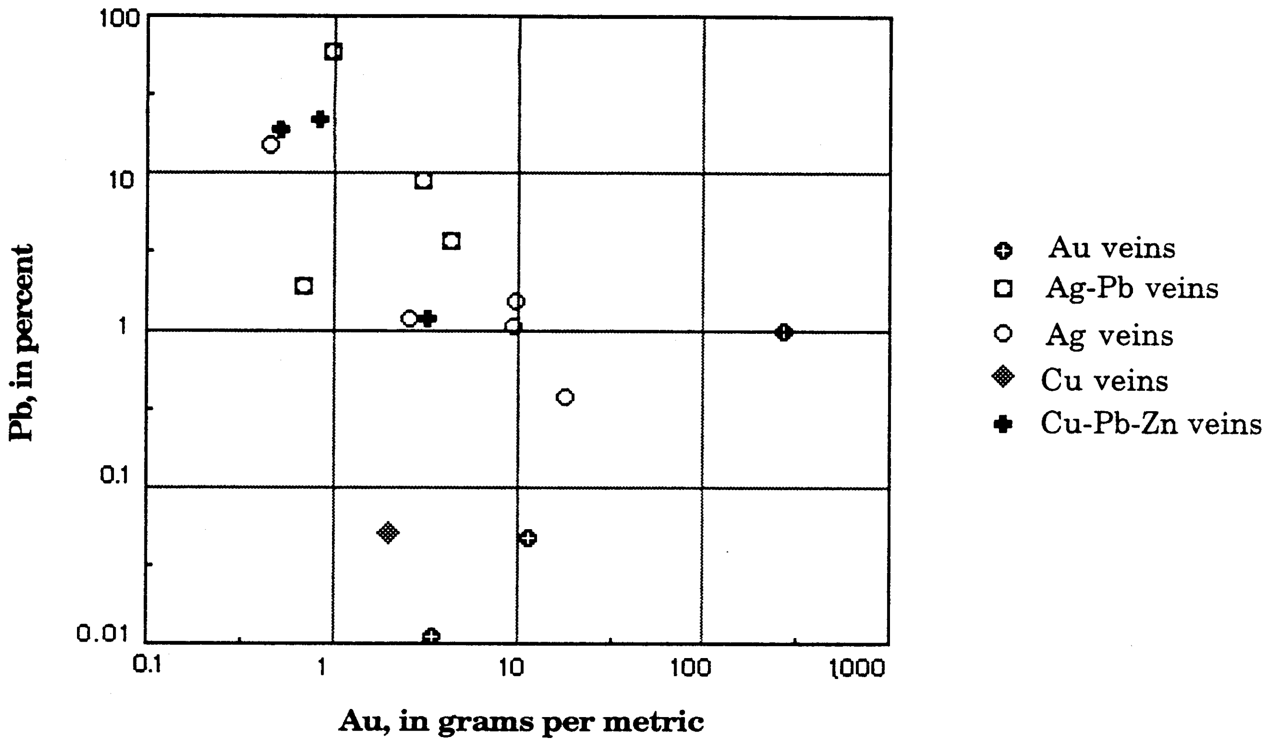

Figure 5. Scatter plot of Pb grade and Au grade of mineral component types.

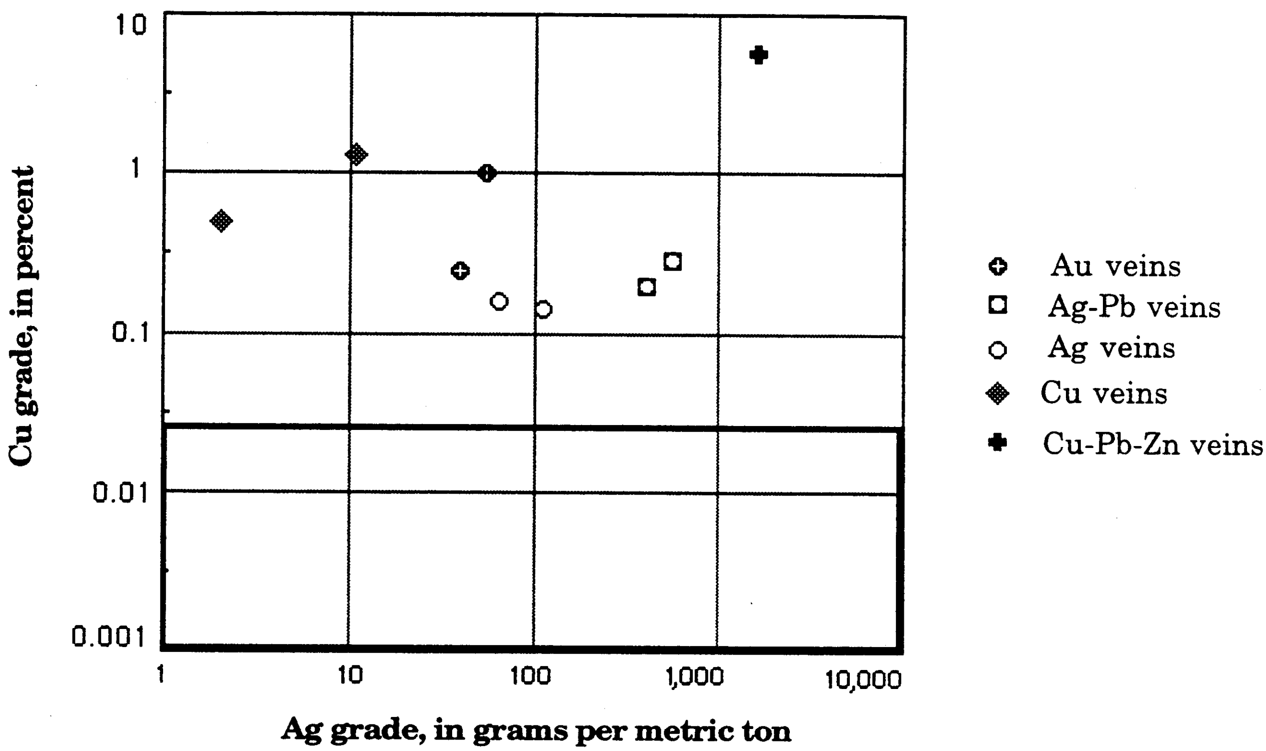

Figure 6. Scatter plot of Cu grade and Ag grade of mineral component types. Cu grades are suspect in bold area (see text).

