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Metallic mineral resources in the U.S. Bureau of Land Management's Winnemucca District and Surprise Resource Area, northwest Nevada and northeast California

by

Stephen G. Peters[1], J. Thomas Nash[2], David A. John[3], Gregory T. Spanski[2], Harley D. King[2], Katherine A. Connors[1], Barry C. Moring[3], Jeff L. Doebrich[4], Dawn J. McGuire[5], George V. Albino[6], Victor C. Dunn[7], Ted G. Theodore[3], and Steve Ludington[3]

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[1] Reno, Nevada 89557
[2] Denver, Colorado 80228
[3] Menlo Park, California 94025
[4] Jeddah, 21431 Saudi Arabia
[5] Denver, Colorado; currently at 155 S. 33rd St., Boulder, Colorado 80303–3425
[6] Jeddah, 21431 Saudi Arabia; currently with SouthernEra, Toronto, Canada
[7] U.S. Bureau of Land Management, Winnemucca, Nevada 89445

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EXECUTIVE SUMMARY

This report presents results of a study conducted between 1992 and 1996 to assess the undiscovered metallic mineral resources in the U.S. Bureau of Land Management's (BLM) Winnemucca District and Surprise Resource Area (WSRA), northwest Nevada and northeast California. A wide variety of mineral deposits are present throughout the WSRA, and they are hosted by rocks and surficial deposits ranging in age from lower Paleozoic to Quaternary—that is, from approximately 570 million years (Ma) to about 1 Ma. The main metal commodities present in the WSRA, from a commercial standpoint, are gold, silver, and, to a lesser extent, tungsten. Gold currently accounts for most mining activities in the WSRA—production of approximately 1.2 million oz Au occurred from 10 mines during 1995. Eight of these 10 mines also produced approximately 7.4 million oz Ag for a combined annual gross value of approximately $550 million. Gold in the WSRA is produced mostly from three types of deposits: (1) sediment-hosted (Carlin-type) deposits, (2) hot-spring and vein-type epithermal gold-silver deposits, and (3) distal-disseminated silver-gold deposits. Some additional gold and silver production also is derived from a variety of less important types of mineral deposits, including minor production from placers.

Mineral discoveries since 1982 in the WSRA have included some extremely large deposits which are amenable to bulk-mining methods. These discoveries have encouraged additional exploration by private industry to proceed throughout the region. However, large areas in the WSRA covered by late Cenozoic unconsolidated deposits and volcanic rocks, which are generally younger than the age of gold mineralization, have presented both an obstacle and a challenge to exploration as well as to our assessment. Development of better techniques to assess the large alluvium-covered areas of the WSRA, at a reasonable cost to society, are essential both for exploration and for a thorough assessment of the resource potential of this mineral-rich region.

Types of mineral deposits in the WSRA are similar, in most cases, to worldwide models that have been synthesized previously in a number of other studies. There are some exceptions, however, and they are noted below. Major attributes of each deposit model are first outlined in this report; they are then followed by a description and discussion of those deposits in the WSRA which closely fit the essential characteristics of that model. Many types of deposits have a tendency to cluster in mining districts or groups of mining districts. This tendency can be represented by delineating prospective or favorable tracts within a more widespread region which is geologically permissive for each of the major types of metal deposits present. Clusters of deposits and their corresponding favorable and (or) prospective tracts also contain a number of characteristics which correspond with, and are associated genetically with, the geology of those tracts. Moreover, these deposit-specific geologic characteristics may be similar to the geology associated with a number of other groups of deposits. However, recognition of the differences among geologic environments associated with many deposits, as well as the physical and chemical signatures associated with specific types of deposits, allows us to make further judgments concerning the relative levels of favorability for the various types of metal deposits present in the WSRA.

Types of metal-bearing deposits in the WSRA include igneous-related ones, such as porphyry copper deposits and their commonly related skarn and polymetallic vein deposits, as well as placer deposits, which have been derived from them. Tungsten skarn deposits are also quite common in the region. Several types of porphyry copper skarn-related deposits are present in the Battle Mountain Mining District, the northern part of which is in the WSRA, and which appears to be part of a north-south alignment of mining districts near the east boundary of the WSRA. The alignment of these mining districts extends from the Potosi Mining District, on the north, to the McCoy Mining District on the south. Distal-disseminated silver-gold deposits—including the Lone Tree deposits and the Marigold deposits that cluster on the northern margin of the Battle Mountain Mining District—also are important current producers of gold, as are the carbonate- or sediment-hosted gold deposits along the Getchell trend in the Osgood Mountains part of the Potosi Mining District. The latter also includes the Twin Creeks gold deposits. Numerous, widely distributed hot-spring and epithermal precious metal deposits, as well as their related mercury and manganese occurrences, have considerable potential for future additional discoveries close to these occurrences. Uranium deposits are present as both volcanogenic and sediment-hosted deposits, as well as small occurrences of igneous-related uranium; the most significant uranium occurrences in the WSRA are associated with the McDermitt caldera complex near the north boundary of the WSRA. Low-sulfide gold-quartz vein deposits are confined mostly to a wide, north-trending mineral belt in the central part of WSRA that coincides with an area of ductilely deformed rocks that probably formed in the Late Cretaceous, at approximately 90 Ma. Massive sulfide deposits, potential exhalative sedimentary lead-zinc deposits, volcanic-hosted magnetite deposits, and

volcanogenic manganese deposits are present with specific sequences of rock mostly in the eastern and central part of the WSRA. Placer Au deposits are spatially associated mostly with low-sulfide gold-quartz vein deposits and with porphyry copper deposits, and they are distributed widely throughout the WSRA.

The assessment process used in this study begins with delineation of areas that are geologically permissive for the occurrence of deposits of a specific deposit type; it is then followed by an estimation of numbers of undiscovered deposits in those areas; and, finally, the process is concluded with a computer simulation to forecast commodity endowments associated with the undiscovered deposits. The assessment is conducted by a panel of experts who are knowledgeable about the area and the deposit types being evaluated and who select the types of deposit to be assessed. Each type of deposit is characterized by a descriptive model detailing the geologic attributes associated with it, and a grade and a tonnage model developed for the model. Grade of a mineral deposit refers to its quality. Higher grades mean more valuable component per unit mass of ore. Tonnage refers to the size of the deposit, meaning the amount of ore that is mined in order to extract the valuable components of the deposit. Tonnage reported for an ore deposit does not include any additional material that must be moved to physically get to the ore. This material, commonly referred to as waste, in many cases is substantially more than the amount of ore that constitutes a deposit. Grade and tonnage models are created using measured grades and tonnages of known economic deposits and non-economic occurrences of a particular type of deposit. When estimating the numbers of undiscovered deposits, it is assumed that all will have grades and tonnages consistent with the ranges in the models and that one-half of the undiscovered deposits estimated to be present will be above, and the other one-half will be below the respective median grades and tonnages for the particular model in question. A Monte Carlo computer simulation technique (Mark3) is used to combine the deposit estimates and model data to produce commodity and ore endowment projections that can be used by land managers and economists.

The team conducting the WSRA assessment possessed a combined 200+ years of cumulative experience relevant to the area. Following a review of the geologic, geochemical, and geophysical information as well as past and present mining activity, permissive terranes for 11 different classes of deposit were delineated. Within many of the permissive terranes, sub-tracts were delineated indicating the belief of the assessors in a higher probability of deposit presence. A prospective designation is assigned to areas of highest expectation and favorable to areas with an intermediate expectation of the presence of undiscovered deposits. Assessors made five estimates of the numbers of deposit expected at five levels of confidence ranging from 90 percent confidence to 1 percent, for each deposit type. The estimate at the 50 percent confidence (median value) is most representative of expectations for a given type of deposit by the assessors. In the WSRA, consensus median estimates of undiscovered deposits by the assessment team were four porphyry copper deposits, 22 hot spring gold-silver deposits, 35 distal disseminated silver-gold depositis, two porphyry molybdenum deposits, six sediment-hosted gold deposits, 35 tungsten vein deposits, two volcanogenic uranium deposits, nine hot spring mercury deposits, five polymetallic vein deposits, 30 Chugach-type, low-sufide gold-quartz vein deposits, and ten volcanogenic manganese deposits. In a few select situations where occurrence potential varies markedly across the WSRA, separate estimates for undiscovered deposits were made to highlight those differences. The Surprise Resource Area was estimated separately for several of the types of deposit to distinguish its very low potential for undiscovered mineral deposits and to meet the administrative needs of BLM.

Mark3 endowment results for all commodities and for all types of deposit are aggregated and the median and mean results are summarized below. They strongly emphasize the high probability of undiscovered precious metal deposits in the WSRA. The mean 77 million Troy ounces Au predicted represents a 64+ year supply at 1995 levels of production in the area. Nearly half of this mean simulated endowment is expected to be present in hot spring gold-silver deposits, another 28 percent is projected to be present in distal disseminated silver-gold deposits, 19 percent in sediment-hosted gold-silver deposits, 5 percent in porphyry copper deposits, and the remaining less than 1 percent in polymetallic vein and low-sulfide gold-quartz vein deposits. In addition to their gold content, the distal disseminated silver-gold deposits are projected to contain 63 percent of the 750 million ounce Ag endowment simulated for the area. As a group, the hot spring gold-silver, distal disseminated silver-gold, sediment-hosted gold-silver, and porphyry copper deposits account for 97 percent of the silver, 99 percent of the gold, and 100 percent of the copper endowments in the WSRA. In terms of environmental impact, this same group is expected to generate 3.7 billion tonnes of ore during the recovery of the latter endowments, or 86 percent of the ore volume projected for all of the estimated deposit types in the WSRA. By comparison the endowments predicted for remaining lead, zinc, mercury, uranium oxide, iron, tungsten trioxide, and manganese abundances are small. The latter group of metals and deposits are not expected to be a source of serious concern for planning in the near term.

Total mineral commodities and tonnage of ore in 11 types of undiscovered metal deposits estimated within the WSRA, Nevada-California (in metric tonnes or, in parentheses, in millions of Troy oz)

Commodity	*Median (50 percent)*	*Mean*
Gold	2,200 (72)	2,400 (77)
Silver	22,000 (700)	23,000 (750)
Copper	6,300,000	11,000,000
Molybdenum	430,000	670,000
Lead	24,000	56,000
Zinc	11,000	40,000
Mercury	5,500	9,900
Uranium oxide	2,400	8,700
Iron	0	270
Tungsten trioxide	9,400	14,000
Manganese	24,000	69,000
Phosphorus	0	870
Ore	3,600,000,000	4,300,000,000

Estimates above are of minimum amounts of metal, metal oxide, or ore contained in all undiscovered types of deposit considered.

Evaluation of the environmental impacts that may be posed by exploitation of any of these simulated endowments is more complex. In arriving at an estimate of numbers of deposits, a 1–km-depth criterion was used. It is therefore correct to assume, as a first approximation, that the estimated population of undiscovered deposits is distributed uniformly throughout this vertical interval unless there are lithologic or structural controls limiting distribution. The latter is probably closer to reality than the former because of the strong tendency for deposits to cluster due to structural controls and other factors. For many types of deposits, mining economics will preclude exploitation of the more deeply buried fraction of the estimated numbers of undiscovered deposits. For example, hot spring gold-silver deposits are mostly mined by open pit methods. Therefore, many undiscovered deposits estimated to be present in the WSRA may be too deep to develop economically with current or reasonably inferred future technologies. In this case, the environmental impact of disturbing an estimated mean 710 million mean tonnes of ore associated with the hot spring gold-silver deposits is not likely to be realized. In addition, it is not likely that all deposits present in the WSRA to a depth of 1 km will be found, regardless of future advances in exploration methodologies, because of the immense problems associated with exploration under thick post-mineral cover.

The reader is asked to exercise extreme care in using the predictive results presented in this assessment. The significance of any single value is lost without the accompanying probabilistic meaning, as well as without the geologic basis for the estimate, including data limitations and conceptual limitations.

INTRODUCTION

Resource assessments or evaluations of tracts of land, as defined in the section below entitled "Definitions," can have a wide variety of societal applications. They are of use to long-range strategic planners, who plan for a nation's mineral supply and national security; to economic planners, who estimate current and future mineral supplies and plan development to sustain prosperity as well as attempt to improve the quality of life; to mineral-production companies, who use them to guide and to help plan mineral-exploration programs; to governmental land-management agencies, who use them to help make decisions among competing land uses; and, finally, to other public agencies, who have the responsibility to lease, trade, or sell publicly-owned mineral resources or to preclude development of mineral resources. As pointed out by the National Research Council (1996a), sustainable development of mineral resources provides a challenge for earth scientists to develop the best available data and to provide a scientific basis requisite for both public policy decisions and management of the environment. Furthermore, development of mineral deposits by private industry in the United States now requires environmentally sound methods of extraction that must be balanced with alternative land-use decisions (National Research Council, 1996b). Our goal in the present study is to assess the undiscovered metallic mineral resources in the U.S. Bureau of Land Management's (BLM) Winnemucca District and Surprise Resource Area (WSRA), which includes all of northwestern Nevada and a much smaller part of northeastern California (figs. 1, 2). The Winnemucca District is made up of the Paradise-Denio and Sonoma-Gerlach Resource Areas (pl. 1). This immense region—totalling some 13.5 million acres—was examined during 1992–1996 by the U.S. Geological Survey, at times subject to severe budgetary limitations. These investigations are the result of joint interagency Memoranda of Understanding among the U.S. Geological Survey, the former U.S. Bureau of Mines (abolished in early 1996), and BLM. On the basis of a national ranking of the exigency for Resource Management Plans (RMPs) of various BLM–administered lands, as required by the Federal Land Policy and Management Act of 1976 (FLPMA), BLM designated the WSRA in 1991 as having its highest priority for the creation of a RMP by 1998. In mid–1996, BLM rescinded its time line for creation of all RMPs. In addition, the Geologic Division of the U.S. Geological Survey underwent a reduction in force in late 1995, which compounded the difficulties of final preparation of this report. Some participants during early stages of the study were terminated during the reduction in force.

We herein present (1) a state-of-the-art classification of the land encompassed by the WSRA, and (2) quantitative estimates of the undiscovered metal resources in the land that is to be evaluated in the overall RMP. During the course of the investigation, BLM at one time requested a separate evaluation of the Black Rock Desert-Emigrant Trail area of withdrawal—the High Rock National Conservation Area—this request subsequently was delayed; however, the results of the evaluation for this withdrawal area are incorporated into this report. In addition, the present report should be read in conjunction with five other recently released reports, one by Doebrich (1996), which presents a succinct description of the geology of the WSRA and its relation to the genesis of contained mineral resources; other reports by King (1996) and King and others (1996), which describe the relations of regional stream-sediment geochemistry to mining districts; a report by Nash (1996), which describes non-metallic mineral resources in the WSRA.; and, finally, a report by Raines and others (1996), which presents color-infrared and color-ratio composites of northwestern Nevada. An assessment of mineral resources, which is defined below in the subsection entitled "Definitions," can take many forms. The simplest assessment might reduce to a statement such as, "Yes, this is a good place to look for minerals," primarily because the rocks look "different" to a prospector. However, other assessments might include an exhaustive, as well as elaborate, inventory of the location, nature, and amount of known resources together with a highly sophisticated subsequent application of the latest exploration methodologies involving geology, geochemistry, and geophysics—the latter including computer-processed, remotely sensed data. All of these indirect evaluations would be followed commonly by a direct examination of the rocks at depth by drilling, if the preliminary evaluations concluded that additional exploration expenditures were warranted.

Estimates of metal endowment may be either qualitative or quantitative. Qualitative estimates of the mineral content of specific areas have been undertaken for decades, if not centuries, and generally employed favorability designations such as "high," "medium," or "low" (Hansen, 1991). All systematic mineral exploration requires decisions about the relative favorability of alternative tracts of ground. Our assessment of undiscovered mineral resources in the WSRA carries the evaluation into the quantitative realm as has been done previously in the U.S. Geological Survey (Singer, 1990, 1992, 1993; see also, Drew and others, 1986; Singer and Cox, 1988; Brew and others, 1991; Root and others, 1992; U.S. Geological Survey Minerals Team, 1996).

Quantitative estimates of the endowment of all of Nevada also have been completed recently (Cox and others, 1996), and the data contained in that report have been utilized heavily in the preparation of the present one. A **quantitative assessment** provides a numerical estimate of the amount and quality of mineralized rock, as well as its contained metal, present within a tract (a specific area that is generally bounded by some geologic entity) to a certain depth. In this report the depth chosen is 1 km, which is consistent with the depth selected for the previous study of the entire state, and with likely mining scenarios in the foreseeable future. However, because of uncertainties inherent in assessments of unknowns, the results obtained are presented probabilistically. Because the resources being assessed are undiscovered, the assessment is necessarily subjective, and its quality is dependent on the collective knowledge and experience of the assessors. An assessment may be well done or poorly done, but because of the probabilistic nature of the results obtained, it cannot be right or wrong. Thus, it is clearly an estimate and not a precise measurement. In the present investigation, the combined expertise of the evaluators amounts to more than 200 person-years experience with the geology, geochemistry, and genesis of a wide variety of mineral deposits.

Definitions of terms used in report

Definitions and concepts pertinent to this resource evaluation are described elsewhere (Cox and others, 1986; John and others, 1993; Theodore, 1996a). In the present report, the definitions put forth by Cox and others (1986) for the terms "ore deposit", "mineral deposit", and "mineral occurrence" are modified somewhat. Specifically, a **mineral occurrence** is "***a concentration of a mineral***that is considered valuable by someone somewhere or that is of scientific or technical interest." However, use of this definition does not imply economic value by the U.S. Geological Survey for the mineral occurrences considered in this report. A **mineral deposit** is "***a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential," a corollary being that drilling has tested the system in the third dimension to the point that a grade and tonnage can be assigned to the volume of rock with some level of confidence. An **ore deposit** is "***a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit." The inclusion of the concept of "profit" in this description put forth by Cox and others (1986) and many others may lead to contradictions when applied to estimates of speculative resources present in an area, because national needs might require extraction of some metals under circumstances that do not yield a financial profit to society as a whole or even to some segment of society (see subsection below entitled "Tungsten-skarn Deposits"). When estimates described below of the numbers of a particular type of deposit either present in a region or present in a favorable area for that deposit are made, then all existing occurrences—regardless of size and prior mining history—are treated as unknowns by us if either the grade or the tonnage at the site is not available to us (Singer, 1993). An ore deposit is the economic, measured and demonstrated, identified-resource part of the resource-reserve classification scheme adopted by the U.S. Bureau of Mines and U.S. Geological Survey (1980). Furthermore, the grade and tonnage of an ore deposit is not necessarily the same as the "geologic resource" of the deposit. The geologic resource includes the grade and tonnage of the mineralized volume of rock, beyond some minimal cutoff grade, that has not been constrained by economic-limiting factors such as topography, site location with regards to existing infrastructure, or beneficiation parameters; the mineralized volume of rock is commonly broken down by variable grades and includes the ore deposit itself (see also, Peters, W.C., 1978). The **reserves**, either measured or indicated, are the demonstrated economic portion of the identified resources in a mineralized system (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Additional categories of reserves can be based on the economics and (or) probability of their presence. As pointed out by Bailly (1981), five major factors are generally involved in the determination as to whether or not a deposit becomes an economic reserve: (1) existence of the deposit, (2) extractability of the elements of value from the deposit, (3) availability of energy and materials for extraction of the elements of value, (4) acceptable environmental requirements, and (5) favorable economics for a potential mining operation at the site of the deposit. In this report, discussion of the various types of deposits are concluded by a short description of our subjective estimates of the overall endowment of the WSRA for the metal commodities usually found in that particular model type. We emphasize that these estimates are current as of the time of this writing (1996) and that future mineral discoveries may alter the judgments made herein with respect to metal endowments.

Mineral occurrences, mineral deposits, and ore deposits are classified further into various types on the basis of descriptive mineral-deposit models that are contained primarily in Cox and Singer (1986), and Kirkham and others (1993), as well as a number of other model-specific reports. The mineral-deposit models are based on groups of mineral deposits that have in common both a relatively wide variety and a large number of attributes, as well as formation or emplacement in a common geologic environment. Table 1 lists mineral occurrences identified in the WSRA by model type and the appropriate references to descriptive models for these deposit types.

Grade-and-tonnage frequency-distribution models contain data for grades and tonnages for groups of mineral deposits from which grades and (or) tonnages at various percentiles may be extracted. They are useful in numerical resource assessments (Singer, 1990, 1992, 1993; see also, Drew and others, 1986; Singer and Cox, 1988; Root and others, 1992; Brew and others, 1991) by providing information about the potential metal content of undiscovered deposits that might be present within a tract of land permissive for a given type or model. The models also are used in economic analyses of these resources, provided that (1) estimates may be made, with some confidence, concerning the number of individual deposits that may be present within that given tract of land, and, further, that (2) any undiscovered deposits have grade and tonnages that are within the limits of the grades and tonnages of the ore-deposit model under consideration. **Grade-and-tonnage models** typically are frequency cumulations; grade is based on average grades of each metal or mineral commodity for an individual deposit, and the associated tonnage is based on the total of past production, reserves, and resources at the lowest possible cutoff grade (Singer, 1990). However, there apparently is even now (1996) some immaturity in the tonnage curves available for the economically important Carlin-type of gold deposits because of the inconsistency between the extremely large tonnages present at the Gold Quarry-Maggie Creek and Betze-Post-Genesis clusters of deposits and the remaining deposits that make up the tonnage curve (Singer, 1993). As pointed out by Singer (1993), many of the other deposits that contribute to this tonnage curve may not be fully explored.

Grade-and-tonnage distribution models currently are usually developed simultaneously by many workers as an integral part of the descriptive aspects of the models (Cox and Singer, 1986). When sufficient grade-and-tonnage data are available to build a model, the grade-and-tonnage data can help refine descriptive mineral-deposit models (Singer, 1990, 1993). Singer (1990, 1993) discussed in detail the formulation of grade-and-tonnage models and some of the problems associated with their development and use. With regard to the WSRA, one major shortcoming of present grade-and-tonnage models involves the bulk mineable, volcanic-hosted gold-silver deposits (John and others, 1993) such as are present in some parts of the WSRA. A lack of sufficient grade-and-tonnage data for these types of deposits, at one time, resulted in the retention by Cox and Singer (1986) of an artificial division of volcanic-hosted deposits into Comstock (adularia-sericite), quartz-alunite (acid-sulfate), and hot-spring types, and all bulk mineable, volcanic-hosted gold-silver deposits were classified as hot-spring deposits (D.A. Singer, oral commun., 1990). However, grade-and-tonnage models for hot-spring gold-silver deposits were derived subsequently by Berger and Singer (1992). In a genetic sense, hot-spring deposits are shallow-level end members of adularia-sericite and quartz-alunite deposits as described by Berger and Henley (1989), and, with continued discoveries of adularia-sericite and quartz-alunite mineralized systems, hot-spring deposits will probably cease to have a separate grade-and-tonnage model (John and others, 1993; see also, Albino, 1994).

Mineral Deposits

A wide variety of mineral-deposit types are present in the WSRA, and they are hosted in a wide variety of geologic environments whose rocks range in age from Lower Paleozoic to Quaternary (pl. 1; table 1). The main commodities produced in the past in the WSRA were gold, silver, and tungsten. Gold presently (1996) accounts for most current mining activity in the WSRA—in 1995, 1.272 million oz Au were produced from 10 of 17 operating mines in the WSRA (Nevada Division of Minerals, 1996). In addition, of these 10 mines, eight yielded a combined total of 7.419 million oz Ag. The seven other non-metal mines produced variable amounts of specialty limestone, precious opal, diatomite, gypsum, and dolomite (Nevada Division of Minerals, 1996). All of this raw mineral production from the WSRA in 1995 had a gross value of more than $550 million. Gold is produced mostly from three types of deposits: (1) sediment-hosted (Carlin-type) deposits, (2) hot-spring and vein-type epithermal gold-silver deposits, and (3) distal-disseminated silver-gold deposits. Some additional gold and silver production is derived from a variety of less important types of mineral deposits, including placer Au deposits (tables 1, 2). Nevada, in 1995, produced 6.76 million oz Au worth $2.6 billion, and 24.6 million oz Ag worth $127.7 million (http://www.aztech-cs.com/nvmining/econ_overview_95.html, Sept. 16, 1996). This production of gold from 38 producing precious metal mines in Nevada during 1995 amounted to approximately nine percent of world production.

Discoveries of mineral deposits in the WSRA since 1982 have included some of the largest deposits now known to be present in it, which has encouraged additional exploration to continue throughout the region. In addition, since 1990 in the northeast corner of the WSRA, many large ecomomic gold deposits have been discovered in bedrock beneath Tertiary and

Quaternary unconsolidated sand, silt, and fanglomerate. The large areas underlain by late Cenozoic basin-fill sediments and volcanic rocks present both an obstacle and a challenge to exploration, as well as to us during the course of our assessment. Development of better techniques to assess the large alluvium-covered areas of the WSRA certainly are essential both for exploration and for proper assessment of the resource potential of this mineral-rich region, but these techniques are currently beyond the limited budgets available. In May, 1996, Hecla Mining Company and Santa Fe Pacific Gold Corporation announced that they had entered into an agreement to develop jointly the Rosebud gold deposit, a deep occurrence of gold in the general area of the Kamma Mountains in the central part of the WSRA (fig. 2). This announcement reinforces our judgment that the general region of the WSRA is one that continues to attract significant attention from the mining segment.

Previous work

The WSRA has been the site of numerous geologic investigations. Early reports on the geology and mineral resources within the WSRA reflect the significant mineral production and interest by the mineral-exploration sector of the mining industry in the region. Geology and mineral resources are summarized in various county reports for this part of Nevada (Ransome,1909; Ferguson, 1929; Vanderburg, 1936a, 1938, 1940; Overton, 1947), as well as the subsequent updates (Willden, 1964; Bonham and Papke, 1969; Willden and Speed, 1974; Johnson, 1977). In addition, wide-ranging summaries and classifications of mining districts overall Nevada include most known clusters of mineralized areas in the WSRA. These summaries were prepared by Hill (1912), Lincoln (1923), Ferguson (1929), Stoddard (1932), Schilling (1976), Wong (1982), and most recently by Tingley (1992), whose mining-district boundaries in Nevada are followed in this report (pl. 1). Mining districts in California have been summarized by Hill (1915a) and Clark (1963). Gay (1966) described the mineral deposits and geology in northeastern California. Statewide mineral resources in Nevada previously were inventoried and summarized by the U.S. Geological Survey and Nevada Bureau of Mines (1964). Mineral resources in the California part of the WSRA also were summarized by MacDonald and Gay (1966).

A number of relatively recent studies of mineral resources in the WSRA are somewhat more site specific than the generally regional compilations cited above. Some of these studies result from Geological Society of Nevada Symposia which have highlighted recent discoveries and active mines (Schafer and others, 1988; Raines and others, 1991; and Buffa and Coyner, 1991; Coyner and Fahey, 1996). Several other general studies of ore-deposit distribution and metallogeny within and surrounding the WSRA include Roberts and Arnold (1965), Roberts (1966), Jerome and Cook (1967), Proffett (1979), Rowan and Wetlaufer (1979), Kutina (1980), Blakely and Jachens (1991), Seedorff (1991), and Thorman and Christensen (1991). Another study that summarizes mineral resources in the southwest part of the WSRA is the exemplary report by John and others (1993).

General studies conducted for the U.S. Bureau of Land Management, which relate specifically to Wilderness Study Areas (WSAs) in the WSRA, are summarized by Barringer Resources Inc. (1982) and Connors and others (1982). Subsequent investigations by the U.S. Bureau of Mines and U.S. Geological Survey of these WSAs are summarized by Marsh and others (1984) and by Conrad (1990). Bonham and others (1985) conducted a mineral inventory in the Paradise-Denio and Sonoma-Gerlach Resource Areas of the WSRA, and Garside and Davis (1992) inventoried mineral resources in the Nevada part of the Susanville Resource Area in the western part of the WSRA. The U.S. Bureau of Land Management (1984) summarized mineral resources and potential for the WSAs in the California part of the WSRA. Miller (1993) conducted an inventory of mineral occurrences and a study of mineral-resource potential in the proposed High Rock National Conservation Area. Resource potential for precious opal, uranium, mercury, and gold in the Charles Sheldon Antelope Range and Sheldon National Antelope Refuge are included in the reports by Greene (1976, 1984) and by Greene and Plouff (1981). Site-specific studies of individual WSAs in the northern part of the WSRA are summarized in table 1. A study of the mineral potential of Nevada has been conducted (Ludington and others, 1993; Cox and others, 1996), and substantial data from that study have been incorporated in parts of this study. A preliminary summary of progress during the present investigation is contained in Doebrich and others (1994).

Geologic history of mineral deposition

The distribution and genesis of mineral occurrences and ore deposits in the WSRA are directly related to evolution of the complex geology of the area. The mineral potential of the area and estimation of undiscovered mineral deposits, furthermore, are linked to the distribution of rock types and geologic environments, which host the ore deposits, by means of metallogenic principles that are well described by Ramovic

(1968), Shcheglov (1979), Laznicka (1985), Cox and Singer (1986), and Kirkham and others (1993). Similarly, the continental-scale tectonic setting and evolution of a region is linked directly to the type and distribution of mineral deposits in that region as discussed by Mitchell and Garson (1981), Tarling (1981), and Hutchinson (1982) and many others. In the following parts of this subsection, we will synthesize briefly some of the major features of the regional geology of the WSRA as described by Doebrich (1996).

The geology and mineralized rocks of the WSRA from the Proterozoic Eon through the Jurassic Period are the result of a protracted series of tectonic events, and these events can be correlated with a number of internally consistent, regionally extensive terranes. Pre-accretionary autochthonous basement in the WSRA presumably includes metamorphosed late Proterozoic and Cambrian Osgood Mountains Quartzite, Cambrian Preble Formation, Ordovician Comus Formation, and some Late Cambrian and Early Ordovician unnamed rocks that crop out in structural windows in the East Range (Doebrich, 1996; see also, Stewart, 1980). All of these rocks are present in relatively small areas in the eastern part of the WSRA, both to the northeast and south of the city of Winnemucca, and they are, in places, the sites of minor syngenetic volcanogenic massive sulfide (VMS) deposits and barite deposits. The autochthonous rocks were subsequently overidden by a number of accretionary terranes—initially during the Late Devonian to Mississippian (Antler orogeny and Roberts Mountains thrust), and subsequently during the Late Permain to Triassic (Sonoma orogeny and Golconda thrust) (Roberts and others, 1958; Silberling and Roberts, 1962).

Accretionary terranes that comprise the Roberts Mountains allochthon may locally contain bedded barite deposits and VMS deposits. The lower Paleozoic allochthonous rocks accreted during the Antler orogeny are overlain unconformably by the autochthonous Pennsylvanian and Permian Antler sequence of Roberts (1964), which also is referred to as a late Paleozoic overlap assemblage. These rocks provided chemically reactive hosts for a number of large epigenetic base- and precious-metal deposits.

The Devonian, Mississippian, Pennsylvanian, and Permian Havallah sequence makes up the upper plate of the Golconda allochthon, which crops out over a relatively wide area in the eastern and southeastern parts of the WSRA (Doebrich, 1996). Devonian (?) and (or) Mississippian basalt and basaltic andesite in the Golconda allochthon locally may host Cyprus-type VMS deposits as well as volcanogenic manganese deposits. The deformed rocks of the Golconda allochthon are, in turn, overlain unconformably by Triassic autochthonous rocks—a lower sequence made up of the Late Permian and Early Triassic volcanic and volcaniclastic Koipato Group, and an upper sequence made up of Early and Late Triassic shelf and platform rocks of the Star Peak Group. These rocks crop out in a 2,500–km^2 area south of Winnemucca that extends from the East Range southeast to the Augusta Mountains, and from the Humboldt Range east to the northern part of the Tobin Range (fig. 2). Triassic autochthonous rocks in the WSRA host a wide variety of epigenetic mineral occurrences, which include low-sulfide gold-quartz vein, hot-spring gold, tungsten skarn, and polymetallic vein deposits.

Allochthonous pelitic basinal sedimentary and mafic plutonic rocks range in age from the Late Triassic to Middle Jurassic, and crop out discontinuously in a broad northeasterly trending area, approximately 10,000 km^2, that is known as the Jungo terrane of Silberling and others (1984, 1987) or the Fencemaker allochthon (Speed, 1978; Elison and Speed, 1988; Oldow and others, 1990). The Jungo terrane, whose sedimentary strata are made up of the upper parts of the Late Triassic and Early Jurassic Auld Lang Syne Group of Burke and Silberling (1973), extends northeast from the south end of the Truckee Range to the Santa Rosa Range (fig. 2). The sole structure of the Jungo terrane is the Fencemaker thrust, which was active from Middle Jurassic through Early Cretaceous (Oldow, 1984). Syngenetic mineral occurrences in evaporitic strata of the Fencemaker allochthon include a number of gypsum deposits (Nash, 1996), and epigenetic occurrences in the allochthon include tungsten skarns, iron endoskarn or plutonic-hosted magnetite deposits, low-sulfide gold-quartz veins, polymetallic veins, and epithermal gold-silver and antimony veins (Doebrich, 1996).

The Jungo terrane is bounded on the northwest by the Black Rock terrane (Silberling, 1991), which is a middle (?) and late Paleozoic and Mesozoic arc-related sequence of mostly andesite, basaltic andesite, diorite, and quartz diorite, as well as volcanogenic sedimentary rocks and pelitic clastic rock, chert, and limestone (Doebrich, 1996). This terrane hosts a number of epigenetic mineral occurrences, including tungsten skarns, low-sulfide gold-quartz veins, and volcanic-hosted magnetite deposits.

The above terranes subsequently were intruded by widely scattered Jurassic and Late Cretaceous plutons, associated with continental compressional regimes, and Tertiary granitic rocks, associated with extensional regimes concomitant with the breakup of the area now encompassed by the Great Basin (Armstrong and others, 1969;

McKee, 1971; Christiansen and others, 1992). Some of these Mesozoic and Tertiary intrusions host, or have generated, porphyry-related copper and molybdenum deposits, tungsten deposits, and base- and precious-metal deposits in the WSRA and, as well, throughout much of the Great Basin.

A gap in the geologic record, lasting from about 70 Ma to about 40 Ma, precedes the beginning of extension and Tertiary magmatism in the Great Basin (Seedorff, 1991). At Battle Mountain, near the east boundary of the WSRA (fig. 2), the onset of this extension has been well documented to have occurred at about 40 Ma (Theodore and others, 1973; Theodore and Blake, 1975). The first intrusive rocks, which were emplaced at approximately 40 Ma to 38 Ma, immediately following the magmatic and tectonic gap in the Great Basin, are associated with important base-metal and gold deposits near the east boundary of the WSRA in the area of Battle Mountain and the Fish Creek Mountains (fig. 2). These intrusive rocks formed the initial intrusive phases of a continental magmatic arc—the interior andesite-rhyolite assemblage (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993)—that continued to be active to about 20 Ma.

The Cenozoic in the Great Basin also was a time in the geologic record when volcanic activity was widespread. This volcanic activity includes (1) a late Eocene to early Miocene (40 Ma to 20 Ma) interior andesite-rhyolite assemblage associated with a continental arc; (2) an early and middle Miocene western andesite assemblage; and (3) a middle Miocene to Holocene bimodal basalt-rhyolite assemblage (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993). In the WSRA, rocks belonging to the andesite-rhyolite assemblage are most widespread in the Black Rock Range (fig. 2), where volcanism began at approximately 25 Ma and is represented by rhyolite and much lesser basalt (Doebrich, 1996). However, the most voluminous rocks of the interior andesite-rhyolite assemblage near the WSRA are present outside the southeast border of the WSRA where they extend from the Stillwater Range on the south, through the Augusta Mountains and the Fish Creek Range, and eventually to the Battle Mountain area (Doebrich, 1996). The rocks in these ranges form the broad terminus of a southeast-trending belt of the andesite-rhyolite assemblage (Stewart and Carlson, 1976). The andesite-rhyolite assemblage also is present in the Pah Rah Range, outside the southwest border of the WSRA (fig. 2). Volcanic rocks of the andesite-rhyolite assemblage do not host any significant mineral occurrences in the WSRA (Doebrich, 1996). However, economically important Carlin-type gold deposits in the eastern part of the WSRA are considered by many (Seedorff, 1991, and many others) to have an approximate 38– to 40–Ma age, and to be related to regional crustal processes involving evolved meteoric waters associated with initial extension of the Basin-and-Range Province (Hofstra and others, 1990; 1991a; 1991b), or, in a small number of deposits, deeply sourced metamorphic or magmatic ore-forming fluids (Cline and others, 1996).

Rocks belonging to the early and middle Miocene western andesite assemblage (approximately 20 Ma to 12 Ma) are present in the WSRA only in the general area of the Calico Mountains, the Granite Range, and the Hays Canyon Range (fig. 2). These rocks are related to the Cascade magmatic arc (Christiansen and others, 1992), and, within the WSRA, they include generally sparse mineral occurrences, although there are some polymetallic veins are present in the Calico Mountains (Doebrich, 1996).

Rocks of the middle Miocene to Holocene bimodal basalt-rhyolite assemblage (approximately 17 Ma to <1 Ma) comprise, by far, the most voluminous of the three volcanic assemblages present in the WSRA (Doebrich, 1996). This assemblage includes large eruptions of peralkaline magma to form large ash-flow sheets in the northern part of the WSRA. The assemblage also includes eruption of widespread basalt flows, locally accompanied by felsic domes (see also, Noble and others, 1970; Noble and others, 1973; Noble, 1988), and resulted in formation of several calderas—Cottonwood Creek volcanic center, Badger Mountain caldera, and McDermitt caldera (Doebrich, 1996)—respectively in the western, northwestern, and northern parts of the WSRA. The bimodal basalt-rhyolite assemblage rocks are associated with hot-spring and sub-hot-spring precious metal deposits and mercury deposits, as well as a number of volcanogenic uranium deposits that are in rocks comprising the moat at the McDermitt caldera (Rytuba and Glanzman, 1979).

Approximately one half of the WSRA is covered by unconsolidated Tertiary and Quaternary basin-fill deposits and lake-bed deposits (Doebrich, 1996; see also, Russell, 1885; Van Houten, 1956). These deposits, in places, host gold-placer and sedimentary uranium deposits, and they also have concealed a number of epithermal gold deposits, Carlin-type gold deposits, and distal-disseminated silver-gold deposits near some mountain-range fronts.

Classification of mineral-deposit tracts

Mineral-resource assessments for undiscovered mineral resources in various parts of the WSRA by the U.S. Geological Survey have previously examined either small Wilderness Study Areas (WSAs) (Conrad, 1990), large areas for the Conterminus United States Mineral Assessment Program (CUSMAP) studies on 1° X 2° quadrangles (John and others, 1993), or even larger regional areas—some of which are statewide assessments (Cox and others, 1996). Small WSAs were previously assessed using a methodology designed in the 1980s that used levels of mineral-resource potential and certainty-of-assessment concepts of "high," "moderate," and "low," as well as "no mineral potential" and "unknown mineral potential." Hansen (1991), following Taylor and Steven (1983), defines these levels of potential as follows:

> "**Low potential** is assigned to areas where geologic, geochemical, and geophysical characteristics define environments in which the existence of resources is unlikely. This broad category embraces areas that have dispersed but insignificantly mineralized rock, as well as areas that have few or no indications of having been mineralized.
>
> **Moderate potential** is assigned to areas (1) where geologic, geochemical, and geophysical characteristics indicate environments favorable for resource occurrence, (2) where interpretations of data indicate a reasonable likelihood of resource accumulation, and (3) where application of knowledge of types of mineral deposits indicates favorable ground for specific types of deposits.
>
> **High potential** is assigned to areas (1) where geologic, geochemical, and geophysical characteristics indicate environments favorable for resource occurrence, (2) where interpretations of data indicate a high degree of likelihood for resource accumulation, (3) where knowledge of types of mineral deposits supports determinations of the presence of resources, and (4) where data indicate that mineral have concentrated in at least a part of the area. Resources or deposits need not be identified for an area to have high resource potential."

These levels of mineral potential also have been applied in the past to some of the CUSMAP 1° X 2° quadrangles studied (Gair, 1989). However, many assessments undertaken by the U.S. Geological Survey more recent than these have used the concepts of permissive terranes and favorable tracts, which terms are defined below, in combination with estimates of numbers of undiscovered deposits, in order to quantify predicted resources (Menzie and Singer, 1990; Singer, 1993).

In our assessment, we have tried to combine useful aspects of both systems, recognizing that current land-planning needs of BLM require judgments about differing levels of favorability within permissive areas. The classification of tracts and their relative ranking in the WSRA utilized in this report contain four categories of prospectiveness and favorability for undiscovered deposits of each deposit model evaluated. It must be kept in mind that the tracts which outline the four categories are three-dimensional and extend to 1-km depths. However, in some local areas of Nevada—for example, along the Carlin Trend of gold deposits in northeastern Nevada—many exploration holes currently (1996) are being drilled routinely to approximately 1-km depths. Nonetheless, in the WSRA, such exploration methodologies are not yet wideapread because of a number of reasons, which include the economics involved with the environmentally sound disposal of any waters extracted from any deep mineralized rocks present in the basins. For each type of mineral deposit, tracts were delineated as follows:

Non-permissive (O)—Areas where the type of mineral occurrence or deposit in question is judged extremely unlikely to be present are termed "non-permissive" on the basis of the understanding of geology by the evaluators when the evaluation was conducted. This category is equivalent to "no mineral-resource potential" at the time of the evaluation in the assessment scheme employed during the preparation of previous WSAs. In other words, the geologic environments of the rocks present in the area are not compatible with a known process of mineralization, or perhaps the age of mineralization, which is understood to be a requisite attribute for the formation of the type of mineral occurrence or deposit under consideration. This ranking also is depth dependent, inasmuch as we consider all volumes of rock below a depth of 1 km to be non-permissive for the presence of any type of metallic resource. Thus, areas on plates 2–11 where alluvium or other post-mineral cover exceeds 1-km thickness are also designated as being non-permissive (see also, Jachens and Moring, 1990; Jachens and others, 1996). They are unpatterned on the plates, and they are generally outside the tracts designated permissive, favorable, and prospective, although there are many instances on the various tracts where a non-permissive domain has been excised through the others because bedrock is apparently at depths greater than 1 km. These non-permissive areas are highly unlikely to be the site of serious mineral exploration and development for the types of deposit being considered herein on the basis of the data available to us.

Permissive (L)—"Permissive terranes" are areas that might contain a certain type of mineral occurrence to a depth of 1 km. Any geologic terrane or geologic environment in the WSRA that is geologically similar to another terrane in the study area or elsewhere, or environment containing mineral deposits that generally formed at the same time as that terrane or environment is considered permissive for the same type of mineralized rocks, whether or not any signs of mineralized rock are present in the area. Some permissive areas are very broadly outlined because their geologic environments that are conducive to the hosting of mineral occurrences in the WSRA are wide ranging. For some types of mineral systems, we cannot demonstrate that a particular type of mineral occurrence actually is present within all areas shown as permissive for that occurrence. Permissive terranes are delineated areally by the geologic environments of mineral formation described in the respective deposit model, such that there is roughly less than 1 in 100,000 to 1,000,000 chance that undiscovered deposits of that particular type are present *outside* the tract. Permissive terranes include favorable and prospective areas. Thus, permissive areas are judged to contain virtually all of the undiscovered deposits to be predicted below. Unless noted as containing favorable or prospective tracts, permissive areas have a ranking that also is comparable to "low" of the WSA assessments mentioned above, and this designation is applied to areas where no geological feature prohibits the presence of a given deposit type. Permissive tracts for igneous-related and hot-spring deposit models for the WSRA are modified from Ludington and others (1993), who, in turn, used data from Jachens and Moring (1990) and Blakely and Jachens (1991). This classification also covers areas where levels of uncertainty may be very high and is therefore sometimes equivalent to the "unknown mineral resource" classification used in the WSAs.

Favorable (M)—"Favorable tracts" are domains within permissive terranes and which are known to contain some positive indications either that a mineralized system, generally irrespective of overall size or grade, is present or that mineralizing processes have occurred. These tracts are qualitatively judged to be areas that have a higher probability of occurrence for the type of deposit under question. Evidence for making such a judgment may include, for example, the presence of some known mined deposits and some mineral occurrences, presence of hydrothermal alteration known to be restricted to a certain type of mineralized system, and presence of plutons of an age and chemical signature that are associated with known mineralized systems elsewhere—these are all considered characteristics for the potential presence of some type of mineralized system in an area. Because positive indications that some type of ore-forming processes have occurred are required to designate an area as favorable for a mineralized system or mineral-deposit model, favorable tracts are commonly of a much smaller areal extent than permissive areas and are more likely to contain undiscovered mineral resources of that type of model. The absence of any recent discoveries of major mineral occurrences in those areas designated as favorable may be interpreted to indicate a diminished likelihood for the presence of any future additional discoveries of the mineral-occurrence model in question. However, many deposits are not being sought as viable targets at all times. Although procedures for the outlining of favorable tracts vary among deposits, the favorable tracts on plates 2–11 were generally delineated to include all known indications of the respective mineralizing process—the indications primarily used are the presence of mineral prospects and occurrences. Furthermore, the classification "favorable" is roughly comparable to "moderate" used in previous WSA assessments mentioned above. "Favorable" also may be applied to a particular area for a particular type of deposit because of the presence in that area of genetically-related deposit types that are known commonly to be linked to occurrences of the deposit being evaluated. In addition, areas of hydrothermal alteration common to either the deposit under consideration or to genetically related ones, as well as geophysical or geochemical anomalies, were used to delineate the favorable tracts. Geochemically anomalous sites were determined from an evaluation of available stream-sediment data bases (King, 1996; King and others, 1996). Favorable areas are likely to be sites of some mineral exploration and possible subsequent development in the next decade.

