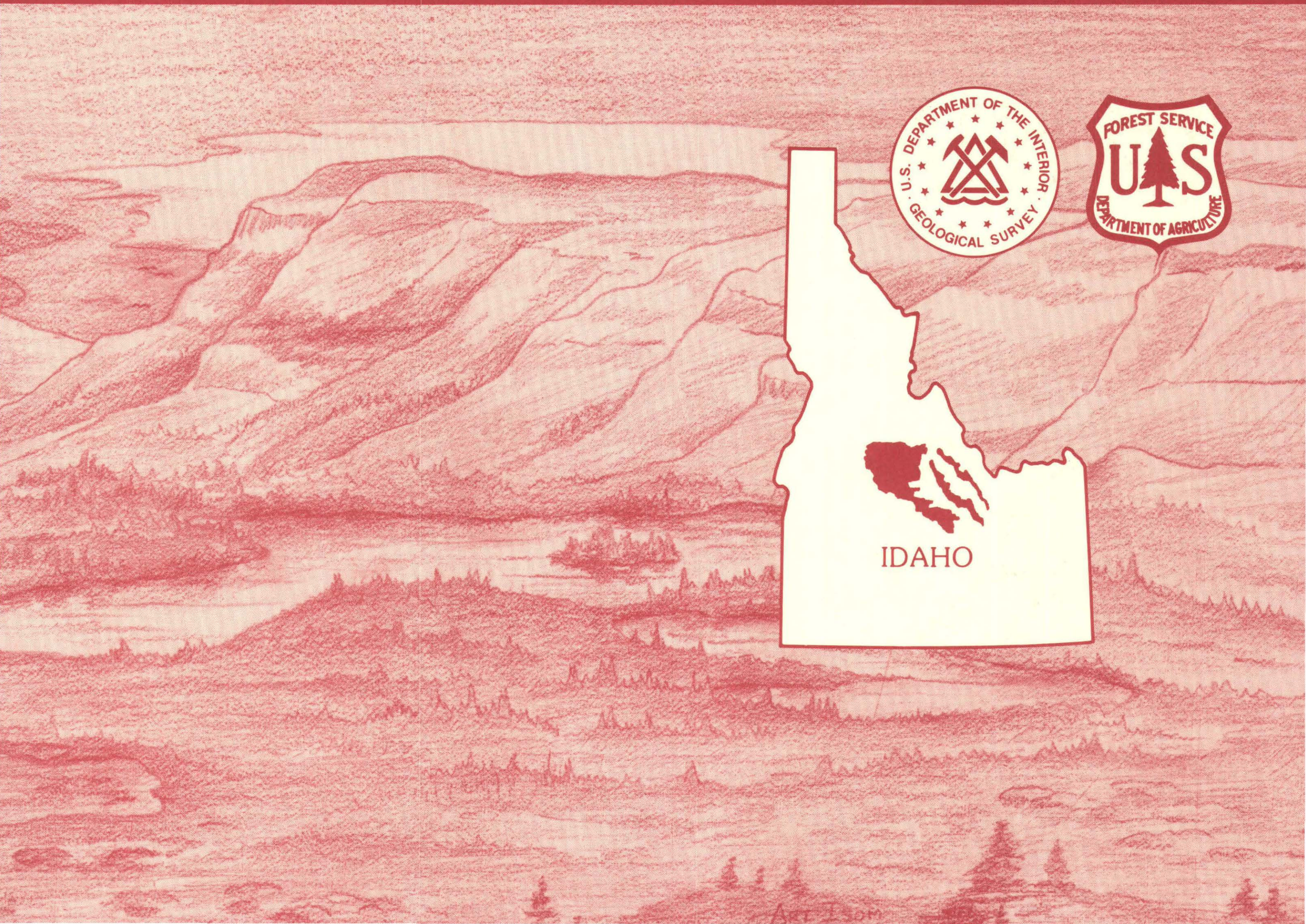
Quantitative Mineral Resource Assessment of Selected Mineral Deposits in the Challis National Forest, Idaho

U.S. GEOLOGICAL SURVEY BULLETIN 1987



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Quantitative Mineral Resource Assessment of Selected Mineral Deposits in the Challis National Forest, Idaho

By MARK W. BULTMAN

U.S. GEOLOGICAL SURVEY BULLETIN 1987

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By Mark W. Bultman

Summary

This quantitative assessment of selected mineral deposits in the Challis National Forest, Idaho, is provided to assist the U.S. Forest Service in complying with Title 36, Chapter 2, part 219.22, Code of Federal Regulations, which requires the Forest Service to provide information and interpretations so that mineral resources can be considered with other kinds of resources in land use planning.

This report is a companion publication to Mineral Resource Potential and Geology of the Challis National Forest, Idaho, U.S. Geological Survey Bulletin 1873, by Worl and others (1989). Geologic, geophysical, geochemical, mineral resource, and mineral deposit data in Bulletin 1873 were used in this study to produce quantitative estimates of the potential resources available from selected mineral deposits in the Challis National Forest.

The quantitative assessment involves three steps (W.D. Menzie, written commun., 1988) that are followed by a computer simulation. Known and possible mineral occurrences are identified and classified into appropriate mineral deposit models in the first step. The second step is the production of a mineral resource assessment map, which delineates tracts that are permissive for the occurrence of deposits described by the models defined in step one. The third step is the estimation of the number of undiscovered mineral deposits in each mineral deposit model. The computer simulation is carried out by a program informally referred to as MARK3. The output from the MARK3 program is a probabilistic estimate of the ore and metal contained in deposits of each mineral deposit model.

Using available information and the MARK3 program, it is estimated at a 50-percent confidence level that undiscovered mineral deposits in the Challis National Forest contain 35 tonnes of gold, 7,700 tonnes of silver, 12,900 tonnes of copper, 4,790,000 tonnes of lead, 7,880,000 tonnes of zinc, 52,700 tonnes of tungsten, and 221,000 tonnes of molybdenum.

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HISTORY OF MINERAL PRODUCTION IN CHALLIS NATIONAL FOREST

The Challis National Forest (herein called "the Forest") contains 4,338 mi^2 of mountainous terrain in three separate areas (fig. 1); elevations range from approximately 6,000 ft on the margin of the Snake River Plain to 12,662 ft on the summit of Bora Peak. The Forest includes the following physiographic features in central Idaho: the Lost River Range, the White Knob Mountains, the Boulder Mountains, the Pahsimeroi Mountains, the Stanley and Copper basins, and parts of the Lemhi Range, the Pioneer Mountains, the Sawtooth Range, and the Salmon River Mountains.

The Forest and the surrounding area have a long history of mineral exploration and mining, which have played a major role in the economy of central Idaho. Metals produced from mines in the Challis National Forest include gold, silver, lead, zinc, tungsten, and molybdenum. Small amounts of fluorspar, uranium, and rare-earth-element minerals have also been produced. A number of other mineral commodities have been reported to be present in the Forest, but have never been produced. These include iron, barite, cobalt, mercury, sulfur, antimony, manganese, and arsenic.

The discovery of mineral deposits in the Forest has been quite sporadic since 1860 (fig. 2). These sporadic discoveries are mostly a reflection of economic cycles in the minerals industry. Gold attracted the first prospectors to the area of the present-day Challis National Forest. From the early 1860's to 1869 most of the known gold placer deposits and a considerable share of the known gold lode deposits were found. Gold placer production died out by 1900, except for a limited reappearance from the 1930's through the 1950's, whereas production from gold lodes has been intermittent since their discovery.

Exploration for silver-lead ores began around 1880 and extended until about 1888. The discovery of numerous silver-lead mineral deposits in the 1880's resulted in the construction of a number of smelters in the region, the last of which closed in 1902.

Most of the mines discovered in the early to middle part of the 20th century produced silver, lead, copper, and zinc from multimetal veins, but tungsten production was also important during this time. There was considerable exploration for uranium in the 1950's and 1960's, resulting in some production of uranium in 1959 and 1960. A number of porphyry molybdenum deposits were discovered in the 1960's, including the Thompson Creek deposit, which is still producing ore today. Another exploration program in the 1960's and 1970's delineated a number of large stratabound deposits in the Bayhorse region, but no mineral production has yet (1989) resulted from the discovery of these deposits.

METHODOLOGY OF THE QUANTITATIVE ASSESSMENT

The quantitative assessment presented in this report is based on the concept of a mineral deposit model. A mineral deposit model can be defined as the systematically arranged information that describes the essential attributes of a particular group or class of mineral deposits (Cox and Singer, 1986). For the most part, these attributes are geologic, but they may also include characteristics affected by the utilization of a deposit, such as the grade of ore produced from it. For a deposit model to be of any use in a quantitative assessment, it must be combined with tonnage and grade models based on a large proportion of the deposits known to belong to the given deposit model. Such models are produced by plotting tonnage and grade against percentage of deposits. The resulting frequency distributions, which are most often approximated by the log normal distribution, show the percentage of deposits of a given model that have a particular tonnage or grade.

The quantitative assessment involves three steps (W.D. Menzie, written commun., 1988) that are followed by a computer simulation. The first step is to identify known and possible mineral deposits in the region and to classify each into a mineral deposit model. This step may include an extensive literature search, a search of computerized data bases, and possibly field verification.

The second step is to produce a mineral resource assessment map. This map delineates all of the geologic terranes (based on rock type) that are permissive for the occurrence of deposits in each of the mineral deposit models identified in step one. These terranes, or tracts, are delineated using the most recent and comprehensive geologic information about the region along with as much geochemical, geophysical, and mineral-occurrence data as possible. If enough data are present, it may be possible to define smaller areas that have a higher potential than other areas in the same tract for the occurrence of a deposit.

The third step in a quantitative mineral resource assessment is to estimate the number of undiscovered deposits in the tracts delineated in step two for each mineral deposit model. This is perhaps the most difficult step in assessing undiscovered mineral resources, and no definitive statements can be made at this time on how to make such estimates (W.D. Menzie, written commun., 1988). In general, the estimates are made subjectively and are based on geologic knowledge of the region in question and knowledge of the deposit model being considered. Often the estimate of the number of undiscovered mineral deposits is made in the form of a probability distribution, and estimates are given for the 10-, 50-, and 90-percent levels of confidence.

The estimates of the number of undiscovered mineral deposits in this report are subjective and are based on the information available to the author at the time the assessment was made. All of the estimates are based on geological analogy. Such estimates begin with an inspection of all of the available geological, geochemical, geophysical, and mineral-occurrence data of the region and the postulation that areas with similar geologic attributes may contain similar densities of mineral deposits.

Estimation of the number of undiscovered deposits was done in two parts. First, estimates were made within known mineral districts and in areas that have geologic attributes favorable for the existence of mineral deposits. In the latter group, deposit densities were assumed to be similar to those in the mineral districts. Included in the latter group are areas of high resource potential delineated by Worl and others (1989), some of which lie outside known mineral districts. The delineation of an area of high resource potential requires, among other things, data that indicate a high degree of likelihood for resource accumulation and evidence of mineral-forming processes in at least part of the area (Worl and others, 1989).

Second, estimates were made in areas that are outside known mineral districts and lack favorable geologic attributes. These areas have the proper host-rock lithology for deposits described by a given mineral deposit model, but they lack a known combination of geological attributes that make it highly probable that such deposits are present. The two types of estimates were then combined in a final estimate of the number of undiscovered deposits of a given mineral deposit model.

Finally, the probability distribution of the number of undiscovered deposits estimated for a given deposit model was combined with the frequency distributions of tonnage and grade for the same deposit model in a simulation procedure. The purpose of the simulation is to estimate the metal contained in deposits of the given deposit model in the region being assessed. A computer program, informally known as MARK3, does the simulation (Drew and others, 1986).

Simulation allows an assessor to create a number of scenarios by submitting probability distributions of the number of undiscovered deposits to MARK3 and examining the results. For each deposit model, MARK3 randomly selects a number of deposits from the probability distribution of deposit occurrence provided by the assessor. It then selects a tonnage and grade for each deposit from tonnage and grade models that are provided by the assessor or are already in the MARK3 program as a result of previous studies (most of the tonnage and grade models used in this study fall into the latter category). The simulator calculates the types and amounts of metals in each of the deposits. The process is repeated many times and produces frequency distributions of metals contained in deposits of the given deposit model.