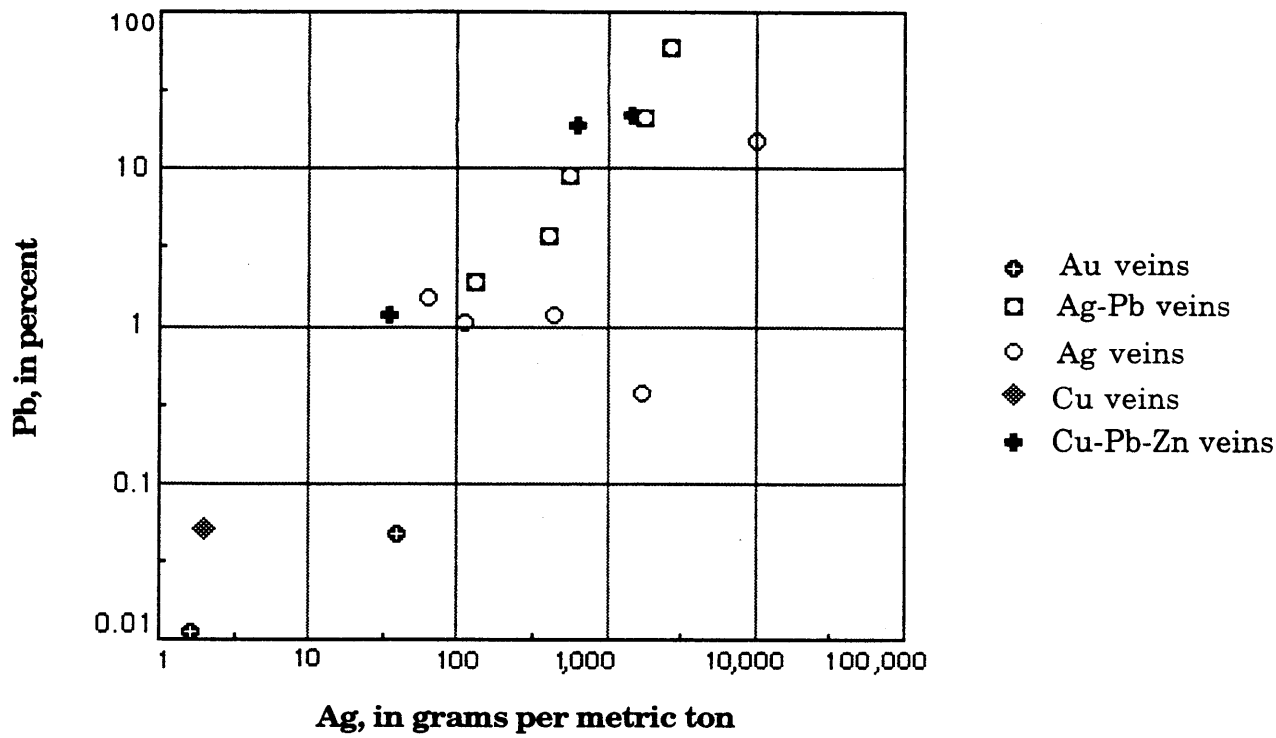

Figure 7. Scatter plot of Pb grade and Ag grade of mineral component types.

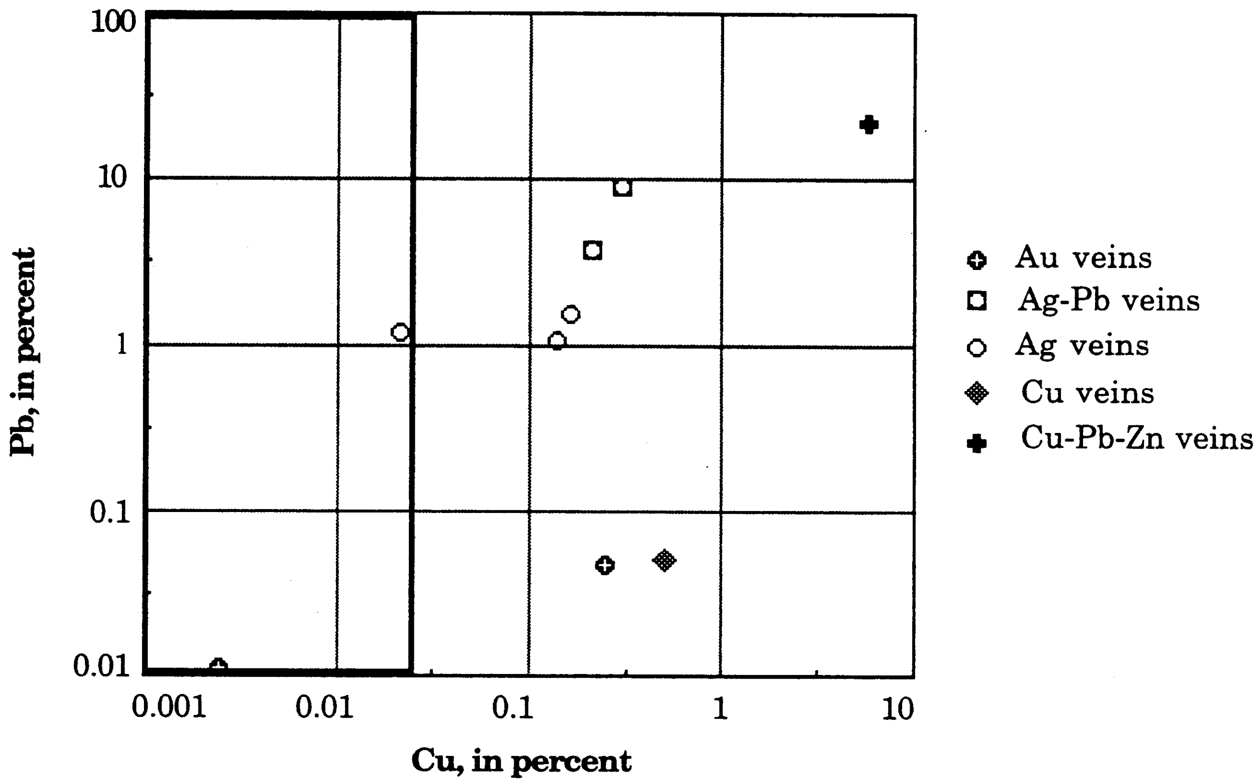

Figure 8. Scatter plot of Pb grade and Cu grade of mineral component types. Cu grades are suspect in area outlined bold (see text).