Prospective (H)—This classification compares to a "high" level of mineral potential used in previous WSA assessments, and it is a subset of the favorable tracts. In areas designated as having a "high" level of mineral potential, geologic environments have been identified that are linked directly to ore-forming processes or there is evidence for such processes having occurred. They generally are small tracts where strong indications of mineralization processes are documented, such as alteration zones, geophysical or geochemical anomalies, strongly favorable host lithologies or structures, and, in most instances in Nevada, a prior history of mineral production. These areas are most likely to have continued or renewed mineral exploration and development in the next decade.

Delineation of deposit-model tracts

Mineral-deposit models (Barton, 1986, 1993), that are compatible with geology and known deposits in the WSRA, are shown on tables 2 and 3 and were assembled using geologic, geochemical, and geophysical (Hoover and others, 1992) criteria (see also, Erickson, 1982; Eckstrand, 1984; Cox and Singer, 1986; Roberts and Sheahan, 1988; Bliss, 1992a; Kirkham and others, 1993). Metallic mineral occurrences were compiled from the U.S. Geological Survey's Mineral Resource Data System (MRDS) and the U.S. Bureau of Mines' Mineral Information Location System (MILS) data bases (pl. 1). Compositing these two data bases produced a working database of 1,168 mostly metallic mineral occurrences that became our primary source of information for mineral occurrences in the WSRA. This database also includes some mineral occurrences of opal, fluorite, and clay minerals because of the importance that these minerals may have as signatures for the potential presence of nearby metals. In addition, prior to its abolishment, the U.S. Bureau of Mines compiled a mineral-occurrence database of approximately 1,600 occurrences for the WSRA (M. Miller, oral commun., 1996; U.S. Bureau of Mines, 1996), which became available to us after this report was in the review process. Some important mineral occurrences outside the WSRA are also shown on plates 2–11 because of the impact that they have on our evaluation of mineral resources in nearby parts of the WSRA. Some cautionary words are necessary about specific locations of mineral occurrences and deposits shown on the plates accompanying this report. Because locations of many mineral occurrences were not verified in the field, we relied on locations assigned in MRDS and MILS databases. Some locations apparently have been purposely offset from one another, especially where there are dense clusters of mineral occurrences, in order to show the type of mineral occurrence adequately at the small scale of our investigation. Mineral occurrences in the working database, which apparently have the same characterisitcs as those contained in the descriptions of the deposit models, initially were assigned model types, when possible, by the senior author of this report, and then many of these assignments were modified by other members of the team who had additional knowledge about a number of occurrences. Nonetheless, as many as 20 percent of the deposit assignments may be in error because of an absence of critical details requisite for proper classification. Only a small fraction of the occurrences with which we have had problems were checked in the field, and, among those occurrences examined, quite a few remain ambiguous, either because of a lack of expertise by the examiners, or because of a lack of critical exposures. The undeniable fact is that we commonly have a hard time observing many critical geologic details after mines are caved and (or) closed. Mine locations were plotted using the coordinates in the original databases. In addition, some other sources—including verification by a number of exploration companies of the geology of specific mineral occurrences, mineral data contained in files of the BLM, preparation of updated gold, silver, and copper production and resource data as of 1995, and the distribution of alteration zones and their contained minerals, particularly in the northwest part of the WSRA—were used to supplement these data. Again, only limited field examinations were conducted to verify the classification of some mineral occurrences. The geology, geochemistry, and geophysics help define the signatures of each cluster or district of similar deposit types, and these criteria were used in constructing tracts. Alteration and exploration permit activity (U.S. Bureau of Land Management, 1990) were also plotted and constitute the majority of the areas designated as being Highly Prospective (H) tracts. Favorable tracts were delineated using 1:500,000–scale geology (Stewart and Carlson, 1978), enlarged to a 1:250,000–working scale.

Tracts were delineated to predict where undiscovered deposits of a particular type are likely to be present. As described above, all areas that are inferred to have Tertiary and Quaternary unconsolidated surficial deposits thicker than 1 km have been classified as being non-permissive for metallic resources in the WSRA. Although permissive tracts are defined to include virtually all undiscovered deposits, in proceeding from permissive to favorable to prospective tracts, it is an uncertain proposition to define what proportion of undiscovered deposits are contained in these successively more tightly defined areas. The boundaries between these tracts are defined by the availability of the information used to construct them, and, for virtually all types of mineral deposits, the quantitative relation between presence of favorable attributes in the geologic environment and the density of mineral deposits is unknown. In general, more than half the undiscovered deposits estimated below are contained in the prospective tracts, and more than half the remaining deposits are contained in the favorable tracts.

Estimation of undiscovered resources

The U. S. Geological Survey has developed a three-part method for the quantitative evaluation of resources (Drew and others, 1986; Singer and Cox, 1988; Singer, 1993). The parts, as described by Singer and Cox (1988), include: (1) a delineation of areas on the basis of the types of mineral deposits that the geology of the areas will permit; (2) an estimation of the number of deposits within each delineated tract; and (3) an estimation of the amount of metal present by means of the applicable grade-tonnage models available for each of the various types of deposits. The latter part also commonly includes some statement about the character of the ores associated with a particular type of deposit. Output from the three parts is processed by computer using a Monte Carlo simulation routine (Mark3 Simulator) to generate a probability distribution of metal and ore tonnage for each type of deposit that is judged to be present within a tract (Root and others, 1992).

Estimation of numbers of deposits

The process of estimating numbers of deposits is a highly subjective task that is conducted by an assessment team possessing a collective knowledge about the geology, geochemistry, geophysics, and metallogeny of an area and the types of deposits being considered. The magnitudes of the estimates are generally conditioned by three factors: (1) size and grade consistency, (2) the type, amount and nature of geological data available, and (3) the type, amount, spatial distribution, and effectiveness of mineral exploration in an area. The influence of each of these factors is discussed by Root and others (1992). For example, the expected size and metal-grade range of the estimated deposit population must be consistent with the size and grade ranges of the deposits included in the deposit models. Extreme care must be exercised to avoid inflating estimates by including deposits falling outside the model population range. Availability and type of data can play a major role in influencing the certainty of the estimates. Where data are scarce or of a non-definitive nature for a specific type of deposit, estimates are likely to exhibit a broader range of values than where data are more abundant. Exploration activity can also substantially impact the overall magnitude of the estimates. Where exploration by mining companies—including the drilling of a number of targets without the discovery of any economically viable mineralized rocks—has been extensive throughout an area, estimates may be low or approach zero, on the one hand, because there is less unexplored land available to test using the currently available exploration models. All targets have been tested. On the other hand, estimates may be high, if the data obtained from such exploration are favorable for the presence of additional occurrences of the types of deposits being sought.

Many of the undiscovered deposits that we estimate to be present in the WSRA are most likely to be under rocks or alluvium younger than the mineral deposits. We qualitatively utilized area percentages of bedrock versus alluvium as a prime factor in our estimates—reasoning that the areas of bedrock covered by thin deposits of alluvium should be as favorable or prospective as the nearby areas that are exposed and explored.

In this study, the estimates are not single values but rather a series of five values representing the minimum number of deposits expected to be present at five levels of probability (90, 50, 10, 5, and 1 percent). A five-tier estimate permits each member of the assessment team to express the uncertainty inherent in the process, as well as still allowing the final estimates to be a consensus from the assembled team of experts.

Estimation of endowments

Estimates of resource endowment reflect the total of metal(s) and ore that are expected to be present in a permissive terrane for an undiscovered population of deposits belonging to a specific type of deposit. The five-tier deposit estimates and grade and tonnage data for the deposit models (for example, Cox and Singer, 1986) are entered into the Mark3 Simulator (Root and others, 1992). A Monte Carlo simulation technique is used to simulate hypothetical endowment population distributions for each of the metals and the ore represented in the models for each type of deposit considered by the team of evaluators. Definitive characteristics for the population distributions can be extracted, which can, in turn, be used for making subsequent economic analyses. Simulated values of endowment at the 90th, 50th, and 10th percentiles of the distribution are presented in tables as part of the following discussions of the types of deposits potentially present in the WSRA. In addition, these tables include the mean endowment and the probability of its existence, as well as the probability of no endowment because no deposits are considered by the panel of experts to be present. A more rigorous presentation of endowment results can be found in Appendix A, which includes data in the form of a table of values at 5 percentile intervals and a graphical presentation from which intermediate endowment values can be interpolated. For a comprehensive discussion of the quantification step the reader is encouraged to read Root and others (1992).

MINERAL-DEPOSIT MODELS

Additional undiscovered deposits of various types are considered to be present in the WSRA, and they are discussed below. Of the 1,168 mineral occurrences evaluated in this report, sufficient geologic information is available to classify provisionally 1,032 of the mineral occurrences into a specific type of model. There is quite a bit of uncertainty in many of these assignments because of the many reasons we cited above. As a comparison, in the statewide study of Nevada, enough information was available to classify into appropriate models approximately 1,500 of 5,500 MRDS records (Cox, 1993), and, in the Reno 1° X 2° study, approximately 300 of 400 occurrences were classified (John and others, 1993). The general geologic environments of the deposits in the WSRA are quite similar, in most cases, to the respective environments documented in the worldwide models described by Cox and Singer (1986). Some exceptions, however, are noted throughout the descriptions for the WSRA that follow. Each model is outlined briefly in the sections below, and it then is followed by a description and discussion of representative deposits which closely fit the parameters of that model in the WSRA. Many types of deposit cluster in mining districts or groups of districts (pl. 1), and this clustering usually is evident within the prospective or favorable tracts shown on plates 2–11. Each cluster of deposits and its corresponding tracts are described in the text and are keyed to a respective plate.

In this report, we have chosen to start the descriptions of types of deposit in the WSRA with the igneous-related ones, such as the various types of porphyry deposits (pl. 2) and their related skarn and vein deposits. The tungsten deposits (pl. 3) are described separately, however, because of the metallogenic importance of tungsten in the WSRA. Several types of porphyry deposits just outside the WSRA, most notably in the Battle Mountain area near the eastern boundary of the WSRA, also are described herein because of their impact on our evaluations of the potential for similar types of occurrences in nearby areas within the WSRA. Copper, zinc, lead, and gold skarns (pl. 4), as well as polymetallic veins and replacement manganese deposits (pl. 5), also are present in the Battle Mountain area and in the WSRA as well. Distal-disseminated silver-gold deposits that cluster on the northern margin of the Battle Mountain Mining District are noted as part of the porphyry-related family of deposit models. They are portrayed with the polymetallic deposits as a separate tract on plate 5, but they also are addressed later in the report with other carbonate- or sediment-hosted gold deposits.

The numerous and widely distributed hot-spring and epithermal deposits of precious metals and their geologically affiliated mercury and manganese occurrences are discussed after the porphyry-related deposits and are portrayed together (pl. 6). Uranium deposits (pl. 7) are described as both volcanogenic and sediment-hosted types within the WSRA. Additional small occurrences of some igneous-related uranium are also noted. Sediment-hosted (Carlin-type) gold deposits of the Getchell trend and those in the Humboldt Range are portrayed on plate 8.

A number of mineral occurrences in many locations throughout the central part of the WSRA have been reclassified in this report as low-sulfide gold-quartz veins. The outline of favorable tracts delineates a north-trending mineral belt of these deposits (pl. 9). Massive sulfide deposits, potential exhalative sedimentary lead-zinc deposits, volcanic-hosted magnetite deposits, and volcanogenic manganese deposits are associated with specific lithologies of various allochthons in the eastern and central part of the WSRA (pl. 10). Gold placer deposits apparently are associated spatially with low-sulfide gold-quartz veins, and porphyry copper environments to a lesser degree, and the gold placer deposits are concentrated in many of the late Tertiary and Quaternary basins (pl. 11).

Porphyry deposits

Porphyry systems are generally large volumes of rock characterized by chalcopyrite, bornite, molybdenite, or gold—as well as a number of other prograde and secondary sulfide minerals—in intensely fractured rocks filled by stockwork veins or disseminated grains in hydrothermally altered porphyritic intrusions and (or) in their hydrothermally altered adjacent wall rock. Much of the mineralized rock in these systems owes its origin to magmatic fluids that were expelled during the process of crystallization of the genetically associated magma, typically present locally in composite intrusive centers. Supergene-altered equivalents of these deposits also may be important because of enrichment processes that have a tendency to enhance the copper grades of the deposits. These types of mineralized systems tend to be developed preferentially in some shallow-level granitoid intrusions. There is a continuum among porphyry deposits, skarn deposits, and some polymetallic vein deposits (see also, Carten and others, 1993; Titley, 1993). The main types of porphyry deposit considered in the WSRA are: (1) porphyry copper and porphyry copper-molybdenum deposits; (2) porphyry molybdenum, low fluorine deposits; (3) Climax molybdenum deposits; and (4) porphyry gold and porphyry copper (gold) deposits.

Porphyry copper or stockwork molybdenum deposits have not been significant sites of base-metal mineral production in the WSRA in the past, but the presence of several prospects for these types of occurrence in the area (Schilling, 1980; Wendt and Albino, 1992), and the proximity of the important Battle Mountain Mining District, indicate that there is some level of potential for these types of deposit in the WSRA. A porphyry copper occurrence is present in the Kennedy Mining District, with suggestions of porphyry affinities for some other mineral occurrences in the Truckee and Copper Valley areas (Wendt and Albino, 1992). One large Cretaceous stockwork molybdenum deposit of the low-fluorine type, and two major occurrences belonging to the same model, are present in the Battle Mountain Mining District; several others, as well, are known to be present in the Sonoma Range (pl. 2). Elsewhere in Nevada, stockwork molybdenum occurrences of the low-fluorine type, which are related to compressional tectonism along the continental margin, are associated with tungsten skarns that are widespread in the WSRA. Thus, the exposed occcurrences of tungsten skarn may be linked genetically at depth to stockwork molybdenum deposits of the low-fluorine type in the WMSRA. Climax-type molybdenum deposits, however, differ from the low-fluorine type in their association with high-silica rhyolites and their typical association with regionally extensive zones of continental extension in areas of thick continental crust (Carten and others, 1993). The enigmatic Majuba Hill occurrence in the WSRA contains molybdenum-, copper-, uranium-, and tin-mineralized rocks related to early Miocene plugs of rhyolite. However, this occurrence includes indications that it is not a Climax-type system, on the basis of the absence of well-developed ore shells, the presence of high concentrations of copper, and the lack of intensely developed zones of silicification and fluorite introduction.

Porphyry copper (molybdenum) deposits (models 17, 21a of Cox and Singer, 1986)

Porphyry copper (molybdenum) deposits (Cox, 1986c, 1986d, 1986e; McMillan and Panteleyev, 1986; Titley, 1993) contain copper-iron sulfide minerals and molybdenite in quartz stockworks, in and adjacent to high level porphyritic intrusions. These typically are large deposits—median tonnage of the worldwide general porphyry copper model is 140 million tonnes (Singer and others, 1986a). Associated rocks are small stocks or dike sets of quartz-feldspar porphyritic quartz monzonite to granodiorite which have intruded cogenetic intermediate composition volcanic rocks or pre-intrusive wall rocks. In the WSRA, Cenozoic examples are most important (Titley and Beane, 1981). Associated types of deposit are copper skarn, gold skarn, polymetallic replacement, distal-disseminated silver-gold, polymetallic vein, high-sulfidation state epithermal vein, and gold placer deposits. Some iron (magnetite) skarn also is associated with a number of productive porphyry copper deposits, exemplified by the Cretaceous porphyry copper system at Ely, Nev. (Einaudi, 1982). Ore minerals typically include chalcopyrite, bornite, and (or) molybdenite in central zones of representative porphyry copper system, and these zones are surrounded peripherally by chalcopyrite-pyrite and local magnetite (Beane and Titley, 1981; Titley, 1993). Peripheral zones are also the sites of elevated concentrations of galena, sphalerite, and sulfosalt minerals. Supergene processes can produce enhanced concentrations of chalcocite, digenite, chrysocolla, malachite, and azurite in rocks beneath the leached capping. Upper parts of many systems are characterized by advanced argillic mineral assemblages.

Fractures are strongly developed episodically in many porphyry systems as the systems evolve, and they preferentially are filled by quartz-sulfide mineral stockwork veins, showing multiple veinlet sets, which commonly have preferred orientations (Titley, 1993). Alteration typically consists of a central, early K–feldspar-secondary biotite±anhydrite zone, mantled in the deep parts of the system by a peripheral propylitic zone dominated by chlorite±epidote±calcite mineral assemblages. In many known deposits, there is a well-developed phyllic (quartz-sericite-pyrite) overprint, generally concentrated at the original potassic-propylitic boundary, although the Yerington, Nev., deposit south of the WSRA has deep Ca–Na alteration (Dilles and others, 1995). In many deposits, however, phyllic alteration also may be concentrated irregularly in the central, upper parts of the system, generally close to some of the igneous phases associated genetically with the system. Ore controls essentially involve proximity to a mineralizing intrusion, which may have been emplaced at the intersections of regionally extensive faults and fractures (Doebrich and Theodore, 1996). In the Battle Mountain Mining District, emplacement of at least four, and probably as many as eight, of these systems occurred in conjunction with the earliest onset of extension documented in the Tertiary. Local ore controls are a function both of wall rock composition and structure, as well as morphology of the associated intrusions, some of which are notably laccolithic in character (Theodore and Blake, 1975; Doebrich and others, 1995). There is a spatial and genetic continuum between porphyry copper deposits and porphyry copper-related skarns in some systems (Cox, 1986f); this is particularly evident in the Battle Mountain Mining District (Theodore and Blake, 1975, 1978).

Weathering of these systems typically results in a well-developed iron-oxide stained "leached" capping in many examples showing well-developed phyllic zones (Cox, 1986d, 1986e; Titley, 1993). The geochemical signature is copper, molybdenum, silver, as well as variable gold and peripheral zinc, lead±silver-gold. The Yerington, Nev., copper deposit has essentially only copper as an oxidation signature.

There are four occurrences in the WSRA that we classify as either generic porphyry copper occurrences (Cox, 1986d, model 17) or as porphyry copper-molybdenum occurrences (Cox, 1986e, model 21a). These porphyry occurrences are in the Fireball Ridge area of the Truckee Mining District, in the Granite Mountain area of the Kennedy Mining District, at Granite Point southwest of Lovelock, and at Elder Creek (Theodore, 1996b; Gostyayeva and others, 1996) along the northeast flank of the Battle Mountain Mining District (pl. 2). We have no data on the either the size or the grade of these three occurrences.

Porphyry molybdenum, low-fluorine deposits (model 21b of Cox and Singer, 1986)

Porphyry molybdenum, low-fluorine deposits—also termed quartz monzonite or calc-alkaline molybdenum stockwork deposits by others—are spatially and genetically associated with quartz monzonite and monzogranite stocks that have multiple intrusive phases. In this part of Nevada, they are generally Late Cretaceous in age, and they were emplaced during compressional tectonic regimes. They can be extremely large systems—the Buckingham, Nev., deposit at Battle Mountain (pl. 2) contains in excess of 1 billion tonnes of mineralized rock (Theodore and others, 1992; Carten and others, 1993), and occurs in the upper 10 percentile of the tonnage curve (Menzie and Theodore, 1986). However, the median tonnage of this type of deposit is much smaller—approximately 100 million tonnes (Menzie and Theodore, 1986). Copper typically is relatively abundant compared to Climax-type molybdenum deposits—to be described below—and, in some related deposits, such as at Copper Basin in the Battle Mountain Mining District (pl. 2), copper was mined from supergene-enriched orebodies marginal to the molybdenum-enriched core of the system (Blake, 1992). Tin is usually absent or is present in extremely low concentrations in the porphyry molybdenum, low-fluorine deposits. However, abundances of tin may be concentrated to as much as 100–200 ppm Sn along some younger veins that cut porphyry molybdenum, low-fluorine deposits (Theodore and others, 1992). Alteration consists of K-feldspar with local phyllic envelopes, and intermediate-argillic assemblages may be pervasive. Topaz and fluorite are relatively common in some deposits (Hall, Nev., and Big Hunch, Calif.), and extremely rare to absent in others (Buckingham, Nev.). This type of deposit is characterized by molybdenite-quartz stockwork veinlets which cut calc-alkaline porphyritic intrusive rocks and the adjacent country rock. As much as 50 percent of the intensely mineralized rock may be in the wall rocks of the multiphase intrusive systems associated with the deposits (Theodore and others, 1992). The stockwork veinlets are typically concentrated in umbrella-shaped volumes of rock that are draped over the genetically associated pulses of magma (Loucks and Johnson, 1992). Compared to Climax-type deposits, however, these deposits, as a whole, are overall deficient in fluorine, have significantly lower molybdenum grades, and are associated genetically with metaluminous intrusive rocks with lower silica content (Theodore and Menzie, 1984; Theodore, 1986). The deposits form during the late stages of intrusion with paleodepths of formation of the ore at 1 to 2 km for stocks and 3 to 5 km for plutons.

There are four sites that we have classified as porphyry molybdenum, low-fluorine occurrences (Theodore, 1986) in the WSRA (pl. 2). One is in the Leonard Creek Mining District, west of Quinn River Crossing and is associated with Cretaceous or Tertiary porphyritic granodiorite (pl. 2). Wendt and Albino (1992) have identified a porphyry molybdenum, low-fluorine occurrence in a Cretaceous granodiorite at Granite Point (pl. 2). The other two occurrences (also classified as porphyry molybdenum, low-fluorine occurrences) are near the south end of the Gold Run Mining District, where the genetically associated intrusions are apparently Cretaceous in age. In addition to these three sites in the WSRA, there are three others in the Battle Mountain Mining District, just to the east of the WSRA, that are also porphyry molybdenum, low-fluorine occurrences (Theodore and others, 1992; Doebrich and others, 1995; Doebrich and Theodore, 1996). The largest and best explored of these three porphyry molybdenum occurrences is the one described above in the Battle Mountain Mining District at Buckingham (Theodore and others, 1992; Carten and others, 1993), which contains more than 1 billion tonnes of rock mineralized at grades of approximately of 0.05 weight percent Mo, and containing substantial amounts of copper, silver, and tungsten. All of the porphyry molybdenum, low-fluorine occurrences in the Battle Mountain Mining District are Late Cretaceous in age (McKee, 1992). The Buckingham deposit is the only one for which reserve data are available from near and (or) in the WSRA .

Climax molybdenum deposits (model 16 of Cox and Singer, 1986)

Climax molybdenum deposits are characterized by stockworks of molybdenite and quartz associated with fluorite in high-silica rhyolite and granite porphyry typically containing more than 75 weight percent SiO_2 (White and others, 1981; Ludington, 1986; Carten and others, 1993). Numerous intrusive phases have zoned, shell-like, alteration patterns and ore zones draped over the apex of these systems and down the steep sides of the complexes (Mutschler and others, 1981; Carten and others, 1988; Carten and others, 1993). Ore shells in these systems typically are related to successively deeper pulses of magma—the last mineralizing magma usually is the one deepest in the system. These deposits form at depths of 1 to 3 km and may be indicated at the surface by the presence of topaz-bearing rhyolites (Christiansen and others, 1986). The igneous complexes contain dikes, breccias, and multistage, subvolcanic porphyritic intrusive rocks, as well as zoned alteration patterns. Molybdenite-quartz stockwork veins commonly are related to aplitic quartz porphyry, and they are usually in the middle stage of several rhyolite porphyry phases. Low-grade mineralized rocks may be present in deep, and slightly younger, coarser-grained igneous phases (Lowe and others, 1985). Lead, zinc, silver, tin, copper, fluorine, and molybdenum are anomalous in alteration zones around these plutons (Westra and Keith, 1981).

Majuba Hill in the Antelope Mining District has been classified provisionally as a Climax molybdenum occurrence (Ludington, 1986) in the WSRA (pl. 2). The relatively large amount of copper at this locality, however, does not compare well with the abundance of copper usually ascribed to this type of deposit. The Majuba Hill occurrence (MacKenzie and Bookstrom, 1976) is associated with 24– to 25–Ma rhyolitic rocks emplaced during multiple pulses into Triassic basinal rocks of the allocthonous Jungo terrane. In addition, the Majuba Hill occurrence is not one of the nine deposits used to construct the grade and tonnage models for the Climax molybdenum deposits (Singer and others, 1986b). Based on available surface and subsurface information (MacKenzie and Bookstrom, 1976), Majuba Hill appears to lack some key aspects of an ideal Climax deposit, such as amount of fluorine, quartz veining, and molybdenum enrichment.

Porphyry copper-gold deposits (model 20c of Cox and Singer, 1986)

Porphyry copper-gold deposits (Cox, 1986f), also termed porphyry gold deposits by others, consist of disseminated and stockwork copper-iron sulfide minerals and magnetite with gold in sub-volcanic intrusions and (or) their coeval volcanic rocks emplaced into island arcs or rift-related continental margins (see also, Sillitoe, 1988; Rytuba and Cox, 1991). Rock types associated with these deposits are early gabbro or quartz diorite, synmineral diorite porphyry, and andesitic country rocks, as well as local marine carbonate rocks and other sedimentary rocks. Associated deposit types are copper skarn, gold skarn, massive pyrite-enargite replacement deposits, and polymetallic replacements and veins. Ore mineralogy consists of chalcopyrite, bornite, magnetite, gold, and platinum-group-element telluride minerals and arsenide minerals. Disseminated copper-iron sulfide minerals are usually early phases and are followed by dense stockwork veins of quartz and sulfide minerals. Alteration is typically early K-feldspar-iron-magnesium silicate minerals such as biotite, amphibole, or pyroxene, as well as anhydrite. Subsequent stages of intermediate argillic alteration are common, and advanced argillic alteration forms the upper parts of some deposits. Ore controls are proximity to late-stage, porphyritic, sub-volcanic intrusions. Geochemical signature is copper, gold, and silver, as well as arsenic.

We have assigned no mineral occurrences in the WSRA to the porphyry copper-gold category of deposits (pl. 2). Although some gold deposits in the Battle Mountain Mining District and the McCoy Mining District, south of Battle Mountain (pl. 1), may appear to belong to this class of deposits because of the widespread presence of precious-metal bearing skarns, the geologic environment in these mining districts does not fit that model. Furthermore, there are no volcanic rocks present in these two mining districts that are coeval with the 38– to 40–Ma magmatic event responsible for the abundant precious metal-mineralized rocks in them (Doebrich, 1995; Doebrich and Theodore, 1995, 1996).

Description of tracts for pluton-related deposits

A number of tracts showing various levels of potential for pluton-related deposits have been delineated in the WSRA (pl. 2). Permissive tracts for pluton-related deposits are modified from a 10–km buffer placed around all Mesozoic and Tertiary plutons shown on the geologic map used as a base, and from a 10–km buffer, as well, around all sites of intrusive bodies inferred to be present on the basis of geophysical data (pl. 2; see also, Jachens and Moring, 1990; Blakely and Jachens, 1991). These tracts differ somewhat from the igneous-related tracts of Ludington and others (1993). In addition, the 10–km buffer has been modified using gravity data to subtract areas where Cenozoic cover most likely exceeds a 1–km thickness (pl. 2). Close spatial relationships among porphyry systems and other deposits such as tungsten skarns, porphyry-related copper skarns, polymetallic veins and other metasomatic deposits in many mining districts elsewhere influenced our delineation of favorable tracts (tracts A–H, pl. 2). The favorable tracts also appear to coalesce into broad coherent patterns that might be thought of as metallogenic belts. Prospective tracts are more restricted in areal extent, and they have been delineated around single porphyry systems or clusters of known porphyry systems. Two large tracts considered to have favorable levels of potential—one herein termed the Battle Mountain-Gold Run porphyry trend (tract A, pl. 2) and the other elongate to the northeast just to the west of the Humboldt Range (tract B, pl. 2)—contain a number of known and inferred porphyry deposits, as do the discrete Tertiary-age Majuba Hill area and the Kennedy Mining District tracts (pl. 2). Other large favorable tracts are present in the southwestern and northern parts of the WSRA, and a number of small areas have mineral occurrences of a type that are known to be associated with porphyry-type mineral occurrences elsewhere.

Battle Mountain-Gold Run porphyry trend

The Battle Mountain-Gold Run Late Cretaceous and Tertiary porphyry trend contains the Battle Mountain Mining District near the east border of the WSRA and is defined by clusters of deposits in a 30 by 80 km zone extending southeast from the Gold Run Mining District to the Battle Mountain Mining District (favorable tract A, pl. 2). The southeastern part of this trend at Battle Mountain—in effect the generally accepted northern terminus of the Battle Mountain-Eureka mineral belt (Roberts, 1966)—contains many more porphyry systems than its northwestern terminus in the Gold Run Mining District which contains no known exposed porphyry systems. Favorable tract A, as shown, also has a significant component that is elongated north-south to encompass the Potosi Mining District on the north as well as the McCoy Mining District on the south along an inferred deep crustal structure originally recognized by Bloomstein and others (1991). This broad favorable tract also includes the Buffalo Mountain and Iron Hat Mining Districts (pl. 1). In addition, an important Tertiary component of the trend extends south into the McCoy Mining District. The Battle Mountain Mining District contains at least seven exposed porphyry-type centers of mineralization, as well as a large number of skarn and replacement deposits. Additional centers of porphyry-type mineralized rock also may be present north of the Battle Mountain Mining District. Types of deposits also present in the mining district include distal-disseminated silver-gold, porphyry-related copper skarn, porphyry copper deposits, gold skarn, supergene copper deposits, and polymetallic veins (Willden, 1964; Roberts and Arnold, 1965; Stager, 1977; Theodore and others, 1982, 1992; and Doebrich and others, 1995; Doebrich and Theodore, 1996). The geology of the mining district is complex and contains rocks of the Roberts Mountains and Golconda allochthons and the intervening rocks of the Pennsylvanian and Permian Antler sequence (Roberts, 1964)—these latter rocks are part of a regionally widespread overlap assemblage of strata derived from the Antler highlands. Intrusive rocks in the mining district include both Cretaceous (86 Ma) and Eocene and Oligocene (41–36 Ma) plutons, as well as important mineralized zones related to intrusions of both periods (Theodore and others, 1992).

Copper-gold-silver deposits and surrounding lead-zinc polymetallic veins at Copper Canyon are associated with a Tertiary granodiorite stock which contains veins and disseminations of hydrothermal biotite and K–feldspar, quartz, minor apatite, and lessor pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, and marcasite (Theodore and Blake, 1975, 1978). These composite mineral assemblages also are present in metasedimentary rocks surrounding the stock. Peripheral to the stock, and extending at least 200–300 m from its contact, is an irregular zone where the content of disseminated sulfide minerals in the rocks exceeds 2 volume percent. This is within a much broader zone where the sulfide mineral content is typically greater than 1 volume percent. The most productive copper deposit was a K–silicate-altered replacement orebody (East orebody), hosted by calcareous and hematitic conglomerate of the Pennsylvanian and Permian Antler sequence. However, there are also a number of copper-bearing skarns that were, and are still (1996), being mined primarily for their gold and silver contents (Doebrich and others, 1995). The most economically important of these deposits is the Fortitude gold skarn (Wotruba and others, 1988; Myers and Meinert, 1991; Myers, 1994), which is near the northernmost extent of a tabular body of skarn hosting the Phoenix gold-silver deposit (Doebrich and others, 1995), now (1996) being prepared for production. The ore zones are within 1,000 m of the stock. These characteristics are compatible with those summarized for porphyry copper, skarn-related deposits by Cox (1986e).

The Buckingham stockwork molybdenum deposit, also in the Battle Mountain Mining district, is a large low-fluorine porphyry molybdenum deposit with published reserves (Loucks and Johnson, 1992; Theodore and others, 1992) of more than 1 billion tonnes at an average grade of approximately 0.1 weight percent MoS_2, and as much as 100 million oz Ag (see also, Carten and others, 1993). Unlike the deposits in the Copper Canyon part of the Battle Mountain Mining District, described above, the Buckingham deposit is Late Cretaceous in age and is related to a composite quartz monzonite porphyry stock emplaced at approximately 86 Ma (McKee, 1992).

Ore at Buckingham is present both in granitic rocks and in the adjoining Paleozoic metasedimentary wall rocks. In addition, the supergene-enriched copper orebodies at Copper Basin are part of a copper shell that surrounds the Buckingham system (Blake, 1992). The central molybdenum orebodies have been extended structurally by a number of Tertiary low-angle faults. The orebodies are composed of stockworks of quartz-molybdenite-pyrite veinlets, with lesser amounts of copper, silver, and tungsten accompanying molybdenum. The orebodies are especially well developed where ore shells have been superposed onto each other as a result of emplacement of loci of magmatic pulses into two separate intrusive centers (Loucks and Johnson, 1992). Alteration at Buckingham includes potassic, propylitic, and intermediate argillic assemblages. Two other apparently Late Cretaceous porphyry molybdenum, low-fluorine occurrences also are present in the Battle Mountain Mining District (Thomas, 1985; Theodore and others, 1992; Doebrich and Theodore, 1996). Intensely silicified zones, including both vein and replacement quartz, are present near the roofs of the intrusive cupolas associated with many occurrences representative of these systems as described by Theodore (1986) and Theodore and Menzie (1984). Such features are considered to be one of the diagnostic features of stockwork molybdenum, low-fluorine occurrences. The presence of silicified zones suggests that additional occurrences of this or associated types of deposit may be present elsewhere in the Battle Mountain-Gold Run porphyry trend.

Numerous stream-sediment and soil samples from the Battle Mountain-Gold Run porphyry trend contain anomalous concentrations of As, Sb, Au, Ag, Cu, Pb, Mo, and Zn (King, 1996). These anomalies are especially concentrated in the Battle Mountain part of the trend.

The Buffalo Mountain and Iron Hat Mining Districts, parts of favorable tract A delineated within the Battle Mountain-Gold Run trend (pl. 2), contain copper-, tungsten-, and molybdenum-mineralized rocks associated with Late Cretaceous quartz monzonite. These metals are present as oxide minerals and in gossan, skarn, and polymetallic veins. Associated minerals are chalcopyrite, galena, and silver with gold (Willden, 1964). These areas also contain a porphyry molybdenum low-fluorine prospect at Gregg Canyon according to Wendt and Albino (1992). In addition, in the Iron Hat Mining District, some areally extensive veins of barite, measuring approximately 2– to 3–m widths and lengths of approximately 400 m, include anomalous concentrations of silver which have been prospected at various times in the past. In the WSRA, molybdenum-mineralized rocks (see also, Schilling, 1980), tungsten skarns, and copper-bearing veins are associated with hornfels that surround granitic plutons (Vanderburg, 1936a; Lawrence, 1963; Johnson, 1977). Clusters of these occurrences define a 10 by 20 km northeast-trending belt of prospective tracts which lie within the broad northwest Battle Mountain-Gold Run porphyry trend (pl. 2). The characteristics of these occurrences are compatible with porphyry-type systems.

Humboldt River porphyry tract

The Humboldt River porphyry tract is defined by a 30 by 100 km north-northeast-trending zone, which generally is west and northwest of Lovelock and is centered on the Humboldt River (tract B, pl. 2). The Humboldt River porphyry tract also apparently broadens in an east-west direction near Lovelock to include the Humboldt Range and the Unionville Mining District (tract B, pl. 2). This favorable tract includes numerous clusters of pluton-related mineral occurrences which have many characteristics compatible with a porphyry copper-related environment. Near the south end of the Humboldt River porphyry tract, the Ragged Top Mining District contains Triassic to Jurassic metasedimentary rocks which have been intruded by Cretaceous granodiorite that produced copper and tungsten skarn, some of which contains molybdenum (Lincoln, 1923; Johnson, 1977; Schilling, 1980; Stager and Tingley, 1988). Southeast of Lovelock, the Wildhorse and Muttlebury Mining Districts (pl. 1) contain many polymetallic veins (Lawrence, 1963; Johnson, 1977), and tungsten skarns, which also contain copper, gold, and silver (Stager and Tingley, 1988). Many mineralized rocks are associated with early-stage thermal metamorphism, are veined by quartz, and contain aplite dikes, such as those at the Long Lease Mine, which also contain molybdenum (Schilling, 1980).

A number of mineral occurrences in the general area of Lovelock are pluton-related. Deposits in the Gold Butte and Trinity Mining Districts, west-northwest of Lovelock (pl. 1), include polymetallic veins which contain tungsten, silver, lead, zinc, and molybdenum in zones of hornfels, in skarn, and in aplite sills (Lincoln, 1923; Johnson, 1977; Schilling, 1980). In the Rye Patch Mining District (pl. 1), Cretaceous granitic rocks have intruded Triassic metasedimentary rocks and produced quartz and pegmatite veins in a surrounding zone within which the veins contain tungsten, fluorite, muscovite, and beryl (Wallace and others, 1969a, 1969b). These veins are spatially associated with both polymetallic veins, that are rich in silver, antimony, lead, zinc, and gold (Lawrence, 1963; Johnson, 1977), as well as with the Empire molybdenum occurrence (Schilling, 1980). However, there also are a group of tungsten deposits in the Humboldt Range, east of Lovelock (pl. 1), that clearly are related to a two mica granite, and they are different from the skarn-related tungsten occurrences in the Mill City Mining District, farther to the north near the north end of the Humboldt River Porphyry Tract (pl. 2), which are associated with granodiorite intrusions.

In the Mill City Mining District (pl. 2), Triassic sedimentary rocks are intruded by Cretaceous granodiorite stocks and quartz monzonite aplite dikes and pegmatites; associated hornfels, tungsten skarn, and copper and tungsten skarn are anomalous in molybdenum, silver, antimony, lead, and zinc (Lincoln, 1923; Johnson, 1977). The Springer tungsten skarn locality also contains molybdenum (Schilling, 1980), and it has been classified as a porphyry molybdenum, low-fluorine deposit by Wendt and Albino (1992), but some members of this team question this interpretation and its resource implications. Consequently, it is not shown on plate 2 as a porphyry molybdenum, low-fluorine deposit. The Mill City Mining District also shows numerous stream-sediment and soil samples that have anomalous concentrations of Sb, As, Au, Ag, and Pb (King, 1996).

Kennedy Mining District

The Kennedy Mining District (tract C, pl. 2) contains molybdenum and copper mineralized rocks in an Oligocene intrusive complex that includes gabbro-diorite and monzonite-quartz monzonite phases (Johnson, 1977; Juhas, 1982). These rocks have intruded Paleozoic rocks on the north and Triassic leucogranite on the south (Whitebread and Sorensen, 1980). Alteration consists of K-silicate assemblages together with phyllic and propylitic alteration (Bowes and others, 1982). Mineralized rocks include disseminated and stockwork chalcopyrite and molybdenite (Thurber, 1982). Polymetallic veins surround the central district—particularly near the east end of the mining district—and contain copper, lead, zinc, arsenic, silver, and gold (Klopstock, 1913; Muller and others, 1951; Wallace, 1977). The east end of the mining district also has numerous stream-sediment and soil samples that have anomalous concentrations of silver (King, 1996). The Kennedy Mining District lies along an east-west regional structural trend, that is interpreted to be the westward extension of an Oligocene and Miocene trough of volcanic rocks (Wallace, 1978; Kutina and Bowes, 1982; T.G. Theodore, unpub. data, 1996). The Oligocene intrusive complex in the Kennedy Mining District represents probably some of the geologically deepest parts of this trough, which also contains a circular magnetic signature at the surface (Hallof, 1982). The trough is regionally composite in that it is filled with early Oligocene Caetano Tuff near its eastern terminus near Cortez, Nev. (Gilluly and Masursky, 1965)—well to the east of plate 2—and it contains younger 20-Ma tuff in the general area of the Fish Creek Mountains (McKee, 1970). Most of these features are consistent with the porphyry copper-molybdenum deposit type described by Cox (1986c).

Majuba Hill

The Majuba Hill occurrences lie south of the Black Rock Desert (fig. 2) and are associated with isolated 24- to 25-Ma potassic, high-silica rhyolite and porphyritic stocks that are the surface expressions of a subvolcanic rhyolite complex of porphyries and breccias (MacKenzie and Bookstrom, 1976). As delineated, the Majuba Hill occurrences are part of favorable tract B (pl. 2). Mineralized rocks include silica veins and replacement zones that contain chalcopyrite, pyrite, and arsenopyrite, as well as anomalous concentrations of molybdenum, uranium, and tin (Smith and Giannella, 1942; Matson, 1948; Trites and Thurston, 1958). Nearby gold placers are thought to be derived from these deposits (Bonham and others, 1985), although the gold placers may also be related to low-sulfide gold-quartz veins which also are in the area. These characteristics are partly, but not completely, consistent with the Climax-molybdenum deposit model described by Ludington (1986). The relative abundance of copper in this system is not consistent with the Climax model, nor is the regional geologic setting and the apparently relative high concentrations of gold suggested by the presence of the gold placers.

Occurrences in the western part of the WSRA

Four favorable tracts for porphyry deposits have been delineated in the western part of the WSRA that include a number of mining districts, which are defined by numerous pluton-related skarn and vein mineral occurrences (tracts D–G, pl. 2). At the Deep Hole Mining District, a 20 by 30 km, northwest-elongated, irregular-shaped zone contains silver-bearing copper and tungsten veins and skarns which are associated with some broad metasomatic zones near granodiorite stocks (Lincoln, 1923; Overton, 1947; Bonham and Papke, 1969). In the Hooker Mining District, in the northern part of a 40 by 15 km north-trending favorable zone, tungsten skarns have associated chalcopyrite, gold, silver, and uranium (Johnson and Benson, 1963; Johnson, 1977; Bonham and Papke, 1969) and molybdenum (Schilling, 1980; Stager and Tingley, 1988). The Nightingale and

Juniper Range Mining Districts are associated with skarns related to a Cretaceous granodiorite, and which contain tungsten, molybdenum, copper, and gold (Smith and Gianella, 1942; Bonham and Papke, 1969; Stager and Tingley, 1988). The Staggs and Seven Troughs Mining Districts lie within two approximately 100 km^2 areas and contain scheelite- and molybdenite-bearing skarn and local quartz stringers associated with felsic dikes and breccia veins (Hess and Larson, 1921; Lincoln, 1923; Bonham and Papke, 1969; Johnson, 1977). The characteristics of many mineral occurrences and deposits in the western part of the WSRA are similar to porphyry copper-molybdenum deposits described by Cox (1986e). The Staggs and Seven Troughs Mining Districts and parts of the Nightingale-Hooker area also have some site-specific characteristics similar to those required for Climax molybdenum deposits (Ludington, 1986); however, the geologic environment is not similar to that of the major deposits of this type in Colorado.

Occurrences in the northern part of the WSRA

The northern part of the WSRA contains a north-northeast-elongated, irregularly-shaped favorable tract approximately 50 by 12 km in area, which is defined by mining districts that contain clusters of skarns and polymetallic veins (tract H, pl. 2). In the Leonard Creek and Warm Springs Mining Districts, polymetallic veins and polymetallic skarns are related to quartz monzonite and granodiorite emplaced into Mesozoic sedimentary rocks (Vanderburg, 1938; Lawrence, 1963; Willden, 1964). Similar mineral occurrences are also present in the Jackson Mountains (fig. 2), as well as in the Red Butte, Sherman, Shon, Potosi, and Rose Creek Mining Districts (pl. 1). All of these mining districts contain mineral occurrences that are known to be linked to porphyry copper-type occurrences elsewhere.

Occurrences in the southern part of the WSRA

Numerous stream-sediment and soil samples along the west flanks of the Muttlebury and Wild Horse Mining Districts, east and southeast of Lovelock (pl. 1), contain anomalous concentrations of molybdenum (King, 1996). Many of these samples have values higher than 11 ppm Mo. On the basis of these geochemical data and the presence of polymetallic veins and skarns in the mining districts, the districts have been delineated as being in a favorable tract for the discovery of additional pluton-related deposits (pl. 2).

Estimates of numbers of undiscovered deposits

On the basis of the existence of pluton-related mineralized rocks both in and adjacent to the assessment area and the presence of a number of inferred intrusive bodies at depth, the team made estimates for both porphyry copper and porphyry molybdenum, low-fluorine deposits. For the 90th, 50th, 10th, 5th, and 1st percentiles, the team estimated a 2, 4, 8, 10, 15 undiscovered deposit distribution for a porphyry copper (North American subset) model (Hammarstrom and others, 1993) and a 1, 2, 4, 6, 10 undiscovered deposit distribution for the porphyry molybdenum, low-fluorine model. The copper deposits at Copper Canyon (East ore body) and Copper Basin in the Battle Mountain Mining District are on the grade-tonnage curves for the porphyry copper, skarn related deposits; however, they probably fall in the lowermost 10 percentile of the tonnage distribution for these types of deposit. The Buckingham stockwork molybdenum system is in the upper 10 percentile of the tonnage distribution. The team did not believe that the deposit potential for either Climax molybdenum or porphyry copper-gold deposits met the minimum occurrence potential of at least one chance in a hundred. Discussion of these results can be found in the section below entitled "Estimation of Undiscovered Resources in the WSRA."