MARK3 assumes that the frequency distribution of the logs of tonnages and grades for a given deposit model can be modelled as individually normal and jointly bivariate normal. The parameters of the distributions are chosen in such a way that the median and mean of the individual normal distributions are equal to the median and mean of the tonnage and grade data. For the bivariate normal distribution, the correlation is chosen so that the mean of the product of the tonnage and grade distributions for a given deposit model is equal to the mean metal content of deposits in the model (Root and Scott, 1988).

Different deposits in the same deposit model may contain different suites of metals. In such a case, the MARK3 program divides the deposit model into subtypes such that the deposits of each subtype all contain the same suite of metals. Distributions of tonnage and grade are calculated separately for each subtype. For example, if MARK3 is working with deposit model A, which has some deposits containing Cu and Au (subtype A_1) and some deposits containing only Cu (subtype A_2), it will calculate distributions of tonnage, Cu grade, and Au grade for subtype A_1, and distributions of tonnage and Cu grade for subtype A_2. When MARK3 is asked to simulate the tonnage and grade of a metal in deposit model A, it will select a subtype at random. Then it will randomly select tonnage and grade values from the tonnage and grade distributions it has constructed for that subtype. The likelihood that MARK3 will select a certain subtype is set equal to the fraction of deposits in the given deposit model that belong to that subtype. After many random selections, MARK3 will have combined tonnage and grade data from the various subtypes of a deposit model. Thus, MARK3 can estimate how much of a certain metal is likely to be contained in deposits of a given deposit model even if that metal is missing in some of the deposits.

MARK3 also allows an estimate of the number of deposits of a given deposit model to be conditioned on the probability that at least one such deposit is present. This is useful when estimates are made of the number of undiscovered deposits of a deposit model not known to be represented in a region. The number of undiscovered deposits can be estimated as if at least one is present in the region and then conditioned according to what the prospects are for that one occurence. The conditional probability for the existence of at least one undiscovered deposit of a given deposit model is subjectively determined by the assessor.

Steps one and two of the three-step quantitative assessment method described above were accomplished by Worl and others (1989) and will be modified slightly for the purposes of this report. Worl and others (1989) presented mineral deposit models (referred to by them as "deposit types") for the mineral deposits that are found in the Forest, and they delineated areas of moderate and high resource potential for each of the deposit models. Modifications have been made to some of their deposit models in order to use existing grade and tonnage models. Also, in place of their areas of high and moderate mineral resource potential, this report presents tracts that are simply permissive for the occurrence of deposits of a given mineral deposit model. Areas of high mineral resource potential, discussed above, are more restrictive than permissive tracts. Areas delineated as having a moderate mineral resource potential include areas where, among other things, "geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits" (Worl and others, 1989); these areas have the possibility of being more restrictive than permissive tracts.

This study focuses on the third step of the quantitative assessment method described above, the estimation of the number of undiscovered deposits, and presents the results of a simulation conducted using MARK3.

QUANTITATIVE MINERAL RESOURCE ASSESSMENT IN CHALLIS NATIONAL FOREST

The Challis National Forest has a complex geologic and metallogenic history. A complete discussion of the geology of the Forest can be found in reports by Worl and others (1989) and Fisher and Johnson (1987).

Several geologic terranes in the Forest are important to the mineral resource assessment. These terranes, defined by Worl and others (1989), are the Proterozoic terrane, the carbonate terrane (Paleozoic), the quartzite terrane (Paleozoic), the flysch terrane (Paleozoic), the black-shale terrane (Paleozoic), the Cretaceous intrusive rock terrane, the Tertiary extrusive rock terrane (the Challis Volcanics), the Tertiary intrusive rock terrane, and the post-Challis cover rock terrane. The occurrence of mineral deposits within a terrane depends on many factors including regional and local structures, facies changes within units, and juxtaposition of terranes.

A quantitative assessment of the mineral resources in a region is based on the availability of tonnage and grade models for each of the mineral deposit models considered. Worl and others (1989) presented a number of mineral deposit models that describe the deposits present, or suspected to be present, in the Challis National Forest. Many of these deposit models are based on local deposits with little or no record of production, and therefore they have no associated grade or tonnage model. Others are identical to or directly related to deposit models in the report by Cox and Singer (1986). Many of the deposit models of Cox and Singer (1986) are accompanied by tonnage and grade models and can be immediately incorporated into the quantitative assessment. Where the tonnage and grade models of Cox and Singer (1986) are used, the name of the mineral deposit model in this report is the same as that of Worl and others (1989; see table 1).

Two strategies have been used in this report to deal with models presented by Worl and others (1989) for which no tonnage and grade information exists. First, an extensive literature search was done in an attempt to create tonnage and grade models for any local deposits with adequate data. Because most mining has long since ceased in this area, records with both grades and tonnages of any deposits were extremely hard to find. Only two deposit models had enough data to allow the creation of tonnage and grade models. These models, to be discussed later, are the precious-metal veins model and the irregular replacement deposits of base and precious metals model.

The second strategy used to deal with mineral deposit models of Worl and others (1989) that lack grade and tonnage information was to aggregate or disaggregate those models until they matched one of the models of Cox and Singer (1986). The four polymetallic vein deposit models presented by Worl and others (1989) are classified on the basis of the terranes in which they occur, one each for the black-shale terrane, the carbonate terrane, the quartzite terrane, and the Tertiary extrusive terrane. The polymetallic vein deposit model of Bliss and Cox (1986) in the report by Cox and Singer (1986) includes all of the above-mentioned terranes as possible host rocks.

In order to use the existing tonnage and grade models for polymetallic veins, it is necessary to assume that the tonnages and grades from all four polymetallic vein models presented by Worl and others (1989) belong to one frequency distribution. To test this hypothesis, data were gathered for the polymetallic vein deposits in the Forest. Unfortunately only seven deposits had enough data to create a tonnage figure, and no good grade data were available. The data from the seven deposits, which include at least one deposit from each terrane, were combined and plotted. The resultant distribution of tonnage (fig. 3*B*) was nearly identical to the tonnage distribution (fig. 3*A*) presented for the polymetallic vein model of Bliss and Cox (1986). Therefore, the four polymetallic vein deposits in the Forest are described by a single deposit model in this report.

Worl and others (1989) described a polymetallic skarn deposit model that contains both copper and tungsten skarns. Their model differentiates copper and tungsten skarns as subtypes of a single deposit model. The report by Cox and Singer (1986) presents separate deposit models for copper and tungsten skarns. In this report, copper and tungsten skarns are assessed separately in order to take advantage of the models of Cox and Singer (1986).

Worl and others (1989) also define two subtypes in their stockwork molybdenum deposit model, namely Cretaceous and Tertiary stockwork molybdenum deposits. In this study these are treated as separate models, the Cretaceous model after Hall (1987) and the Tertiary model after Kiilsgaard and Bennett (1987). The Cretaceous model corresponds to a model presented by Theodore (1986) in the report by Cox and Singer (1986). There is no analog to the Tertiary stockwork molybdenum deposit model in the report by Cox and Singer (1986). Thus, grade and tonnage models are available only for the Cretaceous stockwork molybdenum deposit model, and only the Cretaceous deposits are assessed in this report.

QUANTITATIVE ASSESSMENT OF SELECTED MINERAL DEPOSIT MODELS

A complete list comparing the deposit models used by Worl and others (1989) and the associated tonnage and grade models used in this report is given in table 1. The report by Cox and Singer (1986) is a compilation of mineral deposit models and associated grade and tonnage models produced by many authors. The individual authors of this volume will be referenced from this point.

Due to the lack of tonnage and grade information, only 9 deposit models were used for simulation in this study, but these 9 represent 11 of the 20 deposit models presented by Worl and others (1989). In this section, a summary of each deposit model used in this report is presented along with the median estimate of the number of undiscovered deposits and the mean estimated tonnage of ore and metals in the deposits. For a more thorough discussion of the mineral deposit models used here, see Worl and others (1989), Fisher and Johnson (1986), or Cox and Singer (1986). Those reports are the main sources of the summaries presented below.

Table 1. Mineral deposit models and grade and tonnage models used in this report

Mineral deposit models of Worl and others (1989)	Corresponding mineral deposit models (first citation) and grade and tonnage models (second citation) of Cox and Singer (1986)	Mineral deposit model names used in this report
A. Fluorspar veins	None	None.
B. Polymetallic veins in black-shale terrane.	Polymetallic veins (Cox, 1986a; Bliss and Cox, 1986).	Polymetallic vein deposits.
C. Polymetallic veins in quartzite terrane.		
D. Polymetallic veins in carbonate terrane.		
E. Polymetallic veins in Tertiary extrusive terrane.		
F. Precious-metal veins	None	Precious-metal vein deposits. (Grade and tonnage model presented in this report.)
G. Base-metal veins	None	None.
H. Vein uranium deposits	None	None.
I. Tungsten stockwork and vein deposits	None	None.
J. Stockwork molybdenum deposits:		
Cretaceous	Porphyry Mo, low-F (Theodore, 1986; Menzie and Theodore, 1986).	Stockwork molybdenum deposits (Cretaceous).
Tertiary	None	None.
K. High-level, rhyolite-hosted, precious-metal deposits.	None	None.
L. Polymetallic skarn deposits	W skarn deposits (Cox, 1986b; Menzie and Jones, 1986).	Polymetallic skarn deposits (tungsten skarns and copper skarns).
	Cu skarn deposits (Cox and Theodore, 1986; Jones and Menzie, 1986).	
M. Irregular replacements of base and precious metals.	None	Irregular replacement deposits of base and precious metals. (Grade and tonnage model presented in this report.)
N. Fluorspar breccia manto deposits	None	None.
O. Sediment-hosted, jasperoid-associated, precious-metal deposits.	Carbonate-hosted Au-Ag (Berger, 1986; Bagby and others, 1986).	Sediment-hosted, jasperoid-associated, precious-metal deposits.
P. Precious-metal deposits in volcanic tuffs	None	None.
Q. Stratabound syngenetic deposits of precious and base metals.	Sedimentary exhalative Zn-Pb (Briskey, 1986; Menzie and Mosier, 1986).	Stratabound syngenetic deposits of precious and base metals.
R. Stratiform vanadium deposits	None	None.
S. Gold placer deposits	Placer Au-PGE (Yeend,1986; Orris and Bliss, 1986).	Gold placer deposits.
T. Radioactive black-sand placer deposits	None	None.

Polymetallic Vein Deposits

As explained earlier, the polymetallic vein models were aggregated into one polymetallic vein model (Cox, 1986) in order to use the tonnage and grade models presented by Bliss and Cox (1986).

The polymetallic vein deposits of the Forest produced mainly silver and lead and lesser amounts of zinc, gold, and copper. Some production of tin, antimony, and bromine has been reported. The deposits are found near high-angle faults and flat to steeply dipping shear zones beneath major thrust faults or near regional unconformities, and they are associated with nearby plutonic or hypabyssal rocks (Worl and others, 1989). The host rocks and the alteration associated with the ore bodies are different in each of the terranes and will be discussed on a terrane-by-terrane basis.

Within the black-shale terrane the host rocks are generally black argillite or carbonaceous micritic limestone, but may also include siltite, siltstone, shale, fine-grained quartzite, and gray limestone. Veins are found mainly in contact metamorphic zones close to felsic intrusive bodies where the country rocks have been altered to hornfels, tremolite-bearing limestone, calc-hornfels, and locally skarn. Known polymetallic vein deposits within this terrane all lie within 3.5 mi of a felsic intrusive body (Worl and others, 1989).

Polymetallic vein deposits found within the quartzite terrane are generally hosted by quartzite or dolomitic quartzite. Sandy dolomite, shaly limestone, and black shale are often found near the deposits. Where dolomite is the host, it commonly has been altered to jasperoid. The quartzite host rocks display carbonate replacement and a halo of manganese and iron oxides. The altered and mineralized zones are concentrated in north- to northwest-striking high-angle faults and near north-trending folds and associated thrust faults. The major mineralized zones are found in the dolomitic members of the quartzite, in carbonatized quartzite, or along highly fractured zones in the quartzite (Worl and others, 1989).