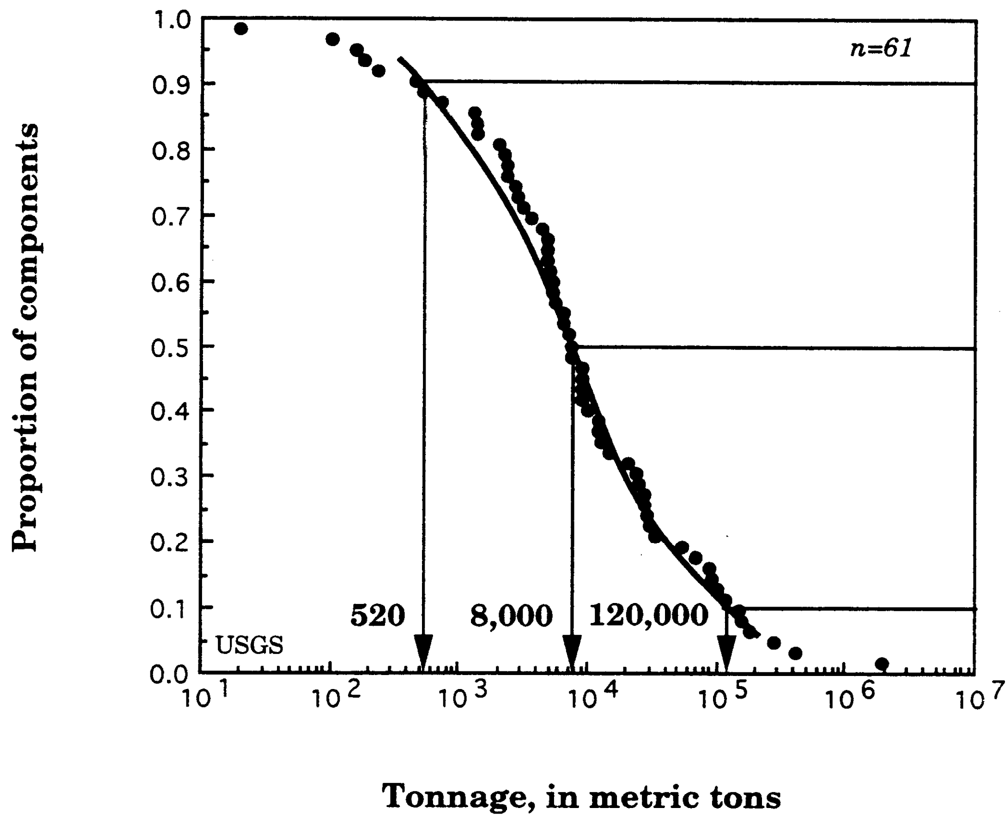

Figure 9. Tonnage of all mineral components in mixed base- and precious-metal veins, Idaho.

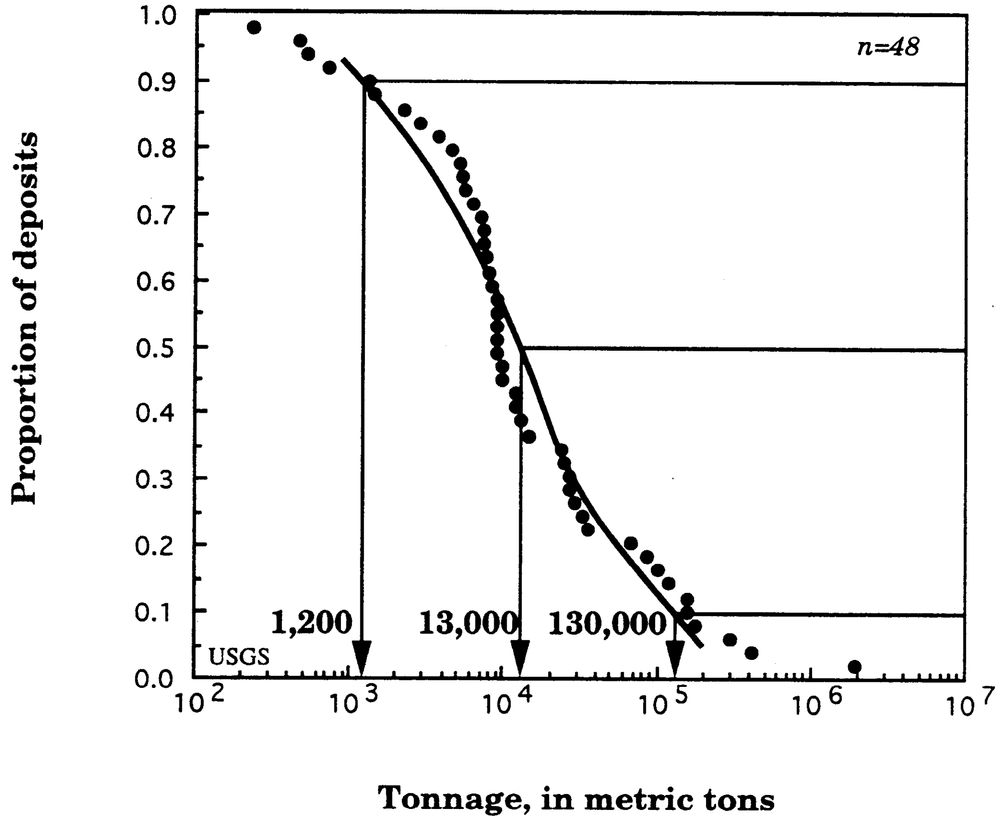

Figure 10. Tonnage of mineral deposits (i.e., sum of all contained mineral components) in mixed base- and precious-metal veins, Idaho.