Tungsten deposits

Tungsten skarn and vein deposits are common in Nevada (Hess, 1911; Hess, 1917; Kerr, 1946; Lemmon and Tweto, 1962; Kornhauser and Stafford, 1978; Stager and Tingley, 1988; John and Bliss, 1994), and are particularly widespread in the WSRA (Schilling, 1963, 1964; Johnson and Benson, 1963), where two of the previously largest tungsten-producing areas in the United States, the Mill City and Potosi Mining Districts, are present (pl. 3). Tungsten mining was an important industry in the WSRA until 1982, when a sharp drop in the price of tungsten resulted in a suspension of production.

The geologic setting of tungsten skarns is consistent, generally occurring at or near the contacts of limestone-bearing strata and granitic plutons (Cox, 1986a, and many others previously). The age of the plutons is generally Early Cretaceous in the Imlay (Vikre and McKee, 1985) and Hooker Mining Districts (pl. 1; Smith and others, 1971), but is Late Cretaceous in the large Mill City Mining District, and in the Potosi Mining District (Silberman and McKee, 1971; Silberman and others, 1974). Tungsten mineralization also occurred in the Late Cretaceous in the Nightingale Mining District (pl. 1). In contrast to porphyry copper deposits, hot-spring gold deposits, and sediment-hosted gold deposits, which have mainly been mined by open pit methods, most tungsten production has come from underground mines. Tungsten deposits are present as both skarn and vein deposits in the WSRA. In addition, tungsten is associated with hot-spring manganese deposits in the Golconda Mining District, in the east-central part of the WSRA (pls. 1, 3).

Tungsten-skarn deposits (model 14a of Cox and Singer, 1986)

Tungsten-skarn occurrences are present at or near contacts of mesozonal quartz monzonite plutons with carbonate wall rocks. Many of these plutons are weakly peraluminous. An association with aplite and (or) pegmatite bodies is common. These occurrences have many similarities and commonly are associated spatially with base-metal skarns (Einaudi and others, 1981; Einaudi and Burt, 1982). Tungsten-bearing skarns commonly form in roof pendants or thermal aureoles of mesozonal plutons. Skarn mineralogy is dominated by grandite garnet and hedenbergitic pyroxene. Mineralized rocks generally contain molybdenite, pyrrhotite, sphalerite, bismuthinite, chalcopyrite, and scheelite, as well as magnetite (Barton and others, 1988). Large areas of early-formed, iron-poor calc-silicate rock, which are formed by isochemical recrystallization, generally extend significant distances from the centers of metasomatism at the sites of the tungsten skarns. Ore controls for tungsten skarns are both stratigraphic and structural, include the configuration of the contact between igneous intrusions and wall rock; this contact influences the channeling and the ponding of ore-forming fluids. Tungsten-skarn occurrences range in size from very small showings (<1 tonne) or trace byproducts to major deposits (>1 million tonnes), and are present in most areas of the WSRA where Late Cretaceous plutons, ranging in composition from diorite—as little as 62 weight percent SiO_2 (see table in John and Bliss, 1994)—to granite, intrude limestone, dolomite, or other chemically reactive rocks (Hess and Larson, 1921; Cox, 1986a; Stager and Tingley, 1988). There are approximately 150 mineral occurrences in the WSRA that have been classified as tungsten skarn (pl. 3). Base metals, molybdenum, and silver accompany tungsten in trace amounts in many of these occurrences. John and Bliss (1994) indicate that the size of tungsten-skarn deposits mined in Nevada is unusually small because they were mainly exploited during times of war when government subsidies were used to stimulate production.

The tungsten metallogenic province of Stager and Tingley (1988) contains many clusters of stream-sediment and soil samples that have anomalous concentrations of molybdenum (King, 1996). The only other strong clustering of anomalous concentrations of molybdenum is in the general area of the Battle Mountain Mining District (pl. 1). In addition, the tungsten province appears to have relatively low concentrations of barium when barium values within it are compared with those in the surrounding region (King, 1996).

Permissive tracts for both tungsten-skarn and vein deposits (pl. 3) are defined by presence of plutons within the WSRA and are similar to the permissive tracts for porphyry-related deposits (compare pl. 2). Favorable tracts for tungsten skarns have been delineated to encompass all known skarn or contact metamorphic occurrences, and tungsten skarn occurrences. The favorable tracts were constructed by using a 5–km buffer around all known intrusions and igneous-related deposits (table 5; pl. 3), because of the absence of radiometric age determinations for each intrusive body in the WSRA. However, only Cretaceous intrusive centers are known to be associated with significant concentrations of tungsten in the WSRA, although some tungsten has been mobilized by fluids as young as approximately 1 Ma (see subsection below entitled "Other Tungsten Deposits"). Stager and Tingley (1988) have defined a northeast-trending tungsten belt through the southern part of the WSRA, which has been followed roughly to establish the patterns of favorable tracts that we show for these deposits (pl. 3). Prospective tracts for tungsten skarns are buffered around known tungsten skarn occurrences and include areas in and around intrusive bodies that have tungsten-skarn occurrences (pl. 3); these tracts also have been delineated around inferred magmatic systems that are assumed to be associated genetically with known clusters of tungsten occurrences. One of the three favorable tracts for tungsten vein occurrences, delineated separately on plate 3 (tracts A–C), is interior to the northeast-trending tungsten belt generally considered to be favorable for the presence of tungsten skarn. Prospective tracts highlight areas where additional tungsten skarns might be present around known occurrences, and especially where they might be associated with two-mica, peraluminous granite in the southeast part of the WSRA (pl. 3).

The Mill City (Kerr, 1934) and Potosi Mining Districts (Klepper, 1943) are located at the east margin of the Cretaceous Lovelock granitoid batholith belt (pl. 3), which is interpreted as the northeast extension of the Sierra Nevada batholith by Smith and others (1971). The largest tungsten skarn deposit is the Springer Mine in the Nevada Massachusetts group (King and Holmes, 1950; Johnson and Keith, 1991), where a small granodiorite stock intruded and metamorphosed a thick Triassic clastic sequence of shale, quartzite, and minor limestone. The Riley Mine in the

Potosi (or Getchell) Mining District in the Osgood Mountains has the third largest recorded production of tungsten in Nevada (Neuerburg, 1966; Taylor, 1976)—the mining district has the second largest production after the Tempiute Mining District in eastern Nevada. Mineralized rocks at the Riley Mine are associated with the granodioritic Osgood Mountains stock, which intruded Cambrian shale and limestone. Tungsten skarn clusters near the contact between the stock and adjacent limestone strata. Wollastonite is the most abundant contact metamorphic mineral (Hobbs and Clabaugh, 1946; Hobbs and Elliot, 1973; Joraleman, 1975). Skarn minerals, associated with ore in both the Mill City and Potosi Mining Districts, include quartz, epidote, garnet, and pyroxene, as well as minor retrograde tremolite. In addition, scheelite, pyrrhotite, molybdenite, chalcopyrite, arsenopyrite, pyrite, sphene, and apatite are present.

Tungsten vein deposits (model 15a of Cox and Singer, 1986)

Tungsten-vein deposits are present as quartz-wolframite veins which contain molybdenite and minor base-metal sulfide minerals (Kelly and Rye, 1979; Cox and Bagby, 1986). They usually form in monzogranite to peraluminous granite stocks or in the contact aureoles of these bodies in surrounding siliciclastic sedimentary rocks and metasedimentary rocks, rather than in carbonate rocks (Ludington and Johnson, 1986; Barton, 1990). Other minerals present include bismuthinite, pyrite, pyrrhotite, arsenopyrite, bornite, scheelite, beryl, fluorite, and tourmaline. The ore typically includes massive quartz veins with minor vugs, parallel walls for the veins themselves, and local breccia. The tungsten vein deposits have produced significantly less than tungsten skarn deposits in the WSRA. Known occurrences are located in New York Canyon (Ludington and Johnson, 1986; Johnson and others, 1986), in the Imlay Mining District, and in the West Humboldt Range, south of Lovelock (pl. 3). Most deposits in the WSRA contain scheelite, rather than wolframite, and, therefore, such occurrences are not directly compatible with the deposit model. In addition, they are apparently much smaller than the tonnages shown in the model. Tungsten deposits in the Humboldt Range (tract A, pl. 3) include veins and pegmatites containing quartz, fluorite, beryl and anomalous uranium (Cameron, 1939; Klepper, 1943)—these are mineral and elemental associations generally not associated with hornblende-bearing granitic (*sensu lato*) rocks. This association suggests that the areas within the favorable tracts for tungsten vein deposits may represent mineralized rocks formed from a magma type different from that associated with tungsten skarn found elsewhere throughout the WSRA. Tungsten skarn generally is associated with hornblende-bearing granitic rocks.

Other tungsten deposits

Other areas in the WSRA that are considered to lie within favorable or prospective tungsten tracts include mining districts that have either minor production of tungsten or known occurrences of tungsten minerals (pl. 3). These tungsten localities have many characteristics similar to those in the large mining districts, but they also may be associated with porphyry-related mineralized rocks (Erickson and Marsh, 1974a, 1974b, 1974c), or they may be associated with epithermal deposits (Willden and Hotz, 1955). Tungsten, as scheelite, is present in some of the low-fluorine porphyry molybdenum deposits in the Battle Mountain Mining District (Theodore and others, 1992).

Tungsten deposits in the Golconda Mining District (pl. 1) have different characteristics. These deposits contain manganese oxide minerals in lacustrine beds associated with Pleistocene Lake Lahontan (Penrose, 1893; Palmer, 1918). The deposits are hosted in fanglomerate under a caliche-like cap, and tungsten is contained within psilomelane and limonite (Pardee and Jones, 1920; Buttl, 1945). These characteristics are not compatible with either the tungsten-skarn or the tungsten vein models, but represent another type of tungsten resource. Kerr (1940, 1946) suggested that these deposits in the Golconda Mining District are associated with recent hot springs—which are still (1996) active in the area—and it is more likely that these deposits are closely allied genetically to epithermal (hot-spring) manganese deposits described by Mosier (1986b). Some have suggested that the tungsten at Golconda may have been remobilized during the Holocene from Cretaceous skarn deposits at depth.

Estimates of numbers of undiscovered deposits

The apparent magnitude of undiscovered tungsten skarn deposits estimated was heavily influenced by the prolific occurrence of known deposits of this type in the WSRA, where conditions for their formation apparently were near ideal. It is anticipated that a large part of the undiscovered deposit potential lies within the deep reaches of the 1-km-deep permissive terrane, which has not yet been tested, and in which tungsten occurrences, if present, are not likely to be economic in the foreseeable future. The team estimated a 90, 50, 10, 5, and 1 percentile deposit distribution of 20, 35, 50, 90, and 150 deposits, using the grade-tonnage models for Nevada-type deposits (John and Bliss, 1994). Most of the undiscovered Nevada-type tungsten skarn deposits probably are under post-mineral cover. In the absence of an appropriate tungsten vein model, no estimates for tungsten veins could be made. Further discussion of these results can be found in the section below entitled "Estimation of Undiscovered Resources in the WSRA."

Other types of skarn deposit

Other types of skarn deposit, as well as some mining districts made up almost entirely of skarn occurrences, are widespread throughout the WSRA. The geology of most skarn-bearing mining districts and the descriptions of their included deposits suggest that several types of skarn or replacement deposits are present in them, including porphyry copper, skarn-related deposits, copper skarn deposits, zinc-lead skarns, polymetallic replacement deposits, iron skarn deposits, gold skarn deposits, distal disseminated silver-gold deposits, and replacement manganese deposits (pl. 4).

Permissive tracts for skarn occurrences other than tungsten skarn, their references, and descriptions of individual localities or mining districts are similar to those delineated for pluton-related deposits and tungsten skarn deposits (pls. 2, 3, respectively). The permissive tracts were constructed using a 10–km buffer around igneous intrusions, and are similar to those for tungsten skarn deposits. Favorable tracts are delineated where known deposits are present or where skarns have been identified (table 5). Prospective tracts are delineated around mining districts and those plutonic complexes which contain one or more types of skarn deposit. Skarn or replacement deposits are known to be present in the Gold Run, Jackson Mountains, Iron Hat, Antelope, Harmony, and Trinity Mining Districts (pl. 1; see also Jones, 1984a, 1985), and are indicated by favorable or prospective tracts in these general areas (pl. 4). In addition, a number of highly productive skarn deposits are present in the Battle Mountain Mining District near the east border of the WSRA (Doebrich and others, 1995; Doebrich and Theodore, 1996).

Porphyry copper, skarn-related deposits (model 18a of Cox and Singer, 1986)

Porphyry copper, skarn-related deposits are usually characterized by chalcopyrite-bearing quartz-sulfide mineral stockwork veinlets in porphyritic intrusive rock and adjacent altered rocks, including skarn (Cox, 1986e). The deposits usually are generated by Mesozoic- to Tertiary-age granitic stocks intruded into carbonate rocks. Associated deposit types are zinc-lead skarn, distal-disseminated silver-gold, and polymetallic vein and replacement deposits. Copper skarn, as defined by Einaudi and others (1981) and Cox and Theodore (1986), generally is restricted to occurrences which are associated genetically with barren stocks, and are thereby excluded from being classified with porphyry copper, skarn-related deposits. Alteration is usually K–silicate in the barren intrusive rock associated with copper skarn, and skarn minerals such as andradite, diopside, wollastonite, and tremolite are present in the adjoining carbonate wall rocks (Einaudi and others, 1981). There are no occurrences in the WSRA that have been classified as porphyry copper, skarn-related occurrences (pl. 4). The best examples of this deposit type proximal to the WSRA are a number of deposits in the Copper Canyon area of the Battle Mountain Mining District, including the East and West orebodies, which produced copper, gold, and silver in the late 1960s through the late 1970s (Theodore and Blake, 1975, 1978). These deposits are associated with a Tertiary (38–Ma) porphyritic granodiorite which contains about 0.25 weight percent Cu in its protore as chalcopyrite. Copper, gold, and silver ore in the Copper Canyon area was produced predominantly from Paleozoic metasedimentary rocks which contained pyrrhotite, chalcopyrite, pyrite, and marcasite, as well as calc-silicate minerals in some places (Theodore and Blake, 1975, 1978). The East orebody, now (1996) mined out (Doebrich and others, 1995), contained K–silicate mineral assemblages without any prograde calc-silicate minerals, even though ore formed in previously calcareous strata. The most likely location for undiscovered deposits of the porphyry copper, skarn-related deposits is in, and around, previously identified porphyry copper systems. Near many of these systems, the rocks are extremely complex structurally because of the large number of tectonic events to which the rocks have been subjected. Relatively small, but economic, targets require substantial drilling to prove or disprove.

Copper skarn deposits (model 18b of Cox and Singer, 1986)

Copper skarn deposits are characterized by chalcopyrite associated with magnetite and pyrrhotite and a variety of other ore minerals (Cox and Theodore, 1986). These deposits are associated with barren stocks (Einaudi and others, 1981). Most of the approximately 20 known copper skarn occurrences in the WSRA (pl. 4) are spatially associated with Jurassic intrusive rocks, but Cretaceous and Tertiary deposits are also present. According to Einaudi and others (1981), copper skarns form in less dynamic magmatic-hydrothermal environments and at greater depths than the porphyry-related skarns, so fluid flow apparently is restricted while crystal growth is retarded, and, therefore, the development of widespread, disseminated mineralized rocks is less likely. Copper skarns typically are relatively small deposits. Permissive and favorable tracts for copper skarn occurrences are similar to those for iron skarn and zinc-lead skarn (pl. 4), all of which share many geologic and geochemical characteristics (Einaudi and others, 1981; Meinert, 1993). The Tomboy-Minnie gold skarn in the Copper Canyon area of the Battle Mountain Mining District contained abundant sphalerite and galena, but was mined only for its precious-metal content (Theodore and others, 1986).

No estimates were made of the number of undiscovered copper skarns that might remain to be discovered in the WSRA.

Zinc-lead skarn deposits and polymetallic replacement deposits (models 18c and 19a of Cox and Singer, 1986)

Zinc-lead skarn deposits also are found where carbonate rocks are intruded by granitic rocks and typically are formed farther away from the mineralizing intrusive rocks than are copper and iron skarns. Their geologic environment of formation and geographic distribution is similar to polymetallic replacement deposits (Cox, 1986g; Morris, 1986). Zinc-lead skarns are characterized by sphalerite and galena in metasomatic calc-silicate rocks derived from carbonate and calcareous clastic sedimentary rocks. Calc-silicate mineralogy typically includes garnet, diopside, epidote, and tremolite. Polymetallic replacement deposits (Morris, 1986) typically form tabular, pod-like, and pipe-like ore bodies which are localized by faults or bedding in sedimentary rocks. The deposits are in sedimentary rocks, chiefly carbonate strata, which were intruded by porphyritic calc-alkaline or alkali-calcic plutons. Thick carbonate beds may fracture during magma intrusion and deformation and act as good host rocks. Polymetallic replacement ores contain galena, sphalerite, tetrahedrite, and silver sulfosalt minerals. Mineral zoning is common so that inner zones are rich in chalcopyrite or enargite, and outer zones contain sphalerite and rhodochrosite. Jasperoid is common as well. One locality in the Dutch Flat Mining District, in the southern part of the Hot Springs Range (pl. 4), has been classified provisionally as a zinc-lead skarn, and there are a number of localities that have been classified as a polymetallic replacement occurrences—two of the latter are in the Gold Run Mining District (pl. 5; see also, Jones, 1983, 1984a), and nine are in the Humboldt Range (Cameron, 1939). Although lead and zinc are present as minor commodities in many other types of skarn in the WSRA, zinc-lead skarn and polymetallic replacement deposits apparently are not important in this region.

No estimates were made for the number of zinc-lead skarns and polymetallic replacement deposits that remain to be discovered in the WSRA.

Iron skarn deposits (model 18d of Cox and Singer, 1986)

Iron skarn deposits typically are related to intermediate composition intrusions, that were emplaced into carbonate strata or other mafic igneous rocks (Cox, 1986b). The deposits contain magnetite or hematite with calc-silicate minerals in contact metasomatic rocks. The most important iron skarns in the WSRA have formed where Mesozoic plutons intruded Triassic and Jurassic carbonate rocks—22 sites in the WSRA have been classified as iron skarn occurrences (pl. 4).

Iron endoskarns along the southern WSRA boundary (prospective tract A, pl. 4) in the Mineral Basin Mining District are associated with the Middle Jurassic gabbroic Humboldt complex (Reeves and Kral, 1955; Shawe and others, 1962; John and Sherlock, 1991). They consist of massive magnetite replacement of gabbroic rocks and stockworks in both plutonic and coeval volcanic rocks accompanied by scapolite and albite alteration and are analogous to the island-arc calcic magnetite skarn model type described by Einaudi and others (1981). The Buena Vista Mine is the largest of these with reserves of 18,000,000 t at 32.7 weight percent Fe (Lowe and others, 1985). The ore is mainly in replacement veins of magnetite and hematite in scapolitized gabbro. The Humboldt complex and its wall rocks also contain small oxidized copper deposits and some occurrences of amygdaloidal copper, as well as some occurrences of nickel and cobalt near the easternmost part of the complex in the Stillwater Range (Ferguson, 1939).

Permissive tracts for iron skarn deposits are similar to those for other skarn deposits (table 5). No specific favorable and prospective tracts are delineated for iron skarn deposits in the WSRA (pl. 4), but known iron skarn deposits, and areas of aeromagnetic anomalies from both plutons and Buena Vista-type deposits, are considered the most likely areas for their occurrence. However, it is possible that some magnetite skarn deposits that have been converted to hematite may not have a strong magnetic anomaly.

No estimates were made for the number of iron skarn deposits that remain to be discovered in the WSRA.

Gold skarn deposits (model of Theodore and others, 1991)

Gold skarn deposits form in contact metasomatic rocks, generally in shallow-level paleoenvironments, formed at or distal to contacts with intrusive rocks that range in composition from diorite to quartz monzonite. Meinert (1989, 1993) suggests that most large gold skarn deposits are associated with reduced rather than oxidized plutons. Rock textures in gold skarns typically are coarse-grained, granoblastic (Meinert, 1989; Theodore and others, 1991). There are no known occurrences that we have classified as gold skarn in the WSRA. Most examples of gold skarn near the WSRA are in the Battle Mountain (Doebrich and others, 1995) and McCoy Mining Districts (Brooks and others, 1991)—near the east boundary of the WSRA—where they have 38– to 40–Ma ages. Deposits that may be associated with gold skarn include porphyry copper, skarn related; copper skarn; zinc-lead skarn; polymetallic replacement; polymetallic vein; distal-disseminated silver-gold; and placer deposits. Many deposits mined in the past for base metals would be most valuable today for their contained gold (Theodore and others, 1991). The mineralogy of gold skarns includes gold and electrum, arsenopyrite, pyrrhotite, pyrite, high-iron sphalerite, chalcopyrite, magnetite, native bismuth, hedleyite, tetradymite, and other telluride minerals. Altered rocks surrounding gold skarns are typically converted to early K–feldspar-biotite, local intermediate-stage grandite, andradite garnet, and hedenbergitic or diopsidic pyroxene, as well as locally abundant retrograde alteration minerals (chlorite, hematite, epidote, actinolite, sericite, and calcite). Limestone beyond the metasomatic silicate front typically is still within the contact aureole of the associated pluton, and, as such, has been converted to marble. Ore controls may include mining district-scale faults or fault intersections (Doebrich and others, 1995; Doebrich and Theodore, 1996). Ore may be distal to source intrusive rocks, near the marble line, or or it may be in apical parts of the intrusive complex. Geochemical signature is typically gold, silver, copper, arsenic, lead, zinc, and bismuth, as well as tellurium with local tungsten.

Gold skarn orebodies are present at Copper Canyon, east of the WSRA, in the Battle Mountain Mining District (Blake and others, 1984; Wotruba and others, 1988; Myers and Meinert, 1991; Myers, 1994). The Fortitude gold skarn deposit at Copper Canyon produced approximately 1.9 million oz Au between 1984 and 1993—it contained approximately 0.2 weight percent Cu (Wotruba and others, 1988). The Phoenix deposit is another important gold skarn deposit in this district that is slated to be brought into production in 1997 (Doebrich and others, 1995). All of the gold deposits at Copper Canyon lie closer to the stock than a well-developed surrounding zone of lead-zinc-silver polymetallic veins (Roberts and Arnold, 1965), but the Tomboy-Minnie gold skarn, which also is mined out (Doebrich and others, 1995), contained high lead and zinc concentrations (Theodore and others, 1986).

Favorable areas for gold skarn in the WSRA lie within the favorable tracts for porphyry-related deposits in the Battle Mountain-Winnemucca trend, (pl. 2), but gold skarn may also be found elsewhere where contact metasomatic or skarn occurrences or porphyry-related districts containing gold production or anomalous concentrations of gold have been reported (pl. 4). No specific favorable tracts have been delineated for gold skarn deposits (pl. 4).

The assessment team made no attempt to estimate populations of undiscovered deposits for gold skarn deposits.

Other types of pluton-related deposits

Other types of deposits that are related to the plutonic geologic environment include distal-disseminated silver-gold deposits, polymetallic vein and replacement deposits, and replacement manganese deposits (table 5; pl. 5). The most important of these in the WSRA are the currently producing distal-disseminated silver-gold deposits at Lone Tree and those at the Marigold cluster of deposits in the northwest part of the Battle Mountain Mining District (prospective tract A, pl. 5). In addition, three distal-disseminated silver-gold deposits that comprise the Trenton Canyon Project of Santa Fe Pacific Gold Corporation, also in the Battle Mountain Mining District, are scheduled to be brought into production during 1997 (Santa Fe Pacific Gold Corp., press release, January, 1996). Two of these three deposits are in the WSRA—in all, there are five deposits in the WSRA that we have classified as distal-disseminated silver-gold types, although a much larger number are known to be present in the northern part of the Battle Mountain Mining District (T.G. Theodore, unpub. data, 1996). Although the term used to describe these deposits includes the modifier "silver-gold," most deposits assigned to this class of deposits in the Battle Mountain Mining District are valuable primarily for their gold contents. Furthermore, polymetallic occurrences are widely distributed throughout the WSRA, with some large examples present in the Leadville, Battle Mountain, and Kennedy Mining Districts—137 occurrences have been classified as polymetallic vein occurrences and 12 sites have been classified as polymetallic replacement occurrences (pl. 5). Also considered under this family of deposits are managanese replacement deposits, which are not as widely distributed in the WSRA—only 11 sites have been classified as replacement manganese occurrences. All of these types of deposit are considered to be related to, but distant from, centers of porphyry copper and other types of porphyry systems. Because fluids associated with the generation of distal-disseminated silver-gold, polymetallic vein and replacement, and replacement manganese occurrences can flow far from their magmatic source, the permissive area used for porphyry copper tracts (pl. 2) has been expanded for the polymetallic vein and replacement deposits to include pre-Cenozoic rocks and deeply eroded Tertiary rocks (pl. 5). Areas with greater than 1 km of Cenozoic cover have been subtracted, as we have done previously, to construct the tracts classified as permissive (pl. 5). Favorable tracts for polymetallic vein and replacement occurrences approximate the favorable tracts for pluton-related occurrences (see also, pl. 2), but also include some epithermal mining districts, which are inferred to be indicative of a favorable geologic environment at depth for the types of porphyry sytems described above. Prospective tracts for polymetallic vein deposits are constructed around known or inferred polymetallic mining districts or localities. A prospective tract for distal-disseminated silver-gold deposits is constructed as a distinct tract north of the Battle Mountain Mining District, and includes known deposits and prospects and extrapolated prospects to the north (pl. 5). No distinct tract delineating replacement managanese deposits was constructed, but undiscovered deposits of this type would most likely be present in the eastern part of the WSRA, west of Battle Mountain, where there are known occurrences (pl. 5).

Distal-disseminated silver-gold deposits (model 19c of Cox and Singer, 1992)

Distal-disseminated silver-gold deposits contain silver and gold in stockworks of narrow quartz-sulfide veins and (or) iron oxide-stained fractures in sedimentary rock, and they contain some trace elements—specifically lead, zinc, manganese, copper, and bismuth—which suggest they may be plutonic-related (Cox and Singer, 1992). In addition, stable-isotope studies indicate that the fluids involved in the generation of the distal-disseminated silver-gold deposits in the northern part of the Battle Mountain Mining District include a significant magmatic component (Howe and others, 1995; Norman and others, 1996). Because many of these deposits are hosted by sedimentary rocks, some previous workers regarded them as Carlin-type gold deposits discussed in a section below. In addition, several deposits of this type show significant potassium metasomatism (Bloomstein and others, 1993), which is comparatively rare in the Carlin-type deposits. Many distal-disseminated silver-gold deposits contain more silver and base metals than most Carlin-type sediment-hosted gold deposits, and the Cove deposit in the McCoy Mining District, east of the WSRA, is one of the largest producers of silver in the United States. In 1995, the McCoy-Cove deposits produced approximately 12 million oz Ag (372,000 kg Ag) (Nevada Division of Minerals, 1996). Distal-disseminated silver-gold deposits are present in or near mining districts that contain major porphyry-related skarn, replacement, and vein base-metal ores, such as the Battle Mountain Mining District. At Battle Mountain, they are preserved in parts of the mining district that have been downdropped by Miocene post-mineral normal faults that have offsets of as much as 700 m (Doebrich and others, 1995; Doebrich and Theodore, 1996; T.G. Theodore, unpub. data, 1996). Surface oxidation of some distal-disseminated silver-gold deposits can result in bonanza silver ore bodies that are rich in silver chloride minerals.

The Lone Tree deposit (pl. 5) is a composite 3–km-long zone of structurally controlled, high-grade gold mineralized rocks, which have many characteristics of distal-disseminated silver-gold deposits, lack jasperoid or organic carbon, and are dominated by mineral assemblages suggestive of quartz-adularia-sericite low-sulfidation alteration (Bloomstein and others, 1993; B.L. Braginton, writtren commun., 1996). Some mineralized quartz veins from the Lone Tree deposit contain as many as seven translucent daughter minerals in their fluid inclusions as well as liquid-vapor proportions that suggest boiling at temperatures higher than 400 °C (D. A. John, oral commun., 1996). Other veins contain fluid-inclusion relations that exhibit filling temperatures greater than 300 °C and salinities higher than 25 weight percent NaCl equivalent (Norman and others, 1996). The deposit is outside previously established mining districts, which suggests that many deposits of this type in a similar geologic setting may have gone unrecognized. The deposit comprises four mineralized zones—these are the Wayne Zone, the Chaotic Zone, the Sequoia Zone, and the Antler Zone (B.L. Braginton, written commun., 1996). As of January 31, 1995, the proven and probable reserves at Lone Tree include 4,679,000 oz Au (146,219 kg Au) in approximately 60 million tonnes (t) ore (B.L. Braginton, written commun., 1996). The Marigold deposits—including the Eight South deposit, the East Hill/UNR deposit, the Top Zone deposit, and the Red Rock deposit—comprise mineralized rocks elongated along a broad north-south trend (Graney and McGibbon, 1991; D.H. McGibbon and A.B. Wallace, unpub. data, 1996). Original reserves for the Eight South deposit—the largest of the four deposits—were 4.5 million t of ore, all oxide, at an average grade of 2.7 g (0.085 oz) Au/t (D.H. McGibbon and A.B. Wallace, unpub. data, 1996). The highest grades are present in mineralized debris flows of the Permian Edna Mountain Formation. Gold, arsenic, antimony, barium (as barite), and mercury are enriched, but silver is generally low (Graney and McGibbon, 1991). The

Marigold deposits, as well as the Lone Tree deposit, are considered by Howe and Theodore (1993) and Howe and others (1995) to be distal-disseminated silver-gold deposits, partly on the basis of the apparently abundant magmatic components of the fluids responsible for their genesis, and partly on the basis of the geologic setting in which they occur (see also, Doebrich and others, 1995; Doebrich and Theodore, 1996).

The prospective tract for distal-disseminated silver-gold deposits in the east-central part of the WSRA reflects an extension to the north of the well-documented favorable geologic environment in the Battle Mountain Mining District for these deposits (tract A, pl. 5).

The assessment team was impressed with aspects of the plutonic history of the area and presence of deposit types associated with the occurrence of distal disseminated precious metal bearing vein mineralization. However, the silver-to-gold ratio in the original grade-and-tonnage global model (Cox and Singer, 1990, 1992) is believed to be too high to characterize the Nevada deposits. The assessment team, therefore, adopted a modified grade and tonnage model based on data supplied by T.G. Theodore (written commun., 1995) for 17 deposits mostly in northwestern Nevada. The modified model differs from the global model in that recoverable gold grades are reported for 16 of the 17 deposits whereas 30 percent of the deposits in the global model have no reported gold. The median silver grade falls from 42 grams per tonne to 5 grams per tonne in the modified model and only 11 of 17 deposits have recoverable silver. Overall size of the two deposit types varies only slightly. The modified model is shown in Appendix A. Using the modified grade and tonnage models, the assessment team estimates a 90, 50, 10, 5, 1 percent probability distribution of 20, 35, 50, 70, and 90 undiscovered deposits respectively that are consistent with the Nevada model.

Polymetallic vein deposits (model 22c of Cox and Singer, 1986)

Polymetallic vein deposits are common intrusion-related types of deposit, which are characterized by locally diverse base- and precious-metal sulfide minerals, including chalcopyrite, enargite, sphalerite, galena, and a large number of sulphosalt minerals and carbonate minerals, as well as quartz, pyrite, arsenopyrite, marcasite, and barite (Cox, 1986j). Polymetallic veins characteristically have envelopes of phyllic or argillic alteration (Cox, 1986j). Such veins are simple or structurally complex and multiphase with a variety of oreshoot shapes (Peters, 1993b). Ore minerals are usually tetrahedrite, sphalerite, galena, chalcopyrite, jamesonite, native bismuth, stibnite, and arsenopyrite, as well as rare electrum or gold. Scheelite, molybdenite, and fluorite are also present in some polymetallic veins. Most polymetallic vein deposits have been mined for silver, but lead, zinc, copper, and gold were also recovered in some deposits, and some veins were mined for their gold content alone. Polymetallic veins are also referred to as felsic intrusion-associated (Sangster, 1984) or Cordilleran veins (Sawkins, 1972, 1983; Guilbert and Park, 1986), and they usually have a direct link to intrusive bodies, although the veins are typically concentrated in zones distal to the intrusive bodies. Polymetallic veins are, in most places, spatially related to other deposit types that are, as well, associated with intrusive activity—the other types of deposit include polymetallic replacement, porphyry copper and porphyry molybdenum, and distal-disseminated silver-gold. There may be a transition between polymetallic veins and epithermal veins at shallow levels, and between polymetallic veins and metamorphic veins at deep levels. In most cases, field evidence and available descriptions in the MRDS records are not adequate to estimate depths of formation.

Permissive tracts for polymetallic veins include the permissive tracts delineated for porphyry and skarn deposits (pls. 2 , 5). In addition, areas that are favorable for epithermal deposits—to be described in the section below entitled "Hot Spring and Epithermal Deposits"—are included in the permissive tract for polymetallic veins, on the assumption that intrusions and deep-seated polymetallic veins may underlie many areas where epithermal veins are present (pls. 5, 6). Favorable tracts include the Battle Mountain-Winnemucca and the Humboldt River porphyry trends, discussed previously, and also include some adjacent major mining districts in epithermal deposits. Prospective tracts have been delineated around mining districts with known polymetallic vein occurrences (pl. 5). However, those vein occurrences that are more likely to be either epithermal or metamorphic-derived are not contained in many prospective polymetallic vein tracts.

Polymetallic veins are found throughout most of the WSRA and their distribution pattern suggests a correspondence with mineralized Mesozoic and Tertiary plutons. At Copper Basin and Copper Canyon in the Battle Mountain Mining District, Roberts and Arnold (1965), Theodore and Hammarstrom (1991), Ivosevic and Theodore (1996) point out that the centers of porphyry-type and skarn mineralized rocks are surrounded by haloes of polymetallic veins whose metal contents are zoned laterally with distance from the centers (see also, Doebrich and others, 1995; Doebrich and Theodore, 1996). In the Kennedy Mining District, polymetallic veins are associated with plutons of both Triassic and Tertiary ages (Wallace, 1977). Many polymetallic vein occurrences in the WSRA are rich in silver and lead, but may contain some copper and gold. They are closely associated with many Mesozoic granitic bodies that also produced tungsten skarn, and many mining districts contain both types of mineralized rocks. Also associated with these deposits are lead- and silver-rich sulfide replacement deposits in limestone. A second group of gold-arsenic-copper veins are also related to Cretaceous intrusive rocks and spatially related to tungsten skarn deposits. It is uncertain whether these represent a different period of mineralization, a different compositional group of intrusive rocks, or some other factor—gold-arsenic (arsenopyrite)-copper (chalcopyrite) veins are, in some places such as the Battle Mountain Mining District, associated with Tertiary rather than Cretaceous intrusive rocks. In some deposits mined in the past, veins are closely spaced through a large volume of rock that probably would have constituted an economic deposit even by today's mining techniques.

The assessment team made an estimate of numbers for these deposits. Examples are numerous within the study area. However, there are some considerations that are unique to the assessment process for the polymetallic veins. Unlike the grade and tonnage models for skarn-type deposits, the grade and tonnage model for polymetallic veins are mixed (that is, they are non-metal specific), and they represent composites of data from all mine workings within 1 km of one another (that is, a mining complex). On the basis of data relating to known mineral occurrences, inferred and known plutonic activity, and surficial geochemical patterns, the assessment team reached a consensus on 90, 50, 10, 5, and 1 percent probability of 3, 5, 12, 18, 25 undiscovered deposits.

Replacement manganese deposits (model 19b of Cox and Singer, 1986)

Replacement manganese deposits are spatially and genetically related to polymetallic replacement deposits, but they contain a higher amount of manganese or manganese oxide minerals and lesser amounts of lead, zinc, and silver minerals and are located more distant from the source pluton than polymetallic veins (Mosier, 1986b, 1986c). Manganese carbonate minerals replace carbonate rocks and fill veins or cavities. The richest part of the ore is usually in the oxidized and weathered zone where carbonate minerals are altered to black manganese oxide and hydroxide minerals. The Golconda and Battle Mountain areas in the east-central part of the WSRA respectively contain hot spring and volcanogenic manganese deposits (Pardee and Jones, 1920; Roberts and Arnold, 1965; Doebrich and others, 1995); the Pennsylvanian and Permian Antler Peak Limestone in the Battle Mountain Mining District is a permissive, but not likely, host for replacement manganese deposits due partially to possible remobilization of manganese during emplacement of Cretaceous and Tertiary porphyry-type systems (pls. 4, 5). However, the primary source of manganese would be rocks of the Devonian, Mississippian, Pennsylvanian, and Permian Havallah sequence which are present structurally above the Antler Peak Limestone.

The relatively sparse number of known examples of this type of mineralized rock in the WSRA suggests to the assessment team that the potential for the existence of any undiscovered deposits consistent with the grade and tonnage model of Mosier (1986c) are less than one chance in one hundred.

Hot-spring and epithermal deposits

Tertiary epithermal gold-silver deposits account for a substantial part of recorded metal production from the WSRA. These types of deposits also are one of the major targets that have been sought recently, and they are continuing to be sought, by substantial exploration efforts in the WSRA. Within the last ten years the Florida Canyon, Lewis-Crofoot, Hog Ranch, and Wind Mountain Mines in the WSRA have produced over 3 million oz Au. Major gold reserves remain at Lewis-Crofoot, as well as at the recently discovered Mountain View, Goldbanks, and Rosebud deposits. The Sleeper, Hog Ranch, and Wind Mountain Mines are being reclaimed (1996), and these deposits presumably are mined out. Other, small mining districts of these types of deposit are widespread in the WSRA, and include the Seven Troughs, Velvet, National, Trinity, Ten Mile, and Willard Mining Districts (pl. 6). Many of these mining districts contain unmined reserves.

Epithermal deposits have mineralogical and geochemical attributes indicative of formation from hydrothermal fluids at shallow depths. Studies of modern and ancient systems indicate temperatures are generally in the range of 100 to 200 °C, but occassionally as high as 300 °C—they may extend from the surface (hot spring deposits) to depths of about 1 or 1.5 km (Guilbert and Park, 1986). Geologists debate the genetic details of these deposits, such as the importance of magmatic sources, but most agree that many processes and rock types can be involved. Some of these deposits appear to be the outermost, distal parts of pluton or porphyry-related hydrothermal systems, whereas others show no spatial relation to either volcanic or plutonic rocks. Geologic models for these deposits tend to be very specific as to ore composition, alteration, and morphology (Cox and Singer, 1986), but, for resource assessment of large tracts as in WSRA, there generally is significant uncertainty as to the depth of erosion and composition of prospects, and hence their classification in detail. For this regional assessment, we will use a generalized model that in essence includes several possible sub-types of hot springs and epithermal deposits.

The most important hot-spring and epithermal deposit types in the WSRA are either shallow-formed, hot-spring-related, hydrothermal deposits of precious metals, mercury, or manganese or somewhat deeper equivalents of these systems. Associated geologically with these epithermal gold-silver deposits, but discussed separately below, are some uranium deposits. Hot-spring deposits are present throughout most of the WSRA (Bonham, 1988; Berger and Henley, 1989; Berger and Bonham, 1990). These deposits are both high level disseminated hot-spring deposits (Silberman, 1982; Berger, 1985, 1986a; Heran, 1992a) and deep epithermal vein zones formed adjacent to or below the discharge zones of geothermal systems (Berger, 1986b; Panteleyev, 1988; Klein and Bankey, 1992). The hot-spring and epithermal gold-silver, mercury (Rytuba, 1986; 1989), and manganese deposits are hosted by many rock types and are geochemically similar. Epithermal deposits associated with volcanic calderas (Rytuba, 1994) are most common in the northern part of the WSRA where they are associated with the McDermitt Caldera complex (pl. 6). Individual deposits and clusters of deposits can differ in morphology (large irregular zones as opposed to narrow, steeply-dipping tabular bodies). The deposits are typified by elevated gold, silver, antimony, manganese, and mercury concentrations. Selenium and (or) tellurium are enriched in many mining districts that host this type of deposit. The abundances of copper, lead, and zinc typically are low, although copper is notably high in some mining districts. Base metals may increase or vary in abundance with depth or may be zoned laterally within the mineralized area (Berger, 1982; Sillitoe, 1993).

Permissive geologic criteria for high level hot-spring gold-silver deposits (exemplified by the Lewis-Crofoot (Sulphur) deposit) include regions of continental extension, particularly where these regions contain bimodal basalt-rhyolite magmatism. Thus, the permissive tract for epithermal deposits for the WSRA includes the entire area. Permissive criteria for the deep epithermal vein gold-silver deposits (exemplified by deposits in the Jessup and National Mining Districts) are the same as for the high level hot-spring deposits, and these deposits appear to be concentrated in the Central Zone of deep epithermal deposits (see section below entitled "Central Zone of Epithermal Tracts"). Erosion has not exposed the deep levels of many hot-spring gold-silver deposits, due to their young age, and it is likely that epithermal vein systems lie below many such hot-spring systems. Favorable criteria include direct evidence of hydrothermal processes, such as siliceous alteration or silica sinter, anomalous concentrations of gold, silver, arsenic, antimony, or mercury in rock, soil, or stream-sediment samples, as well as known gold, silver, or mercury occurrences. Areas where active or Holocene gold-bearing hot-springs are present are not reflected in this tract. A favorable criterion is also the presence of placer gold in the general area, although most placer gold occurrences appear to be associated spatially with low-sulfide, gold-quartz veins. Prospective criteria include geological, geochemical, and geophysical extensions of known epithermal mining districts (pl. 6). Prospective tracts have been extrapolated outward from clusters of known hot-spring or epithermal deposits, using geochemical, geophysical or alteration patterns that aided in delineation of inferred large hydrothermal systems responsible for these deposits. In addition, presence of Tertiary rhyolite domes in an area suggests to us that the area should be highly prospective. High level hot-spring systems, as well as systems containing relatively abundant mercury, generally tend to be present in the southeast and northwest part of the WSRA. The deep, vein type, mercury-poor epithermal deposits are most prolific in a central, northeast-trending zone which is flanked by mercury deposits (pl. 6).

High level hot-spring gold-silver deposits (model 25a of Cox and Singer, 1986)

The model used in this study is generalized to include a number of sub-types such as hot-spring (formed at the surface), sub-hot spring (a bit deeper), and Comstock- or Sado-type veins (Cox and Singer, 1986). The latest grade and tonnage model for "hot-spring Au-Ag" (Berger and Singer, 1992) contains 17 deposits, all but one in Nevada, and all exploited by an open-pit style of mining that is generally favored today. There is no agreement among the geologists on this team, nor among economic geologists in general, as to the classification of the 17 deposits that comprise this model. We believe, however, that whatever model is adopted, it must include more than just the hot-spring environment (*sensu strictu*), and, regardless of semantics, the examples in the model must reflect what is likely to be present in the WSRA. Indeed, five of the 17 deposits (Lewis-Crofoot, Florida Canyon, Hog Ranch, Sleeper, and Wind Mountain) in the Berger and Singer (1992) model are from the WSRA. Recently discovered Middle Miocene gold mineralization at the Mountain View Mine in the Deephole Mining

District (pl. 6)—herein classified as a high level hot-spring gold-silver occurrence—apparently has been superposed on a pre-existing Cretaceeous base-metal mineralization in the Granite Range (Margolis and Marlowe, 1996). Other prototype deposits assigned to other models, such as those in the National and Seven Troughs Mining Districts, should be part of the generalized epithermal model, as used here, but would not plot on the curves because their high grades and low tonnages were determined more by underground mining engineering than by geology. Another general problem in this environment is the difficulty of predicting morpholgy of ore—vein versus breccia or stockworks—without substantial amounts of drill information. Further, some deposits contain both high-grade veins, and large zones of low-grade breccia and stockworks, as at Sleeper (Nash and others, 1991; 1995), whereas others contain only veins (National) or only stockworks (Florida Canyon). The engineering aspects of these deposits can differ greatly, yet the geology and resource endowment are similar.

High level hot-spring deposits form at the surface or at shallow depth and have evidence of a prior paleosurface such as sinter, "mud-pot" deposits, or geyser eggs. Hydrothermal explosion features may be present, and may be pre-ore, syn-ore, and (or) post-ore in timing (Nelson, 1988). Mineralized rocks may include pervasive disseminations in unconsolidated clastic sedimentary rocks or the mineralized rocks may be fracture controlled. Some hot-spring zones are underlain by veins and may be present in either Tertiary volcanic rocks or in pre-Tertiary rocks.

Vein epithermal deposits (Comstock epithermal vein, quartz-sericite-adularia) (models 25c and 25d of Cox and Singer, 1986)

Vein epithermal deposits are found below or adjacent to many hot-spring deposits. They consist of tabular individual or stockwork veins, breccias or disseminations composed of quartz, chalcedony, or opal, commonly with abundant adularia and (or) calcite. These deposits include occurrences of gold-bearing, silicified pyritic breccia veins. Many deposits flare upwards in a funnel shape. Calcite accompanies mineralized rocks as lamellar aggregates, or as quartz pseudomorphous after lamellar calcite (see Berger, 1986c). Within the veins, sulfide minerals are typically very sparse (<1 volume percent), and macroscopic gold, electrum, or silver-selenide minerals are rare but important. The deep parts of the Comstock, Nev., deposit is unusal in that it contained 15 to 20 volume percent sulfide minerals. Mineralized veins locally are high grade with abundant visible gold. Alteration typically includes adularia and silicified wall rocks, as well as argillic or advanced argillic mineral assemblages in the upper parts of the systems; propylitic alteration is widespread and locally abundant.