Polymetallic veins found within the carbonate terrane are hosted by white to blue, massive to thick-bedded limestone. The deposits occur as replacements of limestone along both fractures and bedding planes. The deposits are closely related to high-angle faults and felsic dikes, both of which tend to have a north-northeast strike. The host rocks are not altered and have only a narrow zone of contact metamorphism (containing calcite and some calc-silicate minerals) along some of the veins that are related to the deposits (Worl and others, 1989).

The polymetallic vein deposits of the Tertiary extrusive terrane are hosted by a number of highly altered calc-alkaline, peraluminous volcanic rocks that formed between 51 and 45 million years ago (Fisher and Johnson, 1987) and include flows, pyroclastic deposits, and hypabyssal intrusions. The host rocks have been bleached light gray and display cubes of secondary pyrite; they are silicified, sericitized, and pyritized in the vicinity of the ore bodies. Sericitization is the most extensive form of alteration, extending tens of feet from the lodes, and wall-rock texture is completely obliterated near the lodes (Worl and others, 1989). The polymetallic veins in the Tertiary extrusive terrane are associated with the intersections of northwest-striking and northeast-striking high-angle faults, and they tend to be located in minor fissures and zones of fracturing at the intersections (Worl and others, 1989).

Tracts delineated as permissive for the occurrence of polymetallic vein deposits in the Forest include large portions of the black-shale, carbonate, quartzite, and Tertiary extrusive terranes (fig. 4). Several areas of high resource potential were identified by Worl and others (1989) on the basis of the presence of high-angle faults, evidence of alteration zones, proximity to plutons and hypabyssal bodies, and anomalous concentrations of lead and zinc; these areas were considered in the estimate of the number of undiscovered deposits.

On the basis of available information, it is estimated at a 50-percent confidence level that 12 polymetallic vein deposits remain to be discovered in the Forest. Calculations made using MARK3 indicate that these undiscovered deposits contain 102,000 tonnes of lead, 1,200 tonnes of silver, and 71,000 tonnes of zinc. The total mean tonnage of ore from undiscovered polymetallic vein deposits is estimated at 1,400,000 tonnes. A breakdown of the number of undiscovered deposits and the predicted amount of contained metal in polymetallic veins in the Forest is presented in tables 2 and 3, respectively.

Precious-Metal Vein Deposits

The precious-metal vein deposits found in the Forest are hosted by Cretaceous and Tertiary hypabyssal intrusive rocks that include dikes, stocks, and plugs. Most of these deposits are in the trans-Challis fault system, a series of northeast-striking high-angle fractures, or along other northeast- or northwest-striking high-angle fracture zones. The deposits are epithermal in nature, as indicated by their mineralogy, and are associated with moderate to intense hydrothermal alteration including silicification and argillization near the veins. The alteration is zoned, and propylitization and sericitization occur farther from the vein. Ore was deposited as fissure and breccia fillings and is highest in grade near the premineralization land surface (Worl and others, 1989; Fisher and others, 1987). The commodities produced from these deposits include gold and silver and trace to by-product amounts of lead, copper, and zinc.

Table 2. Probabilistic estimate of number of undiscovered deposits of selected mineral deposit models in Challis National Forest

[A 100-percent probability that one or more deposits are present (see third column) indicates that at least one deposit of the given model has already been discovered in the Forest]

Mineral deposit model (names modified from Worl and others, 1989; see table 1)	Tonnage and grade model	Probability that one or more deposits are present (percent)	Estimated number of undiscovered deposits at given probabilities		
			90 percent	50 percent	10 percent
Polymetallic vein deposits	Polymetallic veins (Bliss and Cox, 1986).	100	5	12	21
Precious-metal vein deposits	Precious-metal vein deposits (this report).	100	4	9	17
Stockwork molybdenum deposits (Cretaceous).	Porphyry Mo, low-F (Menzie and Theodore, 1986).	100	1	1	2
Polymetallic skarn deposits:					
Tungsten skarns	W skarn deposits (Menzie and Jones, 1986).	100	0	1	2
Copper skarns	Cu skarn deposits (Jones and Menzie, 1986).	100	1	2	3
Irregular replacement deposits of base and precious metals.	Irregular replacement deposits of base and precious metals (this report).	100	3	8	15
Sediment-hosted, jasperoid-associated, precious-metal deposits.	Carbonate-hosted Au-Ag (Bagby and others,1986).	20	1	3	7
Stratabound syngenetic deposits of precious and base metals.	Sedimentary exhalative Zn-Pb (Menzie and Mosier, 1986).	100	1	2	4
Gold placer deposits	Placer Au-PGE (Orris and Bliss, 1986).	100	5	8	13

An extensive literature search was conducted in an attempt to create tonnage and grade estimates for these deposits, which have no real analog in the report by Cox and Singer (1986). Although data on contained metal are abundant, only eight deposits have enough tonnage and grade data to allow an accurate estimate. The resulting tonnage and grade models for the precious-metal vein deposits are presented in figures 5, 6, and 7.

The tracts delineated as permissive for the occurrence of precious-metal vein deposits are shown in figure 8. These tracts contain most of the Challis Volcanics (the Tertiary extrusive terrane) along with Tertiary intrusive rocks. A number of recognized areas of high resource potential were considered in making the estimates of undiscovered deposits (Worl and others, 1989). These areas show evidence of precious-metal mineralization, high-angle faults and fractures, Tertiary hypabyssal rocks (including dikes, stocks, and plugs), proximity to the trans-Challis fault system, alteration, and anomalous levels of copper, lead, and zinc in stream sediment samples.

On the basis of available information, it is estimated at a 50-percent confidence level that nine precious-metal vein deposits remain to be discovered in the Forest (table 2). Calculations made using MARK3 indicate that these undiscovered deposits contain 643,000 tonnes of ore containing 5.7 tonnes of gold and 67 tonnes of silver. A breakdown of the estimated number of undiscovered deposits and the contained metal in precious-metal veins in the Forest is presented in tables 2 and 3, respectively.

Stockwork Molybdenum Deposits (Cretaceous)

The Cretaceous stockwork molybdenum deposits in the Challis National Forest are in or associated with granitic plutons and hypabyssal bodies of rhyolite. The plutons are differentiated, low-fluorine, I-type,

Table 3. Probabilistic estimates of tonnages of metals and ore in undiscovered deposits of selected mineral deposit models in Challis National Forest

Mineral deposit model	Metal	Estimated tonnages (in tonnes) at given probabilities		
		90 percent	50 percent	10 percent
Polymetallic vein deposits ---------	Copper	$1.3X10^2$	$1.5X10^3$	$3.1X10^3$
	Gold	$4.0X10^{-2}$	$3.4X10^0$	$9.8X10^0$
	Zinc	$3.3X10^3$	$7.1X10^4$	$1.9X10^5$
	Silver	$7.2X10^1$	$1.2X10^3$	$3.6X10^3$
	Lead	$9.5X10^3$	$1.0X10^5$	$2.3X10^5$
	Ore	$1.3X10^5$	$1.4X10^6$	$3.1X10^6$
Precious-metal vein deposits -------	Gold	$7.0X10^{-1}$	$5.7X10^0$	$1.2X10^1$
	Silver	$3.8X10^0$	$6.7X10^1$	$1.5X10^2$
	Ore	$9.9X10^4$	$6.4X10^5$	$1.3X10^6$
Stockwork molybdenum deposits (Cretaceous).	Molybdenum	$1.8X10^4$	$2.2X10^5$	$6.0X10^5$
	Ore	$2.0X10^7$	$2.8X10^8$	$8.6X10^8$
Polymetallic skarn deposits:				
Tungsten skarns -----------	Tungsten	$4.7X10^2$	$5.3X10^4$	$1.5X10^5$
	Ore	$8.4X10^4$	$7.1X10^6$	$2.5X10^7$
Copper skarns--------------	Copper	$2.5X10^3$	$1.1X10^5$	$3.0X10^5$
	Gold	$0.0X10^0$	$1.7X10^0$	$3.6X10^0$
	Silver	$0.0X10^0$	$1.7X10^1$	$4.4X10^1$
	Ore	$1.6X10^5$	$8.5X10^6$	$2.7X10^7$
Irregular replacement deposits of base and precious metals.	Copper	$3.6X10^1$	$6.5X10^2$	$1.4X10^3$
	Gold	$0.0X10^0$	$4.0X10^{-1}$	$7.0X10^{-1}$
	Silver	$9.0X10^0$	$1.4X10^2$	$3.7X10^2$
	Lead	$3.2X10^3$	$4.9X10^4$	$1.2X10^5$
	Ore	$2.8X10^4$	$7.4X10^5$	$1.9X10^6$
Sediment-hosted, jasperoid-associated, precious-metal deposits.	Gold	$0.0X10^0$	$2.3X10^1$	$7.1X10^1$
	Silver	$0.0X10^0$	$3.9X10^1$	$0.0X10^0$
	Ore	$0.0X10^0$	$9.0X10^6$	$2.7X10^7$
Stratabound syngenetic deposits of precious and base metals.	Zinc	$2.6X10^5$	$7.8X10^6$	$2.0X10^7$
	Silver	$4.1X10^1$	$6.2X10^3$	$1.7X10^4$
	Lead	$1.2X10^5$	$4.6X10^6$	$1.2X10^7$
	Ore	$5.7X10^6$	$1.1X10^8$	$2.6X10^8$
Gold placer deposits ----------------	Gold	$2.7X10^{-1}$	$1.2X10^0$	$2.4X10^0$
	Ore	$3.6X10^5$	$1.7X10^6$	$3.4X10^6$

compositionally zoned bodies with high strontium-rubidium ratios and low niobium concentrations compared to average granites (Worl and others, 1989). The composition of these bodies ranges from quartz diorite to granite. The deposits can be found entirely within the intrusive rocks, entirely within the adjacent country rocks, or partially within both. Where located in the country rocks, the deposits are usually found directly above the intrusive rocks. The deposits are often found on the margins of positive magnetic anomalies that probably reflect associated buried granitic plutons (Hall, 1987a). This deposit model corresponds to the deposit model called "porphyry Mo, low F" by Theodore (1986) in the report by Cox and Singer (1986). An associated tonnage and grade model by Menzie and Theodore (1986) is presented in the same report.

The ore is associated with intensely silicified and pyritized rock surrounded by envelopes of potassic alteration grading outward to phyllic alteration. Some of the deposits are associated with hypabyssal rhyolitic bodies that are aligned with major high-angle fault systems within the Forest (Worl and others, 1989). The major commodity produced from these deposits is molybdenum; also present are trace to by-product amounts of copper and silver.

Tracts that are permissive for the occurrence of Cretaceous stockwork molybdenum deposits in the Forest (fig. 9) include all areas that have evidence of

Cretaceous plutons or hypabyssal bodies. Several areas of high resource potential were identified by Worl and others (1989) on the basis of alteration and geochemistry. These areas were considered in making the estimates of the number of undiscovered deposits.

On the basis of available information, it is estimated at a 50-percent confidence level that one Cretaceous stockwork molybdenum deposit remains to be discovered in the Forest (table 2). Calculations made using MARK3 indicate that undiscovered deposits contain 285 million tonnes of ore and 221,000 tonnes of molybdenum. A breakdown of the estimated number of undiscovered deposits and the predicted contained metal in Cretaceous stockwork molybdenum deposits in the Forest is presented in tables 2 and 3, respectively.