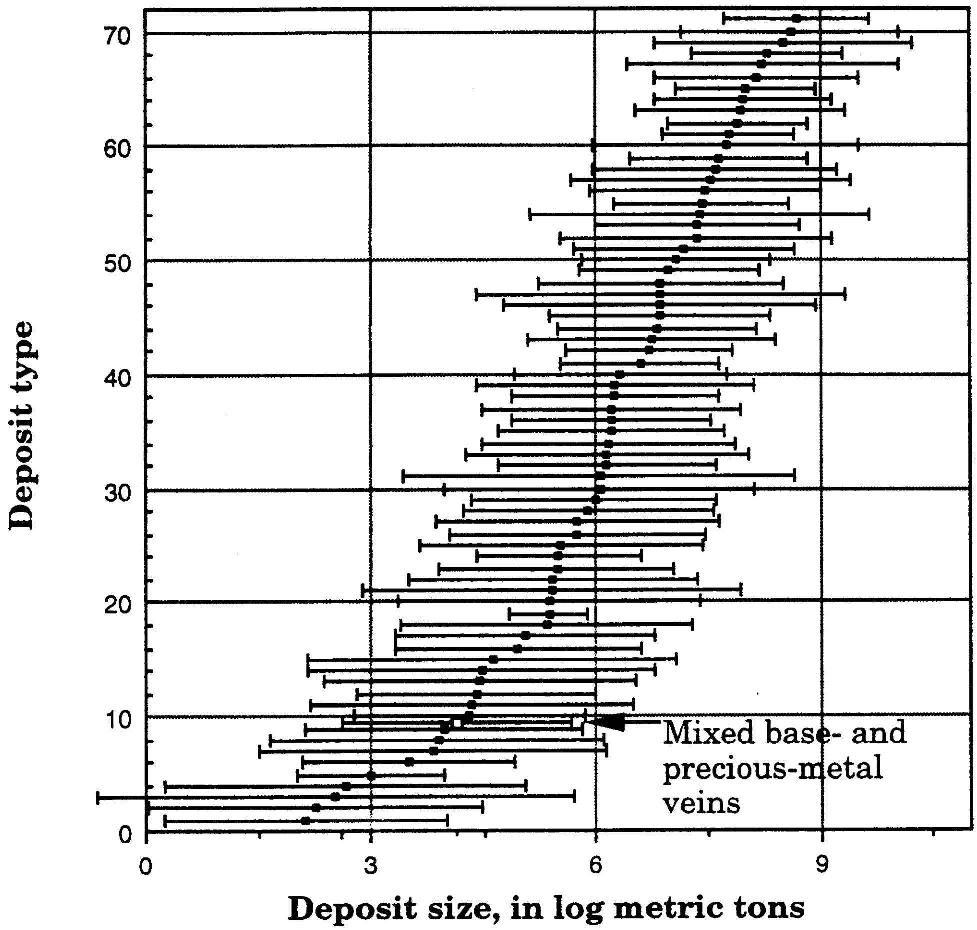

Figure 11. Comparison of tonnage of mixed base- and precious-metal deposits (open symbol) to tonnages of 71 other mineral deposit types (solid symbol) ranked by median size. Bars give the range of 95 percent of the deposits using the fitted distribution (see Table 1, Bliss and others, 1990, for names of deposit types corresponding to numbers along the y-axis).

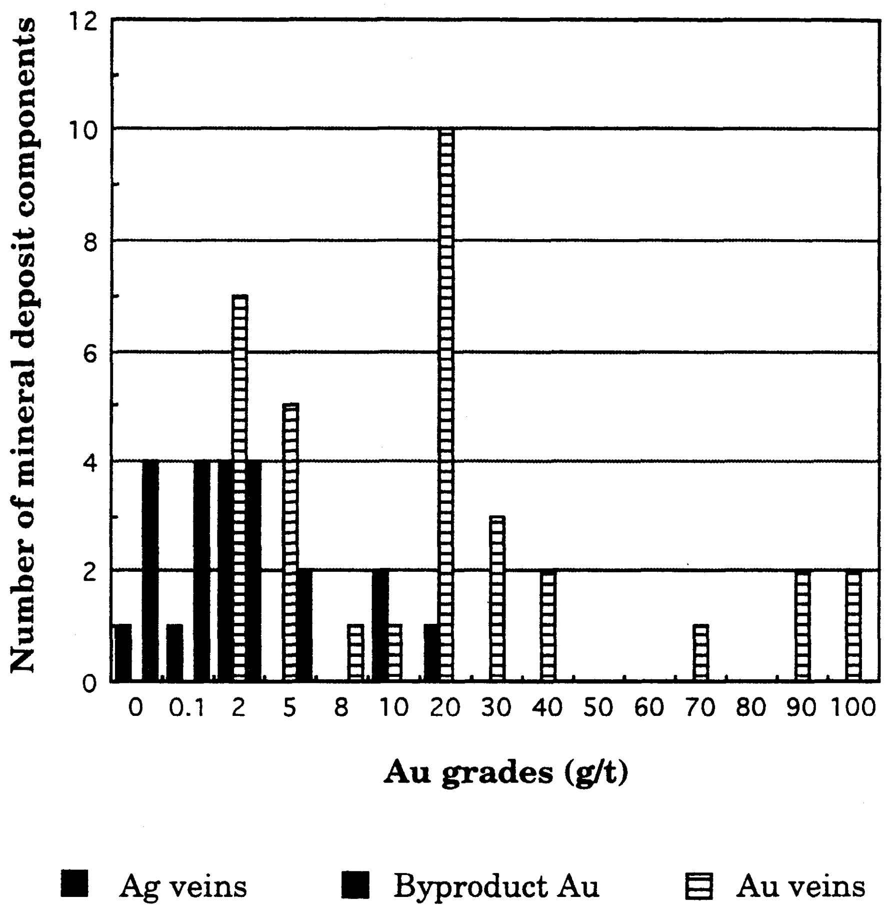

Figure 12. Histrogram showing Au grades for Au veins, Ag veins, and byproduct Au.

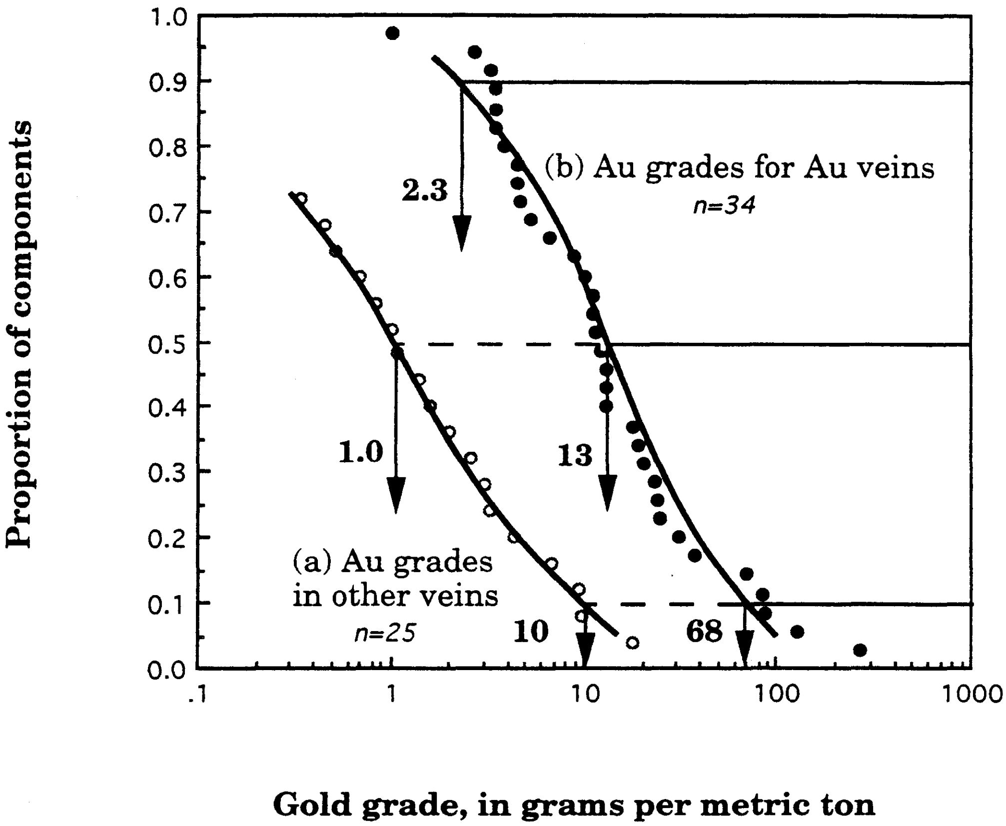

Figure 13. Au grades of byproduct Au (a) and of Au veins (b) in mixed base-and precious-metal veins. The Au grade for Ag veins is characterized by curve (a).