Two main types of epithermal veins, adularia-sericite (low-sulfidation) and quartz-alunite (acid sulfate or high-sulfidation) are have been recognized (Heald and others, 1987; Bonham, 1988). Comstock-type epithermal vein deposits (Berger, 1986c; Mosier and others, 1986) typically include gold and (or) electrum as well as variable amounts of base-metal sulfide minerals in banded quartz veins. They are present in, or associated with, andesite-dacite lava flow and flow breccia sequences, and their associated sub-volcanic intrusions. These deposits in the WSRA are mainly Miocene and younger. Associated deposit types are porphyry copper, polymetallic replacement, various types of skarn, and polymetallic vein. The epithermal veins contain gold or electrum, sphalerite, galena, chalcopyrite, tetrahedrite, silver sulfosalt minerals, hematite, chlorite, manganese carbonate minerals, and rare amythest, barite, and chalcedony. Alteration consists of regionally extensive propylitically altered rocks, local sericite, abundant pyrite, and vein-related sericite and (or) illite-pyrite, locally with a central zone of pervasive silicified rocks with or without adularia.

Ore controls are usually pre-ore faults with moderate to large amounts of displacement, some related to caldera development. Oreshoots typically have strong elevation control, influenced by irregularities along fault planes. Weathering results in an illitic-argillic "cap," which consists of a bleached, goethite-jarosite stained zone along the host fault. The geochemical signature is typically gold, silver, zinc, lead, copper, arsenic, antimony, and manganese and silver:gold ratios range from 25:1, to greater than 1,000:1. In addition, arsenic:gold ratios and base-metal content increase with depth in the veins.

Epithermal quartz-alunite gold-silver deposits (model 25e of Cox and Singer, 1986)

Quartz-alunite gold-silver (acid-sulfate) deposits consist of native gold, enargite, pyrite, silver-bearing sulfosalt minerals, and other base-metal sulfide minerals and telluride minerals. These minerals are present in vuggy veins and breccias in zones of vuggy silica alteration of felsic volcanic rocks. Alteration consists of quartz, alunite, pyrophyllite with peripheral low-temperature kaolinite, and montmorillonite (Berger, 1986c; Albino, 1994). The hydrothermal alteration style is distinctive when studied in detail, but it can be confused with acid leaching produced by supergene processes during weathering. The geologic association of this type of deposit typically is with andesitic composite volcanic centers, some having porphyry-style intrusions (Berger and Henley, 1989). Examples of this deposit type are known at Goldfield, Nev., and Borealis, Nev., Pyramid Mining District, Nev., Paradise Peak, Nev., and Summitville, Colo. These deposits typically have elevated abundances of Au, Ag, As, Sb, Hg, and Cu, as well as local concentrations of Pb, Bi, Zn, Mo, and Sn. There is no agreement among the authors of this report that any prospects in the WSRA have the requisite geology and geochemistry to be classified in this category of deposits—thus, there are no occurrences in the WSRA that have been classified as epithermal quartz-alunite gold-silver deposits (pl. 6).

Hot-spring mercury deposits (model 27a of Cox and Singer, 1986)

Hot-spring mercury deposits are geologically similar to hot-spring gold-silver deposits, although mercury is more abundant than gold (Rytuba, 1986). Mercury is present either as true disseminations in sedimentary rock or ash-flow tuff, or as fracture coatings or silicified zones in volcanic rocks. Some hot-spring mercury deposits contain significant amounts of gold and silver and occasionally are spatially associated with gold-silver epithermal deposits. Permissive criteria for hot spring mercury deposits are the same as for hot-spring gold-silver deposits. Prospective criteria include linear trends defined by alignment of mineral occurrences and mining districts, as discussed above for the hot-spring deposit types, as well as large calderas, particularly of highly siliceous, peralkaline rhyolite. Hot-spring mercury deposits are most common in the northwest and southeast part of the WSRA (pl. 6).

Epithermal manganese deposits (model 25g of Cox and Singer, 1986)

Epithermal manganese deposits are veins which fill faults and fractures in volcanic rocks ranging in composition from rhyolite to basalt. They commonly are associated with vein epithermal and high-level hot-spring gold-silver deposits. Mineralogy includes rhodochrosite, manganocalcite, calcite, quartz or chalcedony, and barite in veins, stringers, nodules and disseminations (Mosier, 1986a). Alteration usually consists of kaolinitized rocks. Geochemical signatures consist of elevated abundances of manganese, iron, lead, silver, gold, and copper. Permissive tracts include Tertiary volcanic rocks and pre-Tertiary basement rocks with the exception of large plutons. Favorable criteria include the presence of hot-spring or epithermal occurrences in belts. Prospective criteria include epithermal or hot-spring mining districts, particularly those with known occurrences of manganese occurrences (pl. 6). Manganese oxides are present in the hot spring manganese-tungsten occurrence at Golconda, as described above, which occurs as a replacement of lake beds of Lake Lahontan. In addition, older gravels mapped by Theodore (1991) at the south end of Lone Tree Hill have been shown to contain manganese oxide-cemented gravels where they have been exposed by mining operations associated with the Lone Tree Mine. These gravels probably are either beach gravels associated with Lake Lahontan, or they are fluvial deposits of a tributary that flowed into Lake Lahontan, although, as currently (1996) exposed, there are no fluted cross beds to suggest a fluvial origin. In addition, there are some hot spring sinter deposits nearby that probably are associated with the replacement manganese oxide minerals.

Description of tracts for epithermal and hot-spring deposits

Permissive, favorable, and prospective tracts for epithermal and hot-spring deposits in the WSRA are widespread (table 5, pl. 6). The hot-spring and epithermal deposits in the WSRA are associated mainly with north-striking Basin and Range faults, and they are hosted by either Miocene volcanic rocks (for example, Sleeper), sedimentary rocks (Wind Mountain, Lewis-Crofoot), or pre-Tertiary rocks (Florida Canyon, Willard). It is possible that some of the older Oligocene volcanic rocks could host these types of deposit also; however, the volume of these rocks in the WSRA is relatively small. A close association with rhyolite domes exists in several mining districts, such as Sleeper and Seven Troughs. Many mining districts, however, lack any evidence of nearby igneous activity at the time of mineralization (e.g. Lewis-Crofoot, Wind Mountain). A close spatial relationship with deep magnetic anomalies may indicate that rift-related basaltic intrusions underlie some of these mining districts.

Mercury-bearing hot-spring deposits in some mining districts (for example Opalite, Goldbanks) are related to somewhat deeper, but still relatively shallow, gold-silver deposits. The presence of mercury may indicate favorability for precious metal deposits at depth. Mercury deposits may be economically important, as in the Opalite Mining District, just south of the Nevada-Oregon border (pl. 6), which was for many years the largest source of mercury in the United States.

The distribution of hot-spring and epithermal deposits within the WSRA is partitioned into three distinct areas: (1) an eastern area of mercury-dominant hot-spring districts; (2) a central north-northeast-trending zone of gold-silver epithermal vein deposits; and (3) a northwestern area of mercury-uranium-(gold-silver)-dominant hot-spring deposits (pl. 6). There is a spatial and genetic relationship between some gold-silver hot-spring or epithermal deposits and many mercury-dominant deposits, and thus we employ the same tracts for both. Epithermal deposits may lie underneath hot-spring deposits or may be overprinted by them after uplift to shallower levels.

East zone hot-spring mercury-dominant tracts

The eastern hot-spring mercury-dominant mining districts lie in a roughly 30–to 10–km–wide and 180–km–long belt that extends from approximately the locations of Winnemucca and Rochester to the east boundary of the WSRA (pl. 6). The Table Mountain Mining District has been a mercury producer (Ransome, 1909; Lincoln, 1923; Bailey and Phoenix, 1944) from cinnabar in hot-spring deposits which also contain sulfur, pyrite, and galena in veins and disseminations (Vanderburg, 1940; Schrader, 1947; Lawrence, 1963). The Mount Tobin Mining District also produced mercury from cinnabar in cavity-fillings of calcite and chalcedony veinlets and in replacements in Tertiary and pre-Tertiary rocks; mercury is associated with pyrite and local enrichment of gold, arsenic, silver, antimony, and zinc (Burke, 1974; Johnson, 1977). The Antelope Springs Mining District contains numerous mercury localities in limestone breccias locally associated with stibnite, pyrite, sphalerite, galena, and silver with gold (Johnson, 1977). The Florida Canyon deposit, however, contains currently active hot springs that obviously are younger than many of the other hot-spring precious metal deposits, and it is possible that young hot springs may overprint some other old epithermal mineral deposits as well. It is one of several hot-spring systems that are present along the western range front of the Humboldt Range. The deposit contains gold and silver in sugary quartz veins in alteration assemblages composed of alunite, kaolinite, adularia, and hematite with elevated arsenic and mercury contents (Richardson, 1987; Hastings and others, 1988). The Goldbanks Mining District contains blanket-like opaline mercury deposits in silicified zones in rhyolite and contains associated stibnite, tetrahedrite and pyrite (Dreyer, 1940; Bailey and Phoenix, 1944) that is being evaluated currently (1996) for gold.

In the north part of the WSRA, the Dutch Flats Mining District contains hot-spring mercury occurrences as well as some other types of deposit (Willden and Hotz, 1955; Hotz and Willden, 1964; Willden, 1964). There, cinnabar is present in quartz veins and as placers (Vanderburg, 1936a; Bailey and Phoenix, 1944). The Poverty Peak Mining District also contains hot-spring mercury deposits in quartz and calcite veins and replacements hosted in silicified Paleozoic sedimentary rocks (Bailey and Phoenix, 1944; Benson, 1956). Manganese deposits in the mining district may be of several types, but those hosted by Tertiary volcanic rocks as veins or replacements are most likely related to hot-spring type of activity.

In the Golconda Mining District, a tight cluster of manganese localities are in Pleistocene lake beds (Penrose, 1893; Palmer, 1918) under a caliche-like cap, and the main ore minerals are psilomelane and limonite (Pardee and Jones, 1920; Buttl, 1945). The localities also contain some tungsten (see section above entitled "Other Tungsten Deposits"). Kerr (1940, 1946) suggested that these deposits in the Golconda Mining District are associated with young hot springs, because of the then, and currently (1996), active hot springs that are continuing to deposit manganese as well as iron sulfide minerals. Geologic characteristics of the deposits in the favorable tract area of hot-spring epithermal deposits in the eastern part of the WSRA (pl. 6) are identical to hot-spring mercury deposits defined by Rytuba (1986). In addition, many outlined tracts are favorable or prospective for the occurrence of hot-spring gold-silver and hot-spring manganese deposits. Epithermal gold-silver deposits are also likely to be present beneath many hot-spring deposits in this area.

Central zone epithermal tracts

The central zone of epithermal mining districts has two parts: a southern part in the Jessup-Sulphur Belt that contains several epithermal mining districts, and a northern part which contains three isolated mining districts (pl. 6). All of these epithermal tracts in the central area lie between the predominantly hot-spring mining districts to the southeast and northwest, and they generally lack abundant mercury, except Sulphur (Lewis-Crofoot). The Jessup-Sulphur Belt is a 20– to 30–km–wide irregularly-shaped favorable tract which extends beyond the southern boundary of the WSRA, bifurcates in the general area of the Lake Mining District, and trends northerly approximately 170 km (pl. 6). The central zone of epithermal deposits spatially is coincident with the Jungo Terrane of Silberling (1991), and it is roughly coincident with a northeast-trending zone of oxidized crust defined by Keith and others (1990). It is possible that this central area of epithermal deposits reflects a region that is geologically older and deeper than the ones to the east and northwest. High-level hot-spring deposits, which would normally overlie these deposits, are not generally present in the central area and may have beeen removed by erosion.

The southern part of the central area contains the Jessup Mining District, which is typified by high grade gold-silver veins and associated arsenic. It is hosted by silicified and brecciated Tertiary rhyolite flow domes (Willden and Speed, 1974). In the Trinity Mining District, brecciated quartz veins contain silver and gold in rhyolitic volcanic rocks (Lincoln, 1923; Johnson, 1977). In the Velvet Mining District, hydrothermal breccia and associated opal, chalcedony, and alunite, host gold-arsenic mineralized rocks in argillically altered Tertiary ash-flow tuff (Vanderburg, 1936a; Johnson, 1977; Masterson and Kyle, 1984). The mineralized rocks comprise veinlets, breccia fillings, and disseminations.

To the north, a large irregular prospective tract, approximately 60 by 20 km, contains several important epithermal deposits (pl. 6). The Seven Troughs Mining District consists of replacements and veins and veinlets rich in gold and silver, which are hosted by rhyolite with adularia-sericite alteration. Associated metals are arsenic and antimony (Ransome, 1909; Lawrence, 1963; Johnson, 1977). The Rosebud deposit is a covered, volcanic-hosted, quartz-adularia-sericite, gold-silver orebody related to faults—the orebody is contained in a multistage breccia and stockwork that is associated with calcite, clay, pyrite, and marcasite, and it has elevated concentrations of mercury, selenium, arsenic, and antimony (Walck and others, 1993). The Sulphur (Lewis-Crofoot) deposit consists of early quartz-adularia, gold-silver epithermal mineralized rocks that have been overprinted by a late hot-spring (acid-leach) event (Ebert and others, 1996; David A. John, unpub. data, 1996). Altered rocks include kaolinite, alunite, illite, barite, and cristobalite. Ore minerals are cinnabar, sulfur, pyrite, nauminite, argentite, uranophane, bromian chlorargyrite, stibnite, and a number of other epithermal minerals. Arsenic, antimony, and mercury contents are conspicuously elevated (Clark, 1918; Bailey and Phoenix, 1944; Wallace, 1987; Ebert and others, 1996).

The Jessup-Sulphur belt (pl. 6) is characterized by three main Tertiary volcanic units. The epithermal mineral deposits of the Jessup, Seven Troughs, and Rosebud Mining Districts are present in the lower two volcanic units—alteration patterns are clearly truncated by the uppermost volcanic unit. Some mineralized rocks also are present in pre-Tertiary rocks at Jessup and Rosebud, and perhaps at Seven Troughs (pl. 6). A subsequent period of mineralization at the Velvet Mining District is hosted in sedimentary units and welded tuff of the upper volcanic unit, where rhyolite domes are synmineral. The main sequence of basaltic rock in the Jessup-Sulphur belt everywhere appears to be post-mineral, except at Sulphur where mineralization has a 2– to 4–Ma age.

Three epithermal mining districts clustered in the northeastern part of the WSRA also lie between hot-spring districts to the south and northwest (pl. 6). The Sleeper deposit in the Awakening Mining District is localized along a Miocene rhyolite flow-dome underneath Quaternary alluvium (Wood, 1988; Conrad and others, 1993; Nash and others, 1995). Mineral deposits are present in high-grade bonanza veins, in breccias and in stockwork veins that contain native gold and electrum, as well as sulfide, selenide, telluride, sulfosalt, iodide, and chloride minerals of base and precious metals. Altered rocks include paragenetically early opal, pervasive clay, and quartz-adularia (Wood, 1987; Saunders, 1990; Nash and others, 1991). Oxidation of ore has produced supergene chlorargyrite and alunite (Saunders, 1993).

The Spring Creek-Paradise Valley Mining District (pl. 6) contains gold-silver mineralized rocks hosted by Paleozoic quartzite, phyllite, and shale, as well as by Triassic sedimentary rocks associated with rhyolite dikes and breccias (Lindgren, 1915; Vanderburg, 1938; Willden, 1964). The ores are characteristically white quartz veins, surrounded by kaolin and sericite, which contain sulfide minerals and silver sulfosalt minerals, and they are enriched in zinc, iron, and copper (Willden, 1964). In the National Mining District, symmetrically banded comb quartz contains electrum, pyrite, chalcopyrite, arsenopyrite, marcasite, selenide minerals, and antimony and bismuth minerals (Lindgren, 1915; Vanderburg, 1938; Lawrence, 1963; Vikre, 1985). Alteration includes quartz, adularia, sericite, and calcite (Berger and Henley, 1989). The mining district, particularly at Buckskin Peak, also contains mercury as cinnabar in veins, opaline sinter, and silicified breccia as well as underlying gold-silver veins (Roberts, 1940; Bailey and Phoenix, 1944; Willden, 1964; Hal Bonham, unpub. data, 1996).

The Sleeper, Spring Creek-Paradise Valley, and National mining areas in the northeastern part of the WSRA contain styles of mineralized rock, alteration, and geochemistry partially consistent with Comstock epithermal quartz-adularia gold deposits described by Mosier and others (1986) and Berger (1986c). The deposits in these areas, however, have a paucity of base-metals compared to the model. In addition, hot-spring mercury (Rytuba, 1986) and hot-spring gold-silver (Berger, 1986a) deposits also apply to the favorable tracts which contain these three mining districts in the northeast part of the WSRA.

Northwest zone hot-spring tracts

Hot-spring deposits in the northwest zone include several important mercury, uranium, and precious metal deposits (pl. 6). The deposits are generally young, high level, and apparently have not been exposed to the same amounts of erosion as those in the southern part of the WSRA. The Warm Springs Mining District (pl. 6) is the southern extension of a 75–km-long north-south trending zone located in Oregon in the Steens and Pueblo Mountains. The geologic setting of this zone is a north-trending fault block of volcanic strata that is tilted 10° to 20° west (Williams and Compton, 1953). Small intrusions of rhyolite, basalt, and diabase also are present. Pre-Tertiary crystalline rocks consist of greenstone, schist, and granite and are present in the southern part of this zone in the north part of the WSRA (Brooks, 1963). Gold and silver are reported in many samples taken throughout the area, but particularly in the WSRA (Ross, 1942; Bailey and Phoenix, 1944), and significant potential for these metals has been advocated by Minor and others (1987) in geologically similar areas in Oregon. Mineral deposits are present as three types: (1) cinnabar along fractures in silicified rhyolite; (2) long narrow 0.3– to 5–m-wide silicified zones in volcanic rocks containing schwatzite (mercurial tetrahedrite), cinnabar, and other sulfide minerals; and (3) gold-rich zones with chalcopyrite, tetrahedrite, and cinnabar. Mineral deposits are located in fault zones which parallel the range fronts. Alteration zones are extensive west of the mineralized area. Mercury lodes are generally low grade, but they have local rich pockets that are both primary and supergene. Associated metals are arsenic, barium, molybdenum, antimony, and copper. These characteristics are also consistent with the model for hot-spring and the somewhat deeper epithermal deposits proposed by Berger (1986a, 1986c) and Rytuba (1986).

The Disaster-Opalite Mining Districts have been actively mining mercury since 1924 (Yates, 1942; Benson, 1956; Brooks, 1963), and they are associated with the McDermitt Caldera complex (Greene, 1976; McKee, 1976; Rytuba, 1976; Rytuba and Conrad, 1981; Rytuba and McKee, 1984), which straddles the Nevada-Oregon border (pl. 6). The Opalite Mining District includes the past-producing Opalite, Bretz, Ruja and Cordero mercury mines (Fisk, 1968), as well as the McDermitt mercury mine. Uranium and lithium deposits are also present. Rytuba and Glanzman (1979), Glanzman and others (1979), Rytuba and others (1979), Rytuba and Conrad (1981), and Noble and others (1988a) investigated mineral deposits in the area. According to Minor and others (1988), the Albisu prospect in Oregon, on the perimeter of the McDermitt Caldera Complex, contains gold-bearing sulfide minerals along a north-northwest-striking fault zone, and consists of brecciated and hydrothermally altered rock. Gold also is present in the McDermitt Mine as an economic resource (see also, Bailey and Phoenix, 1944; Roper, 1976). Mercury mineral deposits consist of near-surface, 400 by 250 m, 30 to 200 m deep, lenticular, siliceous masses (chalcedony) adjacent to steep faults within tuffaceous Miocene lake beds (McCormack, 1986). Cinnabar and local corderoite are contained within silicified zones, faults zones, and unsilicified wall rock as disseminations (Vanderburg, 1938; Hetherington and Cheney, 1985). Mercury ore contents were 6 lbs/t in siliceous ore and 19 lbs/t in nonsiliceous ore (Yates, 1942). Gold grades at the McDermitt Mine are as much as 0.3 g Au/t (Minor and others, 1988). These characteristics are those used by Rytuba (1986) who proposed this area as a type example for the hot-spring mercury deposit model. These characteristics differ, however, from those in the southeastern and eastern WSRA, particularly because of the small number of hot-spring and epithermal gold-silver deposits present near the McDermitt Caldera Complex. The local gold occurrences and hot-spring characteristics of the area are, nevertheless, consistent with most criteria for hot-spring and epithermal gold-silver deposits detailed by Berger (1986a, c) and Mosier and others (1986).

The Virgin Valley Mining District in the northwestern part of the WSRA (pl. 6), contains a broad northeast-trending zone defined by numerous locally uraniferous opaline mercury, manganese, and gold-silver deposits (Castor and others, 1982). These deposits are associated with ash-flow tuff, sedimentary rock, and breccia in Tertiary volcanic flow domes. The mercury mineralized rocks usually are associated with faults or breccias in Tertiary volcanic rock, and they are accompanied by quartz and clay minerals (Cathrall and others, 1978). Numerous cryptomelane (potassium manganese oxide) beds also are present in tuffaceous and volcaniclastic sedimentary rocks (Tuchek and others, 1984).

The Lone Pine Mining District contains cinnabar- and gold-mineralized rocks in an area of Miocene volcanic rocks (Ross, 1941; Bailey and Phoenix, 1944; Benson, 1956; Holmes, 1965; Cathrall and others, 1978). Mercury is present in scattered veinlets, stringers, paint, and disseminations in silicified and argillized volcanic rocks (Bonham and Papke, 1969), as well as along high-angle faults (Tuchek and others, 1984; Greene, 1984). Anomalous metals are antimony, arsenic, gold, silver, and tungsten (Cathrall and others, 1977; Cathrall and others, 1978).

The Leadville Mining District contains three types of mineral deposits. The first is lead-, zinc-, copper- and silver-bearing quartz veins, and the second type is uranium-bearing veins (Garside, 1973) in Oligocene volcanic rocks (Bonham and Papke, 1969; Bonham and others, 1985). The third type is represented by the gold-silver deposits at Hog Ranch (pl. 6), which consist of fine-grained gold with marcasite and pyrite, as well as local stibnite, cinnabar, and realgar in silicified and argillized rhyolite (Jones, 1984b; Harvey and others, 1986). Gold-silver ore is present in veins, breccia, banded quartz veins, and pyrite with late opaline quartz. Ores are enriched in arsenic, antimony, mercury, and molybdenum (Scott, 1987; Rytuba, 1989; Peters and others, 1987; Bussey and others, 1991, 1993).

The Wind Mountain Mining District also contains gold-silver-mercury deposits associated with pervasive alteration of Miocene volcanic rocks in a 2– to 5–km-long zone centered on north-striking high angle faults. The deposits contain cinnabar, native sulfur, and electrum. Alteration minerals are opal, illite, montmorillonite, kaolinite, and alunite (Wood, 1991).

The Deephole Mining District contains some Middle Miocene gold mineralization concealed beneath approximately 100–m-thick alluvium (Margolis and Marlow, 1996). The mineralized rocks in this occurrence at the Mountain View Mine (pl. 6) consist of complex, pyrite-bearing, quartz-adularia stockworks in brecciated volcanic rocks.

In northeastern California (pl. 6), the High Grade Mining District is hosted by Miocene(?) rhyolite and consists of narrow, north- to northwest-striking veins and replacements that include quartz, silicified and brecciated volcanic rock, and fault gouge (Hill, 1915b; Averill, 1929, 1936; Keats, 1985). Ore contains gold, pyrite, and manganese-stained rock having minor copper (Clark, 1963).

These geologic characteristics described above for hot-spring deposits in the northwestern part of WSRA indicate favorable and prospective criteria for both hot-spring mercury (Rytuba, 1986) and epithermal manganese deposits (Mosier, 1986a). In addition, they are permissive and locally favorable and prospective for gold-silver hot-spring deposits (Berger, 1986a), and epithermal gold-silver vein deposits, which may lie beneath the hot-spring deposits (Berger, 1986c; Mosier and others, 1986).

Estimates of undiscovered deposits

Following a review of the available data, the assessment team undertook the estimation of numbers of undiscovered deposits for only three of the five hot spring and epithermal deposit types described above, and for which permissive tracts have been delineated. The evidence supporting the potential existence of either the quartz-adularia or quartz-alunite vein type deposit types is equivocal, and although these systems are commonly found at depth where hot spring types of deposit are present at the surface, the team could not reach consensus on the probable existence of one or more deposits occurring with a frequency greater than one in a hundred. There is, however, ample evidence in the form of known deposits and prospects upon which to quantify estimates for gold- and mercury-enriched hot-spring type mineralization and epithermal manganese vein deposits. The study area may be logically divided into three sub-areas with distinctly differing undiscovered deposit potentials: a northwest area, a central area, and an eastern area (pl. 6). Separate estimates also were developed for the Surprise Resource Area to fulfill an administrative need.

In the case of hot spring gold-silver deposits, four separate deposit distribution estimates were made. Those estimates correspond with the three geographic zones described above and the Surprise Resource Area, which encompasses a somewhat larger geographic area than the northwest zone (compare fig. 2 and pl. 6) The team estimated, at a probability distribution of 90, 50, 10, 5, 1 percent, an undiscovered deposit distribution of 2, 5, 7, 10, 14 deposits for the eastern zone. The distributions in the central and northwestern zones were 6, 12, 20, 30, 45 and 2, 4, 9, 15, 25 deposits, respectively. The narrow range for the eastern zone estimate reflects our belief that the region has been more thoroughly explored than the other two. The estimated number of undiscovered deposits for the Surprise Resource Area was 0, 1, 3, 5, 10 deposits at probability distributions of 90, 50, 10, 5, 1 percent. Results of the endowment simulations appear in the section below entitled "Estimation of Undiscovered Resources in the WSRA."

The team estimated, at a probability distribution of 90, 50, 10, 5, 1 percent, an undiscovered epithermal manganese deposit distribution of 0, 0, 1, 2, 3 deposits for the Winnemucca District. The distributions for undiscovered epithermal manganese deposits in the in the Surprise Resource Area were 0, 0, 0, 1, 2. (see Appendices A, B at the end of this report).

For purposes of estimating undiscovered hot spring mercury deposits, the team chose to partition the study area into three sub-areas. In the northern half of the WSRA, the team estimated a 90, 50, 10, 5, 1 deposit probability distribution of 3, 5, 10, 15, 20 undiscovered deposits, whereas in the southern half, the team estimated 1, 3, 5, 8, 12 undiscovered deposits. In the Surprise Resource Area, the potential for this type deposit declines further to a 0, 1, 3, 5, 10 distribution. Endowment estimates are shown in the section below entitled "Estimation of Undiscovered Resources in the WSRA."

Uranium Deposits

The distribution and type of uranium deposits in the WSRA have been studied previously as part of a nation-wide inventory (Butler and others, 1962; McKelvey, 1957, 1975) and assessment (Bowyer, 1975; Curry, 1978; Harris, 1978; McCammon and Finch, 1993). Belts of uranium-mineralized rocks in northwestern Nevada and contiguous southeastern Oregon were identified by Gambel (1977) and Paterson (1970). Known uranium deposits in the Great Basin were compiled by Davis and Hetland (1956) and Sharp (1956), and deposits in Nevada were summarized by Butler (1964) and Garside (1973, 1979). Assessment for uranium resources directly north of the WSRA in Oregon was conducted by Mathews (1956) and by Walker and Swanson (1968a, 1968b) and has been summarized by Erickson and Curry (1977) and Erickson (1977). Uranium resources in the Reno 1° X 2° quadrangle were summarized by Hurley and others (1982). Uranium mineral deposits in the WSRA are mostly volcanogenic and sediment-hosted, which are two of the main types of uranium deposit (Tilsley, 1988). In addition, uranium deposits in the region also are associated with granites and may be present in the WSRA as pluton-related vein-uranium occurrences. In a recent review of uranium and vanadium resources in the United States, Shawe and others (1991) have pointed to the Great Basin as a region with good resource potential, but warned that Miocene Basin-and-Range faulting and range tilting has dismembered some deposits and may have caused leaching and destruction of other deposits.

Uranium differs from most other metallic mineral resources considered in this study in that it has been considered a strategic metal for military purposes. In the period about 1941 to 1959, bonuses were given by the Atomic Energy Commission for prospecting and production of uranium. Many deposits that were located and brought into production in that period would not have been in prior or subsequent years. During the uranium exploration boom in the 1970s, previously identified deposits were re-examined and new ones located using modern technology and concepts. For a variety of social and economic reasons, no deposits in Nevada were brought into production in the 1970s when free-market prices rose above \$10/pound U_3O_8—societal resistance to nuclear reactors and to uranium mining has increased since the Three Mile Island, Pennsylvania, reactor accident, and prices have remained relatively low in the 1990s. Experience from the 1950s is not readily applied to current and anticipated socio-economic demand for uranium, although some companies are continuing to explore for uranium deposits because of an anticipated shortage in supply.

Individual tracts for both Tertiary and Quaternary volcanogenic uranium and Mesozoic, probably mostly Cretaceous, pluton-related vein-uranium deposits have been delineated (pl. 7). Permissive criteria for volcanogenic uranium deposits include felsic to intermediate volcanic rocks and areas of hot-spring activity (pl. 7). Permissive criteria for sandstone-hosted uranium deposits are not shown on plate 7, but include all alluvial basin margins, fluvial channels, and braided stream deposits with contemporaneous felsic volcanism or felsic plutons undergoing erosion in the WSRA. Favorable criteria for volcanogenic uranium deposits include hot-spring or epithermal mineralized rocks and centers of high-silica rhyolite with high uranium contents and airborne radiometric anomalies (Dodson, 1972; Tilsley, 1988). Favorable criteria for sandstone-hosted uranium deposits include permeable carbonaceous horizons, bedded strata with low dips, areas of low magnetic susceptibility, and Tertiary basins adjacent to known uranium occurrences. Prospective tracts are delineated around known uranium occurrences, airborne radiometric anomalies, and indications of associated mineralized systems. Prospective areas for sandstone-hosted uranium deposits contain known sedimentary uranium deposits, are anomalously radioactive, or have associated anomalously high uranium contents in proximal stream-sediment, soil, or rock samples.

Volcanogenic uranium deposits (model 25f of Cox and Singer, 1986)

Volcanogenic uranium deposits are typified by the presence of uranium-bearing epithermal quartz veins associated with high-silica rhyolitic, subaerial to subaqueous, volcanic complexes. Ore controls are fractures, breccias and volcanic contacts. Alteration consists of an assemblage of kaolinite, montmorillonite, alunite, silica, and rare adularia. Ore minerals usually include coffinite, uraninite, and brannerite, as well as pyrite, molybdenite, fluorite, barite, and gold. Near-surface oxidation produces a variety of secondary minerals and may cause secondary enrichment (Bagby, 1986). Elements associated with this type of deposit are arsenic, antimony, fluorine, molybdenum, and mercury, as well as rare gold and silver. Thirty eight occurrences in the WSRA have been classified as volcanogenic uranium (pl. 7).

Sandstone uranium deposits (model 30c of Cox and Singer, 1986)

Sandstone uranium deposits typically consist of microcrystalline uranium oxide and silicate minerals deposited during diagenesis in locally reduced environments within fine- to medium-grained permeable, feldspathic or felsic tuffaceous sandstone beds (Turner-Peterson and Hodges, 1986). Mudstone or shale is commonly found above and (or) below the ore horizon. The deposits are typically stratabound and tabular. Ore minerals replace wood and other carbonaceous material (Finch, 1982; Marmot, 1988). Alteration includes relict TiO_2 minerals, oxidized iron minerals (up dip), and reduced iron minerals (down dip) from ore (Butler, 1975). Ore minerals include uraninite, and coffinite, which are present with pyrite. Associated elements are vanadium, molybdenum, selenium, and, locally, copper, silver, and gold. Application of uranium deposit models developed from the Colorado Plateau fo the WSRA is problematic—nearly all models include a criterion of tectonic stability following ore deposition (Finch, 1982; Shawe and others, 1991), which is not the case in Nevada. One occurrence in the WSRA has been classified as a sandstone uranium deposit, and that occurrence, in the Leonard Creek Mining District, is referred to as the Leonard Creek prospect (Willden, 1964).

Pluton-related vein-uranium deposits

The predominant ore mineral in those plutonic rocks favorable for the presence of uranium deposits is uraninite (UO_2). Ballhorn (1989) recognized three compositional types of pluton worldwide that have been shown to host uranium deposits: (1) metaluminous anorogenic granite of alaskitic composition, exemplified by those at Rossing, Namibia, whose ore is related primarily to magmatic differentiation; (2) peraluminous granite, exemplified by the Mississippian to Permian, mostly two-mica granites in the Central Massif, France; and (3) alkaline granite, exemplified by the Jurassic granite at Bokan Mountain, Alaska. Uranium-enriched rocks, specifically vein-uranium deposits, associated with the latter two types of granite apparently are related to circulation of mostly subsolidus fluids. Nokleberg and others (1987) designated uranium-bearing granites in Alaska to be included within a felsic-plutonic type of deposit, and they described this deposit type as follows. Felsic-plutonic uranium deposits in Alaska consist of uranium minerals, thorium minerals, and rare earth element (REE) minerals in fissure veins and disseminated in alkaline granite dikes in or along the margins of alkalic and peralkaline granitic plutons or in granitic plutons. The ore-forming environment is mainly in or along the margins of epizonal to mesozonal granitic plutons. Ore minerals in the deposits include allanite, thorite, uraninite, bastnaesite, monazite, uranothorianite, and xenotime, sometimes with galena and fluorite. Notable examples are the Roy Creek (Mount Prindle) deposit in east-central Alaska and the Bokan Mountain deposits in southeastern Alaska. There are approximately a dozen occurrences that may be classified as pluton-related vein-uranium deposits in the WSRA (pl. 7). This is in addition to their primary classification as other types of deposits. An example is the stockwork molybdendum occurrence at Majuba Hill, which contains low-grade uranium concentrations in some of its quartz veins (Smith and Gianella, 1942; Thurston and Trites, 1952).

Description of tracts

The major prospective tract for undiscovered volcanogenic uranium resources (tract A, pl. 7) lies in the northwestern part of the WSRA in the McDermitt caldera complex, and nearby favorable tracts for these types of deposit are present in the Virgin Valley and Soldier Meadow areas. Five additional small areas (tracts B–F, pl. 7) that are judged to be favorable for the presence of pluton-related vein-uranium deposits lie to the south (table 5). Uranium resources in the area of the McDermitt caldera complex are of both sedimentary and volcanogenic origin. The volcanic rocks of the McDermitt caldera complex are anomalous in uranium (Dayvault and others, 1985; Noble and others, 1988a). On the north side of the caldera complex in Oregon, the Blue Moon deposit consists of disseminated iron oxide minerals and uranium minerals in lacustrine sediments, whereas the Aurora deposit, in the Opalite district on the south side of the complex, is controlled by northwest-striking faults parallel to the margin of the caldera. The ore zone in the latter is contained within 0.3 m thick, argillically altered, vesicular to scoraceous flow tops and breccia layers of icelandite (Wallace and Roper, 1981). The zone contains 0.05 weight percent U_3O_8 and is covered by lake beds. Another uranium occurrence at the western margin of the caldera north of the WSRA is confined to a zone of K–feldspar alteration in rhyolite domes (Brooks, 1963; Rytuba and others, 1979).

The Moonlight, Granite Point, Horse Creek and King River deposits (tract A, pl. 7) are mostly contained within brecciated Tertiary volcanic rocks along a ring fracture zone of the McDermitt caldera complex between rhyolite in the hanging wall and intermediate composition volcanic rocks in the footwall, as described by Taylor and Powers (1955), Sharp (1956), and Backer and others (1995). Mineralized rocks in these deposits are argillically altered, include silica-flooded fractures, and are associated with mercury ore, chalcedony, fluorite, quartz, aragonite, and pyrite. Uranium is mostly within fine-grained hydrothermal zircon. These characteristics are compatible with those proposed by Bagby (1986) for volcanogenic uranium deposits. Secondary or transported sediment-hosted uranium deposits are also consistent within areas having these geologic characteristics. Uranium is present at the Aurora deposit near the Bretz Mine, just north of the WSRA, in lake sediments, and contains 13 million tons of reserves averaging 1 lb (0.5 weight percent) U_3O_8/ton. The potential for additional uranium resources within and surrounding the McDermitt caldera complex is good, particularly where airborne radiometric anomalies are present in adjacent basins of largely unconsolidated Tertiary deposits. Areas proximal to the caldera margin, near known hot-spring mercury deposits, and sediments within and adjacent to the caldera delineate prospective tract A (pl. 7).

Uranium resources in the Virgin Valley and Soldier Meadows Mining Districts constitute a trend of deposits and prospective areas which stretches from the McDermitt caldera complex southwesterly into California. The northeasterly-trending zone is bounded by the Black Rock Desert on the south (pl. 7). This belt trends north into Oregon in the Pueblo Mountains and is spatially associated with the hot-spring mercury deposits of the Steens-Pueblo region (Ross, 1942; Williams and Compton, 1953; Peterson, 1958; Wilkerson, 1958). The uranium deposits in the Oregon part of the uranium belt have been described by Wagner (1955), Schafer (1956), and Peterson (1959, 1969). Host rocks consist of moderately dipping ash-flow tuff, rhyolite, porphyritic andesite, schistose greenstone, schist, basalt and flow-banded dacite. Volcanic rocks are anomalous in uranium and thorium throughout the belt (Stuart and others, 1983). Mineral deposits include bedded opaline quartz, local quartz veins, silica zones, pyritic chalcedony, and fracture coatings. Ore minerals are mainly autunite associated with pyrite or manganese oxide minerals. Copper sulfide minerals and copper oxide minerals, mercury and molybdenum minerals, carnotite ($K_2O•2UO_2•V_2O_5•3H_2O$), schroeckingerite ($NaCa_3UO_2SO_4(CO_3)_3F•10H_2O$), torbernite ($Cu(UO_2)_2P_2O_8•12H_2O$), metatorbernite ($Cu(UO_2)_2P_2O_8•8H_2O$), and ilsemannite ($Mo_3O_8•nH_2O$) have also been reported (Lovering, 1954; Staatz and Bauer, 1951). Ore is controlled by north-striking high-angle faults and quartz veins, breccia-rhyolite contacts, dike contacts, and fractures in massive rhyolite.

Although a significant volcanic-hydrothermal component is present in the mineral deposits, many of the mineralized zones are probably supergene, as are those described to the north by Erickson and Curry (1977). Therefore, the highest uranium grades probably are enriched by supergene processes. Potential exists for transported uranium in the adjacent Quaternary basins which are peripheral or within the prospective tract (see also, Wyant and others, 1952; Davis and Hetland, 1956), but real potential at depth is unknown because of poor knowledge of the underlying stratigraphic sequence, as well as uncertainties in the location of possible structural traps required for uranium enrichment. The secondary and near-surface hydrothermal processes observed in the area may indicate original large deposits at depth that have been remobilized to the surface. The area is coincident with hot-spring gold-silver and mercury mineralized rocks and is prospective for undiscovered uranium deposits (pls. 6, 7).

The deposit model that is most applicable to these deposits is the volcanogenic uranium deposit model proposed by Bagby (1986), although the large hydrothermal, supergene, and adjacent sedimentary composite components of these systems suggest that secondary or transported sedimentary uranium occurrences may also be present.

Some uranium occurrences in the southern part of the WSRA have characteristics different from those in the northwest and appear to be pluton-related vein-uranium occurrences (tracts B–G, pl. 7). At Majuba Hill (tract B, pl. 7), uranium is associated with a Miocene porphyry-related system and consists of large areas of low-grade uranium-mineralized rocks as fracture and vug coatings, along bedding planes in slate and phyllite wall rock, and in uraniferous breccias and 1–m-wide quartz veins (Smith and Gianella, 1942; Thurston and Trites, 1952; Lovering, 1954). Ore minerals include torbernite, zeunerite ($Cu(UO_2)_2As_2O_8•8H_2O$), autunite ($Ca(UO_2)_2P_2O_8•8H_2O$), gummite (an alteration product of uraninite of uncertain composition), and hydrous uranium phosphate minerals associated locally with tourmalinized rhyolite and secondary copper minerals (Matson, 1948; Trites and Thurston, 1958; MacKenzie and Bookstrom, 1976). These uranium-bearing minerals should, in fact, be considered secondary mineral curiosities that should not be construed as indicating the presence of additional uranium resources. These mineral settings have some similarities to volcanogenic uranium deposits (Bagby, 1986), but are more compatible with uranium-rich areas in porphyry systems. This association with porphyry systems would also apply to the Kennedy Mining District (tract G, pl. 7). Adjacent sedimentary basins to southwest of the Majuba Hill area are prospective for sedimentary deposits (pl. 7; see also, Garside, 1973).

In the Humboldt Range (tract C, pl. 7), the Stalin's Present deposit is present in a 0.3–m-thick diopside-rich layer in granite which contains scattered grains of pitchblende associated with chlorite, quartz, calcite, pyrite, and gummite (Staatz, 1951; King and others, 1952). Prospective and favorable tracts are delineated around these and similar deposits and airborne radiometric anomalies. These deposits have characteristics associated with pluton-related uranium deposits. The adjacent sedimentary basins and hot-spring deposits are also considered favorable due to possible secondary processes.

The Nightingale Mountains and Selenite Range Mining Districts (tract D, pl. 7) consist of a dozen uranium localities and an airborne radiometric anomaly associated with granite. Mineralized rocks are mostly contained in pegmatite or felsic dikes or quartz veins in roof pendants or contacts of the granite with the surrounding Mesozoic metasedimentary rocks. The deposits contain autunite and other uranium minerals (Garside, 1973). These deposits are pluton-related and are spatially associated with tungsten skarn deposits. Some uranium deposits are composed of uranophane-bearing opal and uraniferous coatings in basalt dikes, a relation which indicates that younger epithermal or volcanogenic uranium deposits are also present possibly as a result of remobilization of Mesozoic uranium during the Tertiary. The Tertiary basins to the west of the Nightingale Mountains and Selenite Range Mining Districts have both thorium and uranium airborne radiometric anomalies indicating favorable areas for sedimentary uranium deposits in this area (pl. 7).

Estimates of undiscovered deposits

The assessment team developed estimates for only the volcanogenic uranium type deposits. At the present time, there is no grade and tonnage model that is appropriate for the sandstone-hosted uranium deposits in the region. The team, again for administrative reasons, prepared separate estimates for the Winnemucca District and the Surprise Resource Area. As with several other types of deposit, the deposit distribution of 0, 0, 1, 2, 3 for the Surprise Resource Area is lower than the 1, 2, 5, 8, 10 estimates for the Winnemucca District. This difference continues a trend that reflects the overall less favorable geologic environment in the Surprise Resource Area.

Sediment-hosted gold-silver deposits (model 26a of Cox and Singer, 1986)

Sediment-hosted gold-silver (carbonate-hosted or "Carlin-type") deposits consist of generally submicron-sized gold, commonly within the crystal structure of disseminated pyrite, in variably silicified, argillized, and decalcified sedimentary rocks and volcanic rocks and a number of other minor rock types (Tooker, 1985; Berger, 1986d). Host rocks include calcareous or siliceous sedimentary rocks, skarn, mafic metavolcanic, and felsic intrusive rock. However, the most abundant host rocks are thin-bedded, flaggy, mixed carbonate-siliciclastic rocks. Deposition of ore minerals was at moderate depths of approximately 1 to 3 km (Rytuba, 1985; Kuehn and Rose, 1985; Kuehn, 1989), in contrast to the shallow paleodepths for the epithermal deposits described above. Mineralogy in the ore zones includes gold-bearing arsenian pyrite, marcasite, stibnite, realgar, orpiment, cinnabar, thallium-sulfide minerals, rare silver-antimony and lead-antimony sulfosalt minerals, and sphalerite. Total sulfide mineral content ranges from less than 1 volume percent to local massive accumulations of pyrite (Bagby and Berger, 1985; Percival and others, 1988; Berger and Bagby, 1991). The physical characteristics of the deposits are variable depending on the nature of the host rock. In calcareous rocks, stratabound replacement and local brecciation is common. In non-reactive rocks, mineralized rocks make up millimeter-sized stockwork veinlets to meter-sized vitreous quartz veins, as well as variably colored jasperoid coursing through fractures that controlled their irregular distribution. Stratabound jasperoid is also common at contacts between rock units. Ore-associated alteration is typically decalcification of carbonate strata. The local formation of secondary dolomite in some of the best ore hosts probably occurs during diagenesis (A.K. Armstrong, unpub. data, 1996). Silicified rocks are also present as jasperoidal replacement, silica cementation, or as open-cavity fillings of quartz. K–feldspar alters to illite and kaolinite in the most intensely altered areas. Barite and calcite also are present commonly in those areas that have massive replacement by silica.