Polymetallic Skarn Deposits (Tungsten Skarns and Copper Skarns)

The host rocks for the polymetallic skarn deposits are carbonate or carbonate-bearing rocks—mainly clean to impure limestone, carbonaceous micritic limestone, and limy sandstone—that are in contact with felsic intrusive rocks. The carbonate rocks within the contact zone have been altered to Fe-Mg-Mn-silicate mineral assemblages. Skarns occur where conditions were right for carbonate minerals to be replaced by silicate and ore minerals. This location is controlled by the ability of ore-forming solutions to penetrate the rocks, which is itself controlled by the relationship between bedding planes, faults, and breccia zones at the contact between the intrusive body and the carbonate host rock (Worl and others, 1989; Cookro and others, 1987). The commodities produced from these deposits vary according to the type of skarn. Tungsten skarns produce mainly tungsten, whereas copper skarns produce copper, silver, and gold.

Several tracts in the Forest have been delineated as permissive for the occurrence of polymetallic skarns (fig. 10). The tracts are divided into those that are permissive for tungsten skarns, those that are permissive for copper skarns, and those that are permissive for both. In general, the tungsten skarn tracts include roof pendants in the Idaho batholith, the eastern margin of the Idaho batholith, and areas where Cretaceous plutons are in contact with calcareous rocks. The copper skarn tracts include areas where plutons are found in the black-shale and carbonate terranes. A number of areas of high resource potential were defined by Worl and others (1989) using evidence of ore mineralization, skarn mineral assemblages, and geochemical anomalies. These areas were considered in making estimates of the number of undiscovered deposits.

Separate assessments were made of the tungsten and copper skarns, using the grade and tonnage model of Menzie and Jones (1986) for tungsten skarns and the grade and tonnage model of Jones and Menzie (1986) for copper skarns. These models (especially the tungsten skarn model) are for the most part district based rather than deposit based. This means that production data from individual deposits have been combined and reported by district, and only the district totals were available for construction of grade and tonnage models. The estimates of undiscovered deposits were converted to estimates of undiscovered districts to make them compatible with the grade and tonnage models. The conversion was made by dividing the estimate of undiscovered deposits by the number of deposits generally found in a district. The resulting estimates of undiscovered districts were combined with the district-based grade and tonnage models in the MARK3 program to produce estimates of copper and tungsten contained in undiscovered deposits in the Forest.

It is estimated at a 50-percent confidence level that there is one tungsten skarn remaining to be discovered in the Forest. Also, it is estimated at a 50-percent confidence level that there are two copper skarns remaining to be discovered in the Forest. Calculations made using MARK3 indicate that undiscovered tungsten skarns contain 53,000 tonnes of tungsten and 7,100,000 tonnes of tungsten ore. Undiscovered copper skarns are estimated to contain 109,000 tonnes of copper and 8,600,000 tonnes of copper ore. A breakdown of the estimated number of undiscovered deposits and the predicted contained metal in tungsten and copper skarns in the Forest is presented in tables 2 and 3, respectively.

Irregular Replacement Deposits of Base and Precious Metals

The irregular replacement deposits of base and precious metals in the Forest are hosted by calcareous rocks or dolomitic rocks with varying amounts of impurities. The movement of ore-forming solutions was controlled by high-angle faults and shear and brecciated zones. These solutions were trapped in some areas by overlying impervious shale and siltstone strata that had been emplaced by thrusting. Anticlines also formed large solution traps. In the Forest, the ores are found in the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation, and generally occur as selectively replaced strata. In general, local dolomitization is present near the ore bodies, but pervasive hydrothermal alteration is missing (Worl and others, 1989; Hobbs and others, 1987). The commodities that have been produced from these deposits include silver, lead, and zinc; copper and gold are by-products.

There is no good analog of this deposit model in Cox and Singer (1986) and therefore no associated tonnage and grade models. Enough data were available to allow the creation of tonnage and grade models from deposits within the Forest. Data from 22 deposits were used, including data from the Pittsburgh-Idaho, Ramshorn, Clayton, and Latest Out mines, and the models are shown in figures 11 through 15. The deposits in the Forest may be similar to those described in the polymetallic replacement deposit model of Morris (1986); however, that model's associated grade and tonnage model is based not on deposits but on districts with over 100,000 tonnes of production (Mosier and others, 1986), and it is quite different from the deposit-based model used here.

The tracts delineated as permissive for the occurrence of irregular replacement deposits in the Forest are shown in figure 16. The tracts outline the rocks of the black-shale terrane and part of the flysch terrane. Areas of high resource potential, identified by Worl and others (1989), are defined by north-striking high-angle faults, nearby intrusive rocks, the presence of gossans, and evidence of base- and precious-metal mineralization. These areas were considered in making estimates of the number of undiscovered deposits.

The tonnage and grade model presented here was used for the quantitative assessment of irregular replacement deposits. On the basis of available information, it is estimated at a 50-percent confidence level that eight irregular replacement deposits of base and precious metals remain to be discovered in the Forest. Calculations made using MARK3 indicate that these undiscovered deposits contain 49,000 tonnes of lead, 650 tonnes of copper, and 140 tonnes of silver in 740,000 tonnes of ore. A breakdown of the estimated number of undiscovered deposits and the predicted contained metal in these deposits is presented in tables 2 and 3, respectively.

Sediment-Hosted, Jasperoid-Associated, Precious-Metal Deposits

The sediment-hosted, jasperoid-associated, precious-metal deposits are found in carbonaceous limestone and dolomite, calcareous carbonaceous shale and siltstone, and bioclastic limestone. This deposit model is here considered identical to the carbonate-hosted Au-Ag model of Berger (1986), for which an associated grade and tonnage model was constructed by Bagby and others (1986). The host rocks are commonly thinly bedded and sufficiently silicified to be termed jasperoids. High-angle faults are present near all deposits and controlled the flow of solutions that formed the ore. Intermediate to silicic plutonic or hypabyssal intrusions are generally present near deposits, although the relationship of the intrusions to the precious-metal mineralization is unknown (Worl and others, 1989). Most known deposits are Cretaceous to middle Tertiary in age, and the typical commodities are gold and silver; arsenic, antimony, thallium, and mercury are present in trace amounts.

Currently, no sediment-hosted, jasperoid-associated, precious-metal deposits have been recognized in the Challis National Forest or the surrounding area. There are, however, several areas with the appropriate geology for the occurrence of these deposits in the Forest. These areas, shown as tracts in figure 17, were delineated on the basis of carbonaceous sedimentary rocks that could serve as host rocks for these deposits; they include the black-shale terrane and parts of the flysch terrane.

Since no sediment-hosted, jasperoid-associated, precious-metal deposits exist in the Forest, the estimate of undiscovered deposits was conditioned on the premise that there is a 20-percent chance that at least one such deposit exists in the Forest. On the basis of available information, it is estimated at a 50-percent confidence level that there are three undiscovered sediment-hosted, jasperoid-associated, precious-metal deposits in the Challis National Forest. Calculations made using MARK3 indicate that these undiscovered deposits contain 23 tonnes of gold, 39 tonnes of silver, and 9,000,000 tonnes of ore. A breakdown of the number of estimated undiscovered deposits and the predicted contained metal in these deposits is presented in tables 2 and 3, respectively.

Stratabound Syngenetic Deposits of Precious and Base Metals

The host rocks of the stratabound syngenetic deposits of precious and base metals are generally euxinic marine sedimentary rocks. They include black siliceous-facies carbonaceous argillite and fine- to medium-grained gray limestone or micritic carbonaceous limestone. The deposits are stratiform masses and lenses rich in sphalerite and galena; also present are pyrite, pyrrhotite, barite, arsenopyrite, quartz, calcite, clay minerals, and tremolite. The deposits formed in restricted depositional environments where metal-bearing geothermal brines were localized (Worl and others, 1989; Hall, 1987b). The commodities produced from these deposits include zinc, lead, silver, and gold; vanadium and molybdenum are present in trace to by-product amounts. This deposit model is considered to be identical to the sedimentary exhalative Zn-Pb deposit model of Briskey (1986).

The tracts that are permissive for the occurrence of stratabound syngenetic deposits of base and precious metals are shown in figure 18. These tracts include the black-shale terrane and the part of the flysch terrane (the Copper Basin and McGowan Creek Formations) that shows evidence of a marine basinal black-shale setting. Areas of high resource potential were delineated by Worl and others (1989) on the basis of anomalous con-

Table 4. Summation of probabilistic estimates of tonnages of metals and ore in undiscovered deposits in Challis National Forest

Metal	Estimated tonnages (in tonnes) at given probabilities		
	90 percent	50 percent	10 percent
Gold	$1.1X10^0$	$3.5X10^1$	$1.0X10^2$
Silver	$1.2X10^2$	$7.7X10^3$	$2.1X10^4$
Copper	$2.7X10^3$	$1.3X10^4$	$3.1X10^5$
Lead	$1.3X10^5$	$4.8X10^6$	$1.3X10^7$
Zinc	$2.6X10^5$	$7.9X10^6$	$2.0X10^7$
Tungsten	$4.7X10^2$	$5.3X10^4$	$1.5X10^5$
Molybdenum	$1.8X10^4$	$2.2X10^5$	$6.0X10^5$

centrations of zinc and (or) lead, and these areas were considered in the estimate of the number of undiscovered deposits.

The tonnage and grade model used for these deposits is by Menzie and Mosier (1986). On the basis of available information, it is estimated at a 50-percent confidence level that there are two undiscovered stratabound syngenetic deposits of base and precious metals in the Forest. Calculations made using MARK3 indicate that these undiscovered deposits contain 7,800,000 tonnes of zinc, 6,200 tonnes of silver, 4,600,000 tonnes of lead, and 10,700,000 tonnes of ore. A breakdown of the number of undiscovered deposits and the contained metal in these deposits is presented in tables 2 and 3, respectively.

Gold Placer Deposits

The gold placer deposits in the Forest are fluvial accumulations of elemental gold with sand, gravel, and boulders. Gold, silver, and other heavy minerals were concentrated by streams where turbulent and irregular flow patterns separated the light and heavy mineral fractions being transported downstream. Ilmenite, magnetite, euxenite, brannerite, zircon, monazite, cinnabar, stibnite, and garnet are some of the other mineral components of gold placer deposits in the Forest. These deposits are commonly found in terraces a few to several hundred feet above the present stream levels and downstream from lode deposits (Worl and others, 1989). They are young, ranging from Pleistocene to Holocene (present-day) in age.

Tracts delineated as permissive for the occurrence of gold placer deposits are shown in figure 19. These tracts include mapped fluvial accumulations or possible fluvial accumulations. Worl and others (1989) identified areas of high resource potential, defined by the occurrence of precious metals in stream sediments and locations within 5 mi (downstream) of a known gold lode deposit. These areas were considered in making estimates of the number of undiscovered deposits.

The tonnage and grade model used for these deposits is by Orris and Bliss (1986). It is estimated at a 50-percent confidence level that there are eight undiscovered gold placer deposits in the Challis National Forest. Calculations made using MARK3 indicate that these undiscovered deposits contain 1.2 tonnes of gold and 1,730,000 tonnes of ore. A breakdown of the number of estimated undiscovered deposits and the predicted contained metal in these deposits is presented in tables 2 and 3, respectively.

SUMMARY OF QUANTITATIVE ASSESSMENT OF CHALLIS NATIONAL FOREST

The summary of the quantitative analysis is presented in tables 2, 3, and 4. The models used in the report and the probability distributions of undiscovered deposits (used as input to the MARK3 program) are presented in table 2. The distributions of metal endowment for each deposit (the results of the MARK3 procedure) are given in table 3. The results of table 3 are summed for each metal and shown in table 4, which thus presents a distribution of the total contained metal (in deposits of the mineral deposit models used in this report) in the Challis National Forest.

Note that although this information is presented in a quantitative, probabilistic format, the analysis is based on subjective estimates of the number of undiscovered mineral deposits for each specific mineral deposit model considered. These estimates are based solely upon the author's knowledge at the time of the assessment (1989) and are not probabilistic in a statistical sense.