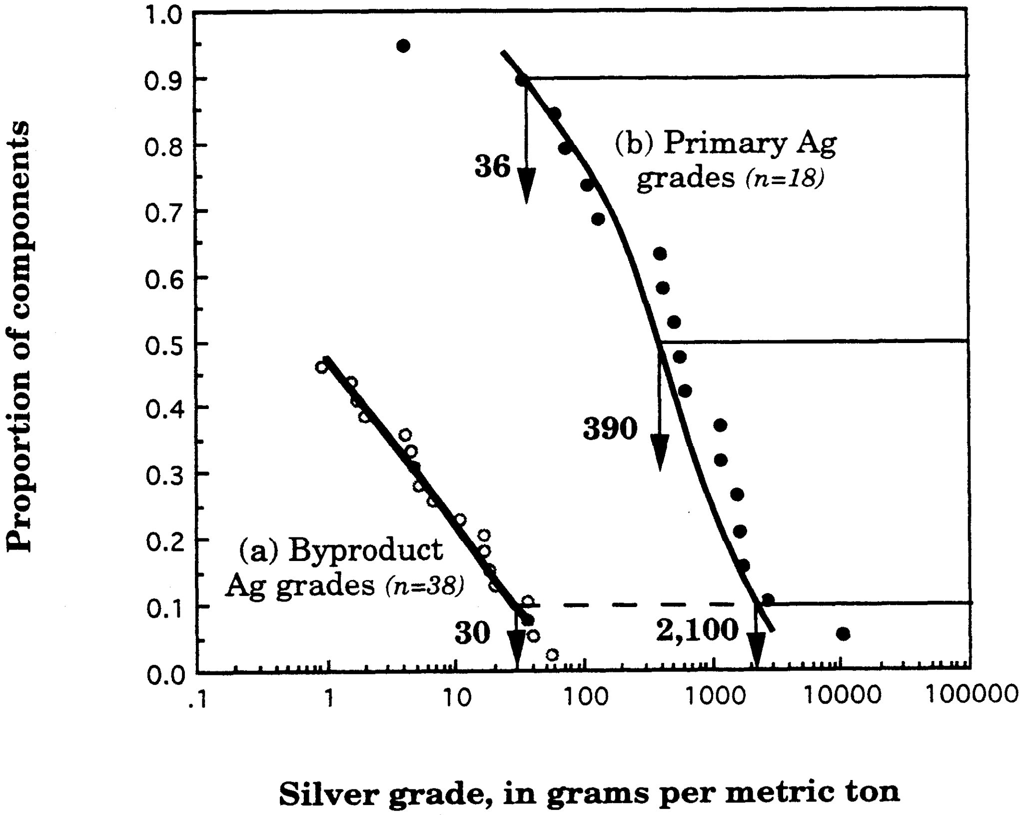

Figure 14. Ag grade of byproduct Ag (a) and of primary Ag (b) in mixed base- and precious-metal veins.

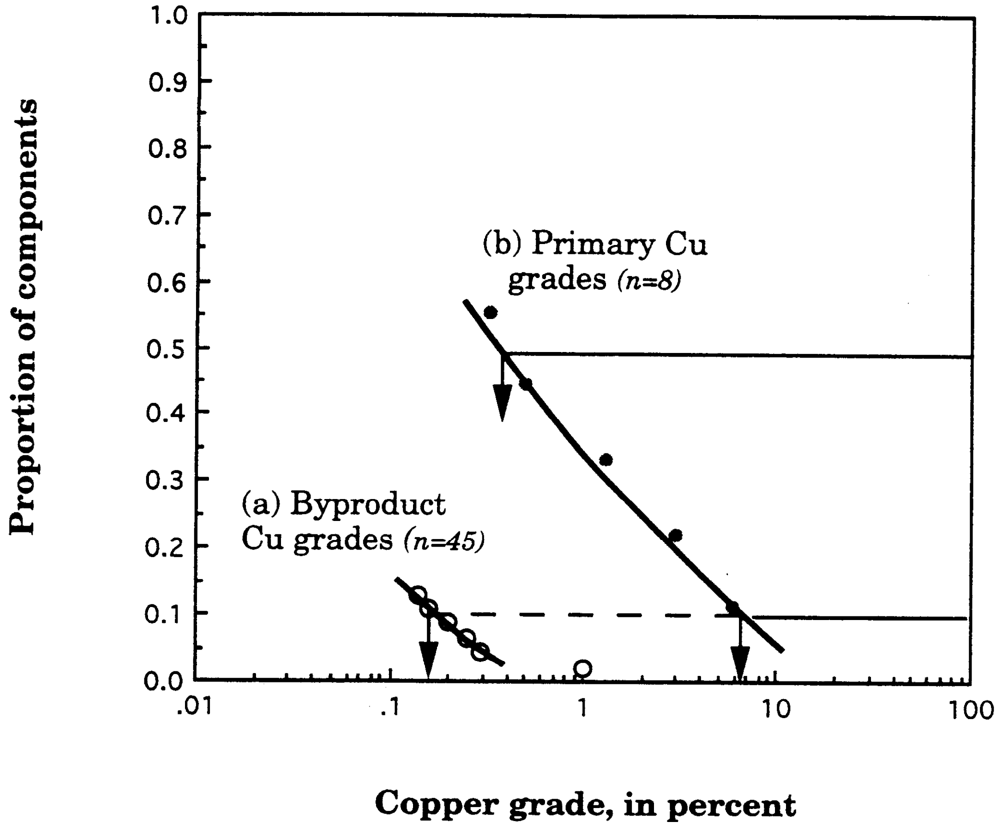

Figure 15. Cu grades of byproduct Cu (a) and of primary Cu (b) in mixed base- and precious-metal veins, Idaho.