Ore controls may be considered at a number of different scales. Generally, first-order control at regional scales is defined by "trends" or areas (Shawe and Stewart, 1976; Berger and

Henley, 1989; Bagby, 1989; Shawe, 1991) that commonly are associated with tectonic windows through regional thrust faults in a region of tectonically overthickened crust in the Great Basin. Second-order control is location of deposits along or adjacent to steeply-dipping normal faults, which are subparallel to the overall first-order "trends." Close spatial association exists between some sediment-hosted gold deposits and Mesozoic plutons (Silberman and others, 1974); closely related Tertiary intrusive rocks are uncommon and are interpreted as post-ore in many of the large sediment-hosted gold-silver deposits. However, evidence from a regional perspective suggests that the sediment-hosted gold-silver deposits may owe their origins to the initial extension of the Great Basin and all of its attendent physical and chemical ramifications of deeply circulating meteoric fluids (Seedorff, 1991; Ilchik and Barton, 1995). Structures in Proterozoic basement may be important localizers of deposits and districts (Grauch, 1986; Grauch and others, 1995). Local control can be either typically structural (see also, Peters, 1995; Peters and others, 1995) or stratigraphic. Formations and even narrow stratigraphic intervals or zones within them are considered to be significant factors in localizing gold.

The generally deep weathering of the deposits usually results in outcropping or sub-cropping mineralized rocks which have some prominent outcrops of hematitic jasperoid. The geochemical signature is typically gold, silver with silver:gold ratios generally less than 1 (that is, silver is not of significant value), arsenic, antimony, and mercury. Thallium is anomalously high in some deposits, but minor to absent in others. Tellurium and bismuth are usually absent to very low (Hill and others, 1986). Base metals are usually at background levels, but, locally in some deposits such as Gold Quarry (Hausen and others, 1982; Rota, 1987), base metals attain concentrations in the thousands of parts per million in the upper parts of the deposit, although they do not contribute to the overall value of the deposit. The sediment-hosted gold-silver deposits bear some similarities to the distal-disseminated silver-gold deposits (Cox and Singer, 1990), which we believe are directly attributable to fluids emanating from porphyry copper systems. Ore-forming fluids responsible for most sediment-hosted gold-silver deposits do not show isotopic and chemical evidence for a relationship to porphyry-type systems (Seedorff, 1991), although some recent data suggest that some of these deposits (Twin Creeks, Getchell) may have been generated from fluids involving a significant magmatic component (Norman and others, 1996). It also is possible that the deposits at Twin Creeks and Getchell have been misclassified. Ilchik and Barton (1995) postulate the genesis of most of these deposits is associated with amagmatic thermal processes associated with middle Tertiary extension in the Basin and Range.

A workshop, which was completed during November, 1996, and was sponsored by the Ralph J. Roberts Center in Economic Geology (CREG) at the Department of Geological Sciences, University of Nevada—Reno, on geochemical modeling of fluids associated with genesis of Carlin-type systems in Nevada, listed the following characteristics of these deposits:

- Hosted by sedimentary rocks, mostly Paleozoic marine carbonate strata and shale, whose overall porosity and permeability have been enhanced by authigenic conversion of magnesian calcite to dolomite (A.K. Armstrong, oral commun., 1996), although some deposits (Twin Creeks) are hosted, in places, by Paleozoic basaltic rocks (see this section below);

- Generally sub-micron sized particles of free gold, although some deposits (for example, Rodeo), in places, contain free gold as much as 3 mm wide;

- Geochemical association of gold with (1) arsenic (strong positive correlation between gold and arsenic), with (2) antimony (antimony generally later than the bulk of the gold), and with (3) mercury. Gold:silver roughly ≥ 1; arsenic:gold ≈ 1000; antimony:gold ≈ 50;

- Gold-rich arsenical pyrite rims on pyrite (iron derived probably from ferroan carbonate minerals) resulting from sulfidation reactions (Hofstra and others, 1990) involving sulfur derived from premineralization "dead," thermally mature oil (A.K. Armstrong, written commun., 1996);

- Presence of solid carbon in a cryptocrystalline state before the arrival of gold, although "live" oil is present in some occurrences, such as the Alligator Ridge deposits (Vantage orebodies);

- Associated with prominent district-scale, steeply-dipping, deep-seated faults, many in areas with solid cryptocrystalline carbon (as much as 0.1 to 3 volume percent graphite plus disordered carbon), as well as extremely low electrical resistivities (10^{-6} to 10^{-8} ohm–m) and anomalous $C_2H_5^+$ in soil gases (J. H. McCarthy, oral commun., 1996) if gold deposits are covered by post-mineral unconsolidated sediments;

- Presence of brecciated rocks of several different origins in many of the deposits;

- Boiling in genetically associated fluids not documented by many comprehensive fluid-inclusion studies;

- Main-stage ore-forming event at 200 to 250 °C, 400 to 800 bars on the basis of fluid-inclusion studies;

- Presence of pre-ore igneous dikes, except at Alligator Ridge, Twin Creeks, and Gold Bar;

- Wide range of $\delta^{34}S$, –5 to +20 per mil, in gold-associated minerals;

- Dilute (mostly 0.5 to ≤ 10 weight percent NaCl equivalent) hydrothermal fluids dominantly formed from evolved meteoric water (Hofstra and others, 1991a; 1991b), except Getchell and Twin Creeks (Cline and others, 1996);

- Alteration characterized by dissolution of carbonate minerals, and presence of silicified rocks and clay minerals, as well as open-space orpiment and realgar in many deposits.

Permissive areas for sediment-hosted gold-silver deposits in the WSRA comprise pre-Tertiary sedimentary and metasedimentary rocks within the area covered by tectonically thickened crust due to Paleozoic and Mesozoic thrust faulting (table 5; pl. 8). These permissive areas exclude post-accretionary plutons larger than 100 sq km, but include local areas of late Paleozoic overlap assemblage rocks that have been further categorized as belonging to favorable and (or) prospective tracts. In the WSRA, the permissive area for sediment-hosted gold-silver deposits includes most of the Golconda and Roberts Mountains allochthons, Paleozoic miogeosynclinal or platformal rocks in the East Range, and the Jungo Terrane, including both Triassic basinal allochthonous rocks in the upper plate of the Fencemaker allochthon and Triassic platformal rocks in the lower plate of the Fencemaker allochthon (pl. 8; see also, Doebrich, 1996). Favorable criteria include known sediment-hosted gold-silver deposits present within 10 km, and, in the WSRA, the western projection of the Roberts Mountains allochthon beneath the sole of the Golconda thrust. The prospective areas in the WSRA include the Getchell trend of gold deposits, as well as the area surrounding the Twin Creeks deposits, the latter of which are apparently controlled locally by the north-south Rabbit "suture" of Bloomstein and others (1991). Northeast- and northwest-striking faults host many of these deposits (Berger and Taylor, 1980; Wallace, 1991), and it is likely that many deposits lie within or adjacent to the Rabbit suture, a mineralized corridor, which extends from the Twin Creeks deposits on the north to the Marigold cluster of deposits on the south, and possibly even continuing as far south as the McCoy Mining District (see also, Bloomstein and others, 1991). However, those parts of the Rabbit suture in the general area of the Lone Tree area, the Battle Mountain Mining District, and the McCoy Mining District are dominated by pluton-related gold deposits associated with a variety of porphyry systems (see section above entitled "Porphyry Deposits").

Description of tracts

Most important known sediment-hosted gold-silver deposits in the WSRA lie to the north of the projection of the northwest-trending Battle Mountain-Eureka mineral belt of Roberts (1966) (tract A, pl. 8). Two small sediment-hosted gold-silver deposits, the Standard and the Gold Standard deposits, are present in the Humboldt Range in the Imlay and Rye Patch Mining Districts (tract C, pl. 8). The area of all other known sediment-hosted gold-silver deposits in the WSRA lies in the northeast-trending Getchell trend along the eastern edge of the Osgood Mountains (Hoover, and others, 1991; Grauch and Bankey, 1991; Pierce and Hoover, 1991; Pitkin, 1991), and north of the Battle Mountain Mining District (pl. 8). Total production and reserves of the known deposits from the area of the Getchell trend exceed 12 million oz Au.

A number of sediment-hosted gold-silver deposits are concentrated along the east side of the Osgood Mountains, many in areas covered by Tertiary and Quaternary unconsolidated gravel, where the possibility of additional discoveries are high (tract A, pl. 8) The Pinson-Mag deposit, which is one of the relatively recent discoveries along the Getchell trend, is concealed under Quaternary alluvium (Smith and Kretschmer, 1992) in Late Ordovician carbonate mineral-bearing shale and slate that is proximal to an area of contact metamorphism (Foster and Kretschmer, 1991). Ore in the deposits includes the following minerals: native gold, arsenopyrite, barite, chalcopyrite, sphalerite, galena, stibnite, and a number of others. The deposit is typified by elevated concentrations of gold, mercury, arsenic, and thallium, as well as lesser concentrations of barium, fluorine, molybdenum, nickel, and zinc (Kretschmer, 1984a, 1984b; Madrid and Bagby, 1988; Bagby and others, 1988). The Preble gold deposit is in thin bedded fossiliferous limestone and carbonaceous shale. Paleozoic bedded barite is present nearby in the Cambrian Preble Formation and some sulfide minerals in the Preble gold deposit, including pyrite and chalcopyrite, may be syngenetic (Madden-McGuire, 1991). Alteration is shown predominantly by the presence of widespread silicified rocks that are zoned outwards into areas of jasperoid and calcite veins and, finally, calcite-only veins. Geochemical enrichments include arsenic, silver, barium, antimony, thallium, and fluorine (Erickson and others, 1964; Kretschmer, 1984a, 1984b). The Getchell deposit contains gold in the Getchell fault zone in Cambrian and Ordovician limestone and shale (Joralamen, 1951). Recent deep extensions of the deposit have been found at Turquoise Ridge. The mineralogy of typical ore includes pyrite, arsenopyrite, quartz, calcite, and abundant realgar and orpiment (Berger and Tingley, 1985; Bagby and Cline, 1991). The orebodies contain elevated contents of arsenic and mercury (Erickson and others, 1964; Brooks and Berger, 1978; Berger, 1985). The gold areas are concentrated only on the east side of the Osgood Mining District, whereas tungsten skarns surround the Late Cretaceous plutons throughout the remaining parts of the mining district (Joralamen, 1975).

The Chimney Creek deposit is hosted in Pennsylvanian and Permian argillite, litharenite and limestone in silicified zones and jasperoids or in steep sericitized feeder pipes in Paleozoic basalt (Osterberg and Guilbert, 1988). Elevated contents of silver, arsenic, antimony, lead, thallium, and mercury are present (Osterberg, 1989; Osterberg and Guilbert, 1991). The Rabbit Creek deposit adjoins the Chimney Creek deposit on the south, and mining operations at these two deposits have been consolidated into one operation through a change in ownership— the consolidated operation is now referred to as the Twin Creeks Mine. Some of the Twin Creeks deposit originally was covered by 60 to 165 m of Quaternary alluvium (Madden-McGuire and others, 1991). The deposit is hosted in Early Ordovician black calcareous shale, siltstone, chert, and basaltic tuff. Minerals in the deposit include native gold, pyrite, realgar, orpiment, cinnabar, stibnite, galena, and sphalerite. The types of alteration present include decalcification, silicification, dolomitization, and minor sericitization. Elevated contents of arsenic, antimony, mercury, barium, silver, and gold are present, as well as a silver:gold ratio of less than 0.1 (Bloomstein and others, 1991).

The sediment-hosted gold-silver deposits in the WSRA are hosted by a variety of sedimentary rocks of many lithologies and ages, including Lower Paleozoic calcareous siltstone and shale (Getchell, Pinson, Rabbit Creek), argillite (Preble), and basaltic rocks (Chimney Creek, Rabbit Creek), and calcareous sandstone and siltstone (Chimney Creek). Although host rocks vary, the ore mineralogy, alteration, and geochemical signature of the deposits described above along the Getchell trend are all similar to other major sediment-hosted gold-silver deposits described by Berger (1986d). The Kramer Hill deposit (Kretschmer, 1991), however, has some geologic similarities with both the sediment-hosted gold-silver deposits and with low sulfide gold vein deposits, as well as some characteristics which may be interpreted as being hot-spring related. The nearby Lone Tree and Marigold deposits, described earlier (pl. 5), share some characteristics with the sediment-hosted gold-silver deposits, but their geologic setting, alteration, geochemistry, and istopic and fluid-inclusion (Lone Tree, Norman and others, 1996) signatures suggest that they are distal-disseminated silver-gold deposits related to porphyry copper systems at depth (table 5).

The sediment-hosted gold-silver deposits in the Humboldt Range are smaller in size than those in the Osgood Mountains, but they are geologically similar (tract C, pl. 8). Sediment-hosted gold-silver deposits were mined at the Standard and Relief Canyon deposits, and are present in other areas in the Humboldt Range. These deposits have associated jasperoid zones at stratigraphic contacts or along thrust faults that separate Triassic limestone from fine-grained siliciclastic rocks (Vanderburg, 1936a; Johnson, 1977; Wallace, 1989). Ore consists of disseminated gold- and silver-bearing zones in brecciated, decalcified, and silicified limestone that contains local chalcedony. Elevated concentrations of arsenic, antimony, mercury, and fluorine are present (Fiannaca and McKee, 1983; Parratt and others, 1987). These characteristics are similar to the sediment-hosted gold-silver model of Berger (1986d), and suggest that these two known deposits are distinct from other gold-bearing polymetallic deposits in the Humboldt Range (tract C, pl. 8).

In the East Range, a broad, north-south elongate area that is underlain at its north end by lower Paleozoic marbles and at its south end by presumably lower Paleozoic carbonate rocks has been designated as prospective for sediment-hosted gold-silver deposits (tract B, pl. 8). The carbonate rocks at these localities are the westernmost exposures of rocks belonging to the lower plate of the Roberts Mountains allochthon. In addition, placer deposits in the northern part of tract B appear to be derived from bedrock areas centered on the exposed Paleozoic marbles. In this general area, a number of mineralized faults contain anomalous concentrations of gold.

Estimates of undiscovered deposits

On the basis of current (1996) understanding and data, the team believes that there is high potential for other discoveries of this type of gold deposit in the WSRA. The relatively recent discovery of several of these deposits in down-faulted blocks adjacent to range front fault systems, and buried beneath thin blankets of basin fill, increases the probability of additional deposits occurring in similar situations—irrespective of the fact that exploration for these types of deposit has been intense in recent years. The presence of recently discovered deep high-grade Carlin-type systems along the Carlin Trend has led explorationists to consider drill depths that heretofore were preposterous. The team reached a consensus on a 90, 50, 10, 5, 1 probability distribution of 3, 6, 10, 20, 30 undiscovered deposits.

Low-sulfide (Chugach-type) gold-quartz vein deposits (models 36a and 36a.1 of Cox and Singer, 1986 and Bliss, 1992a)

Low-sulfide (Chugach-type) gold-quartz vein deposits in the WSRA were important in the past, when they were exploited as small high-grade underground mines. Most of the deposits mined were discrete veins with little evidence of large, potentially bulk-mineable zones, and, hence many of the mining districts have been idle for 50 years or more. An exception is the Rochester Mining District, where modern bulk mining techniques at the Coeur Rochester Mine currently (1996) are being used to mine a large stockwork zone of silver-gold mineralization. The Coeur Rochester Mine produced approximately 6.5 million oz Ag and 59,000 oz Au in 1995 (Nevada Division of Minerals, 1996). Numerous occurrences of this type are present in the WSRA, and many of them may not have been fully assessed for their bulk-mining potential.

Low-sulfide (Chugach-type) gold-quartz veins, or metamorphic veins in the terminology of others, considered here are those which form in brittle to brittle-ductile shear zones (that is, at depths greater than 3 km). They are similar to the gold-quartz deposits of the California and Victoria type classified by Lindgren (1933) and more recently by Böhlke (1982), Berger (1986b), and Heran (1992b). These Phanerozoic deposits form at greater depths than near-surface epithermal veins (see also, Henley, 1985; Hodgson, 1993), and polymetallic vein deposits (Cox, 1986j), but not as deep as most Archean gold-quartz deposits (Kerrich, 1983; Colvine and others, 1988) to which they are related. They are hosted by prehnite-pumpellyite to amphibolite facies metamorphic rocks or by intermediate to ultramafic igneous rocks.

The genesis of these deposits generally is attributed to deep circulation of orogenic metamorphic fluids or distal magmatic fluids, although meteoric waters have been proposed by some (Nesbitt and Muelenbachs, 1989, 1991; Peters and others, 1991). The typical deposits are high-grade (1.0 to 100 g Au/t), narrow (0.1–to 1–m-wide), multiple quartz veins with fine-grained gold averaging 800 fine and 5 to 10 volume percent sulfide minerals. The veins also contain trace to sub-economic amounts of silver, arsenic, lead, zinc, antimony, mercury, molybdenum, and tungsten. Some of these deposits contain higher contents of these metals than elsewhere in the world—this is particularly true in the Humboldt Range where the deposits are silver- and antimony-rich. These deposits in the WSRA are not gold rich, and thus do not fit the global model—they are significantly different economically from those elsewhere in the world.

The gold and silver in these deposits are generally either in well-defined quartz veins or in diffuse, commonly sheared, altered zones. The quartz in the veins is characteristically massive, milky bull quartz, locally dark, and may display a ribbed texture (Dowling and Morrison, 1989). The veins include quartz, ankerite, white mica, or albite, as well as pyrite, galena, sphalerite, or arsenopyrite (Peters, 1993a, 1993b). The vein deposits fill fractures associated with brittle to brittle-ductile faults, which may show an early phase of ductile deformation typified by mylonitic or phyllonitic fabrics.

The tectonic setting of these deposits elsewhere usually is in accretionary terranes where rocks that are partly oceanic in origin have been structurally emplaced onto the edge of a continental craton (Nesbitt and Muelenbachs, 1989, 1991; Peters and others, 1991). As a result, they may be present in ophiolite complexes and zones of tectonic and (or) sedimentary melange or, at least, are characterized by metamorphic deformation. Most or all regions with this style of mineralized rocks also were subjected to plutonism subsequent to terrane accretion. Deposits are present in major regional fault zones or are in minor, local structures, commonly adjacent to the major faults. The deposits are hosted by many different types of rock , including metasedimentary, metavolcanic, and igneous rocks, although the central parts of large granitic bodies are typically poorly mineralized to barren.

Permissive criteria for low-sulfide gold-quartz veins include all pre-Tertiary rocks with metamorphic fabrics; these areas are zones of accreted terranes where rocks have been metamorphosed to prehnite-pumpellyite up to middle amphibolite facies. Plutons and margins of batholiths are also permissive. Favorable tracts enclose all prospective areas and possibly define a regional shear zone (pl. 9). Favorable tracts in the eastern part of the WSRA are delineated along belts of known or suspected clusters of low-sulfide gold-quartz veins, especially if adjacent placer gold occurrences are present. Prospective tracts are delineated to include clusters of occurrences (pl. 9).

Description of tracts

In the WSRA, known low-sulfide gold-quartz veins are present in shear zones cutting pre-Tertiary rocks in a broad north-striking zone (pl. 9). The veins in these mining districts are mesothermal, and they are associated with the development of ductile fabrics in enclosing rocks. Classic ribbon textures and other features characteristic of mineralized rocks at lithostatic and greater pressures are present in some deposits. The mineralogy and metal content of these deposits varies with the nature of the enclosing rocks. These veins are found both in the Jackson and Jungo terranes, and locally in the Golconda terrane. Where hosted by Cretaceous granitic rocks or metavolcanic rocks of the Triassic Koipato Group (or other Mesozoic sedimentary rocks), most deposits are lead and antimony rich and principally were mined for their silver content, as in the Rochester, Star, Sierra, and Unionville Mining Districts. Some occurrences classified as low-sulfide gold-quartz veins in these mining districts may in fact be polymetallic vein and (or) polymetallic replacement occurrences. It is difficult to discriminate, in places, between the age of ductile fabric and the age of the introduced base and precious metals. In the Denio and Dun Glen Mining Districts, where the veins are hosted by marine metasedimentary and metavolcanic rocks, the major metals exploited were copper and gold, and the deposits apparently were worked mainly for gold.

In the Imlay, Unionville, and Rochester Mining Districts (prospective tract A, pl. 9), milky-white quartz veins fill and replace faults and phyllonitic shear zones and display local ribbon textures. Altered metavolcanic rocks are typically quartz-sericite-pyrite envelopes. Altered limestone and slate generally are sparse in the Unionville Mining District, and some of the occurrences there are polymetallic replacement and polymetallic vein deposits (Cameron, 1939). Nonetheless, sericitic envelopes are present in some ductile shear zones in diorite dikes in the Imlay Mining District (Schrader, 1914; Knopf, 1924). The deposits are thought to have formed at depths between 400 to 500 m on the basis of fluid-inclusion relations (Vikre, 1981), which is shallower than typical deposits of this type. The Sierra Mining District (pl. 9), in the northern part of the East Range, contains vein deposits composed of white massive quartz with spots of gold, sphalerite, galena, tetrahedrite, and chalcopyrite hosted in shear zones that are locally as much as 1 km long (Vanderburg, 1936a; Johnson, 1977) and in limestone, shale, and granodiorite. Gold-placers are adjacent to the mining district.

The eastern part of the Trinity Mining District (prospective tract C, pl. 9) contains small quartz veins which pinch and swell in pods of sheared and altered granodiorite. Gold, chalcopyrite, galena, and silver sulfide minerals are present as wispy or ribboned streaks in quartz (Vanderburg, 1938; Johnson, 1977). In the San Jacinto and East Antelope Mining Districts (prospective tract D, pl. 9), 3– to 10–cm-wide veinlets and 3–m-wide veins of quartz and calcite form irregular masses in Triassic to Lower Jurassic slate, quartzite, and limestone; the veins are subparallel to bedding, shear zones, or cleavage. Ore minerals include galena, arsenopyrite, gold, stibnite, and pyrite and are accompanied by silicified rocks in the adjacent wall rock (Vanderburg, 1936a, 1938; Johnson, 1977). In the Haystack and Jungo Mining Districts (prospective tracts E and F, respectively, pl. 9), pods of milky white, locally contorted, quartz are hosted by folded metasiltstone, phyllite, granodiorite, and shear zones as much as 3 m wide. Ore minerals include gold, native silver, galena, and other sulfide minerals (Willden, 1964; Johnson, 1977).

In the northern Mill City Mining District (tract F, pl. 9), dark, greasy, white, tabular quartz veins are contained in shear zones in phyllitic shale, foliated Triassic to Lower Jurassic limestone, and diorite. Alteration minerals include sericite and quartz with local chlorite and kaolinite. Ore minerals are gold, native silver, galena, arsenopyrite, pyrite, and chalcopyrite (Willden, 1964; Lemmon, 1977). To the north, in the Ten Mile Mining District (pl. 9), quartz and calcite veins host gold and silver in shear zones in slate, quartzite diorite, and granodiorite, and are distinct from Miocene quartz-adularia epithermal gold veins. Some highly sheared low-sulfide gold-quartz veins are parallel to the foliation. Others form as tension-gash fillings in boudins of quartzite in phyllite or in minor thrust faults.

The eastern Awakening Mining District (tract G, pl. 9) contains milky quartz veins in metasedimentary rock, quartz monzonite, and andalusite grade, blue-black slate and quartzite. Ore control is related to thrust surfaces and fold axes (Lincoln, 1923; Calkins, 1938; Vanderburg, 1938; Willden, 1964). These deposits are distinct from the epithermal deposits in the western part of the mining district (pls.1, 8).

In the northern part of the WSRA, in the Jackson Terrane, the Varyville Mining District (tract H, pl. 9) contains quartz-sulfide mineral veins that are distinct from the kuroko massive sulfide occurrences and from the porphyry-related tungsten-molybdenum veins that are also present in the mining districts. Gold placers are also located nearby (Vanderburg, 1938; Willden, 1964). Tract J, made up of parts of the Pueblo, Vicksburg, and Trident Peak Mining Districts (pl. 9), also contains bull quartz veins in shear zones, some as much as 9 m wide, in gneissic granodiorite. Associated elements are gold, silver, copper, barium, bismuth, lead, antimony, and zinc (Vanderburg, 1938; Willden, 1964; Bennett, 1973).

These deposits all have characteristics—such as the presence of shear zones and metasedimentary or metaigneous host rocks, bull or milky white metamorphic quartz, locally with ribbon texture or in contorted configurations—which are similar to low-sulfide gold-quartz veins. In addition, narrow sericite and silicified alteration halos around the veins are typical of this type of deposit. These characteristics allow classification of these deposits and their respective tracts as belonging to the low-sulfide gold-quartz vein model of Berger (1986b). The deposits and their enclosing metamorphic hosts may represent some of the youngest pre-Tertiary features in the region, based on cross-cutting relationships with Late Cretaceous granitic rocks and their metamorphic aureoles in the Humboldt Range. This period (from approximately 80 Ma) is poorly understood in terms of the geologic and structural history of the region, as there are essentially no rocks preserved from the 85– to 40–Ma age range and few of the old underground workings are accessible for detailed study. The structures hosting these veins appear to have formed in a compressive environment because of their apparent genetic association with well-developed metamorphic fabrics, indicating that these deposits may mark one or more late Mesozoic tectono-thermal compressional events. This speculation is compatible with the pattern of the favorable tracts which cuts across several Paleozoic and early to middle Mesozoic allochthonous terranes (pl. 9). A number of placer mining districts are present in alluvial drainages where these deposits are known in their upper reaches—the placers appear to be derived from them. The large size of some of the placer deposits suggests that the low-sulfide gold-quartz environment has the potential to host economically significant deposits.

Estimates of undiscovered deposits

The abundance of quartz veins in exposures of metamorphosed Phanerozoic basement rocks, some containing low-sulfide gold-quartz veins, serves as a basis for the estimate by the team for the numbers of undiscovered deposits. The modest size of these known occurrences also supports our decision to use the Chugach-type low-sulfide gold-quartz veins (Bliss, 1992b) grade and tonnage model rather than the worldwide low-sulfide gold-quartz veins model of Bliss (1986). The latter is a mining district-based model in which production for closely spaced mines is aggregated producing a deposit size range that is inconsistent with the deposits present in the WSRA. The team estimates that there may be 20, 30, 50, 100, 200 undiscovered deposits, consistent with the Chugach-type model at the 90, 50, 10, 5, 1 percent probability distribution. However, the Chugach-type model used is markedly depleted in silver, which relation does not fit well recorded production from many of these types of deposit in the WSRA (see above).

Volcanogenic massive sulfide and associated deposits

The WSRA contains rocks that are permissive for several types of massive sulfide types of deposit, such as the Cyprus-type (Singer, 1986a), the Besshi-type (Cox, 1986k), and the kuroko-type (Singer, 1986b, 1992). These deposits are characterized by a variety of host rocks, metal suites, and form in a variety of geologic environments. They also have different grade and tonnage curves (Doe, 1982). In addition, the WSRA may have potential for sedimentary-exhalative lead-zinc, volcanogenic manganese, and volcanic-hosted magnetite deposits. Each of the allochthonous terranes (Silberling and others, 1987) may have potential for some type of massive sulfide deposit or its geologically associated deposits (Snyder, 1978; Ketner, 1983; Sherlock, 1989; Doebrich, 1996).

Volcanic rocks in accreted Paleozoic and Mesozoic terranes in the WSRA are permissive for many host rocks and geologic environments (pl. 10) in which massive sulfide and associated deposits form (see also, Franklin and others, 1981; Lyons, 1988a, 1988b). A permissive tract for Sierran kuroko deposits was outlined in the northwest part of the WSRA in the Black Rock-Jackson Mountains terranes (permissive tract A, pl. 10), but plutons and areas where basement rocks are greater than 1 km deep, as interpreted from geophysical data, have been subtracted from the permissive tracts. Two irregularly-shaped favorable tracts for Sierran kuroko deposits are delineated within this broad termissive tract (favorable tracts B, C, pl. 10). These two favorable tracts are drawn around exposed areas and prospects and occurrrences of possible Sierran kuroko-type massive sulfides in the northwest part of the WSRA. Near the eastern and southeastern parts of the WSRA, there are several other broad permissive tracts delineated: one for Cyprus, Besshi, and Franciscan manganese deposits (permissive tracts D, E, pl. 10), and the other for sedimentary exhalative and Besshi deposits (tract

F). These are largely coextensive with rocks of the Goldconda and Roberts Mountains allochthons respectively (see also, Doebrich, 1996). Permissive tract E (pl. 10) for Cyprus, Besshi, and Franciscan manganese deposits, east and southeast of the town of Winnemucca, also includes favorable tract G which includes the Big Mike Cyprus-type massive sulfide deposit. This favorable tract is judged to have a level of potential higher than the remaining parts of permissive tract E farther to the east (in the general area of the Battle Mountain Mining District), because of the abundance of Mississippian marine basalt and basaltic andesite in tract G (pl. 10). Nonetheless, there are some known Franciscan-type manganese occurrences and prospects in rocks of the Golconda allochthon in permissive tract E in the eastern part of the Battle Mountain Mining District (pl. 10). Prospective tracts have not been delineated for any of the various types of volcanogenic massive sulfide and their related occurrences.

Cyprus-type massive sulfide deposits (model 24a of Cox and Singer, 1986)

Cyprus-type massive sulfide deposits are found within ophiolite complexes, at the top of the pillow lava sequences or at the stratigraphic break between different volcanic flow units. They consist of massive sulfide minerals that formed as chemical sediments and in underlying stringer-type zones. Deposits typically are copper-dominant with minor peripheral zinc and gold-rich parts. Iron and manganese-rich sediments with gold may overlie these deposits. Permissive criteria for Cyprus-type massive sulfides are the presence of ophiolite-related mafic lava sequences in the strata. Site-specific criteria that can be used to establish a favorable level of potential include: (1) the presence of electromagnetic conductor(s) with or without associated magnetic highs; (2) stream-sediment or soil anomalies in copper, zinc, or gold; (3) locally-developed manganese-rich interflow sedimentary units; (4) chloritized, base-leached zones in basalts; (5) the presence of copper-rich stringers in ophiolitic metabasalt or sheeted dikes; and (6) copper-rich and gold-rich gossans, as well as copper anomalies in pillowed volcanic rocks.

The Upper Paleozoic pelagic and turbiditic sedimentary and volcanic rocks of the Golconda terrane (Silberling and others, 1984, 1987) are permissive for, and locally favorable for, Cyprus-type massive sulfide deposits (tracts D, pl. 10; Sherlock, 1989). The Big Mike massive sulfide deposit is hosted in Late Devonian to Permian carbonaceous chert and argillite above and within pillow lavas (Snyder, 1977). The ore body is lens shaped and consists of massive pyrite, framboidal pyrite, and stringer ore, with local zinc-rich parts (Rye and others, 1984). The deposit is spatially and geologically associated with a belt of volcanogenic manganese deposits (Crittenden, 1964; Schilling, 1962), and with local bedded barite occurrences (Papke, 1984). The permissive tract for Cyprus deposits, the Besshi deposits, and the Franciscan manganese deposits coincides with Devonian, Mississippian, Pennsylvanian, and Permian Havallah sequence rocks in the Golconda allochthon, and the delineated favorable tract is coincident with a number of small Cyprus-type massive sulfide occurrences, as well as some manganese and barite occurrences (pl. 10).

Besshi-type massive sulfide deposits (model 24b of Cox and Singer, 1986)

Besshi-type massive sulfide deposits are typically located near basalt-pelite and (or) psammite contacts in mixed basaltic-clastic sedimentary sequences (Cox, 1986k; Slack, 1993). These types of deposit are characterized by the general lack of carbonate rocks and the general absence of nearby felsic volcanic rocks, as well as a strong association with clastic sedimentary rocks (Slack, 1993). All known examples are in strongly deformed orogenic Proterozoic and Phanerozoic terranes, and they consist of extensive, thin sheets or stratiform lenses of massive sulfide minerals with diffuse footwall zones of disseminated sulfide minerals in chloritic rocks. Copper and zinc are the dominant metals, although their ratio is variable. In addition, cobalt and sulfur may also be significant economic constituents, and cobalt:nickel ratios are typically high (Slack, 1993). Permissive criteria for Besshi-type massive sulfide deposits are of mixed siliciclastic sediment and mafic volcanic sequences, such as the rocks in the Golconda allochthon (tracts D, E, and H, pl. 10). Favorable criteria are quite similar to those for Cyprus-type deposits. Besshi-type massive-sulfide deposits have been recognized in the Roberts Mountains allochthon to the east of the WSRA at the Rio Tinto copper deposits near Mountain City, Nev. (Coats and Stephens, 1968; Proffett, 1979), where they are present in black shale of the Ordovician Vinini Formation. Other deposits of this type are also present in this terrane (Sherlock, 1989). A permissive tract for Besshi-type massive-sulfide deposits is defined by rocks of the Roberts Mountains terrane (tract F, pl. 10), which includes thick sequences of the Ordovician Valmy Formation, which is generally a somewhat deeper-water facies of the Vinini Formation and includes higher proportions of marine basalt than the Vinini Formation (Roberts, 1964).

Sierran kuroko-type massive sulfide deposits (model 28b of Cox and Singer, 1986)

Sierran kuroko-type massive sulfide deposits are found throughout the world proximal to deep-water felsic domes (Ishihara, 1974; Franklin and others, 1981; Hutchinson and others, 1982; Ohmoto and Skinner, 1983; Singer, 1986b). The marine rhyolitic volcanism usually overlies mafic to felsic volcanic rocks. The deposits consist of seafloor-deposited massive sulfide minerals with underlying stringer zones, and locally transported vent breccia ore zones. The massive-sulfide lenses are bulbous, and associated with extensive zones of pyritic chert and bodies of massive gypsum, anhydrite, and barite. Deposits are zoned from upper pyrite and copper-rich areas downward to zinc and silver-rich zones. Upper Triassic to Middle Jurassic felsic and intermediate volcanic rocks of the Black Rock terrane (Doebrich, 1996), specifically in the Jackson Mountains and the Pine Forest Range (Sorenson and others, 1987; Sherlock, 1989), are the areas where kuroko-type massive sulfide deposits are most likely to be present. These deposits may also be associated with volcanogenic magnetite deposits (Horton, 1962; Reeves, 1964), and local barite occurrences (Papke, 1984). The Red Boy deposit, which is one of two kuroko-type massive sulfide deposits in the Jackson Mountains, is hosted in andesite flows, tuffs, agglomerate and breccia (Willden, 1964). There, mineralized rocks include disseminated pyrite, chalcopyrite, bedded barite, and siliceous breccia (Hamilton, 1987). Farther to the north, at the Farnham prospect in the Pueblo Mountains of Oregon, gold and copper-bearing gossans formed from massive pyrite are present in quartz-sericite schist beneath massive, chloritized rock (Howard, 1974), and they may represent a continuation of the Black Rock terrane to the north.

The permissive tract for Sierran-type kuroko massive sulfide deposits includes the rocks of the Black Rock terrane, and two favorable tracts are delineated around known deposits—these tracts extend northward into the Pueblo Mountains (tracts A, B, pl. 10). Permissive criteria for kuroko-type massive sulfide deposits include the presence of deep-water felsic volcanic rocks, especially if rhyolite domes are present. Site-specific favorable criteria in geologic terranes, which are made up of marine felsic volcanic rocks, include electromagnetic conductors, stream-sediment or soil samples that are anomalous in base or precious metals or barium, metal-enriched pyritic (or hematitic) chert or cherty tuff, and zones of alteration in volcanic rocks including chlorite schists formed by magnesium metasomatism. In places, potassium halos also are favorable.

Sedimentary exhalative zinc-lead (copper, barite) deposits (models 31a and 31b of Cox and Singer, 1986)

Sedimentary exhalative zinc-lead deposits consist of stratiform sulfide and sulfate minerals interbedded with massive sedimentary rocks in tabular sheets or lenses, or they may be distributed throughout a large stratigraphic interval (Briskey, 1986). Host rocks are typically black shale, siltstone, chert, dolomite, and limestone, as well as local volcanic rocks. Age is commonly Proterozoic or Cambrian to Carboniferous. An associated type of deposit is bedded barite (Orris, 1986). The mineralogy includes fine-grained, layered or disseminated, galena, barite, and chalcopyrite. Alteration is weak to non-existent. Oxidation usually forms gossans (Large, 1983). Many of the massive sulfide occurrences in the WSRA are not hosted in volcanic rocks and have some characteristics which are similar to exhalative sedimentary zinc-lead type deposits. Bedded barite occurrences in the Cambrian and Ordovician sedimentary rocks of the Osgood Mountains locally contain iron-staining and gossan (Papke, 1984), and stratiform sulfide minerals are present in the stratigraphic section (Kretschmer, 1984a, 1984b; Madden-McGuire, 1991), which suggests syn-sedimentary deposition of sulfide minerals occurred over a wide area. Presence of autochthonous lower Paleozoic rocks and (or) allochthonous rocks of the Roberts Mountains terrane were used to delineate the permissive tracts for these types of deposit (Besshi-type deposits, pl. 10). Favorable criteria include the presence of bedded barite occurrences.

Volcanogenic manganese deposits (model 24c of Cox and Singer, 1986)

Volcanogenic manganese deposits are discontinuous lenses of manganese-oxide minerals within interflow sedimentary units of ophiolitic sequences. Host rocks are thin shales and cherts within volcanic units. Permissive criteria for volcanogenic manganese deposits are ophiolitic or other basalt-shale suites having preserved interflow sedimentary sequences. Favorable criteria include stratigraphic units which host known manganese occurrences. Stratabound manganese oxide minerals associated with chert and other deep marine sedimentary and volcanic rocks are described as Franciscan-type volcanogenic manganese deposits by Mosier and Page (1987), and are locally common in the Golconda terrane in the WSRA. The Black Diablo deposits (Pardee and Jones, 1920; Schilling, 1962; Crittenden, 1964) and the Black Rock Mine at Battle Mountain (Roberts and Arnold, 1965; Doebrich, 1995) are good examples of this type of deposit.

They consist of massive lenses of ore, enclosed in red jasperoid that grade into thin-bedded chert (Johnson, 1977). The main manganese ore is a chert containing braunite intergrown with chalcedony. The permissive and favorable tracts coincide with those of the Cyprus massive sulfide deposits (pl. 10).

Volcanic-hosted magnetite deposits (model 25i of Cox and Singer, 1986)

Volcanic-hosted magnetite deposits are massive lenses or irregular bodies of magnetite, hematite, and apatite that are present in andesitic to trachytic volcanic rocks (Cox, 1986h). The volcanic rocks near the deposits are commonly altered to diopside or biotite, scapolite, and rare sericite. Most deposits worldwide are in subaerial volcanic rocks. Some magnetite deposits in the WSRA in the Black Rock terrane are hosted in both marine and non-marine volcanic rocks (Horton, 1962; Reeves, 1964), which is not entirely consistent with the deposit model. Volcanic-hosted magnetite deposits are present in Jurassic strata in the Jackson Mountains at the Iron King Mine, and they consist of lenses of magnetite and hematite surrounded by chlorite along faults near diorite-andesite contacts. Permissive and favorable tracts coincide with those of the kuroko-type massive sulfide deposits (pl. 10).

Estimates of undiscovered volcanogenic manganese deposits

The assessment team restricted their quantification effort to a single deposit type in the overall volcanogenic massive sulfide class of deposits; namely, volcanogenic manganese deposits. The team felt the available data on the massive sulfide deposits were too ambiguous to support the use of one massive sulfide grade and tonnage over that of another. We made estimates of undiscovered volcanogenic manganese deposits, utilizing the grades and tonnages for the Franciscan sub-type (Mosier and Page, 1987). The team estimates a 90, 50, 10, 5, 1 probability distribution of 2, 10, 15, 20, 30 undiscovered manganese deposits of this type. No estimates were generated for either the exhalative type deposits or the volcanic-hosted magnetite deposits because of an insufficiency of data.

Placer Au–PGE deposits (model 39a of Cox and Singer, 1986)

Placer Au–PGE (platinum group element) deposits consist of elemental gold (electrum)- and platinum-group alloys in grains and nuggets hosted in gravel, sand, silt, and clay. Although we refer to these deposits as placer Au–PGE in the section heading in order to follow the published descriptive model, we do not have any evidence for PGEs in placer deposits of the WSRA. Therefore, in the remainder of this section, we refer to these deposits simply as placer–Au deposits. The main hosts of placer–Au deposits in the WSRA are coarse clastic alluvial gravel and conglomerate, commonly containing abundant clasts of vein quartz. Most deposits are late Cenozoic in age. The gold placers apparently are derived mainly from low-sulfide gold-quartz vein deposits and epithermal gold deposits in the WSRA, as well as porphyry copper, copper skarn, gold skarn, and hot-spring gold-silver deposits. Highest gold grades commonly are present at the base of the gravel deposits in traps, such as natural riffles on the floor of a river or stream bed, in fractured bedrock such as slate, schist, and dikes, and also above clay layers that inhibit downstream migration of gold grains. Geochemical signatures include high amounts of silver, arsenic, mercury, antimony, copper, and iron in panned concentrates. Minerals of high specific gravity are also present in panned concentrates, and include minerals such as magnetite, chromite, ilmenite, hematite, pyrite, zircon, garnet, and rutile (Wells, 1973; Boyle, 1979; Yeend, 1987; Heran and Wojniak, 1992).

The placer–Au deposits in the WSRA are gravel deposits which are contained either along the drainages of present stream beds and gulches or preserved as alluvial benches, usually less than 60 m above present stream beds (Johnson, 1973). The thickness of gravels is usually less than 20 m. Paleoplacers may be covered by, or be interbedded with, young volcanic rocks (such as those near the abondoned townsite of Bannock at the south end of the Battle Mountain Mining District), lake sediments, or alluvial fans. Gold is usually concentrated on bedrock, although it may be dispersed throughout the gravel pile (see also, Roberts and Arnold (1965) for a depiction of the distribution of gold contents in the Natomas placer deposit). Some areas in the WSRA also contain placer mercury, uranium or thorium, and other metals. The placer–Au deposits generally are located close to areas of lode gold deposits (Smith and Vanderburg, 1932; Vanderburg, 1936b; and Johnson, 1977). Some are in fluvial deposits that discharged into Lake Lahontan, exemplified by occurrences north of Sulfur.

Permissive areas for gold-placer deposits are all Tertiary basins throughout the WSRA to a depth of 1 km (pl. 11). Permissive tracts are delineated by the distribution of map units Qa, Qp, and QToa from the geologic map of Nevada, and map units Q and Qs from the geologic map of California. Favorable areas are delineated by a 3–km buffer around the prospective areas, which are delineated by a 2–km buffer around all placer–Au occurrences (pl. 11).

Description of tracts

Three large clusters of placer–Au deposits are present in the WSRA, and are located in the Humboldt Range, in the Kamma Mountains, and in the area of the Battle Mountain and Gold Run Mining Districts (pl. 11). The largest placer–Au area is centered around the Humboldt Range, which has produced over 700,000 oz Au (Vanderburg, 1936a, 1936 b; Johnson, 1977), in the Imlay, Unionville (Cameron, 1939), Rochester (Schrader, 1914; Knopf, 1924; Bergendahl, 1964), and Spring Valley (Ransome, 1909; Schrader, 1914; Lincoln, 1923) Mining Districts. The Trinity (Vanderburg, 1936b) and Antelope (Jones and others, 1931) Mining Districts also contain some areas that were important producers from placer–Au occurrences (pl. 11). In addition, the Sierra Mining District (Lincoln, 1923; Ferguson and others, 1951; Vanderburg, 1936a, 1936b), was also a significant producer.

In the Kamma Mountains area, placer–Au deposits are present in the Rosebud, Rabbit-hole, Placerites, and Sawtooth Mining Districts (Smith and Vanderburg, 1932; Vanderburg, 1936a, 1936b; Lincoln, 1923; Johnson, 1973), and much of the gold is less than 3 m deep in the Quaternary gravels. The source may the pre-Quaternary alluvial deposits in the area as well as local lode-gold occurrences. A similar occurrence is in the Seven Troughs Mining District (Ransome, 1909).

The Battle Mountain and Gold Run Mining Districts contain placer–Au deposits which have been derived from porphyry-related deposits and skarns (Roberts and Arnold, 1965; Koschmann and Bergendahl, 1968; Theodore and Roberts, 1971).

The geologic characteristics of the placer–Au occurrences within the WSRA, and those inferred to be present in the adjacent basins, are the same as those described by Yeend (1987) and Heran and Wojniak (1992) in the deposit model.

Estimates of undiscovered deposits

Although placer–Au deposits are present in the study area and it is highly likely that additional deposits are present, the team did not attempt to estimate their numbers. At present there is no suitable grade and tonnage model available, and without a model, it is impossible to make estimates.

ESTIMATION OF UNDISCOVERED RESOURCE ENDOWMENT

The estimation of resource endowments is based on the assumption that the grade and tonnage characteristics of yet-to-be-discovered deposits of a given mineral deposit type can be accurately predicted using the grade and tonnage characteristics for a sample population of known deposits of the same deposit type. The Mark3 Simulator combines probabilistic estimates of numbers of undiscovered deposits with the sample population grade and tonnage data in a Monte Carlo simulation to create a large, statistically stable population of hypothetical deposit scenarios each with an unique set of endowment values (Root and others, 1992). This quantification of resource potential thus makes it possible to extract easily key statistical or probabilistic information that can be inserted directly into a decision-making process that uses quantitative input or can be used as input for further economic analysis. Our objective in the WSRA study is to generate the hypothetical endowment populations, identify several key statistical properties of these populations, and provide sufficient population data to permit probabilistic conclusions to be drawn by the reader.