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FIGURES 1–19

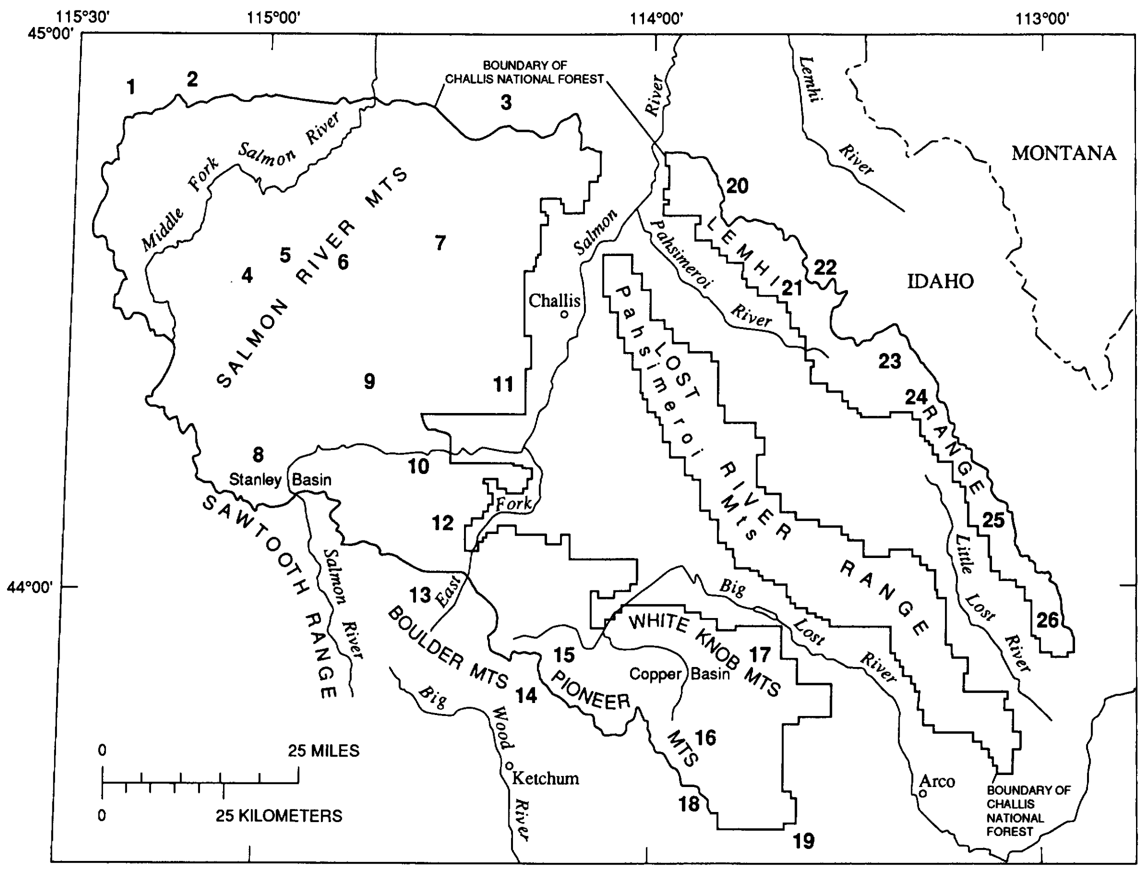


Figure 1. Location of Challis National Forest and principal mining districts within or partially within its boundaries (Worl and others, 1989). Mining districts: 1, Yellow Pine; 2, Thunder Mountain; 3, Gravel Range; 4, Sea Foam; 5, Sheep Mountain; 6, Loon Creek; 7, Parker Mountain; 8, Stanley; 9, Yankee Fork; 10, Robinson Bar; 11, Bayhorse; 12, Boulder Creek; 13, East Fork; 14, Warm Springs; 15, Alto; 16, Copper Basin; 17, Alder Creek; 18, Little Wood River; 19, Lava Creek; 20, McDevitt; 21, Blue Wing; 22, Junction; 23, Texas; 24, Spring Mountain; 25, Hamilton; 26, Dome.

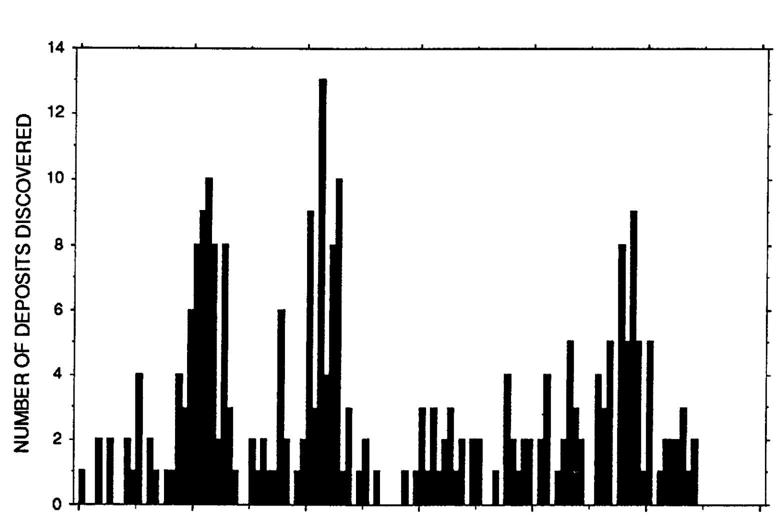
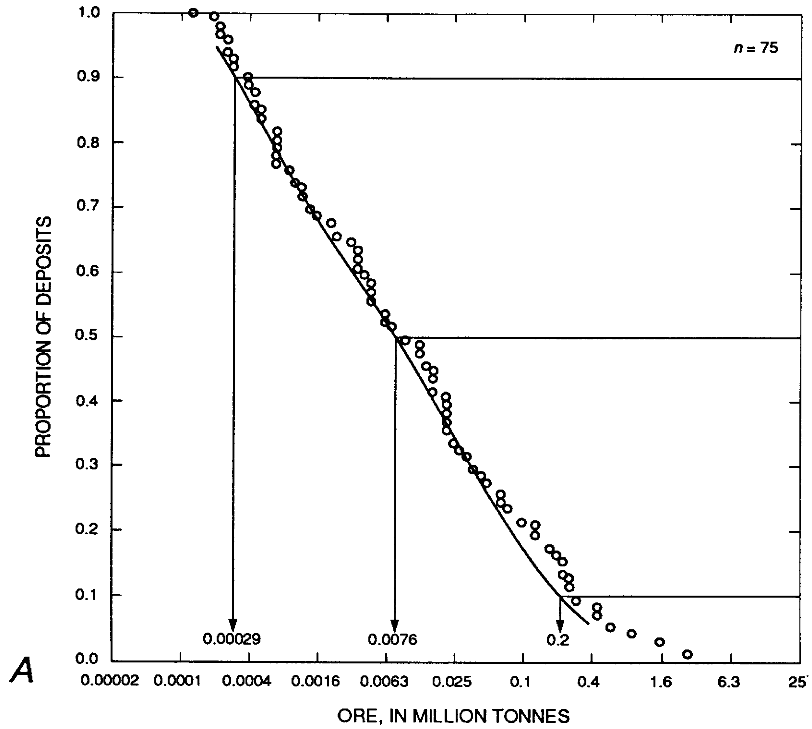


Figure 2. Discoveries of mineral deposits in Challis National Forest (compiled from data available in Mineral Resources Database System, U.S. Geological Survey, 1988).



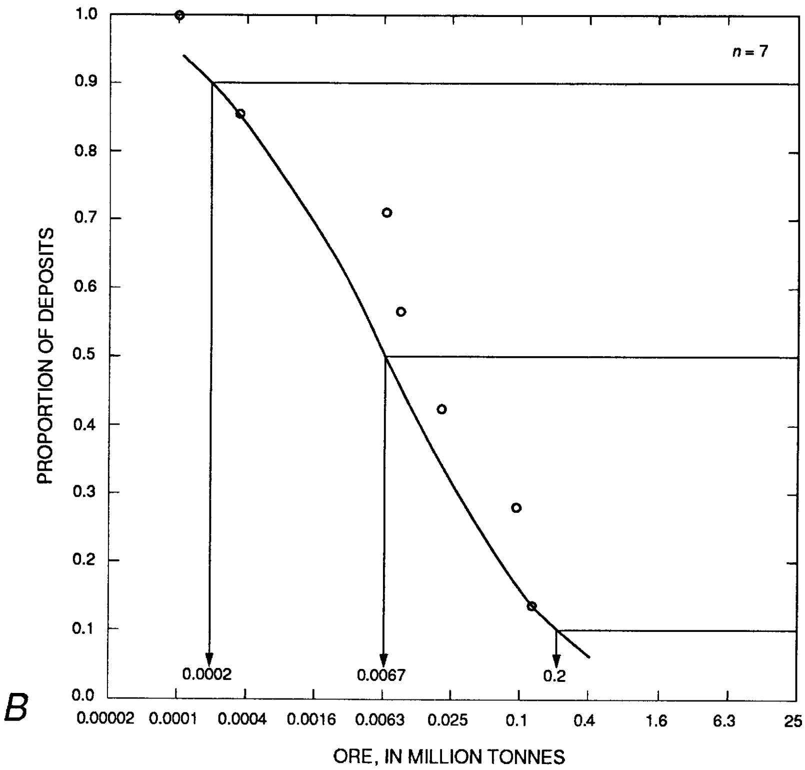


Figure 3. Tonnages of ore in polymetallic vein deposits. *A*, Bliss and Cox (1986); *B*, this report. *n*, number of deposits used to construct graph. Tonnages for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

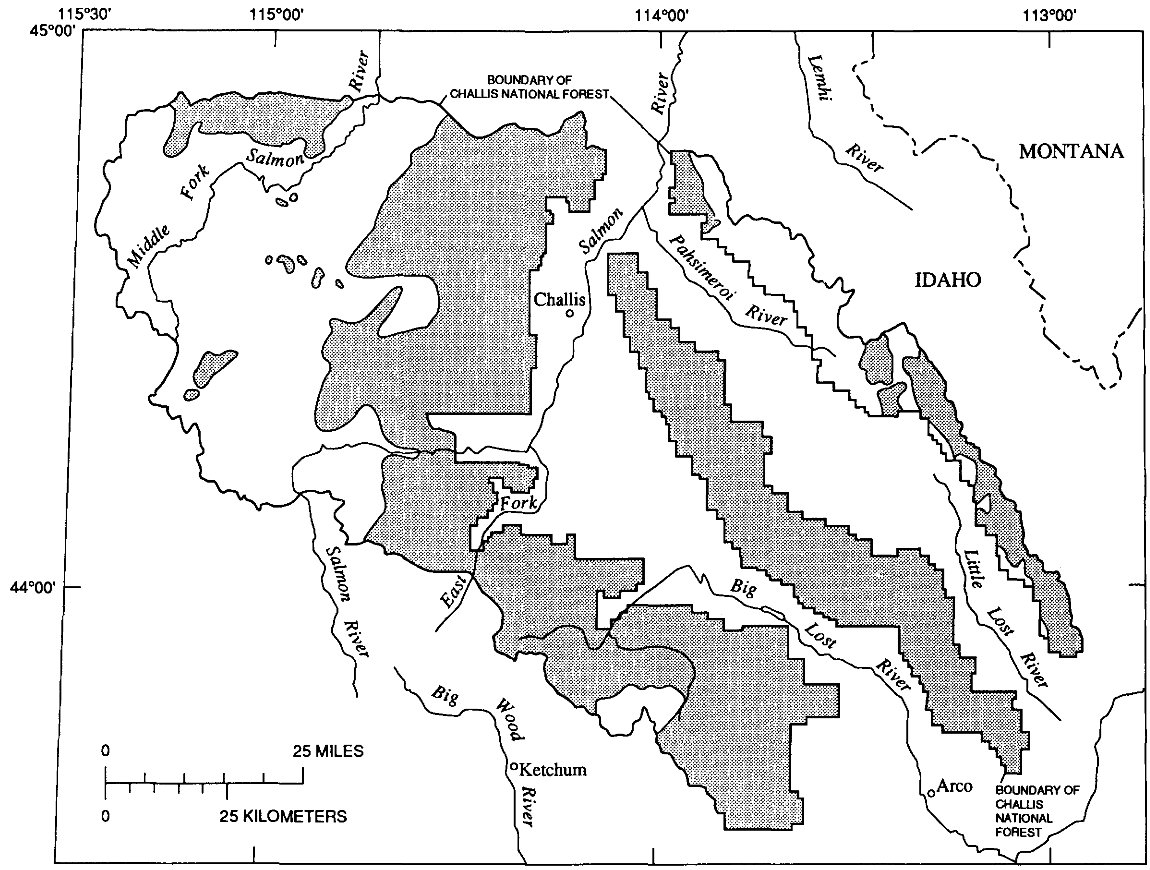


Figure 4. Tracts (shaded) permissive for occurrence of polymetallic vein deposits.