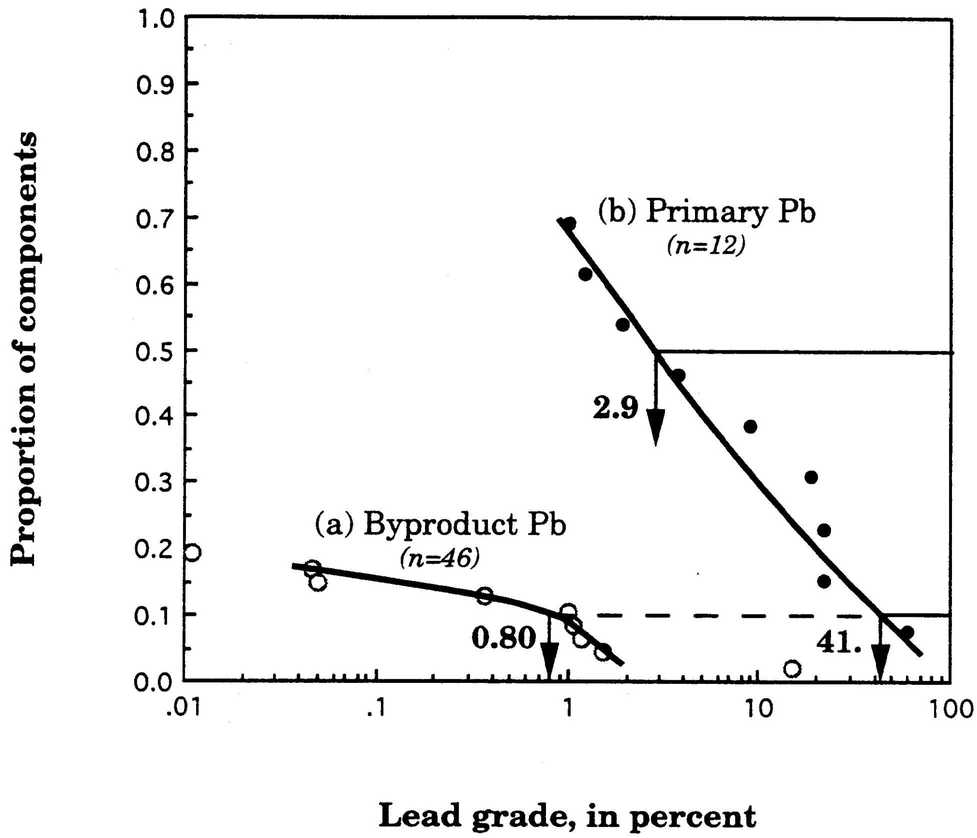

Figure 16. Pb grades of byproduct Pb (a) and of primary Pb (b) in mixed base- and precious-metal veins.

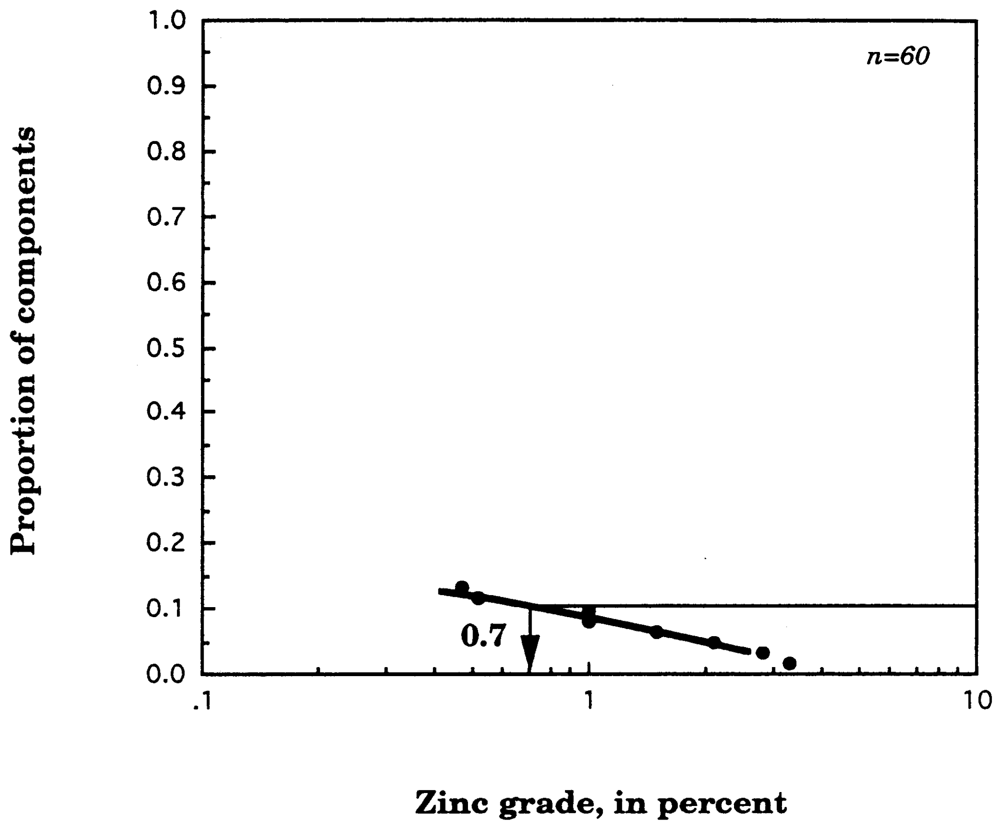

Figure 17. Zn grades of byproduct and primary Zn in mixed base- and precious-metal veins, Idaho.