Of the 31 deposit types considered by the assessment team to be permissive in the WSRA, 11 were judged to have sufficient data to allow the development of undiscovered deposit estimates. The other 20 lacked (1) an overall deposit existence probability exceeding one chance in a hundred, (2) suitable models characterizing deposit grade and tonnage, or (3) suitable knowledge about the type of deposit in the WSRA by the assessors. The Mark3 endowment data summaries that follow, and the more comprehensive totals that appear in Appendix A.2, are limited to the 11 deposit types. The total number of Mark3 runs is expanded to 19 as a result of division of permissive tracts for hot spring gold-silver, epithermal manganese, hot-spring mercury, and volcanogenic uranium deposit types at the request of BLM. Each set of endowment values is derived using a single set of undiscovered deposit estimates, and as is true for the deposit estimates, the endowment values apply to the entire permissive tract. Sub-tract designations of prospective or favorable, although inferring that there may be a greater expectation for the occurrence of undiscovered deposits and thus endowments, in actuality provide no basis for partitioning of the endowments among the three designations.

The summary tables that follow include endowment values for the 90th, 50th, and 10th percentiles of the simulated endowment populations and the mean endowment for each of the commodities traditionally recovered from a given deposit type and for the rock (ore) processed during recovery of the commodities. These values provide the reader with a quick means of gauging the overall importance of the deposit type in contributing to the potential metal supply for an area and possible magnitude of environmental concern that is attendant with mining operations. These same values also can be used to gauge to some degree the uncertainty that exists in the estimates. Large differences between the 90th and 50th and 50th and 10th values suggest a high degree of uncertainty, small differences greater certainty. The mean probability value (probability of the mean endowment actually existing) can also be used as an indicator of uncertainty. As the difference between the mean probability value and the probability of the median (50 percent) grows, uncertainty increases. The uncertainty is best judged by looking at the mean probability for the ore endowments. Low mean probability values for the ore and primary commodities recovered is generally the result of a rapid increase in the estimated numbers of deposits at the 5th and 1st percentiles relative to estimates for the 90th and 50th percentiles. For secondary commodities, those recorded as recoverable in only a fraction of the deposits used in the construction of the grade model, mean probability values will run even lower. The former represent assessment uncertainty, whereas the latter is an uncertainty inherent in a deposit model. The latter can be quickly checked by referring to the appropriate deposit grade model in Appendix A.

The summary tables also present three other values which are of some interpretive interest. An estimate of a probability of no deposits reflects the relative confidence of the assessors in the presence of deposits. An estimate of probability of the median number of deposits occurring is a function of the estimates of undiscovered deposits' values and distribution. Large deposit populations result in small probabilities of any one fixed population. The mean expected number of deposits value is another indicator of assessor uncertainty but reflected in the terms of deposits rather than endowments.

The following discussion of summary endowment results is arranged by deposit type and follows in the same order as that used in the previous chapters. For the reader desiring more detail, Appendix B presents a more thorough breakdown of Mark3 results. Endowment estimates at 5 percentile intervals are tabulated and graphically presented using a format similar to that used for the grade and tonnage models. A key to interpretation of the diagrams prefaces the Appendix.

Porphyry deposits

Although the assessment team considered the possible existence of four porphyry-related deposit types, only two types of porphyry-related deposits were estimated: porphyry copper and porphyry molybdenum, low-fluorine. The grade and tonnage models of Menzie and Theodore (1986) (see fig. A.2) were adopted for use in modeling the latter deposits; however, a modified subset of the global models of Singer and others (1986a) (see fig. A.1) was adopted by the team for modeling deposits of the former. This North American subset of the porphyry copper model has been used in the Custer-Gallatin National Forest assessment (Hammarstrom and others, 1993) and is believed to be more representative of porphyry systems found in the North American cordillera. In a comparison involving mean values, this model contains 6 percent less ore, 20 percent less copper, 45 percent less molybdenum, 31 percent less gold and 8 percent more silver than in the global model, producing comparable differences in the endowment estimates generated by the Mark3 Simulator. The team did not believe that the available data could support the existence of either a Climax molybdenum or porphyry copper-gold deposit at a minimum occurrence probability of at least one chance in a hundred.

Results of Mark3 endowment simulations for a porphyry copper undiscovered deposit distribution of 2, 4, 8, 10 and 15 deposits at the 90th, 50th, 10th, 5th and 1st percentiles and a deposit distribution of 1, 2, 4, 6, and 10 for porphyry molybdenum, low-fluorine deposits are summarized in tables 6 and 7. More complete results can be found in Appendix B (figs. B.2 and B.3).

For land-planning purposes, the two porphyry deposit types are of significant importance, because they contain virtually all (99 percent) of the copper and molybdenum potential in the WSRA and because of the enormous volumes of ore and metal they can contain. The porphyry copper deposits have a median ore tonnage of 140 million tonnes and the porphyry molybdenum deposits a median ore tonnage of 94 million tonnes. The assessors' expression of confidence in the potential existence of from 1 to 4 of these deposits at the 90th and 50th percentile and further acknowledgment that at a 1 percent level of probability there might be as many as 15 porphyry copper and 10 porphyry molybdenum deposits adds to this importance. However, the uncertainty exhibited in the deposit estimates suggests that median endowment values are the better indicators of commodity and ore potential than are the mean values, which have probabilities in the mid 30 to upper 20 percent range. The reader is also cautioned to keep in mind, that the assessment process we assumed considers deposit occurrence to a depth of 1 kilometer and some unknown proportion of the estimated deposit population for each of these two deposit types is expected to fall in the deeper half of this interval or even below 1 km considering the vertical extent of these types of deposit. In a land-use planning analysis based on near-term economics, such deep seated deposits would not be viable and it would be necessary to adjust the endowment values downward before analyzing for their economic or environmental impacts.

Tungsten skarn deposits

Numbers of undiscovered tungsten skarn deposits were estimated using a model developed by John and Bliss (1994). The model contains data for 113 deposits located within Nevada, which the team felt would be typical of deposits in an undiscovered deposit population (fig. A.3). Caution should be exercised, however, when the economics of these deposits are considered since a preponderance of these deposits were commercially productive only under wartime conditions. The impact of using this model is that a significant but undetermined portion of the endowment would be present in currently (1996) non-commercial deposits. The team estimated a 90, 50, 10, 5, and 1 percentile deposit distribution of 20, 35, 50, 90, and 150 deposits. In the absence of an appropriate tungsten vein model, no estimates for this type of deposit could be made. Endowment estimates are shown in table 8, and in Appendix B (fig. B.4).

All of the tungsten trioxide (WO_3) endowment estimated in the WSRA is limited to that which is present in skarn deposits. Although tungsten is known to be present in vein-type deposits in the WSRA, data are insufficient for construction of predictive models. The interpretation of endowment totals for the skarn deposits is, however, of interest from the standpoint of the economic bias built into the grade and tonnage models and the observation that a disproportionate part of the predicted deposit population is expected to occur in the lower half of the 1 kilometer interval of consideration. For land-planning purposes, in a peace time economy, there would be an economic truncation of the grade and tonnage models resulting in a reduction in the numbers of estimated undiscovered deposits. Increasing the average depth of occurrence of the undiscovered deposit population clouds the interpretation even more. It is suggested that the future development of these deposits does not appear to constitute a major economic or environmental issue in the near future for WSRA planning.

Distal disseminated silver-gold deposits

For purposes of endowment modeling the assessment team felt the silver-to-gold ratio in the global model (Cox and Singer, 1992) is too high to characterize properly this type of deposit in Nevada. A modified grade and tonnage model based on data supplied by T.G. Theodore (written commun., 1995) for 17 deposits occurring in northwestern Nevada was used in place of the global model. The modified model differs from the global model in that the roles of gold and silver grades are reversed. Gold is reported in 94 percent of the deposits in the modified model versus 70 percent in the global model. Median silver grade falls from 42 grams per tonne to 5 grams per tonne in the modified model and only 65 percent of the deposits in the model have recoverable silver reported. However, the size range of the two deposit types varies only slightly. The modified models are shown in Appendix A (fig. A.4). Based on the modified grade and tonnage models, the assessment team estimates a 90, 50, 10, 5, 1 deposit distribution of 20, 35, 50, 70, and 90 deposits respectively.

Results of the endowment simulation are shown in Table 9 and in Appendix B (fig. B.5). The simulation results indicate that deposits of this type could contribute substantially to the precious metal potential in the WSRA. The relatively high mean probability values suggest the assessors felt a high degree of confidence in their estimates and that there is little distinction between the median and mean values. As a deposit type, these deposits are expected to contain approximately one fourth of the total predicted gold potential in the WSRA and nearly two thirds of the silver based on mean endowment values (see table 25 below). Assuming a median deposit size of 5.6 million tonnes and median number of 35 undiscovered deposits, they represent an important class of deposits to be factored into a land-management plan.

Polymetallic vein deposits

The assessment team accepted the global polymetallic vein grade and tonnage models of Bliss and Cox (1986) without modification for the WSRA. The model (fig. A.5) is a mining district hybrid meaning endowment data for deposits used to construct the models includes some aggregated production for groups of mines where the spacing between mines is 1.6 km or less (equivalent to a

Table 6.—Estimate of mineral resources in undiscovered porphyry copper deposits within the Winnemucca District and Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	2	4	8	10	15

Mark3 output

Estimate of probability of 0 deposits: 4%

Estimate of probability of the median number of deposits (4) occurring: 16%

Estimate of mean expected number of deposits: 4.7

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Copper	74,000	6,300,000	29,000,000	11,000,000	32%
Molybdenum	1,200	89,000	610,000	240,000	26%
Gold	0	39 (1.7)	260 (8.3)	110 (3.4)	27%
Silver	0	1,300 (41)	8,500 (270)	3,100 (99)	30%
Ore	170,000,000	1,300,000,000	5,300,000,000	2,100,000,000	37%

Values in parens are Troy ounces expressed in millions.

Table 7.—Estimate of mineral resources in undiscovered porphyry molybdenum, low-fluorine deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	1	2	4	6	10

Mark3 output

Estimate of probability of 0 deposits: 6.2%

Estimate of probability of the median number of deposits (2) occurring: 30%

Estimate of mean expected number of deposits: 2.5

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Molybdenum	19,000	220,000	1,200,000	430,000	29%
Ore	22,000,000	270,000,000	1,600,000,000	560,000,000	31%

mining district in some cases). These models are commonly characterized by an extended tail on the high end of the tonnage curve. The assessment team reached consensus on a 90, 50, 10, 5, 1 deposit probability distribution of 3, 5, 12, 18 and 25 deposits.

Table 10 contains the summary results of the Mark3 endowment results with more complete results given in Appendix B (fig. B.6).

On the basis of the above estimates, the polymetallic vein deposits are not viewed as significant contributors to the mean precious metal endowment in the WSRA. They are projected to contain less than 1 percent of the mean gold and 3 percent of the mean silver potential, although with mean probabilities of 21 percent and 18 percent respectively, those percentages would be overstating their relative contributions to the median precious metal endowments in the WSRA. These deposits also contain all of the assessed lead and zinc potential in the WSRA, which is trivial in amount for these commodities. From the standpoint of future mine development, it is possible that a few of the predicted population of deposits of this type could serve as the focus of development efforts; however, it is more likely that some of the predicted deposits would be developed where they occur together in a mix with one or more of the other porphyry-related deposit types. There is no predictive model developed to deal with the latter situation, but it is a reality that can be expected to exist anywhere within the bounds of the permissive tracts for porphyry-related deposit types.

Hot spring gold-silver deposits

On the basis of geologic and structural considerations, the assessment team subdivided the Winnemucca District into three zones, eastern (southeastern), central, and northwestern (pl. 6). A fourth estimate was made for the Surprise Resource Area to satisfy an administrative need. It was felt that, although the deposit potential among zones was distinctly different, the grade and tonnage characteristics of the hot spring Au-Ag deposit models (fig. A.6) of Berger and Singer (1992) applies across all four zones. The team estimated a 90, 50, 10, 5, 1 deposit distribution of 2, 5, 7, 10, 14 for the eastern zone. The distributions in the central and northwestern zones were 6, 12, 20, 30, 45 and 2, 4, 9, 15, 25, respectively. The relatively narrow range for the eastern zone estimates reflects our belief that the area has been more thoroughly explored than the other two. The estimate for the Surprise Resource Area was 0, 1, 3, 5, 10. Results of the endowment simulations appear in tables 11–14, and in Appendix B (figs. B.7–B.10).

The hot spring type deposits are forecast to contain the single most significant source of precious metal potential in the WSRA. In the Winnemucca District, the assessment team estimates a mean deposit population of slightly over 23 deposits with an expected mean gold content of 36 million oz or one-half of the total estimated mean gold potential for the WSRA. These same 23+ deposits are also predicted to hold a mean endowment of 148 million oz Ag in 810 million tonnes of ore. Even assuming that a third of the predicted deposits occur too deep to recover economically, this class of deposits constitutes a formidable planning challenge. The Surprise Resource Area, on the other hand, is viewed as having a much more modest hot spring deposit potential in the form of a mean deposit population of 1.6 deposits, a mean content of 2.4 million oz Au and content of 10 million oz Ag with low probabilities reflecting the assessment uncertainty; median values of one deposit containing 0.77 million oz Au and 29 million oz Ag are more realistic projections for planning purposes.

Epithermal manganese deposits

To satisfy the administrative need for land-use planning, the assessment effort for epithermal manganese vein deposits included separate undiscovered deposit estimates for the Winnemucca District and the Surprise Resource Area. The team estimated a 90, 50, 10, 5, 1 probability distribution of 0, 0, 1, 2, 3 for the permissive tracts in the Winnemucca District and a 0, 0, 0, 1, 2 distribution for the Surprise Resource Area. Using the global grade and tonnage models developed by Mosier (1986a) (see fig. A.7, Appendix A), the Mark3 Simulator produced the results shown in tables 15 and 16.

The existence of epithermal manganese vein deposits in the WSRA is viewed as rather unlikely by the assessment team. The deposit estimation ranges equate to a 70 percent expectation of no deposits of this type in the Winnemucca District permissive terrane and a 93 percent expectation in the Surprise Resource Area. The low probability of existence suggests that the discovery and development of a deposit of this type would be a highly unlikely event, and in terms of land-use planning for these deposits, they are of trivial concern.

Hot spring mercury deposits

The mercury-enriched hot spring systems were treated separate from the hot spring gold-silver systems. The assessment team believed

Table 8.—Estimate of mineral resources in undiscovered tungsten skarn deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	20	35	50	90	150

Mark3 output

Estimate of probability of 0 deposits: 0.46%

Estimate of probability of the median number of deposits (35) occurring: 2.7%

Estimate of mean expected number of deposits: 39

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Tungsten trioxide	810	9,400	34,000	14,000	37%
Ore	140,000	1,800,000	5,200,000	2,300,000	40%

Table 9.—Estimate of mineral resources in undiscovered distal disseminated silver-gold deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	20	35	50	70	90

Mark3 output

Estimate of probability of 0 deposits: 0.48%

Estimate of probability of the median number of deposits (35) occurring: 2.4%

Estimate of mean expected number of deposits: 36

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	260 (8.3)	620 (20)	1,100 (37)	670 (21)	44%
Silver	3,100 (99)	13,000 (420)	29,000 (920)	15,000 (470)	43%
Ore	210,000,000	490,000,000	860,000,000	520,000,000	45%

Values in parens are Troy ounces expressed in millions.

Table 10—Estimate of mineral resources in undiscovered polymetallic vein deposits within the Winnemucca District-Surprise Resource Area, Nevada-California.

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	3	5	12	18	25

Mark3 output

Estimate of probability of 0 deposits: 2.9%

Estimate of probability of the median number of deposits (5) occurring: 12%

Estimate of mean expected number of deposits: 7

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	0.0017 (0.000054)	0.18 (0.0058)	5 (0.160)	1.8 (0.058)	21%
Silver	8.7 (0.28)	180 (5.8)	1,300 (43)	710 (23)	18%
Lead	1,200	24,000	140,000	56,000	29%
Zinc	220	11,000	120,000	40,000	28%
Copper	0	60	1,400	760	16%
Ore	14,000	350,000	2,100,000	780,000	31%

Values in parens are Troy ounces expressed in millions.

Table 11.—Estimate of mineral resources in undiscovered hot spring gold-silver deposits within the eastern zone of the Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	2	5	7	10	14

Mark3 output

Estimate of probability of 0 deposits: 3.5%

Estimate of probability of the median number of deposits (5)occurring: 17%

Estimate of mean expected number of deposits: 4.9

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	31 (0.99)	160 (5.1)	500 (16)	230 (7.4)	37%
Silver	24 (0.77)	590 (19)	2,200 (70)	950 (30)	34%
Ore	22,000,000	110,000,000	390,000,000	170,000,000	35%

Values in parens are Troy ounces expressed in millions.

Table 12.—Estimate of mineral resources in undiscovered hot spring gold-silver deposits within the central zone of the Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	6	12	20	30	45

Mark3 output

Estimate of probability of 0 deposits: 1.6%

Estimate of probability of the median number of deposits (12) occurring: 6.1%

Estimate of mean expected number of deposits: 13

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	140 (4.5)	510 (16)	1,200 (38)	620 (20)	40%
Silver	410(13)	1,900 (61)	5,700 (180)	2,600 (83)	37%
Ore	100,000,000	380,000,000	880,000,000	450,000,000	41%

Values in parens are Troy ounces expressed in millions.

Table 13.—Estimate of mineral resources in undiscovered hot spring gold-silver deposits within the northwestern zone of the Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	2	4	9	15	25

Mark3 output

Estimate of probability of 0 deposits: 4.3%

Estimate of probability of the median number of deposits (4) occurring: 15%

Estimate of mean expected number of deposits: 5.5

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	27 (0.86)	160 (5.1)	640 (20)	270 (8.6)	34%
Silver	3.1(0.099)	610 (20)	2,700 (86)	1,100 (35)	31%
Ore	19,000,000	110,000,000	460,000,000	190,000,000	34%

Values in parens are Troy ounces expressed in millions.

Table 14.—Estimate of mineral resources in undiscovered hot spring gold-silver deposits within the Surprise Resource Area, California-Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	0	1	3	5	10

Mark3 output

Estimate of probability of 0 deposits: 30%

Estimate of probability of the median number of deposits (1)occurring: 30%

Estimate of mean expected number of deposits: 1.6

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	0	24 (0.77)	220 (7)	76 (2.4)	28%
Silver	0	22 (0.72)	900 (29)	330 (10)	26%
Ore	0	17,000,000	160,000,000	53,000,000	26%

Values in parens are Troy ounces expressed in millions.

there is a marked decline in potential from north to south within the Winnemucca District and chose to divide the area into two zones. Again, the potential in the Surprise Resource Area was characterized by a third set of numbers. In the northern half of the Winnemucca District the team estimated a 90, 50, 10, 5, 1 deposit probability distribution of 3, 5, 10, 15, 20 and a mean deposit potential of 6.4 deposits, whereas in the southern half they estimated 1, 3, 5, 8, 12 range with a deposit mean of 3.3. In the Surprise Resource Area, the potential for this type deposit declines further to a 0, 1, 3, 5, 10 distribution and mean of 1.2. Endowment estimates using the global grade and tonnage models (fig. A.8; Rytuba, 1986a) are shown in tables 17–19 and in Appendix B (figs. B.13–B.15).

Similar to the gold-silver hot spring deposits, the mercury-bearing systems appear to possess a significant potential for future development and must be considered in the formulation of any land-use plan. Eighty-nine percent of an estimated 9,900 tonnes predicted mercury endowment is expected to be present in the permissive area of the Winnemucca District and two-thirds of that in the northern zone, based on mean endowment figures. The attendant environmental concern with development is lessened somewhat if median figures are used in planning. The expected deposit population declines some from 9.7 to 8; however, the mercury endowment drops to 2,500 tonnes from a mean of 8,800 tonnes and the ore volume shows a substantial decrease from 2 million tonnes to 620,000 tonnes. The potential environmental problem is lessened even more when one considers that a third or more of the median number may be too deep to be economically developed if identified.

Volcanogenic uranium deposits

The assessment team developed estimates for an uranium endowment in volcanogenic type deposits and, although there are some recognizable differences between deposits within the Winnemucca District from north to south, a single estimate is applied to the whole area. As with several other deposit types, a separate estimate of the undiscovered deposit population was made for the Surprise Resource Area. The deposit predictions of a 0, 0, 1, 2, 3 for the Surprise area and a 1, 2, 5, 8, 10 distribution for the Winnemucca District continues the established trend reflecting the overall less favorable mineral resource potential that the assessors associate with the Surprise Resource Area. The global grade and tonnage models (fig. A.9) of Mosier (1986d) were used in Mark3 to produce the endowment estimates shown in tables 20 and 21and in Appendix B (fig. B.16).

The uranium potential in the WSRA may be characterized as modest at best. Individually, these deposits have a median size of 340,000 tonnes and the median prediction for the Winnemucca District is two deposits. Due to the low probabilities (mid 20 percent range) attached to the mean ore and uranium oxide endowment values, these figures should not generally be used in planning other than possibly in a worst case scenario.

Sediment-hosted gold-silver deposits

The sediment-hosted gold-silver deposits are recognized as the third most important contributor to the precious metal potential in the WSRA, behind the hot spring gold and distal disseminated silver-gold deposit types. The assessment team reached consensus on an undiscovered deposit distribution of 3, 6, 10, 20, 30 with a mean of 7+ deposits in the WSRA. Using the grade and tonnage models (fig. A.10) of Mosier and others (1992), Mark3 generated the endowments shown in table 22 and in Appendix B (fig B.18).

In terms of mean endowments, these deposits account for 18 percent of the gold potential in the WSRA. The diffuse character of mineralized rocks in these deposits results in open pit mining of large volumes of ore in most deposits. In the WSRA, the endowment simulations project a mean ore total of 210 million tonnes which is equivalent to 14 percent of the total mean ore volume projected for the three most important gold-bearing deposit types. However, the deposit estimates for the sediment-hosted gold-silver deposits also have the greatest expressed uncertainty of the three types. If median ore endowments are considered, as opposed to mean values, these deposits make up less than 7 percent of the total ore volume.

Low-sulfide gold-quartz vein deposits

The low-sulfide gold-quartz vein deposits as a deposit type display an unusually high degree of variation in grades and tonnage. There are presently three grade and tonnage models available for assessing commodity potential for these types of deposits. After reviewing the geologic setting in the WSRA, the assessment team chose the Chugach-type low-sulfide gold-quartz vein grade and tonnage models. Their deposit estimates assume a population of deposits with a range of metal and ore values consistent with this model. The team produced

Table 15.—Estimate of mineral resources in undiscovered epithermal manganese deposits within the Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	0	0	1	2	3

Mark3 output

Estimate of probability of 0 deposits: 70%

Estimate of probability of the median number of deposits (0) occurring: 70%

Estimate of mean expected number of deposits: 0.4

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Manganese	0	0	31,000	16,000	14%
Iron	0	0	0	210	1.5%
Phosphorus	0	0	0	16	0.7%
Ore	0	0	120,000	53,000	14%

Table 16.—Estimate of mineral resources in undiscovered epithermal manganese deposits within the Surprise Resource Area, California-Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	0	0	0	1	2

Mark3 output

Estimate of probability of 0 deposits: 93%

Estimate of probability of the median number of deposits (0) occurring: 93%

Estimate of mean expected number of deposits: 0.1

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Manganese	0	0	0	3,600	5.3%
Iron	0	0	0	57	0.4%
Phosphorus	0	0	0	16	0.1%
Ore	0	0	0	53,000	5.4%

Table 17.—Estimate of mineral resources in undiscovered hot spring mercury deposits within the northern Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	3	5	10	15	20

Mark3 output

Estimate of probability of 0 deposits: 2.9%

Estimate of probability of the median number of deposits (5) occurring: 14%

Estimate of mean expected number of deposits: 6.4

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Mercury	99	1,900	18,000	5,900	31%
Ore	29,000	450,000	3,700,000	1,300,000	34%

Table 18.—Estimate of mineral resources in undiscovered hot spring mercury deposits within the southern Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	1	3	5	8	12

Mark3 output

Estimate of probability of 0 deposits: 7.3%

Estimate of probability of the median number of deposits (3) occurring: 21%

Estimate of mean expected number of deposits: 3.3

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Mercury	0.82	600	10,000	2,900	22%
Ore	270	170,000	2,600,000	660,000	22%

Table 19.—Estimate of mineral resources in undiscovered hot spring mercury deposits within the Surprise Resource Area, California-Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	0	1	2	4	7

Mark3 output

Estimate of probability of 0 deposits: 30%

Estimate of probability of the median number of deposits (1) occurring: 41%

Estimate of mean expected number of deposits: 1.2

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Mercury	0	16	1,900	1,100	15%
Ore	0	5,900	410,000	240,000	15%

Table 20.—Estimate of mineral resources in undiscovered volcanogenic uranium deposits within the Winnemucca District, Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	1	2	5	8	10

Mark3 output

Estimate of probability of 0 deposits: 6.5%

Estimate of probability of the median number of deposits (2) occurring: 26%

Estimate of mean expected number of deposits: 2.8

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Uranium oxide	48	1,800	26,000	7,700	27%
Molybdenum	0	0	1,700	3,700	13%
Ore	50,000	1,700,000	25,000,000	7,600,000	28%

estimates of 20, 30, 50, 100, 200 for deposits consistent with the Chugach-type model (fig. A.11; Bliss, 1992b). The simulated metal and ore endowments for this deposit appear in table 23 and in Appendix B (fig. B.19).

Although the assessment team forecasts a mean population of 39 deposits and median of 30 deposits, the overall impacts associated with their potential discovery and development remain modest because of their small size. The grade and tonnage models (fig. A.11) suggest that 80 percent of the new discoveries will have ore endowments falling between 400 and 26,000 tonnes and gold grades between 1.2 and 31 g Au/tonne—both of which are relatively wide-ranging values. The development of one or more deposits of this type is a near certainty in the WSRA, but total economic and environmental impacts are expected to be low to moderate because of a median content of 85,000 oz Au and a relatively small 290,000 tonnes of ore.

Volcanogenic manganese (Franciscan-type) deposits

Although the WSRA contains permissive terrane for several types of volcanogenic deposits, the assessment team restricted their quantification efforts to volcanogenic manganese deposits. Consensus was reached on making estimates of undiscovered volcanogenic manganese deposits using the grade and tonnage for the Franciscan sub-type model (fig. A12; Mosier and Page, 1987). The team estimated a 90, 50, 10, 5, 1 deposit distribution of 2, 10, 15, 20, and 30 deposits. Endowment results are summarized in table 24. and in Appendix B (fig. B.20)

These deposits serve as the primary contributors to the manganese potential in the WSRA. Their predicted mean manganese content is more than three times that estimated of the epithermal manganese deposits. The assessors believe there is a much greater likelihood of these deposits occurring, predicting a median of 10 deposits. In a sample population of 184 deposits, the median ore endowment for these deposits is 450,000 tonnes, which gives them a low to moderate relevance in terms of land-use planning and environmental impact issues when these values are balanced against national needs and current (1996) availability of manganese in the world market.

Summary of endowment results

Selected results of the Mark3 endowment simulations are summarized in tables 25 and 26. Table 25 contains aggregated results for all commodities and ore in the WSRA without regard to source. Table 26 provides insight concerning the potential each deposit type has for surface disturbance. Each table provides information that can be used to make judgments about the relative importance of individual deposit types to the land-use planning process.

Cumulative endowment results provide an overview of the latent mineral resource potential in the WSRA. For example, the gold endowment values suggest that the assessors believe the WSRA has a substantial potential undiscovered gold, ranging from a conservative (90 percent probability) 1,300 tonnes to an optimistic (10 percent probability) 3,700 tonnes with a median of 2,200 tonnes. The interpretation can be extended by utilizing mean endowment values to evaluate the relative importance of each deposit type in contributing to the area total. Mean values are statistically stable values and are additive, meaning the mean gold endowment for an individual deposit type can be used as an indicator of its relative contribution to the area whole. Thus, the 670 tonne mean gold endowment recorded for distal disseminated silver-gold deposits represents 28 percent of the 2,400 tonne mean gold area total. The latter type of evaluation can, however, be misleading in cases where there is a high degree of uncertainty present in the undiscovered deposit estimates. In those cases, the endowment populations produced by the Mark3 Simulator are highly skewed and mean endowments, which have low probabilities of existence, imply a degree of significance that for comparative purposes is unjustifiably high. Wherever mean endowment values are available, similar interpretations are possible.

A second qualification must be considered when using the endowment data: use of the 1 km-depth criterion. It should be assumed that the estimated deposit populations are distributed uniformly throughout the vertical interval unless otherwise indicated. Mining economics for some deposit types can reduce the importance of a significant proportion of an estimated deposit population. For example, hot spring gold-silver deposits are largely mined by open pit methods, though examples of underground recovery do exist, and many of the estimated undiscovered deposit population may be too deep to be economically developed. Therefore, some modifications to the endowment data must be made before they are input into the planning process.

In addition to commodity forecasts, Mark3 also provides valuable insight on the magnitude of the mining effort that can be expected to accompany the recovery of these commodity endowments. The deposit occurrence and ore endowment data in table 26 focuses attention on

Table 21.—Estimate of mineral resources in undiscovered volcanogenic uranium deposits within the Surprise Resource Area, California-Nevada

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	0	0	1	2	3

Mark3 output

Estimate of probability of 0 deposits: 73%

Estimate of probability of the median number of deposits (0) occurring: 73%

Estimate of mean expected number of deposits: 0.36

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Uranium oxide	0	0	1,100	950	11%
Molybdenum	0	0	0	430	1.8%
Ore	0	0	1,300,000	960,000	11%

Table 22.—Estimate of mineral resources in undiscovered sediment-hosted gold-silver deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	3	6	10	20	30

Mark3 output

Estimate of probability of 0 deposits: 2.8%

Estimate of probability of the median number of deposits (6) occurring: 12%

Estimate of mean expected number of deposits: 7.2

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	36 (1.1)	200 (6.4)	1,100 (37)	440 (14)	29%
Silver	0	0	14 (0.44)	3.8 (0.12)	28%
Ore	16,000,000	81,000,000	550,000,000	210,000,000	32%

Values in parens are Troy ounces expressed in millions.

Table 23.—Estimate of mineral resources in undiscovered low-sulfide gold-quartz vein deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	20	30	50	100	200

Mark3 output

Estimate of probability of 0 deposits: 0.5%

Estimate of probability of the median number of deposits (30) occurring: 2.9%

Estimate of mean expected number of deposits: 39

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons (millions of Troy ounces) at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	0.95 (0.03)	2.7 (0.085)	6.1 (0.2)	3.5 (0.11)	33%
Silver	0.16 (0.005)	0.43 (0.014)	1 (0.033)	0.57 (0.018)	33%
Ore	120,000	290,000	630,000	370,000	35%

Values in parens are Troy ounces expressed in millions.

Table 24.—Estimate of mineral resources in undiscovered volcanogenic manganese deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Mark3 input

Estimate of minimum number of deposits at the following probabilities.

Probability	90%	50%	10%	5%	1%
Number of deposits	2	10	15	20	30

Mark3 output

Estimate of probability of 0 deposits: 4.2%

Estimate of probability of the median number of deposits (10) occurring: 6%

Estimate of mean expected number of deposits: 9.6

Estimates of minimum amounts of metal/ore contained in all undiscovered deposits in metric tons at selected probabilities and mean with the probability for existence of the mean.

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Manganese	300	12,000	160,000	49,000	28%
Ore	950	47,000	640,000	200,000	29%

the quantity of rock that is extracted as ore during recovery and the substantial differences that exist between deposit types. The actual tonnage of material moved during mining also includes a large proportion of waste that results from whatever stripping ratios are established for a particular mining enterprise. For comparative purposes, median values with a 50 percent likelihood of existing are listed in order of decreasing ore endowments. The first five deposit types generally are characterized by mineralization that is of a broad, diffuse nature, not restricted or confined to distinct bodies bounded by sharp grade discontinuities. Economic viability for these low-grade deposits depends on accessibility, and traditionally they are extracted using bulk mining methods. These five deposit types can be expected to pose a significant planning concern from the standpoint of their potential for impact on the environment.

The median prediction of 69 deposits may be misleading due to the use of the standard 1–km depth of occurrence criteria. Some undefinable portion of their estimated undiscovered deposit populations will be present at depths that make them uneconomic. It is not possible within the scope of this study to predict what the impact will be. The remaining seven deposit types have predicted mean ore endowments that are substantially less than the first five types of deposit listed in table 26.

The reader is cautioned to exercise extreme care in using the quantitative results presented in this assessment. It should be remembered that they are the product of a very subjective analysis. The process in extremely sensitive to the state of understanding of ore deposit formation, gescience rock data that are available, the adequacy and relevance of grade and tonnage models, and the backgrounds of the experts conducting the assessment. The reader is also reminded of the probabilistic nature of the output and that singular values without accompanying probability values are meaningless and can be extremely misleading.

Table 25.—Total estimated mineral commodities occurring in all types of undiscovered deposits within the Winnemucca District-Surprise Resource Area, Nevada-California

Commodity	90%	50% (median)	10%	Mean	Mean Probability
Gold	1,300 (43)	2,200 (72)	3,700 (120)	2,400 (77)	43%
Silver	9,900 (320)	22,000 (700)	39,000 (1,200)	23,000 (750)	43%
Copper	740,000	6,300,000	29,000,000	11,000,000	32%
Molybdenum	93,000	430,000	1,600,000	670,000	32%
Lead	1,200	24,000	140,000	56,000	34%
Zinc	220	11,000	120,000	40,000	26%
Mercury	800	5,600	25,000	9,900	37%
Uranium Oxide	110	2,400	28,000	8,700	28%
Iron	0	0	0	270	1.7%
Tungsten oxide	800	9,400	34,000	14,000	37%
Manganese	800	24,000	200,000	69,000	31%
Phosphorus	0	0	0	870	0.8%
Ore	1,900,000,000	3,600,000,000	7,600,000,000	4,300,000,000	38%

Estimates are of minimum amounts of metal, metal oxide or ore contained in all undiscovered deposit types, given in metric tons (millions of Troy ounces) at selected probabilities and at the mean, with the probability for the existence of the mean.

Table 26.—Predicted median deposit occurrence and ore endowments for deposit types expected to be present within the Winnemucca District-Surprise Resource Area, Nevada-California

Deposit type	Number of deposits	Ore endowment (million tonnes)
Porphyry Cu	4	1,300
Hot spring Au-Ag	22	620
Distal disseminated Ag-Au	35	490
Porphyry Mo, low-fluorine	2	270
Sediment-hosted Au	6	81
Tungsten veins	35	1.8
Volcanogenic U	2	1.7
Hot spring Hg	9	.62
Polymetallic veins	5	.35
Chugach low-sulfide Au-quartz veins	30	.29
Volcanogenic Mn	10	.047
Epithermal Mn veins	0	0

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APPENDIX A—GRADE AND TONNAGE MODELS

The geologic environment of the Winnemucca District-Surprise Resource Area is determined to be permissive for the potential occurrence of mineral deposits representing 12 distinct mineral deposit types for which descriptive models exist and grade and tonnage curves have been constructed. The deposit types include hot spring gold and hot spring mercury, porphyry copper and low-fluorine porphyry molybdenum, tungsten skarns, polymetallic veins, distal disseminated silver-gold, epithermal manganese, sediment-hosted gold, low-sulfide gold-quartz veins, and volcanogenic manganese, and volcanogenic uranium. The descriptions of 11 of the 12 models are available in the cited references with their respective plots of the grade and tonnage data. However, for the convenience of the user, the grade and tonnage curves which have been used in the Mark3 endowment simulations are reproduced here. The grade and tonnage models for the distal disseminated silver-gold deposit type is original to this study and is based on data provided by T. G. Theodore (written commun., 1995) for this study. All other references are cited in the figure captions.

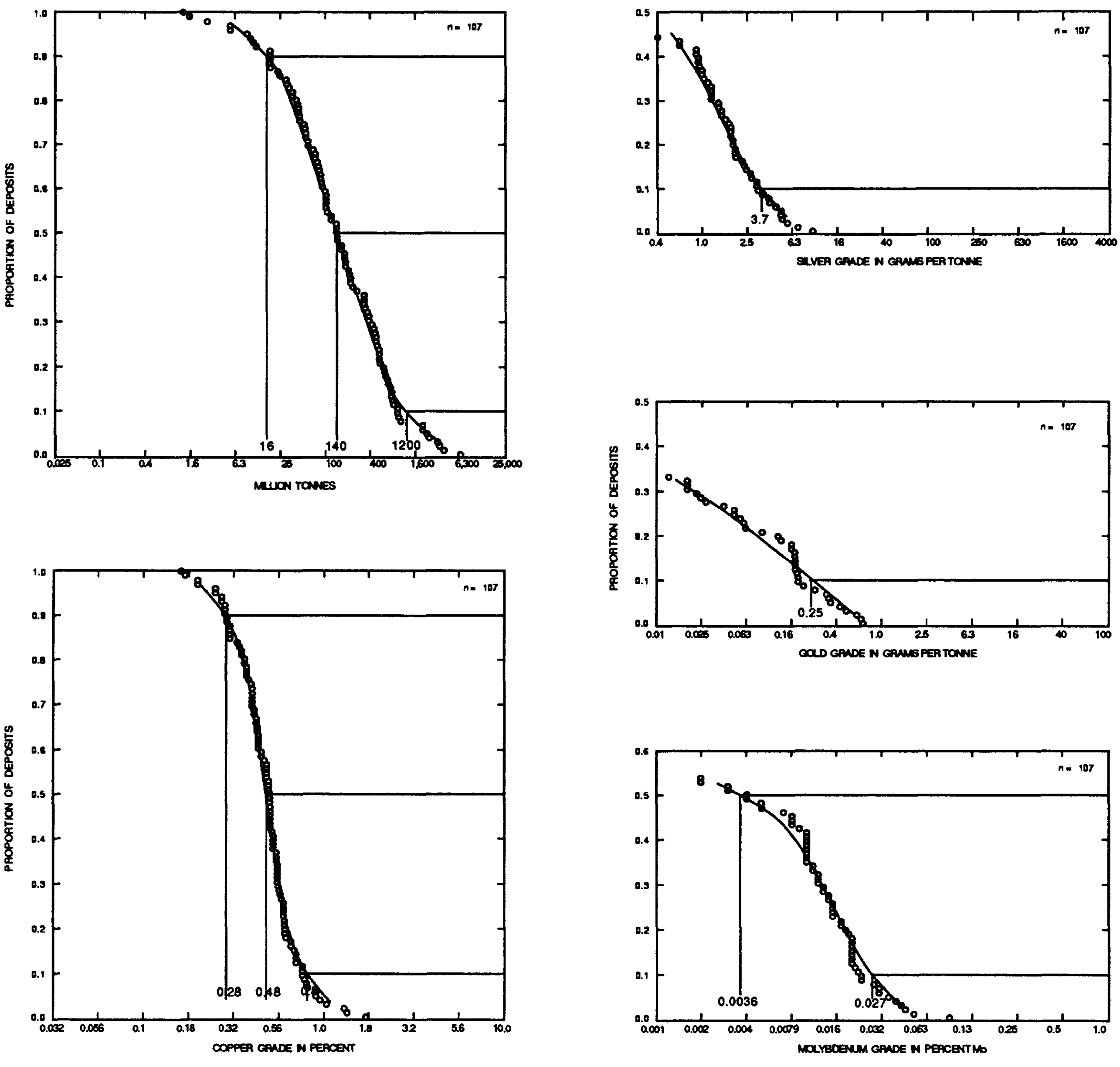

Figure A.1—Grade and tonnage models of North American porphyry copper deposits (Hammerstrom and others, 1993).

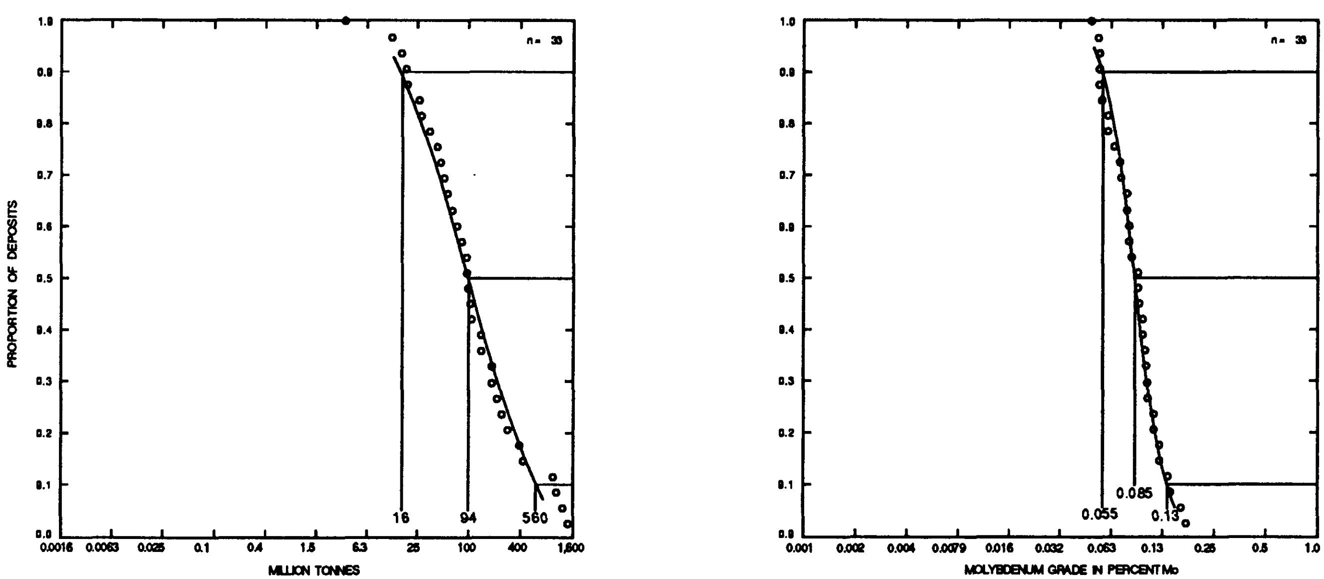

Figure A.2—Grade and tonnage models of porphyry molybdenum, low-fluorine deposits (Menzie and Theodore, 1986).

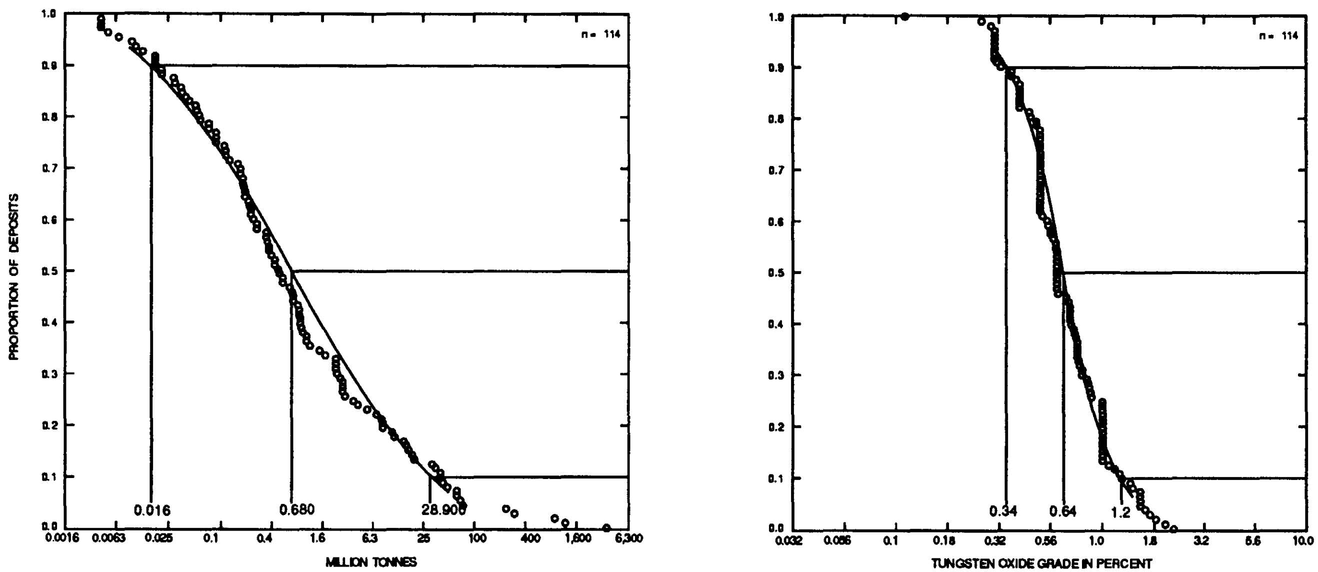

Figure A.3—Grade and tonnage models of tungsten skarn (Nevada) deposits (John and Bliss, 1994).