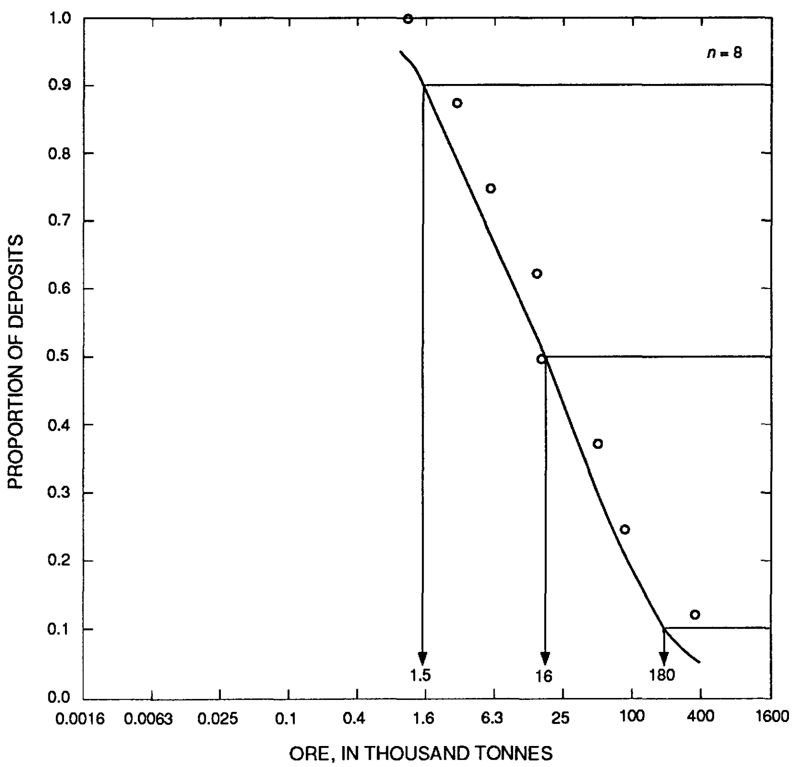


Figure 5. Tonnages of ore in precious-metal vein deposits. *n*, number of deposits used to construct graph. Tonnages for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

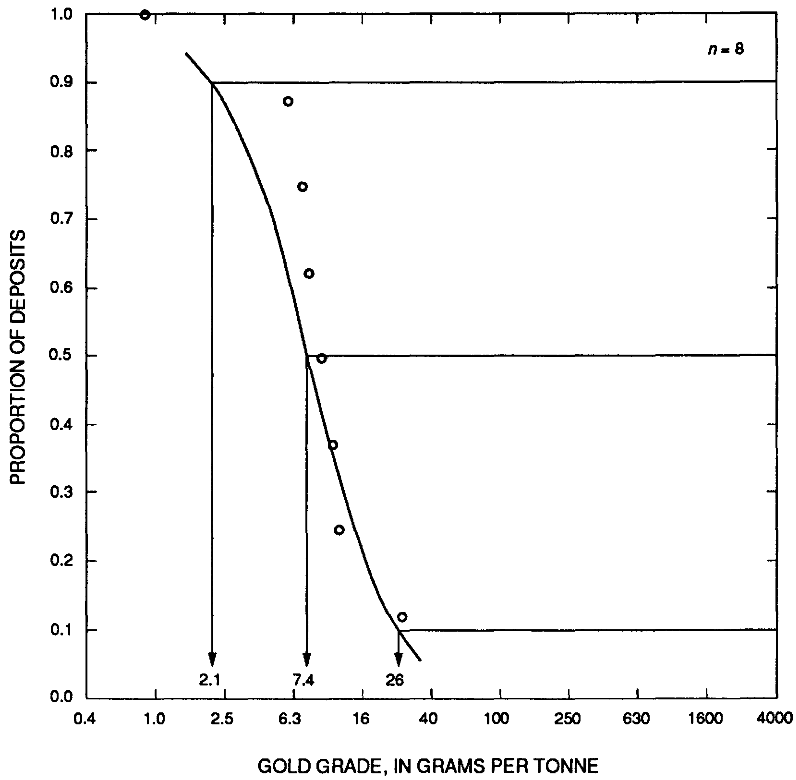


Figure 6. Gold grades of ore in precious-metal vein deposits. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

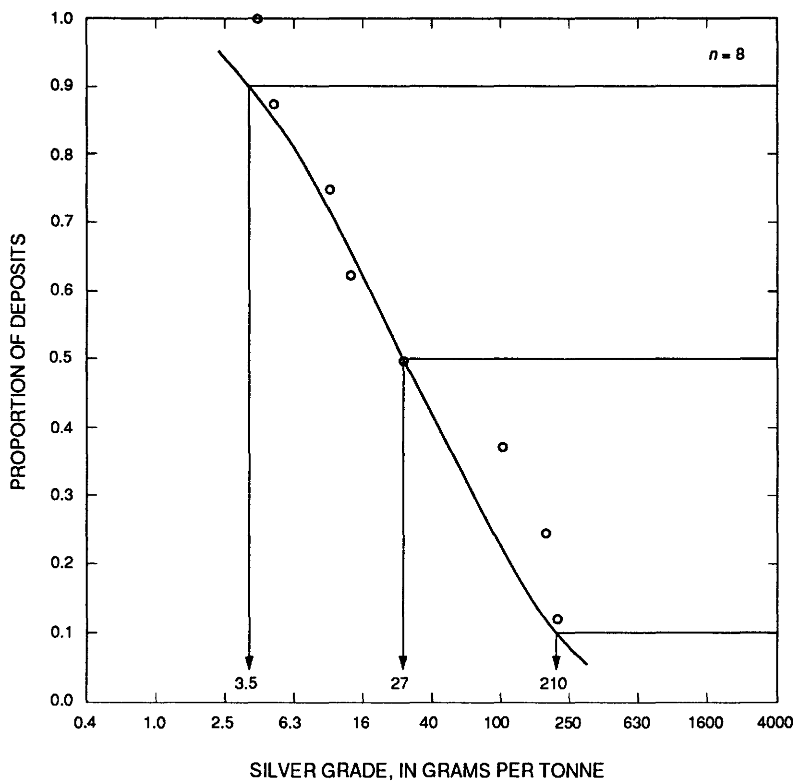


Figure 7. Silver grades of ore in precious-metal vein deposits. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

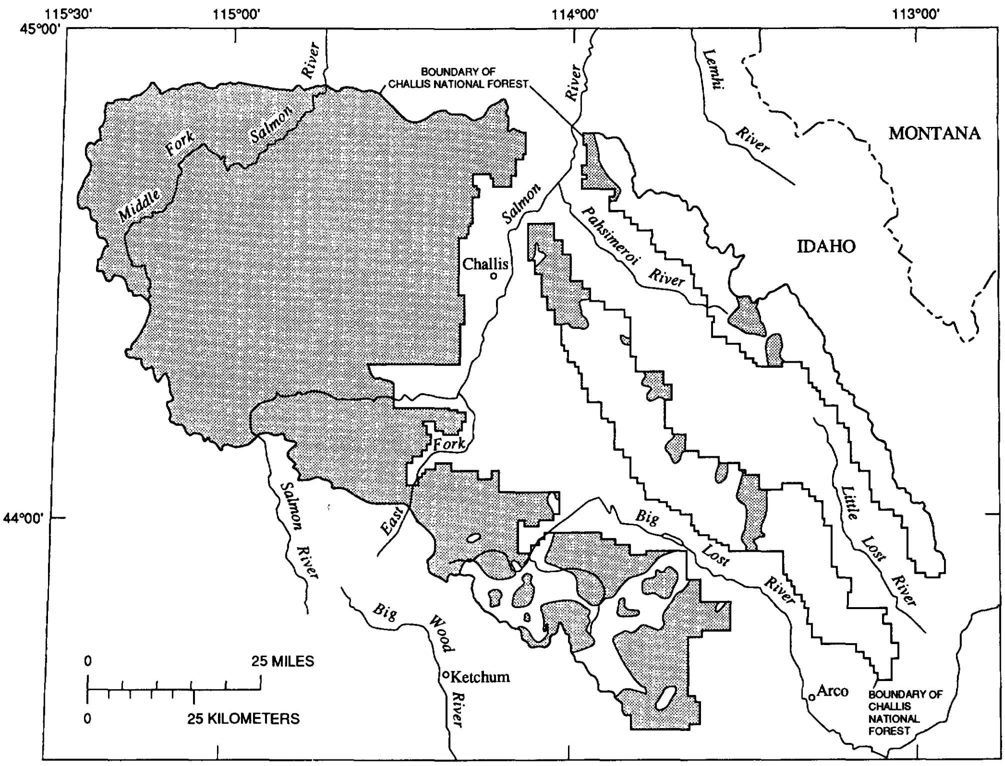


Figure 8. Tracts (shaded) permissive for occurrence of precious-metal vein deposits.

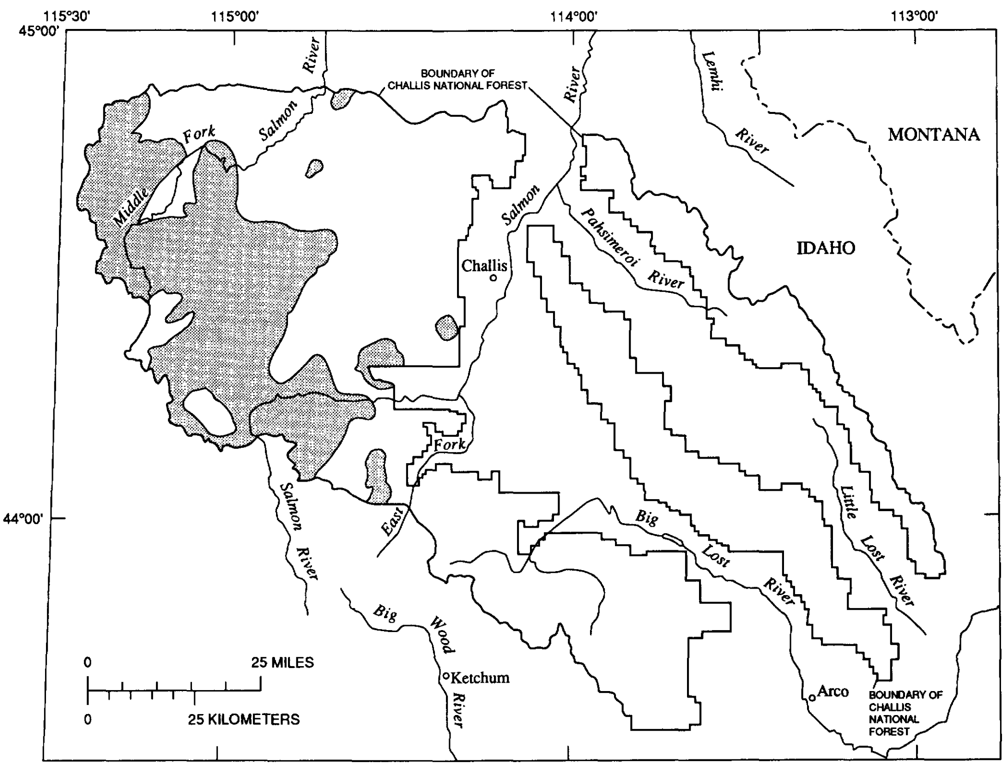


Figure 9. Tracts (shaded) permissive for occurrence of Cretaceous stockwork molybdenum deposits.