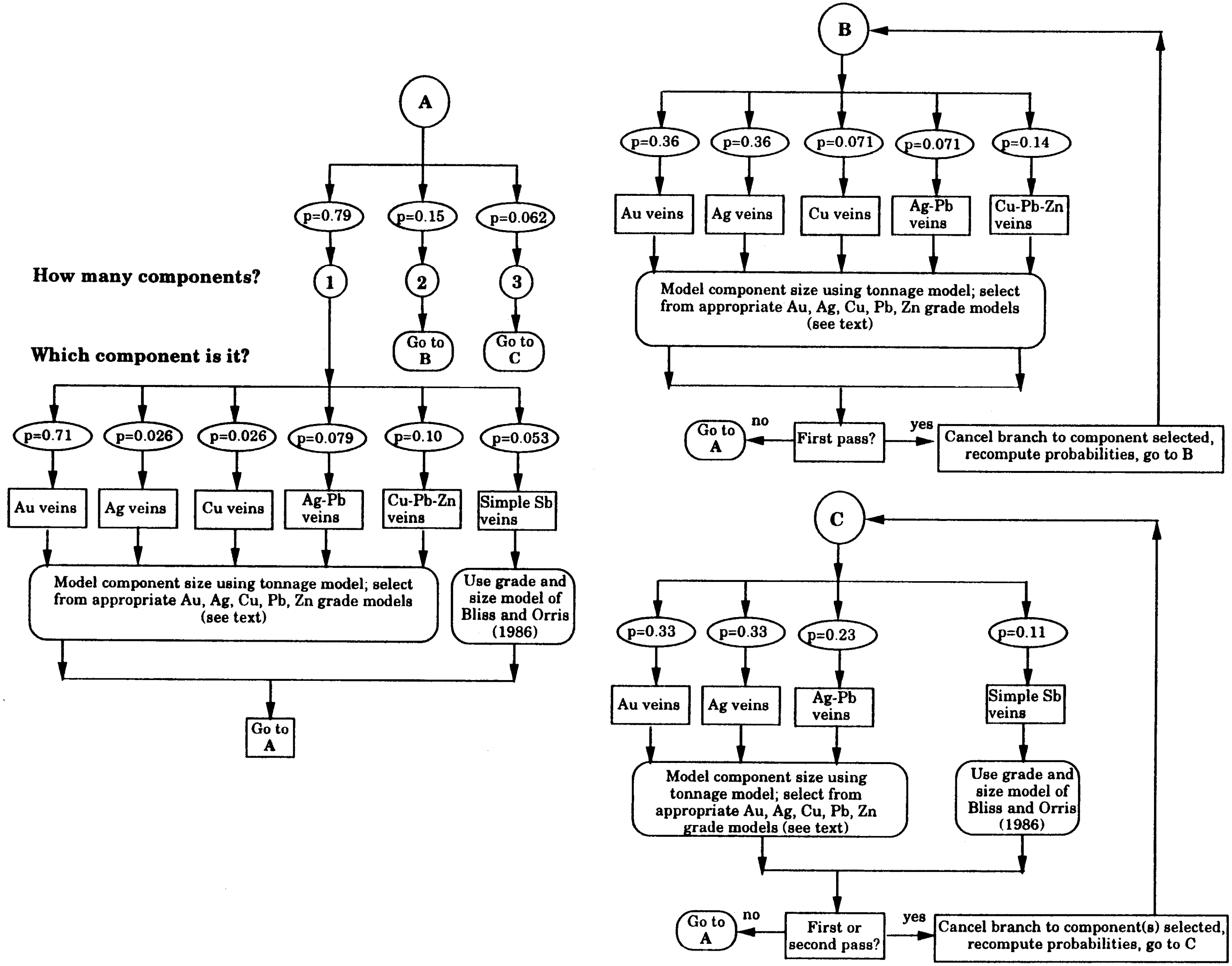

Fig. 18. Scheme giving probabilities (p) applicable during computer simulation and list of mineral component types applicable to undiscovered mixed base- and precious-metal veins, Idaho batholith, Idaho.

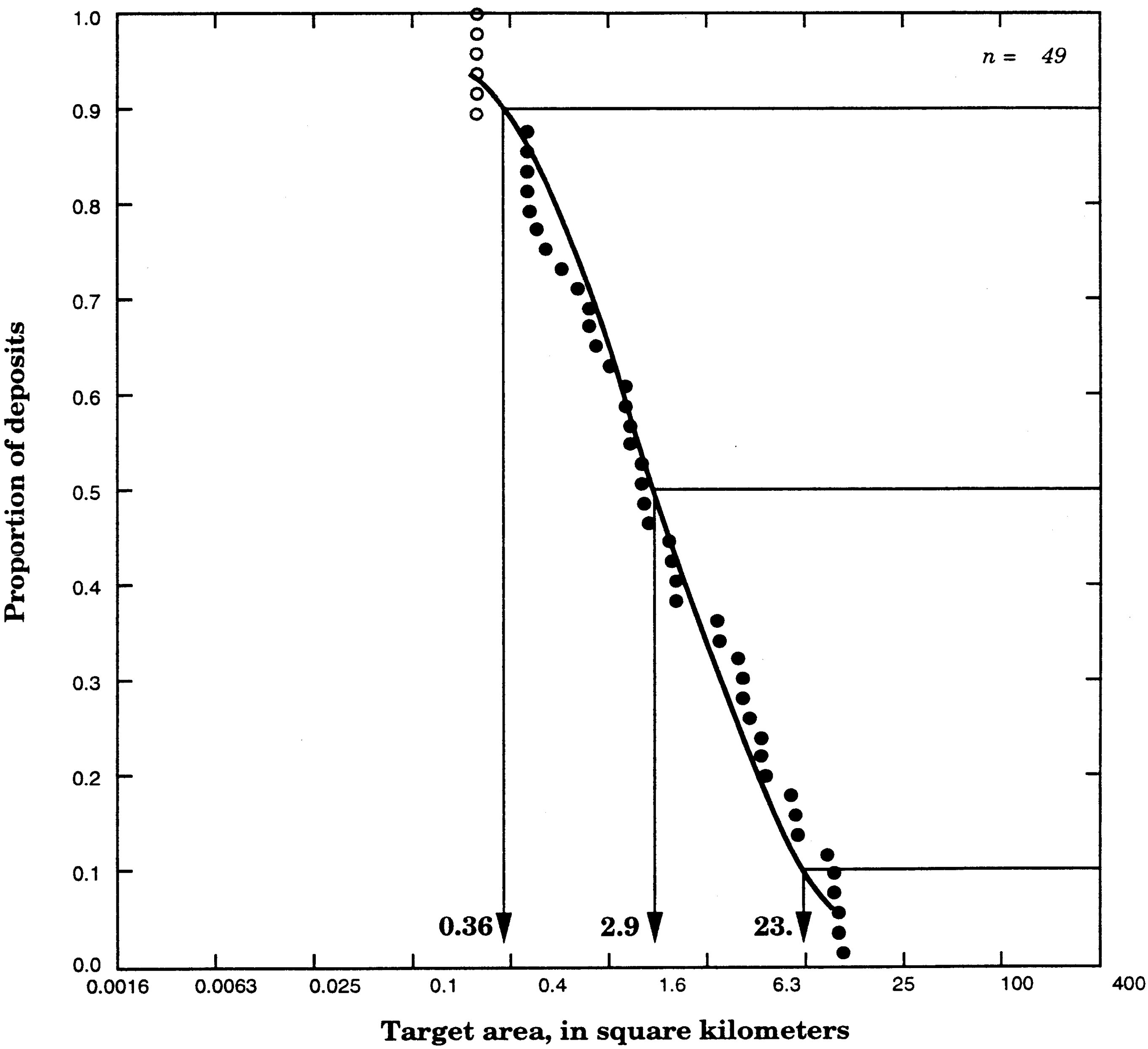

Figure 19. Target-area model of mixed base- and precious-metal veins. Open circles are for default areas of 0.25 square kilometers (25 hectares) for single property deposits.