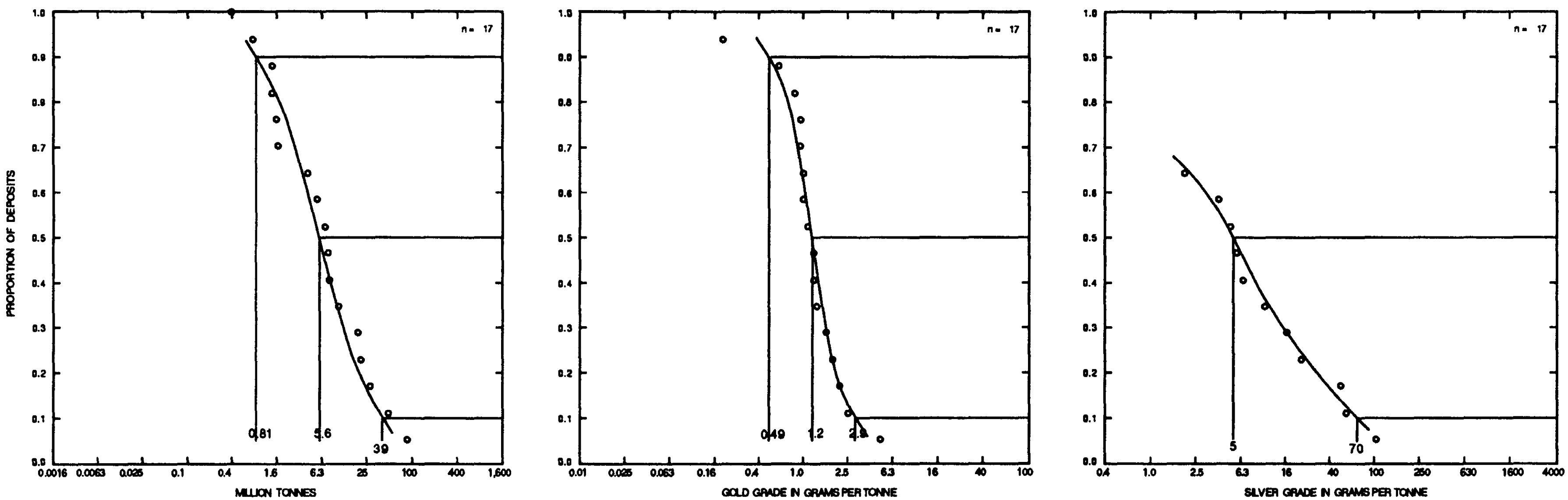

Figure A.4—Grade and tonnage models of distal disseminated Au-Ag deposits in the Great Basin Province, Nevada (data provided Ted Theodore, 1995).

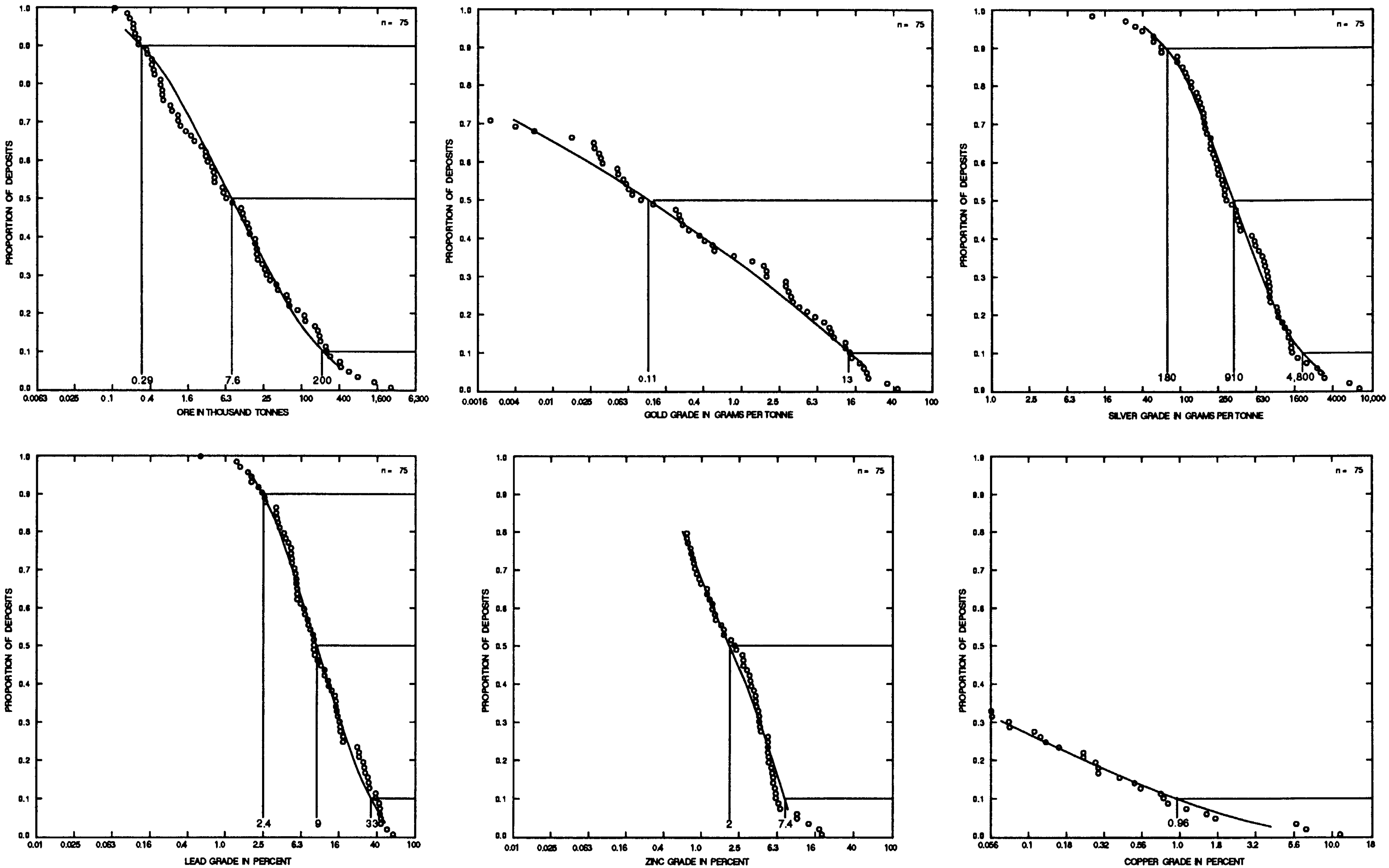

Figure A.5—Grade and tonnage models of polymetallic vein deposits (Bliss and Cox, 1986).

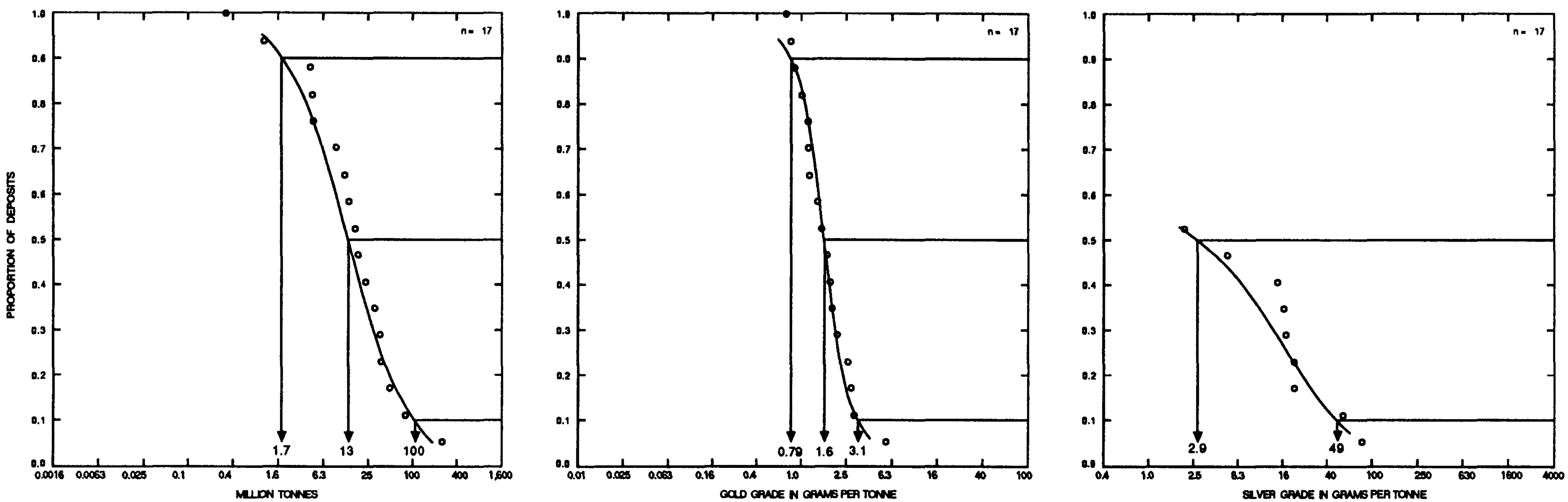

Figure A.6—Grade and tonnage models for hot-spring gold-silver deposits (Berger and Singer, 1992).

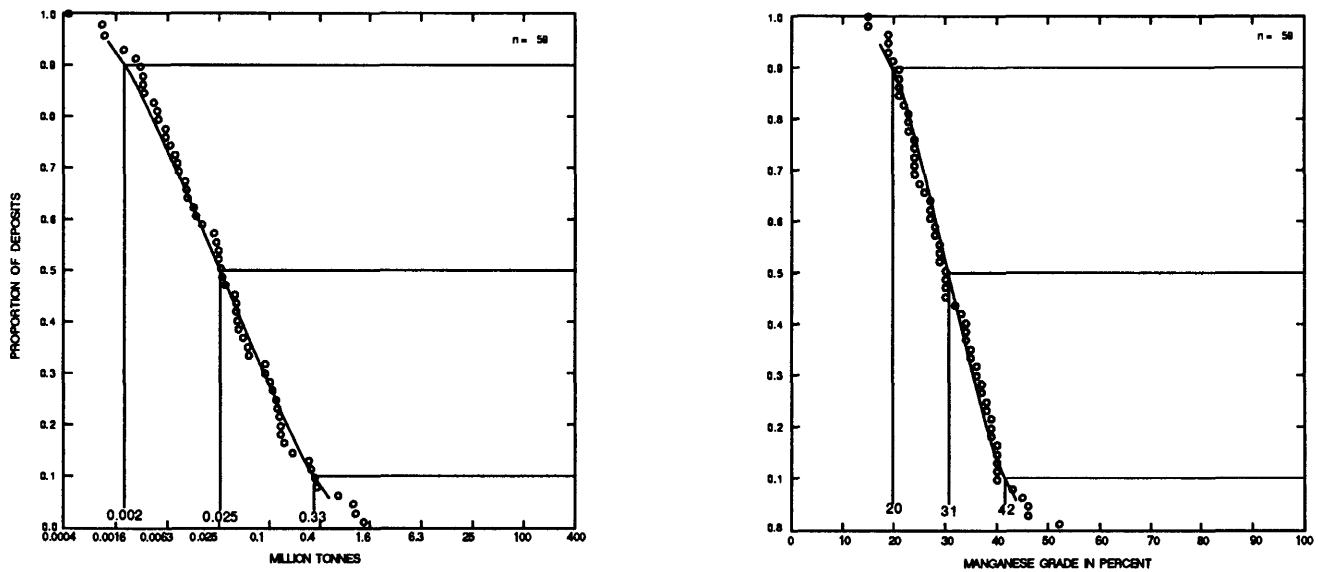

Figure A.7—Grade and tonnage models of epithermal manganese deposits (Mosier, 1986a).

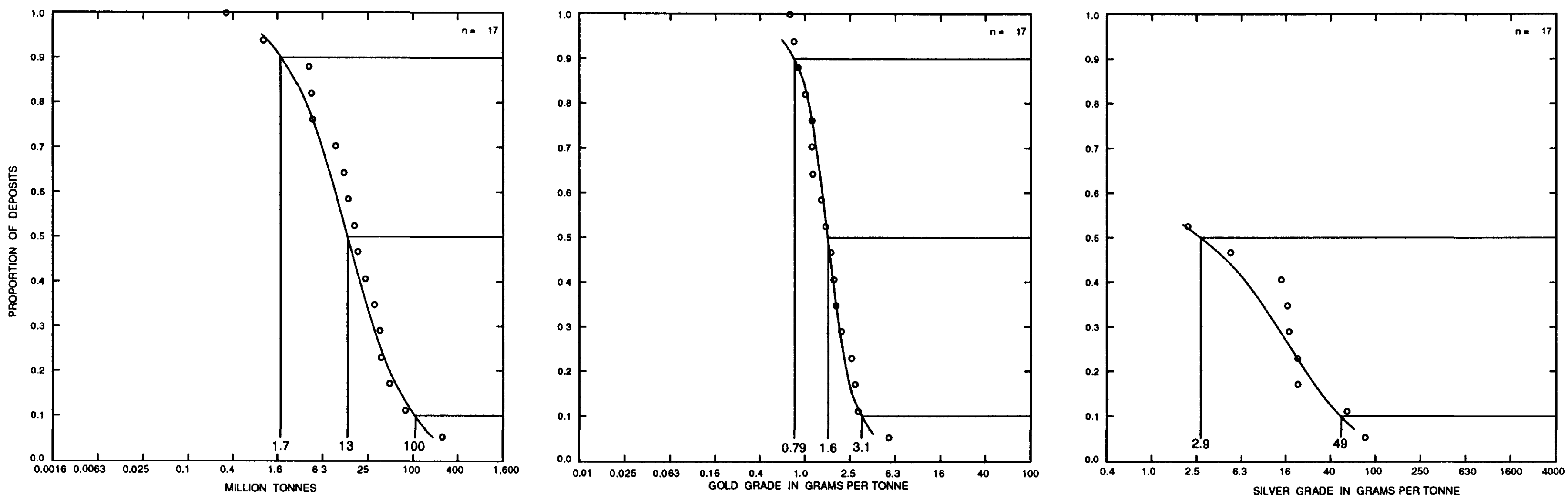

Figure A.6—Grade and tonnage models for hot-spring gold-silver deposits (Berger and Singer, 1992).

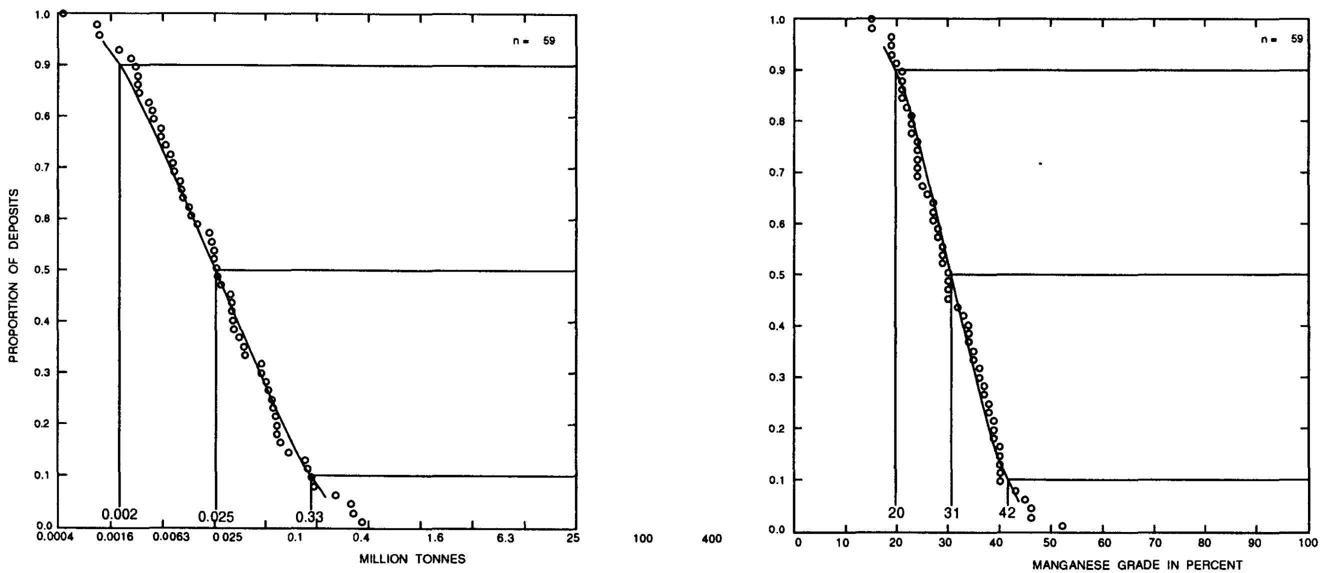

Figure A.7—Grade and tonnage models of epithermal manganese deposits (Mosier, 1986b).

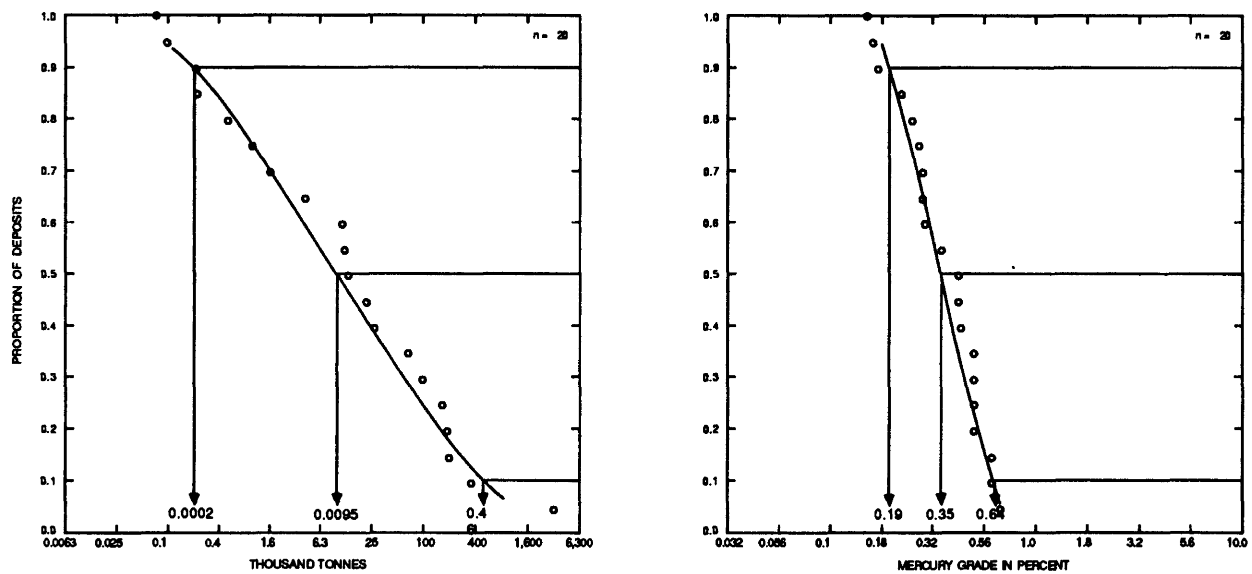

Figure A.8—Grade and tonnage models for hot-spring mercury deposits (Rytuba,1986).

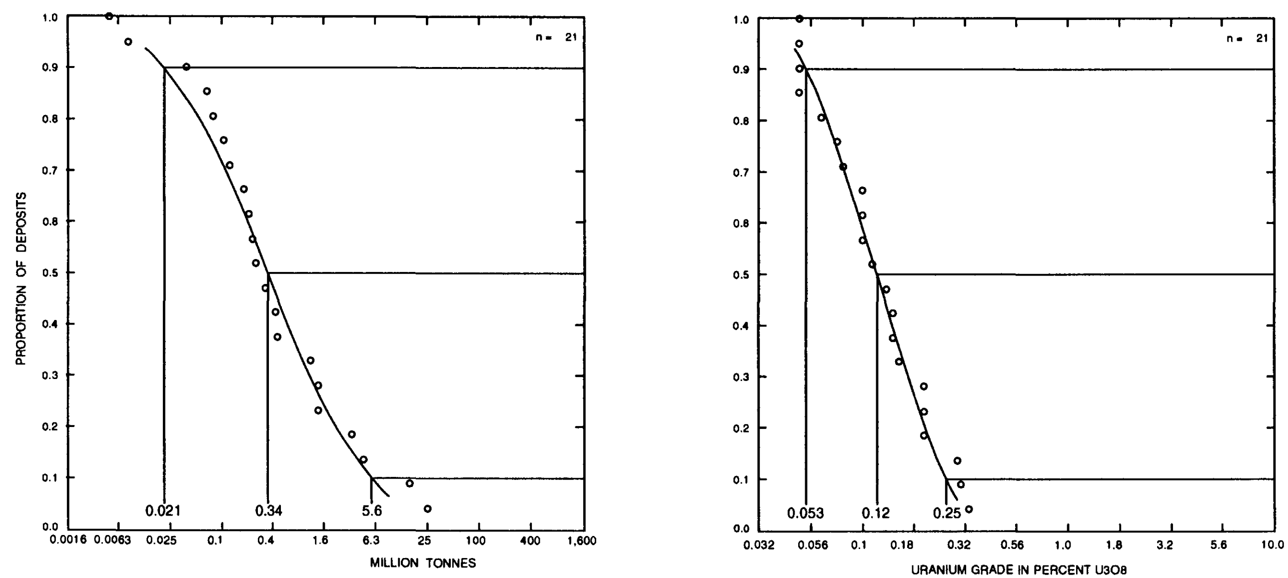

Figure A.9—Grade and tonnage models for volcanogenic uranium deposits (Mosier, 1986).

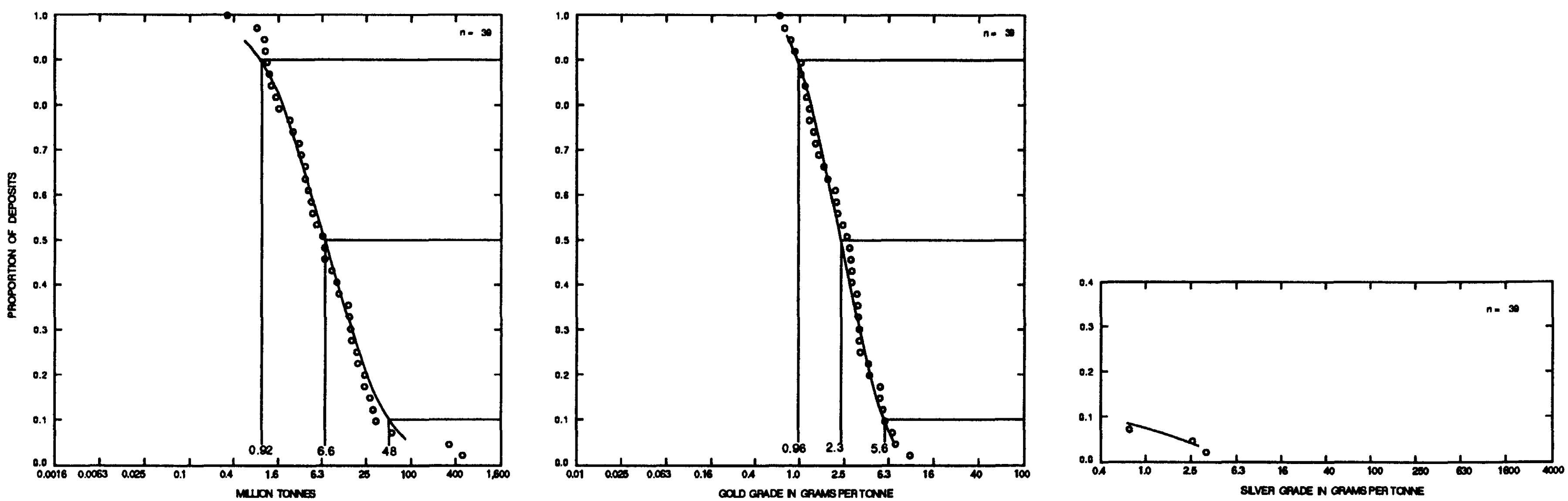

Figure A.10—Grade and tonnage model of sediment hosted Au deposits (Mosier and others, 1992).

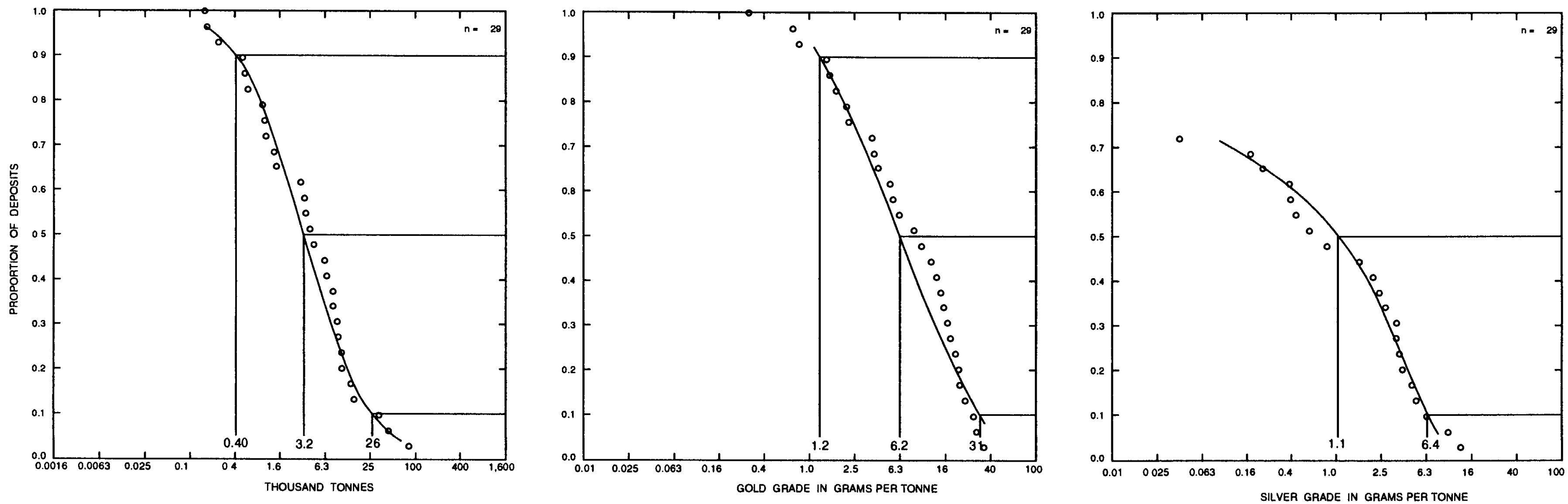

Figure A.11—Grade and tonnage models of Chugach-type low-sulfide Au-quartz veins (Bliss, 1992a)

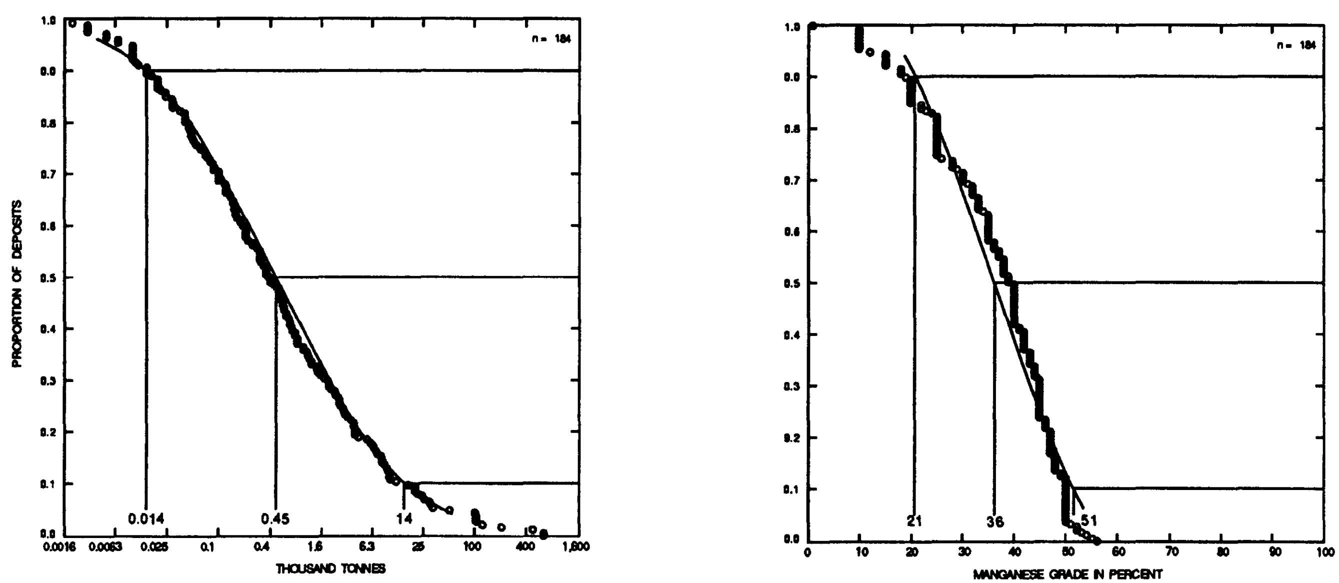

Figure A.12—Grade and tonnage models of volcanogenic manganese (Franciscan-type) deposits (Mosier and Page, 1987).

APPENDIX B—RESULTS OF THE MARK3 ENDOWMENT SIMULATIONS

Estimated ore tonnage and metal endowment populations for eleven types of deposit in the WSRA have been simulated using the U.S. Geological Survey Mark3 Simulator (Root and others, 1992). Input to the Simulator includes estimates of the numbers of undiscovered deposits that a team of expert assessors believe are likely to exist in a defined area or tract estimated at the 90th, 50th, 10th, 5th and 1st percentile levels of confidence, and the grade and tonnage model data. Mark3 uses a Monte Carlo simulation methodology to compute populations of theoretical ore and metal endowments which are consistent with the input data. Each population consist of 4,999 estimates, which have been used to construct the following plots from which probabilistic conclusion can be drawn. Tables of endowment values at .05 percentile intervals are included with each plot. To assist the user in interpreting the plots a brief explanation of the plot format follows.

Explanation of Graphical Display of Mark3 Output

In the concluding step of the quantitative resource assessment process the Mark3 simulator, using a Monte Carlo simulation technique, produces 4,999 hypothetical ore and metal(s) endowment estimates which are applicable to the lands within an assessment study area designated permissive for deposits of a specified deposit type. The calculation of a total ore and metal(s) endowment in a given simulation run is conditioned on a value for the number of undiscovered deposits drawn randomly from the undiscovered deposit distribution estimated by the assessment team and deposit grade and tonnage values randomly selected from the mineral deposit models. The resulting population of 4,999 cumulative metal(s) and ore endowment values are sorted in order of increasing values and graphically displayed in a log linear plot of ore or metal endowments versus the proportion of simulation runs. The user can readily obtain information about the mean and median of the population and other probabilistic characteristics which would be applicable in describing the possible ore and metal endowment potential for any area in which the mineral deposit conditions are similar.

Key interpretative elements of a typical plot of Mark3 results (see Figure B.1.) are cross referenced by letter to the following descriptive explanations.

(A) Title—Identifies the mineral deposit type, the probabilistic estimates of undiscovered deposits (in parentheses) and the type of endowment plotted. In a figure format, this information is contained in the caption.

-- In the example, endowment estimates are displayed for a simulated population of hot-spring Au-Ag deposits where 2, 4, 9, 15 and 25 undiscovered deposits were estimated at the 90th, 50th, 10th, 5th and 1st percentiles, respectively.

(B) Vertical axis (left)—Linear scale of proportion of the 4,999 simulation runs graduated in 0.1 increments.

(C) Horizontal axis—Endowments are measured in tonnes. A logarithmic scale is used to accommodate the skewed character of these populations which precludes the display of the zero endowment portion of a simulated population.

-- In the example, ore endowments from 6,300 to 6,300,000,000 tonnes are plotted, expressed in millions of tonnes.

(D) Endowment value—Open circular symbol denotes values occurring at .05 intervals in the simulated endowment population. A table of values for these points is included in an appendix.

-- In the example, the ore endowment at the 35th percentile is 72 million tonnes.

(E) Smallest endowment—Solid circular symbol denotes the smallest non-zero endowment value simulated. The symbol is annotated with the magnitude of the endowment and the proportion of simulations producing a zero endowment is noted on the flattened extension of the endowment curve to the left of the symbol.

-- In this example, the smallest ore endowment in the population is 170,000 tonnes of ore and 0.04 or 4 percent of the simulations produced endowment estimates of zero.

(F) No deposit field—The lightly shaded field denotes that portion of the simulations where a zero deposits present conditions was tested. This field will be present in every plot as there is always a zero deposits condition possible in an undiscovered deposit distribution. In cases where an endowment is simulated for a metal that is known to be absent in some of the deposits in the grade model, a gap occurs between the no deposits field and the endowment curve at the smallest endowment value.

-- In the given example, 4 percent of the simulations tested conditions where no deposits were present and the ore endowment was zero. In the remaining 96 percent of the simulations one or more deposits was present which resulted in ore endowments of 170,000 tonnes or more.

(G) Maximum endowment—Open circular symbol denotes the value of the largest estimated endowment in the simulated population.

-- In the example, the largest ore endowment is equivalent to 1,800 million tonnes.

(H) Median endowment—Open circular symbol at .5 represents the median value in the simulated endowment population. One half of the 4,999 simulation produced values smaller than this value and one half produced larger values. In a probabilistic sense, given the simulation conditions, the probabilities of the endowment being larger or smaller than this value are 50 percent or equal.

-- In the example, the median ore endowment is equal to 110 million tonnes. The probability of an endowment greater or less than 110 million tonnes is equal.

(I) (J) Endowments at the 10th and 90th percentiles—Values commonly reported in past assessments as defining the upper and lower limits of the endowment for a given deposit type. Highlights that portion of the simulated endowment population (K) that is symmetric about the population median and excludes values occurring in the tails of the population.

-- In the example, the ore endowment at the 10th percentile is 18 million tonnes and the 90th percentile 470 million tonnes. It may be assumed, therefore, that in any area where similar simulation conditions apply, there will be an 80 percent probability of occurrence of an ore endowment falling between 18 and 470 million tonnes in size. Users may at their discretion choose a different percentile interval, however, it is recommended that the interval remain centered on the median to insure that the probabilities of existence of endowments either greater or smaller remain equal.

(L) Mean endowment—A square symbol denotes the position of the population mean. It is annotated with an endowment value and the percentile of the population that has values less than that of the mean.

-- In the example, .67 of the simulated ore endowment population (M) has values less than the mean of 190 million tonnes. In predictive terms, there is a 67 percent probability the ore endowment in an area will be less than 190 million tonnes if the area possesses similar mineral deposit potential characteristics. Means, though statistically robust, can be skewed to the high percentile end of the simulated population and lose their significance in reflecting mineral potential, because the probability of the presence of an endowment as large or larger than the mean are greatly diminished. Mean values should be reported without including a probability statement.

(N) Exceedance probability—Indicates the probability of a value on the endowment curve being exceeded.

-- In the example there is a 33 percent probability that an ore endowment equal to or larger than the mean endowment of 190 million tonnes might occur under the given conditions.

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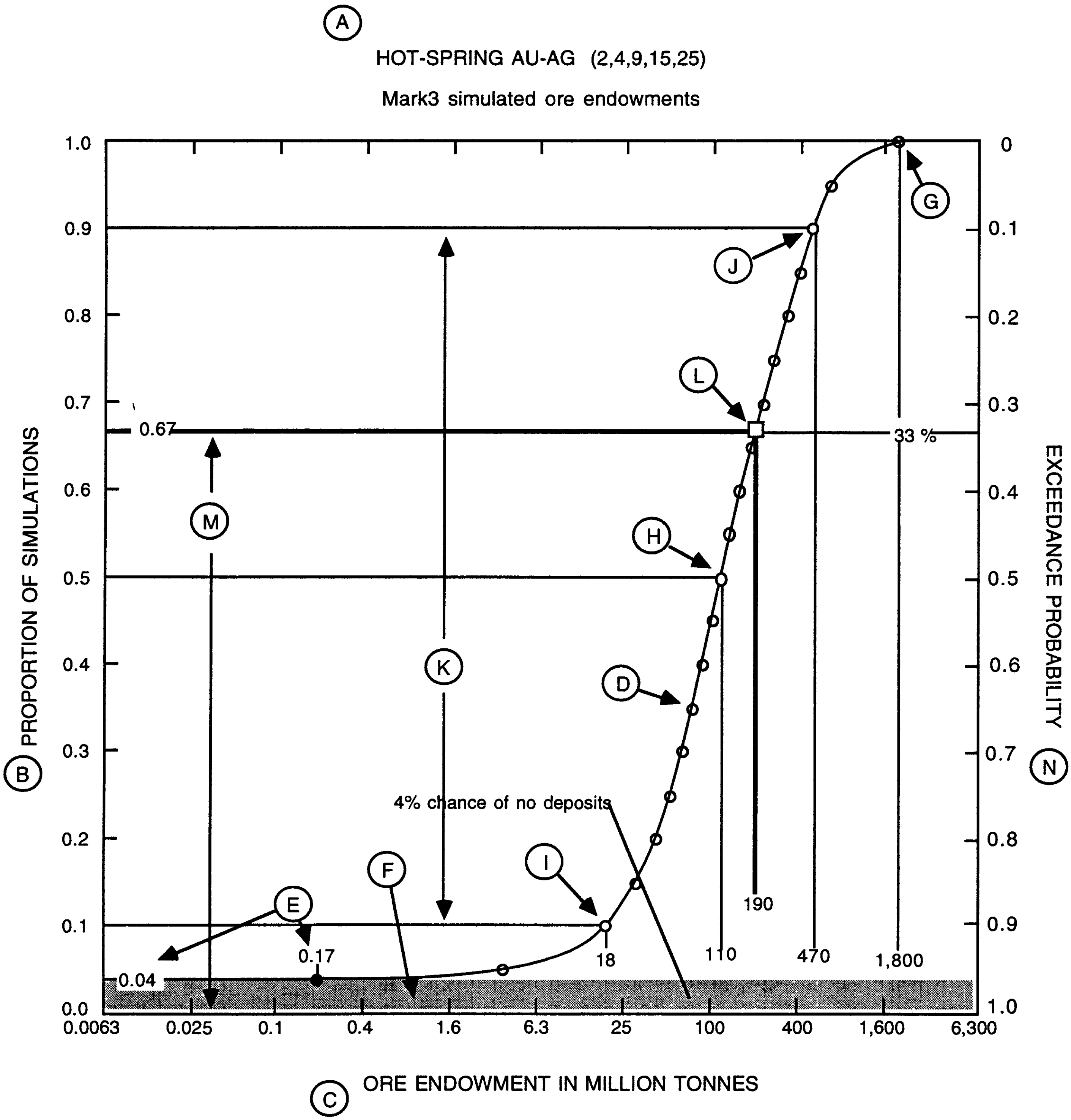
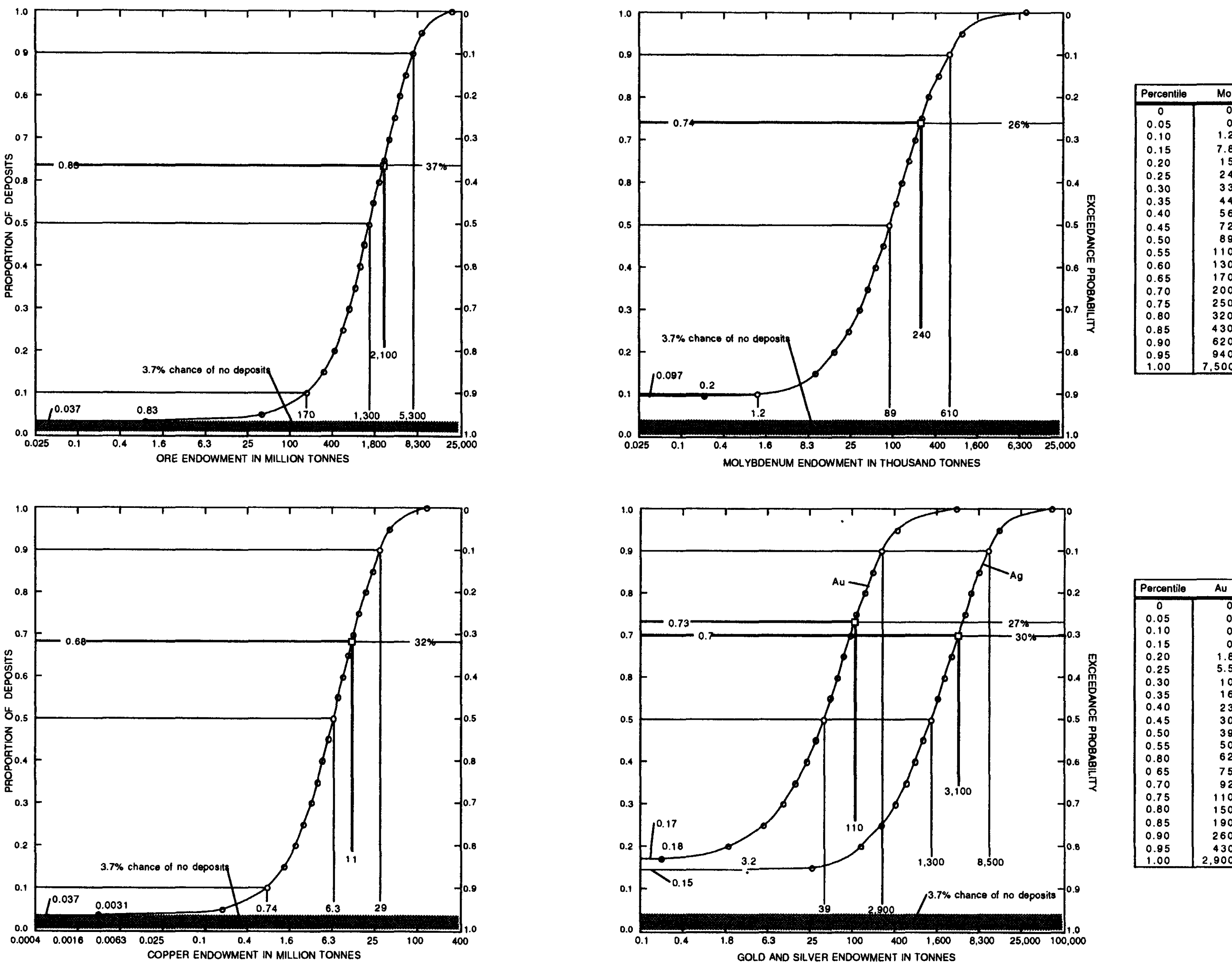


Figure B.1. Key to plot of Mark3 endowment population results.

MARK3 ENDOWMENT RESULTS

Percentile	Ore
0	0
0.05	40
0.10	170
0.15	290
0.20	420
0.25	560
0.30	690
0.35	820
0.40	960
0.45	1,100
0.50	1,300
0.55	1,500
0.60	1,800
0.65	2,100
0.70	2,500
0.75	3,000
0.80	3,500
0.85	4,200
0.90	5,300
0.95	7,000
1.00	18,000

Percentile	Mo
0	0
0.05	0
0.10	1.2
0.15	7.8
0.20	15
0.25	24
0.30	33
0.35	44
0.40	56
0.45	72
0.50	89
0.55	110
0.60	130
0.65	170
0.70	200
0.75	250
0.80	320
0.85	430
0.90	620
0.95	940
1.00	7,500

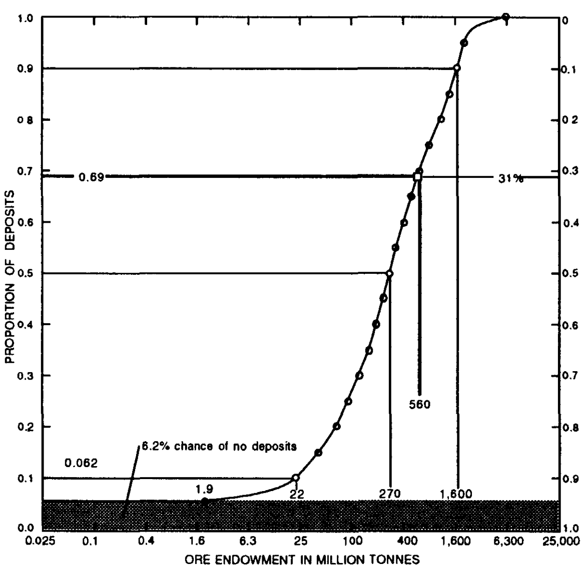


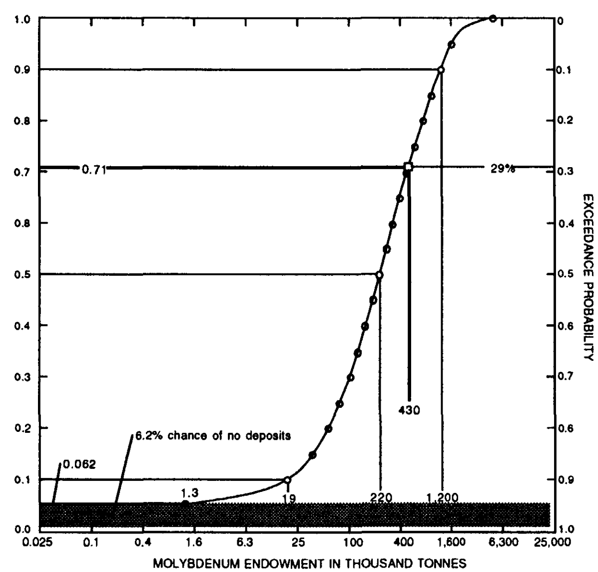
Percentile	Cu
0	0
0.05	170
0.10	740
0.15	1,300
0.20	1,900
0.25	2,500
0.30	3,200
0.35	3,800
0.40	4,600
0.45	5,400
0.50	6,300
0.55	7,500
0.60	8,700
0.65	11,000
0.70	12,000
0.75	15,000
0.80	18,000
0.85	23,000
0.90	29,000
0.95	40,000
1.00	130,000

Percentile	Au	Ag
0	0	0
0.05	0	0
0.10	0	0
0.15	0	27
0.20	1.8	140
0.25	5.5	260
0.30	10	410
0.35	16	590
0.40	23	760
0.45	30	1,000
0.50	39	1,300
0.55	50	1,600
0.60	62	2,000
0.65	75	2,500
0.70	92	3,100
0.75	110	3,900
0.80	150	4,900
0.85	190	6,200
0.90	260	8,500
0.95	430	12,000
1.00	2,900	67,000

Figure B.2—Porphyry Cu (North American modification) deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 2, 4, 8, 10, 15 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California.