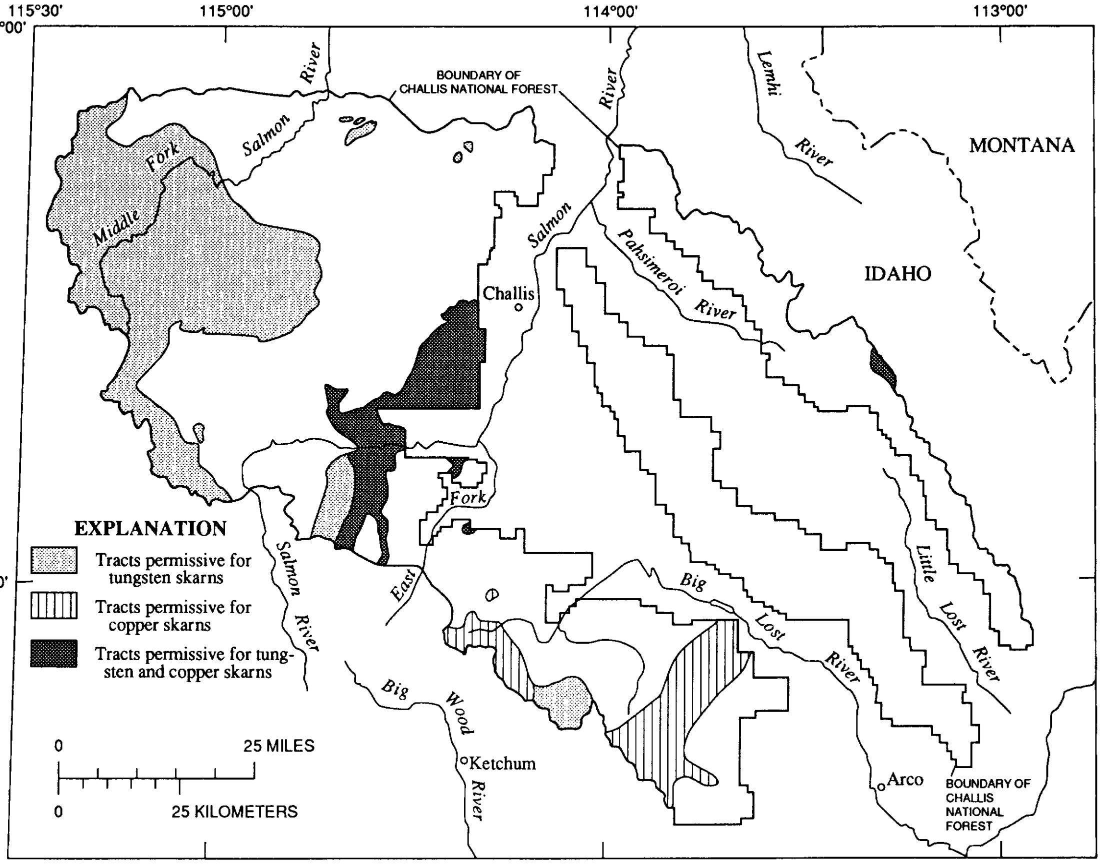


Figure 10. Tracts permissive for occurrence of tungsten skarns and copper skarns.

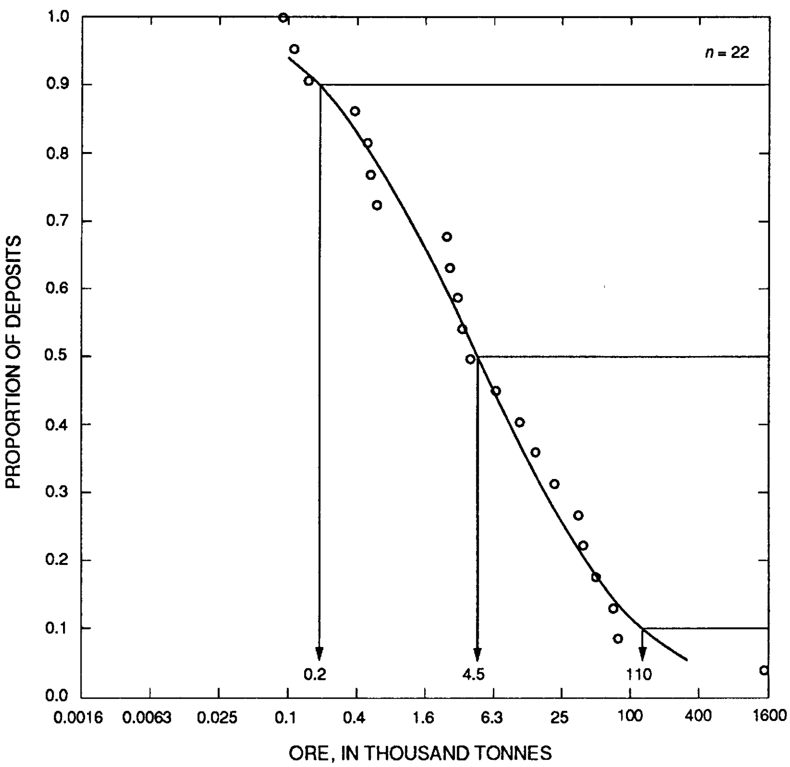


Figure 11. Tonnages of ore in irregular replacement deposits of base and precious metals. *n*, number of deposits used to construct graph. Tonnages for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

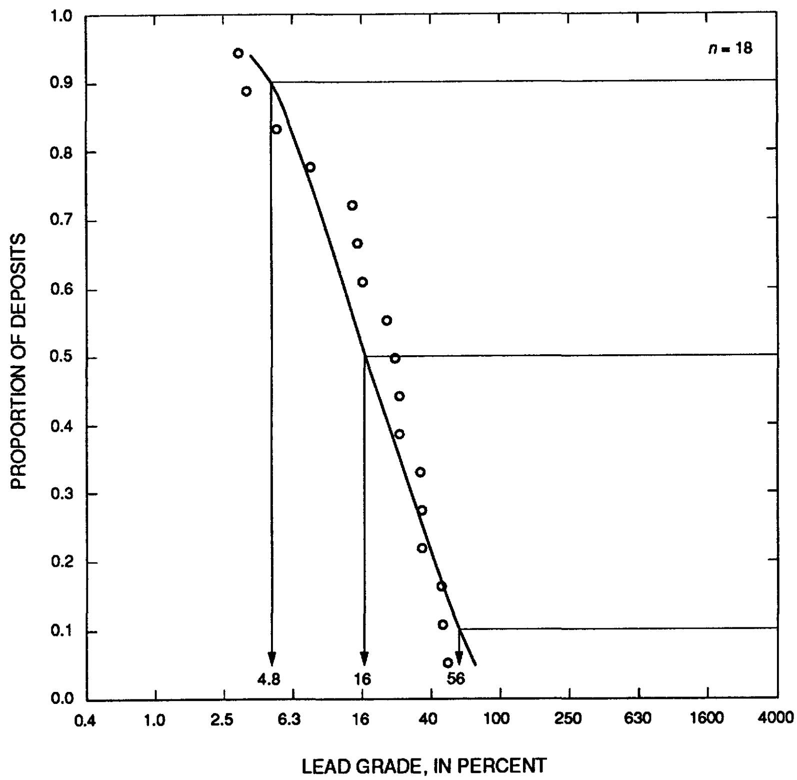


Figure 12. Lead grades of ore in irregular replacement deposits of base and precious metals. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

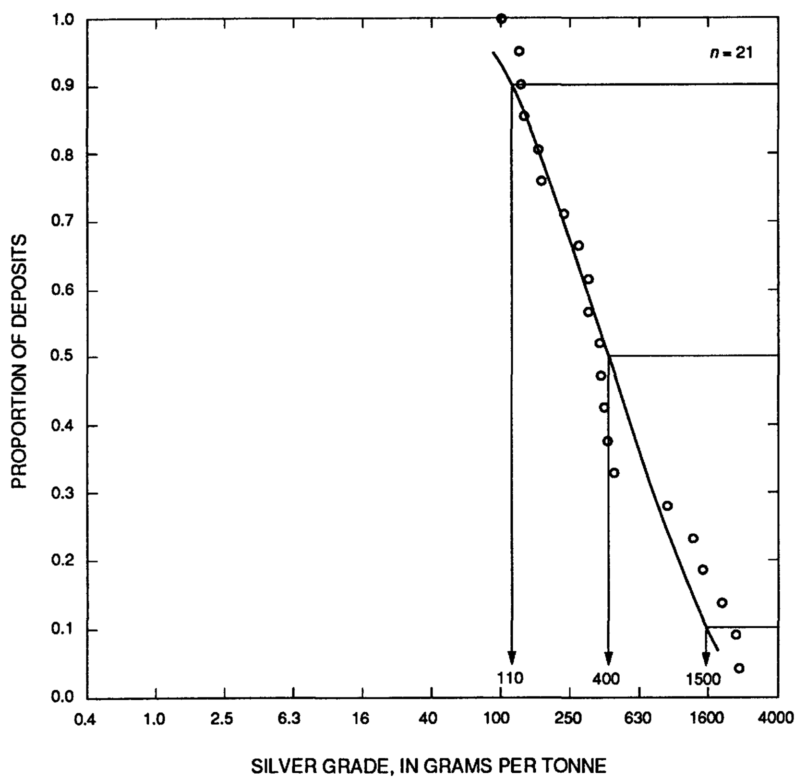


Figure 13. Silver grades of ore in irregular replacement deposits of base and precious metals. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

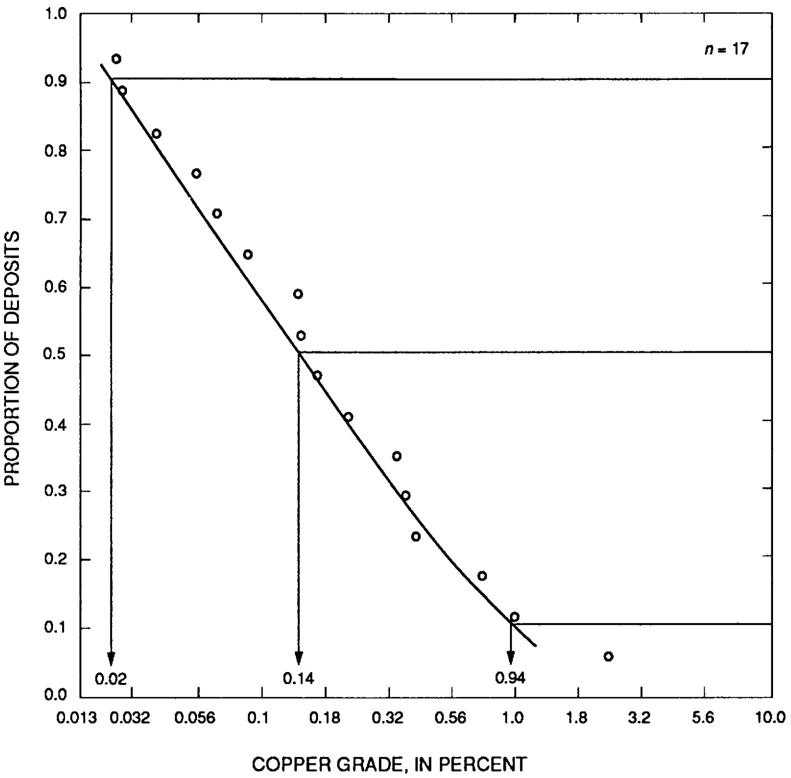


Figure 14. Copper grades of ore in irregular replacement deposits of base and precious metals. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

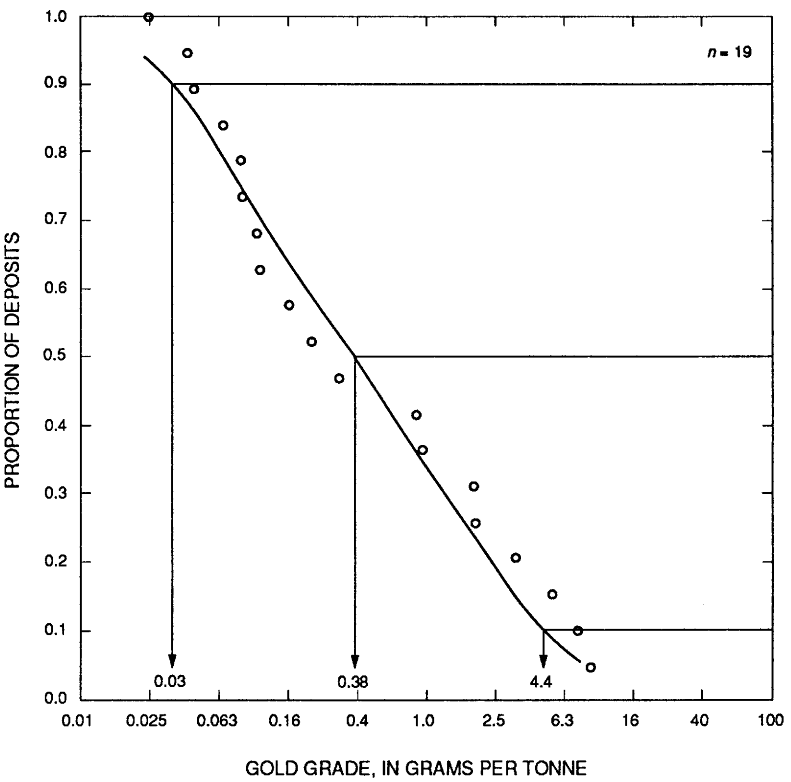


Figure 15. Gold grades of ore in irregular replacement deposits of base and precious metals. *n*, number of deposits used to construct graph. Grades for 90 percent, 50 percent, and 10 percent of deposits are written from left to right above horizontal axis.