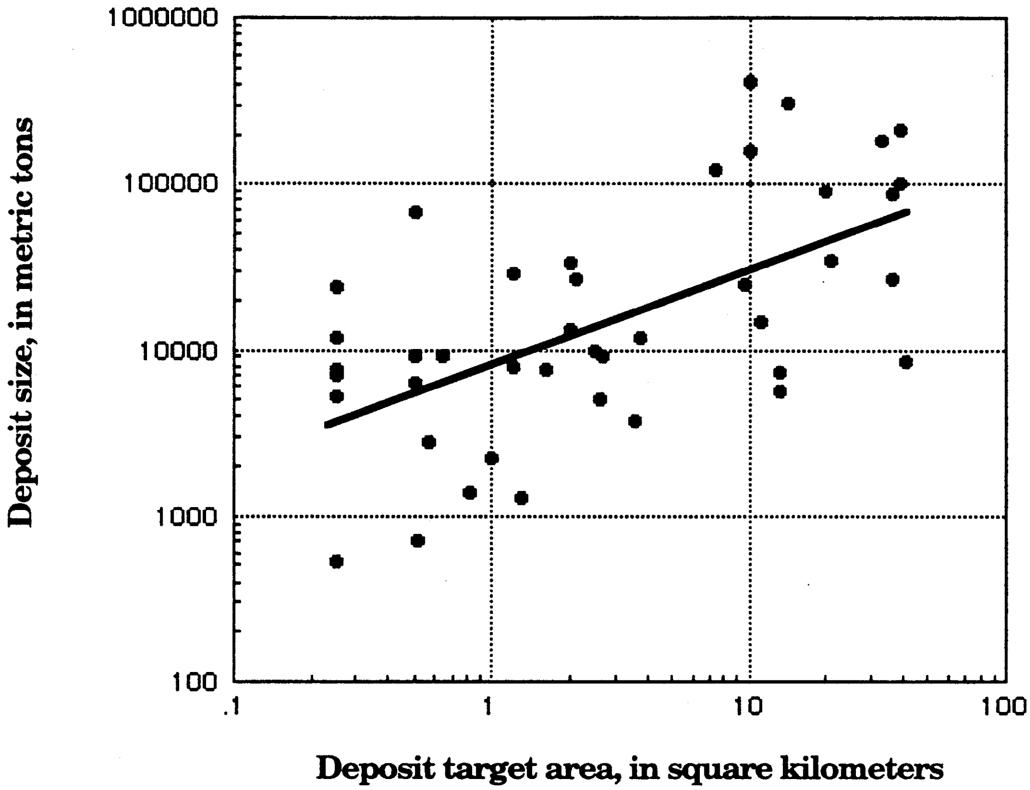

Figure 20. Scatter plot of deposit size (metric tons) and deposit target area (square kilometers). Atlanta deposits exclude due to its relatively large tonnage compared to rest of the data. See text for equation 1.

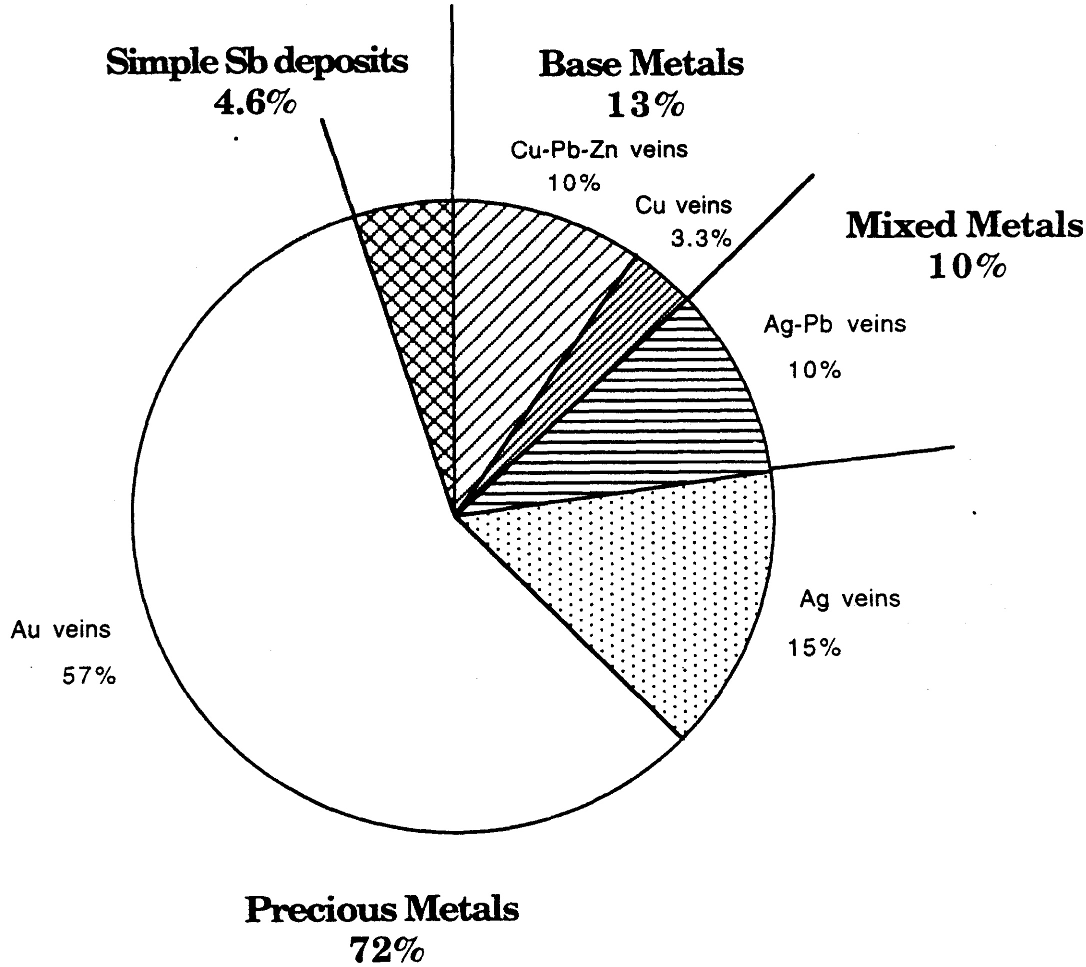

Fig. 21. Pie diagram grouping components by primary metals produced. Percent are of all components identified in mixed base- and precious-metal veins of the Idaho batholith, Idaho.