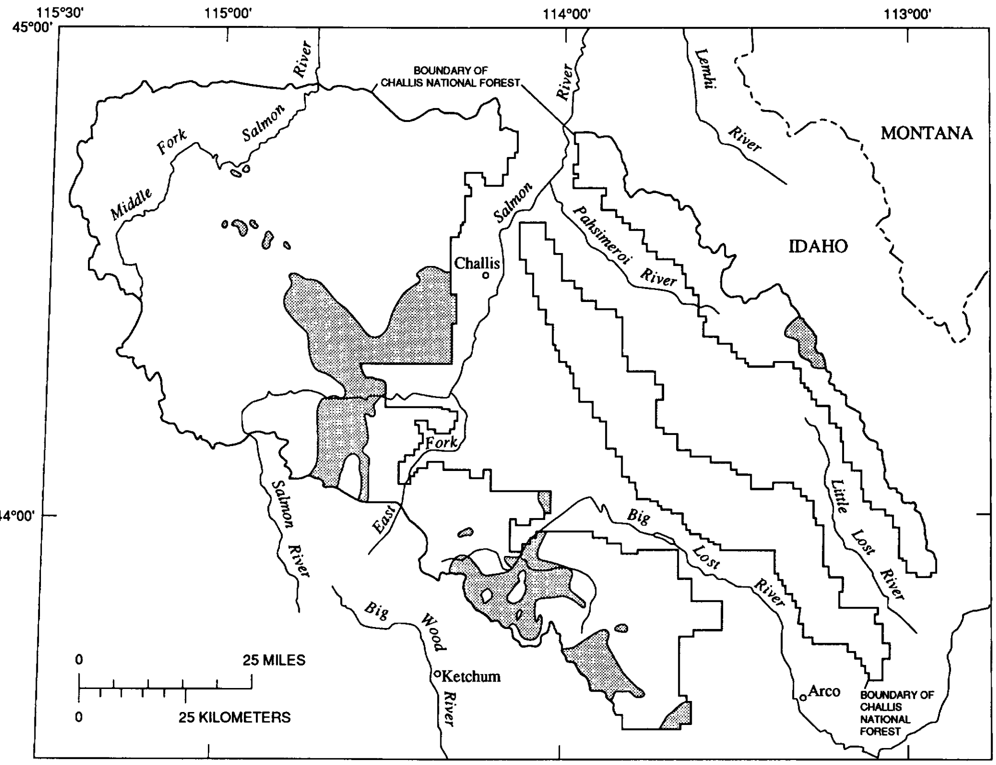


Figure 16. Tracts (shaded) permissive for occurrence of irregular replacement deposits of base and precious metals.

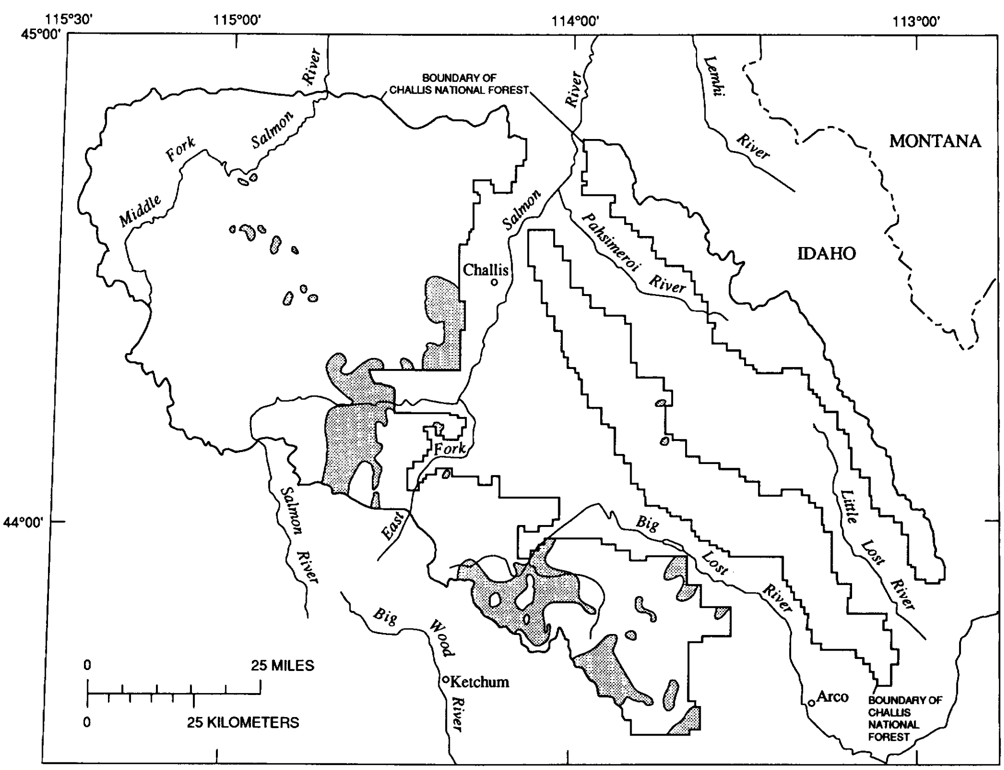


Figure 17. Tracts (shaded) permissive for occurrence of sediment-hosted, jasperoid-associated, precious-metal deposits.

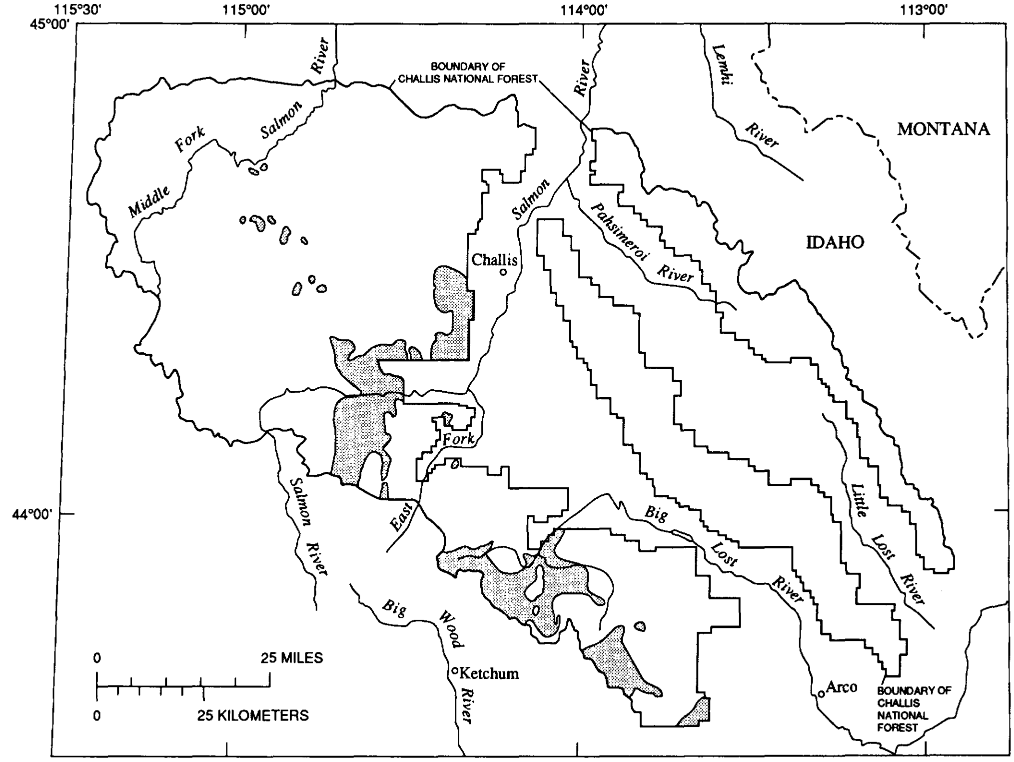


Figure 18. Tracts (shaded) permissive for occurrence of stratabound syngenetic deposits of precious and base metals.

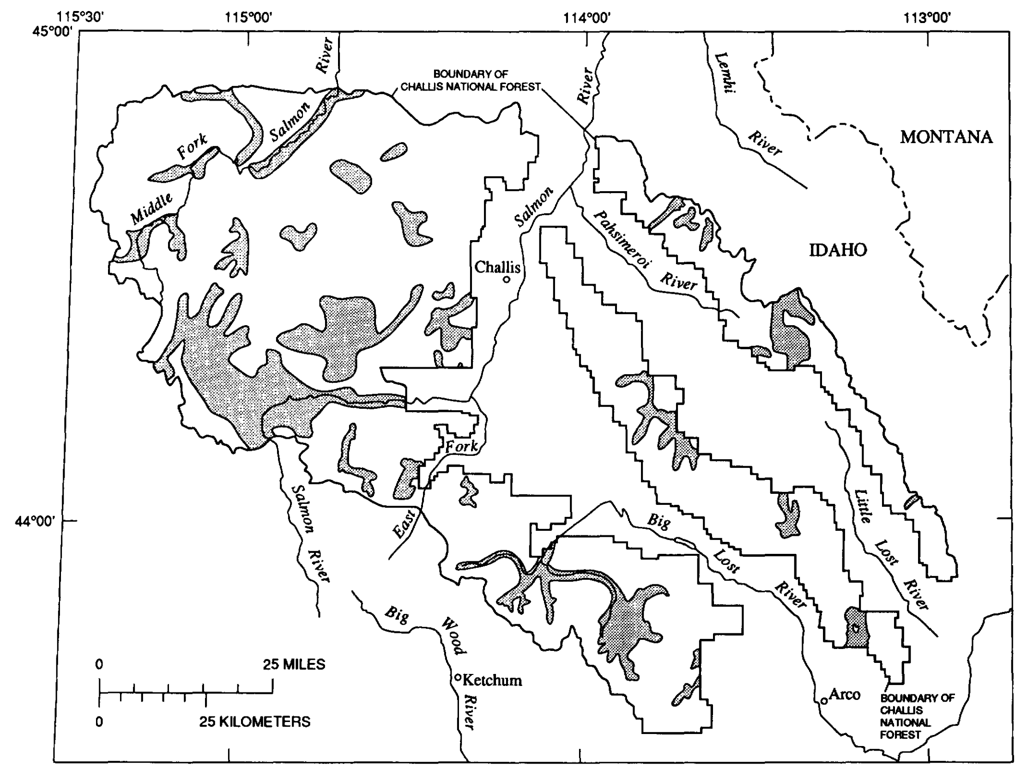


Figure 19. Tracts (shaded) permissive for occurrence of gold placer deposits.

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