Percentile	Ore
0	0
0.05	0
0.10	22
0.15	40
0.20	64
0.25	89
0.30	120
0.35	150
0.40	190
0.45	220
0.50	270
0.55	310
0.60	390
0.65	470
0.70	580
0.75	770
0.80	1,000
0.85	1,300
0.90	1,600
0.95	1,900
1.00	5,900

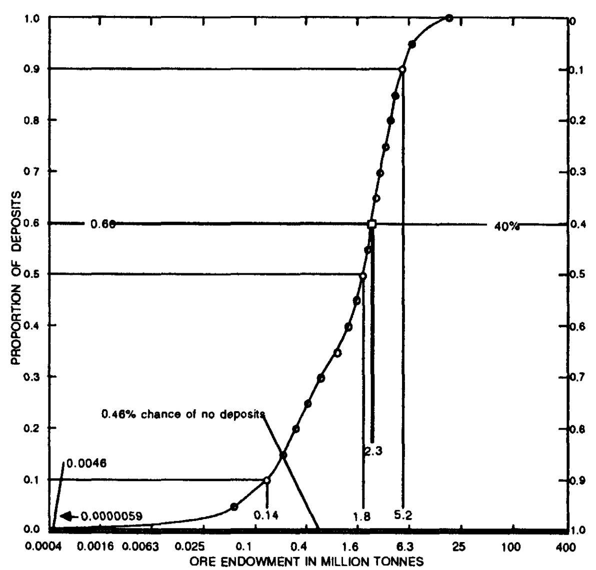


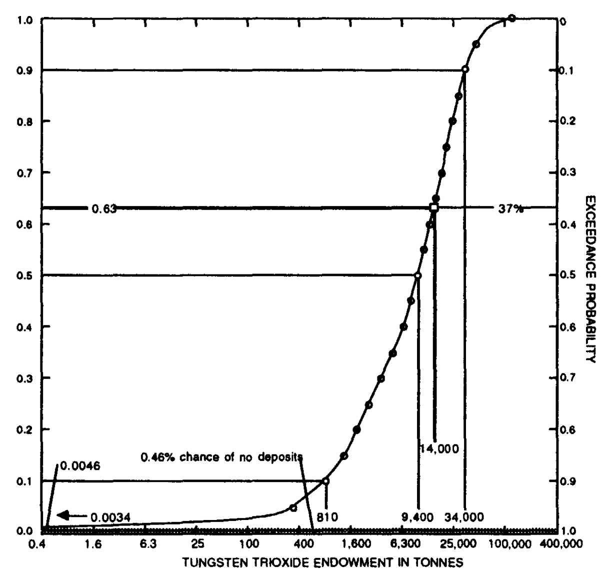


Percentile	Mo
0	0
0.05	0
0.10	19
0.15	37
0.20	56
0.25	78
0.30	100
0.35	120
0.40	150
0.45	190
0.50	220
0.55	260
0.60	310
0.65	380
0.70	460
0.75	570
0.80	710
0.85	910
0.90	1,100
0.95	1,600
1.00	4,800

Figure B.3—Porphyry molybdenum, low-fluorine deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 1, 2, 4, 6, 10 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California

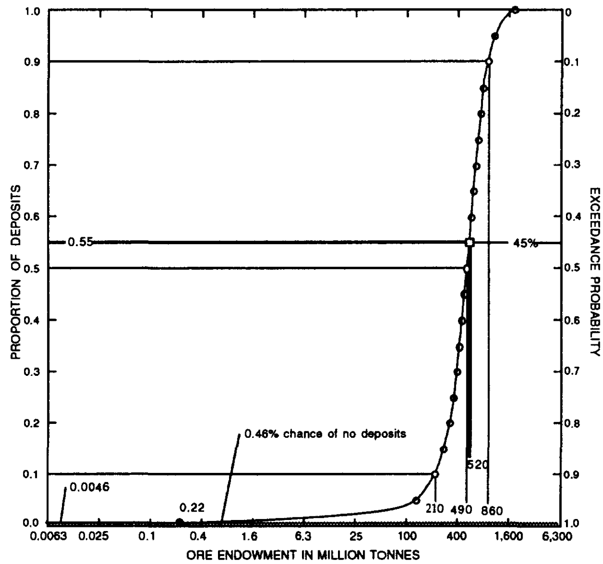
Percentile	Ore
0	0
0.05	0.058
0.10	0.14
0.15	0.21
0.20	0.3
0.25	0.41
0.30	0.59
0.35	0.92
0.40	1.2
0.45	1.5
0.50	1.8
0.55	2
0.60	2.3
0.65	2.5
0.70	2.9
0.75	3.3
0.80	3.8
0.85	4.3
0.90	5.2
0.95	6.7
1.00	18



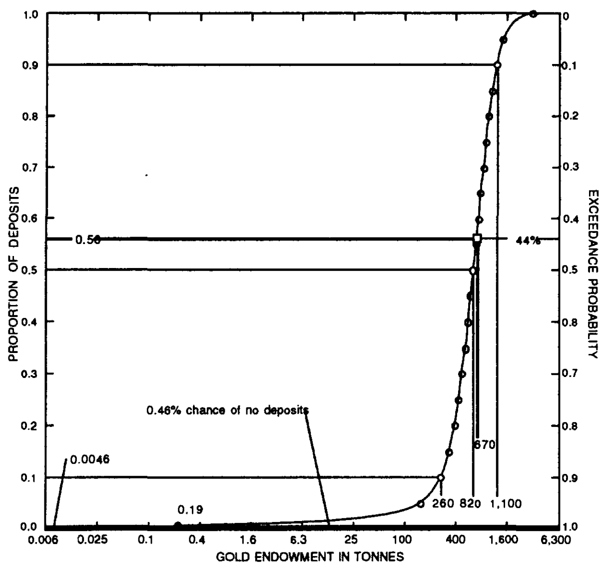


Percentile	WO_3
0	0
0.05	340
0.10	820
0.15	1,300
0.20	1,800
0.25	2,500
0.30	3,500
0.35	4,800
0.40	6,400
0.45	7,800
0.50	9,400
0.55	11,000
0.60	13,000
0.65	15,000
0.70	18,000
0.75	20,000
0.80	24,000
0.85	28,000
0.90	34,000
0.95	46,000
1.00	120,000

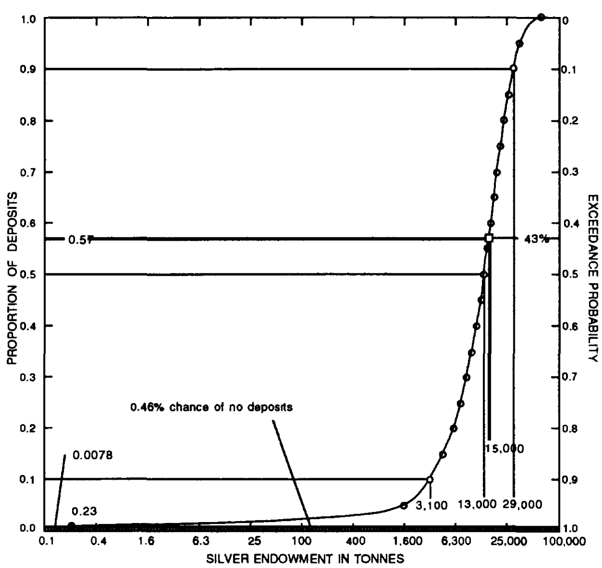
Figure B.4—Nevada tungsten skarn deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 20, 35, 50, 90, 150 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California



Percentile	Ore
0	0
0.05	130
0.10	210
0.15	270
0.20	310
0.25	350
0.30	380
0.35	410
0.40	440
0.45	460
0.50	490
0.55	520
0.60	560
0.65	590
0.70	630
0.75	670
0.80	720
0.85	780
0.90	860
0.95	1,000
1.00	1,800



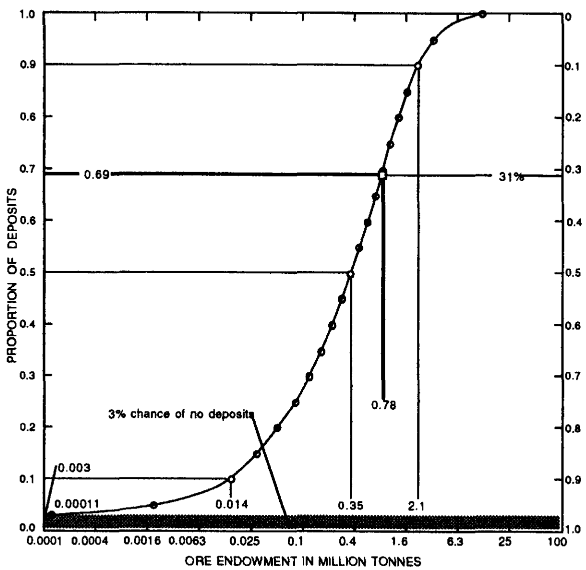
Percentile	Au
0	0
0.05	150
0.10	260
0.15	320
0.20	370
0.25	420
0.30	460
0.35	500
0.40	540
0.45	580
0.50	620
0.55	660
0.60	710
0.65	750
0.70	810
0.75	860
0.80	930
0.85	1,000
0.90	1,200
0.95	1,400
1.00	3,000

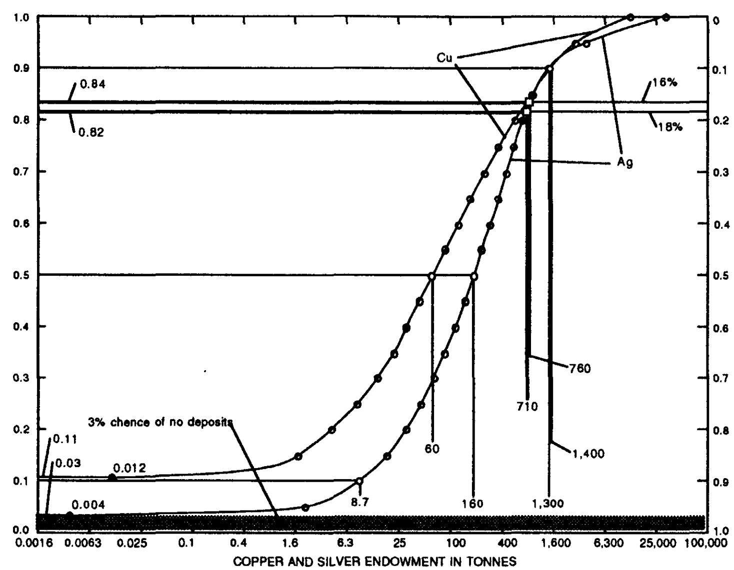


Percentile	Ag
0	0
0.05	1,500
0.10	3,100
0.15	4,400
0.20	5,700
0.25	7,100
0.30	8,400
0.35	9,400
0.40	11,000
0.45	12,000
0.50	13,000
0.55	14,000
0.60	16,000
0.65	17,000
0.70	19,000
0.75	20,000
0.80	23,000
0.85	25,000
0.90	29,000
0.95	34,000
1.00	59,000

Figure B.5—Distal disseminated Ag-Au (Great Basin modification) deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 20, 35, 50, 70, 90 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California

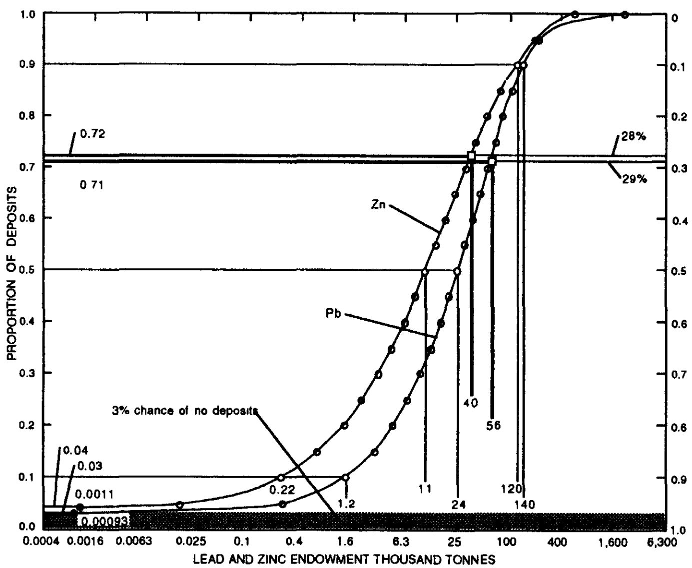
Percentile	Ore
0	0
0.05	0.0019
0.10	0.014
0.15	0.029
0.20	0.049
0.25	0.081
0.30	0.12
0.35	0.17
0.40	0.22
0.45	0.28
0.50	0.35
0.55	0.44
0.60	0.55
0.65	0.68
0.70	0.83
0.75	1
0.80	1.3
0.85	1.6
0.90	2.1
0.95	3.2
1.00	12

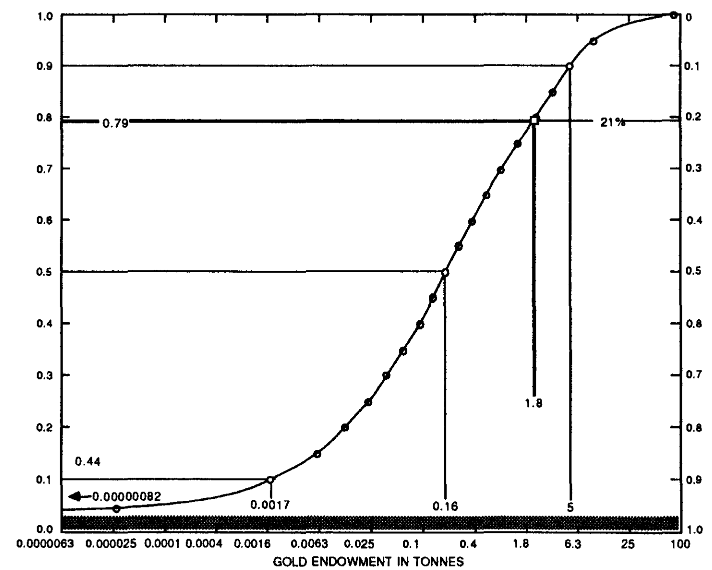




Percentile	Cu	Ag
0	0	0
0.05	0	2.1
0.10	0	8.7
0.15	1.7	18
0.20	4.1	30
0.25	8.2	45
0.30	14	64
0.35	22	85
0.40	31	110
0.45	43	150
0.50	60	180
0.55	85	230
0.60	120	280
0.65	170	350
0.70	240	440
0.75	350	530
0.80	540	660
0.85	850	880
0.90	1,400	1,300
0.95	2,800	3,700
1.00	12,000	31,000

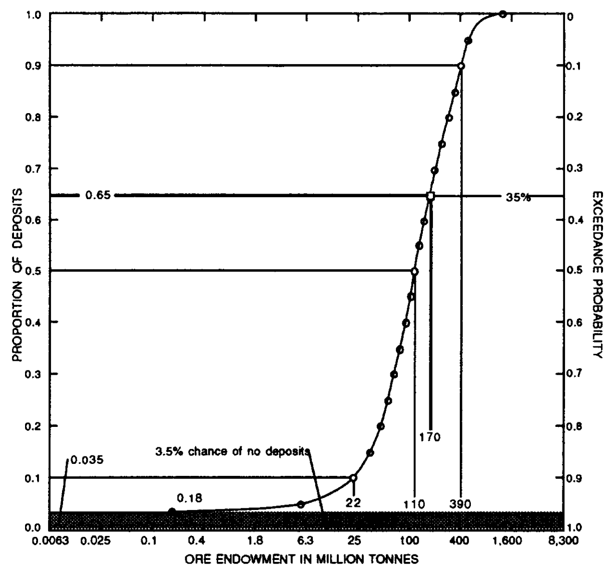
Percentile	Pb	Zn
0	0	0
0.05	230	15
0.10	1,200	220
0.15	2,700	600
0.20	4,300	1,200
0.25	6,400	1,900
0.30	9,000	3,000
0.35	12,000	4,300
0.40	15,000	6,000
0.45	19,000	8,000
0.50	24,000	11,000
0.55	30,000	14,000
0.60	36,000	18,000
0.65	44,000	23,000
0.70	54,000	31,000
0.75	67,000	41,000
0.80	82,000	58,000
0.85	110,000	78,000
0.90	140,000	120,000
0.95	210,000	200,000
1.00	2,200,000	580,000



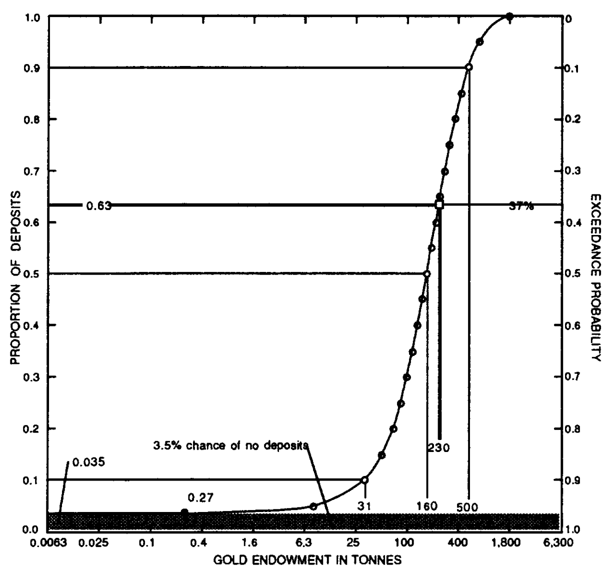


Percentile	Au
0	0
0.05	0.000027
0.10	0.0017
0.15	0.006
0.20	0.013
0.25	0.023
0.30	0.038
0.35	0.059
0.40	0.091
0.45	0.13
0.50	0.18
0.55	0.26
0.60	0.37
0.65	0.53
0.70	0.77
0.75	1.2
0.80	2
0.85	3.2
0.90	5
0.95	9.5
1.00	81

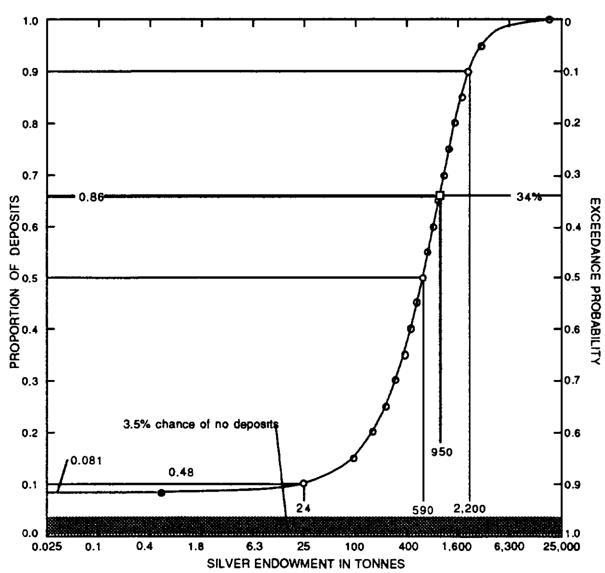
Figure B.6—Polymetallic vein deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 3, 5, 12, 18, 25 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California



Percentile	Ore
0	0
0.05	5.3
0.10	22
0.15	34
0.20	46
0.25	56
0.30	66
0.35	76
0.40	88
0.45	100
0.50	110
0.55	130
0.60	150
0.65	170
0.70	200
0.75	230
0.80	280
0.85	330
0.90	390
0.95	480
1.00	1,200

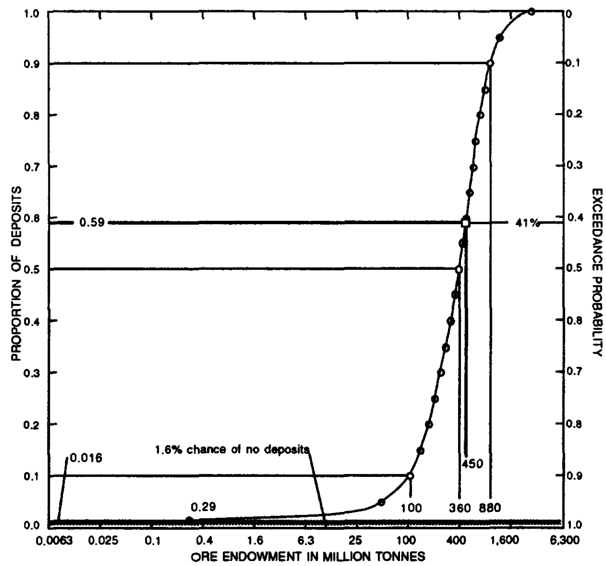


Percentile	Au
0	0
0.05	7.8
0.10	31
0.15	49
0.20	86
0.25	82
0.30	96
0.35	110
0.40	130
0.45	150
0.50	180
0.55	190
0.60	210
0.85	240
0.70	270
0.75	300
0.80	350
0.85	420
0.90	500
0.95	680
1.00	1,600

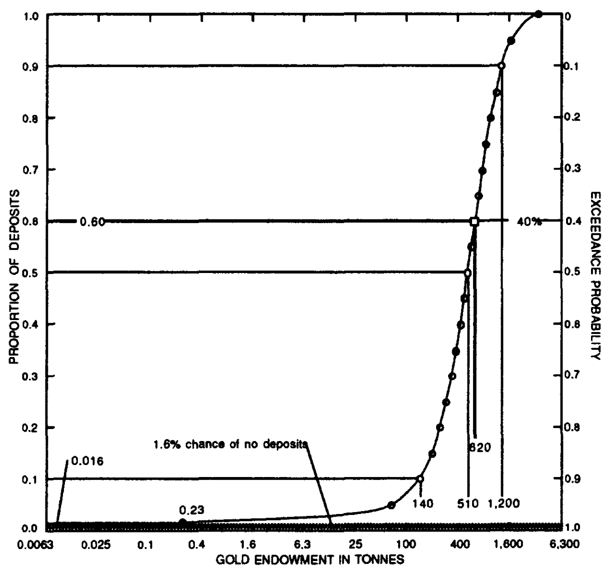


Percentile	Ag
0	0
0.05	0
0.10	24
0.15	93
0.20	160
0.25	220
0.30	290
0.35	360
0.40	440
0.45	510
0.50	590
0.55	680
0.60	790
0.65	910
0.70	1,100
0.75	1,200
0.80	1,400
0.85	1,700
0.90	2,200
0.95	3,200
1.00	19,000

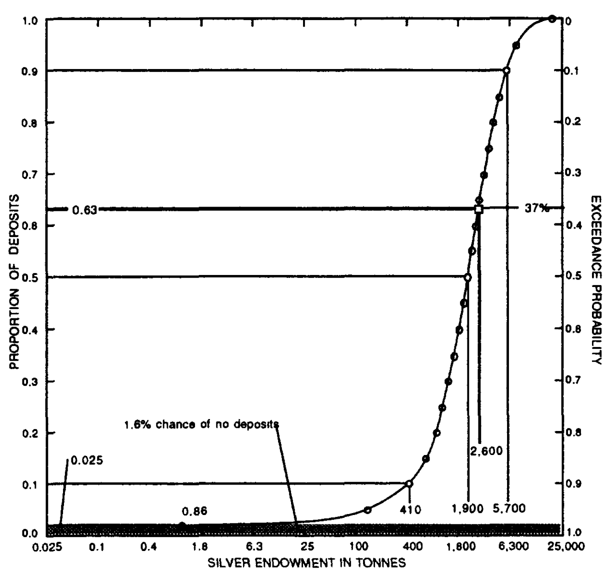
Figure B.7—Hot spring Au-Ag deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 2, 5, 7, 10, 14 estimated to be present in the southeastern zone of the Winnemucca District, Nevada



Percentile	Ore
0	0
0.05	47
0.10	100
0.15	140
0.20	170
0.25	200
0.30	230
0.35	270
0.40	300
0.45	340
0.50	380
0.55	420
0.60	460
0.65	500
0.70	550
0.75	600
0.80	670
0.85	760
0.90	680
0.95	1,100
1.00	2,700

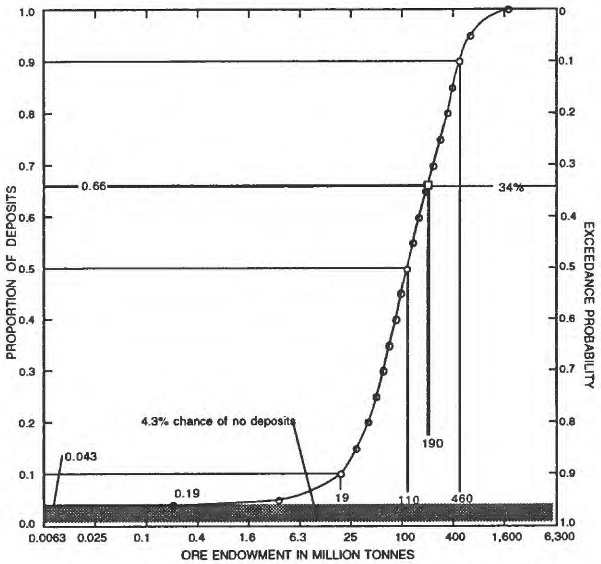


Percentile	Au
0	0
0.05	65
0.10	140
0.15	200
0.20	240
0.25	280
0.30	330
0.35	370
0.40	420
0.45	470
0.50	510
0.55	560
0.60	620
0.65	670
0.70	750
0.75	820
0.80	920
0.85	1,100
0.90	1,300
0.95	1,600
1.00	3,400

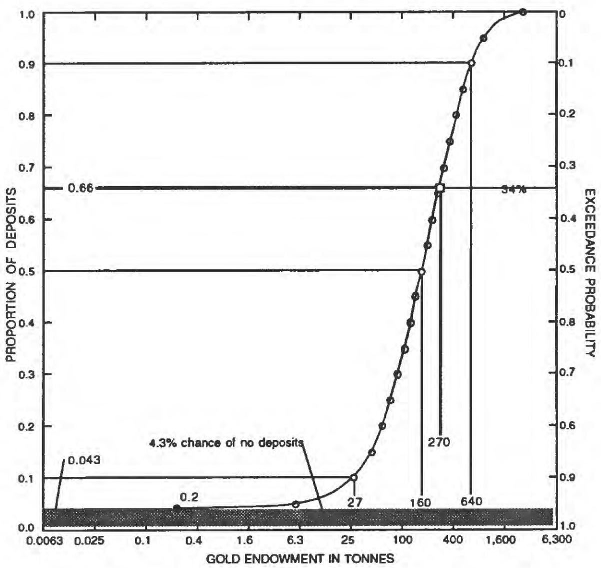


Percentile	Ag
0	0
0.05	130
0.10	410
0.15	640
0.20	840
0.25	1,000
0.30	1,200
0.35	1,400
0.40	1,500
0.45	1,800
0.50	2,000
0.55	2,200
0.60	2,500
0.65	2,700
0.70	3,100
0.75	3,500
0.80	4,000
0.85	4,600
0.90	5,700
0.95	7,300
1.00	19,000

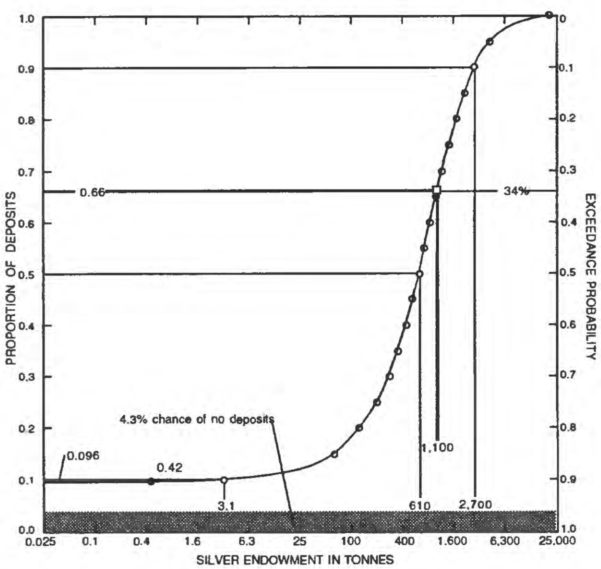
Figure B.8—Hot spring Au-Ag deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 6, 12, 20, 30, 45 estimated to be present in the central zone of the Winnemucca District, Nevada



Percentile	Ore
0	0
0.05	3.5
0.10	19
0.15	28
0.20	39
0.25	49
0.30	60
0.35	70
0.40	84
0.45	96
0.50	110
0.55	130
0.60	160
0.65	190
0.70	220
0.75	270
0.80	330
0.85	380
0.90	460
0.95	620
1.00	1,700



Percentile	Au
0	0
0.05	5.6
0.10	27
0.15	43
0.20	57
0.25	73
0.30	88
0.35	100
0.40	120
0.45	140
0.50	170
0.55	190
0.60	220
0.65	260
0.70	300
0.75	350
0.80	420
0.85	510
0.90	640
0.95	870
1.00	2,500



Percentile	Ag
0	0
0.05	0
0.10	3.1
0.15	61
0.20	120
0.25	190
0.30	280
0.35	350
0.40	430
0.45	510
0.50	610
0.55	710
0.60	820
0.65	960
0.70	1,100
0.75	1,400
0.80	1,700
0.85	2,100
0.90	2,700
0.95	4,000
1.00	20,000

Figure B.9—Hot spring Au-Ag deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 2, 4, 9, 15, 25 estimated to be present in the northwestern zone of the Winnemucca District, Nevada

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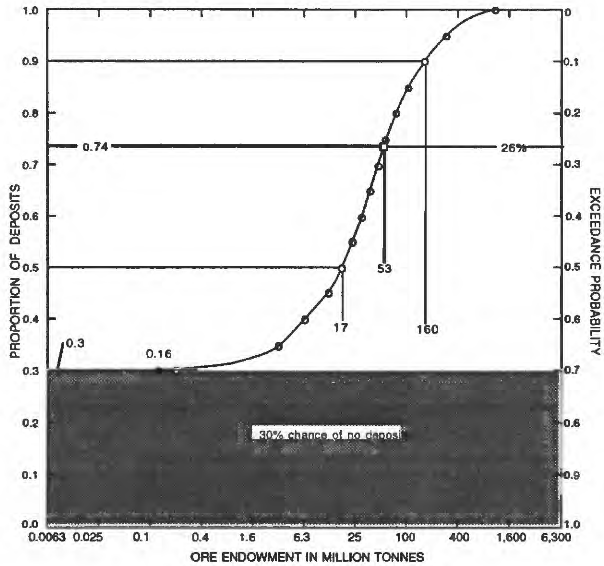
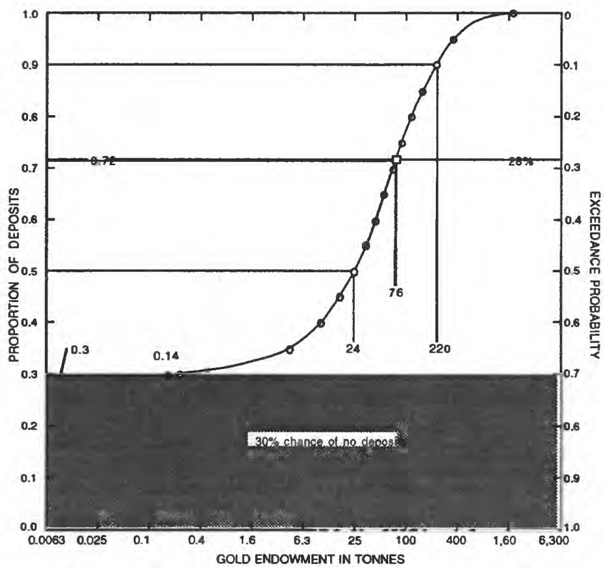
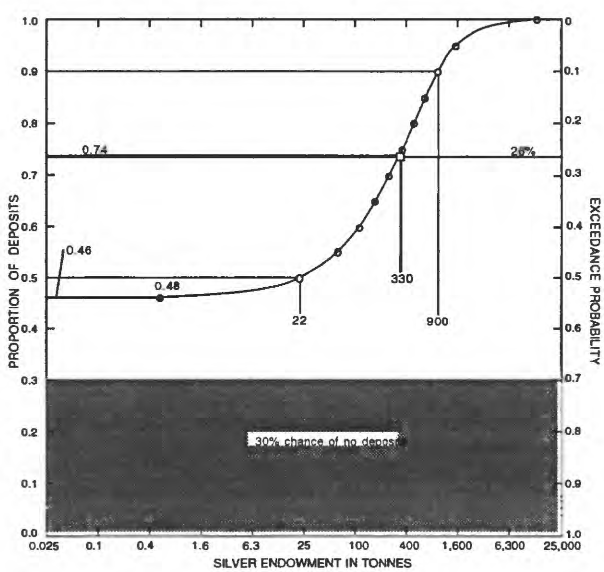


Percentile	Ore
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0.2
0.35	3.1
0.40	6.3
0.45	12
0.50	17
0.55	22
0.60	29
0.65	37
0.70	45
0.75	56
0.80	74
0.85	100
0.90	160
0.95	280
1.00	1,000



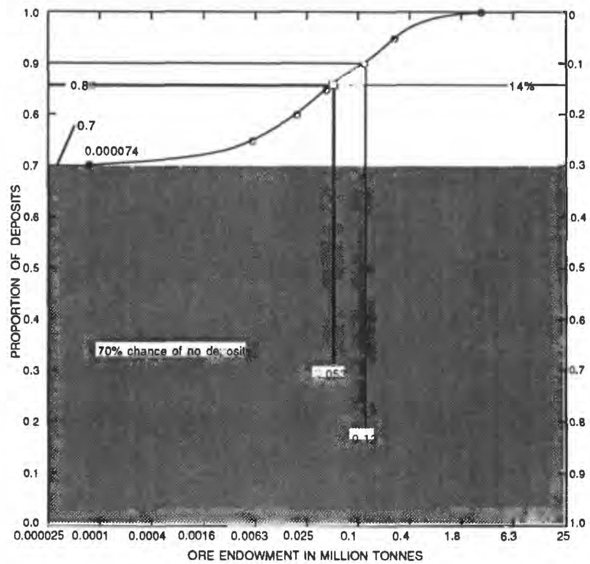
Percentile	Au
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0.23
0.35	4.2
0.40	9.7
0.45	16
0.50	24
0.55	33
0.60	43
0.65	54
0.70	69
0.75	87
0.80	110
0.85	150
0.90	220
0.95	340
1.00	1,700

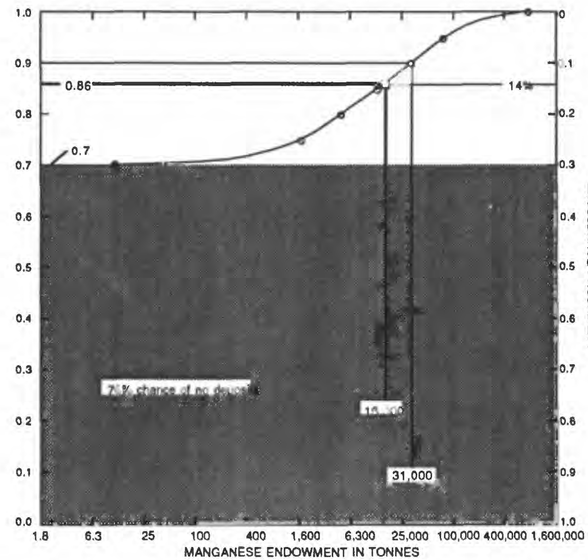


Percentile	Ag
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	22
0.55	62
0.60	110
0.65	170
0.70	250
0.75	350
0.80	470
0.85	630
0.90	900
0.95	1,500
1.00	13,000

Figure B.10—Hot spring Au-Ag deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 0, 1, 3, 5, 10 estimated to be present in the Surprise Resource Area, California-Nevada

Percentile	Ore
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0.0059
0.80	0.019
0.85	0.042
0.90	0.12
0.95	0.27
1.00	2.6

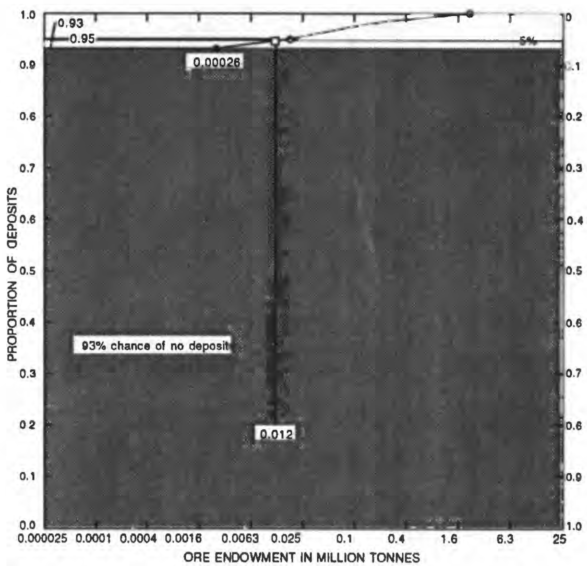


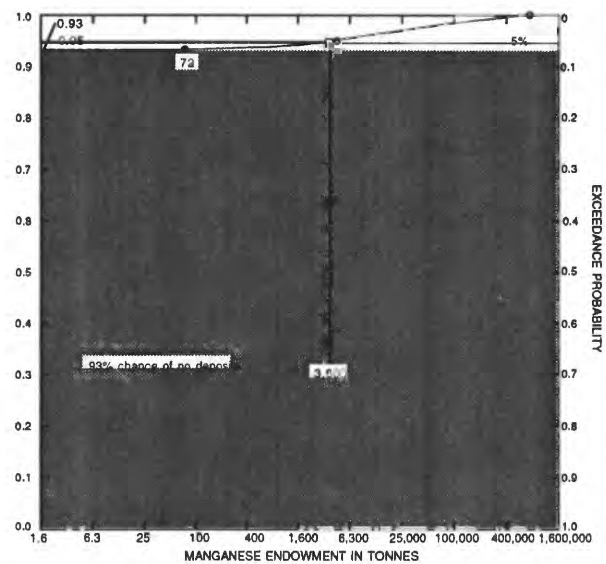


Percentile	Mn
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	1,700
0.80	4,900
0.85	13,000
0.90	31,000
0.95	75,000
1.00	750,000

Figure B.11—Epithermal manganese deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 0, 0, 1, 2, 3 estimated to be present in the Winnemucca District, Nevada

Percentile	Ore
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0
0.80	0
0.85	0
0.90	0
0.95	0.018
1.00	2.1

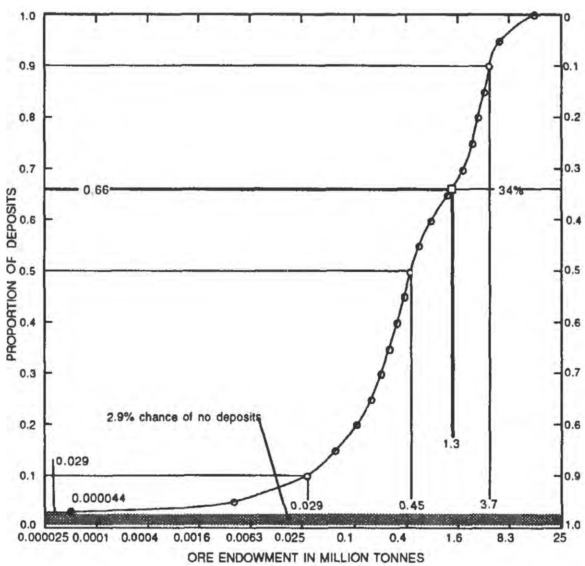


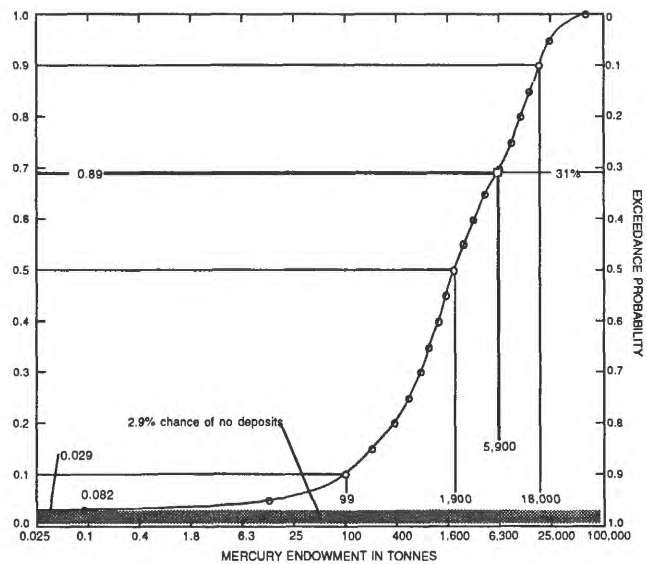


Percentile	Mn
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0
0.80	0
0.85	0
0.90	0
0.95	4,400
1.00	710,000

Figure B.12—Epithermal manganese deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 0, 0, 0, 1, 2 estimated to be present in the Surprise Resource Area, Nevada

Percentile	Ore
0	0
0.05	0.0041
0.10	0.029
0.15	0.061
0.20	0.11
0.25	0.16
0.30	0.21
0.35	0.26
0.40	0.31
0.45	0.37
0.50	0.45
0.55	0.56
0.60	0.75
0.65	1.2
0.70	1.8
0.75	2.4
0.80	2.8
0.85	3.2
0.90	3.7
0.95	4.9
1.00	12

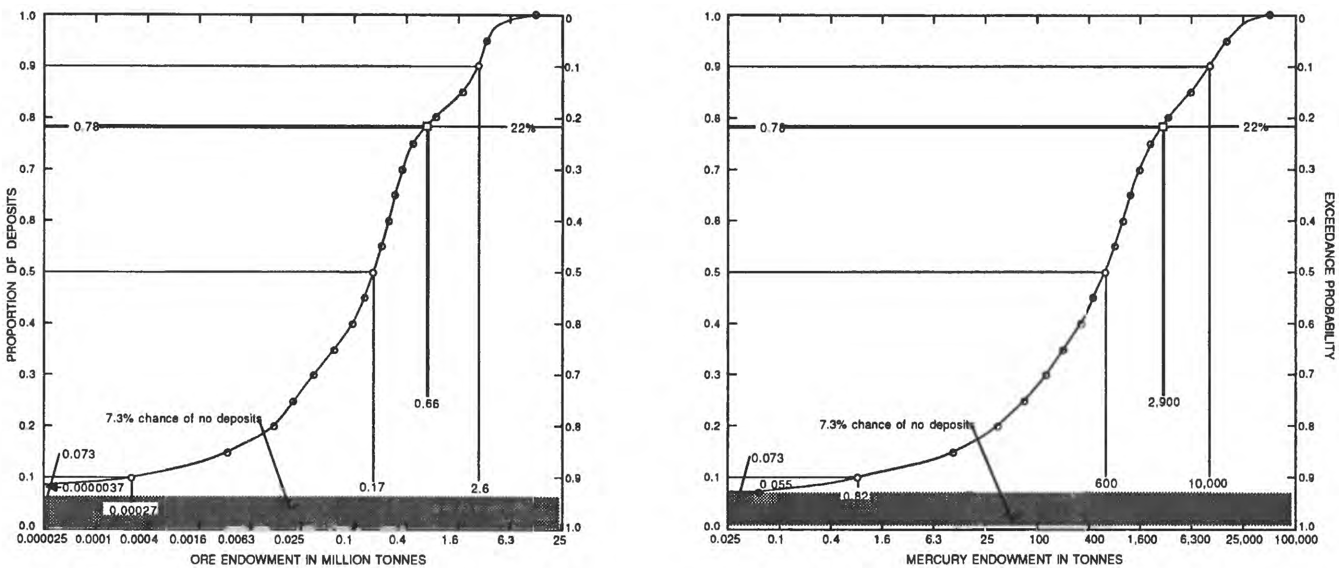




Percentile	Hg
0	0
0.05	13
0.10	99
0.15	200
0.20	370
0.25	540
0.30	740
0.35	950
0.40	1,200
0.45	1,500
0.50	1,900
0.55	2,300
0.60	3,100
0.65	4,300
0.70	6,200
0.75	8,400
0.80	11,000
0.85	14,000
0.90	18,000
0.95	24,000
1.00	62,000

Figure B.13—Hot spring Hg deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 3, 5, 10, 15, 20 estimated to be present in the northern zone of the Winnemucca District, Nevada

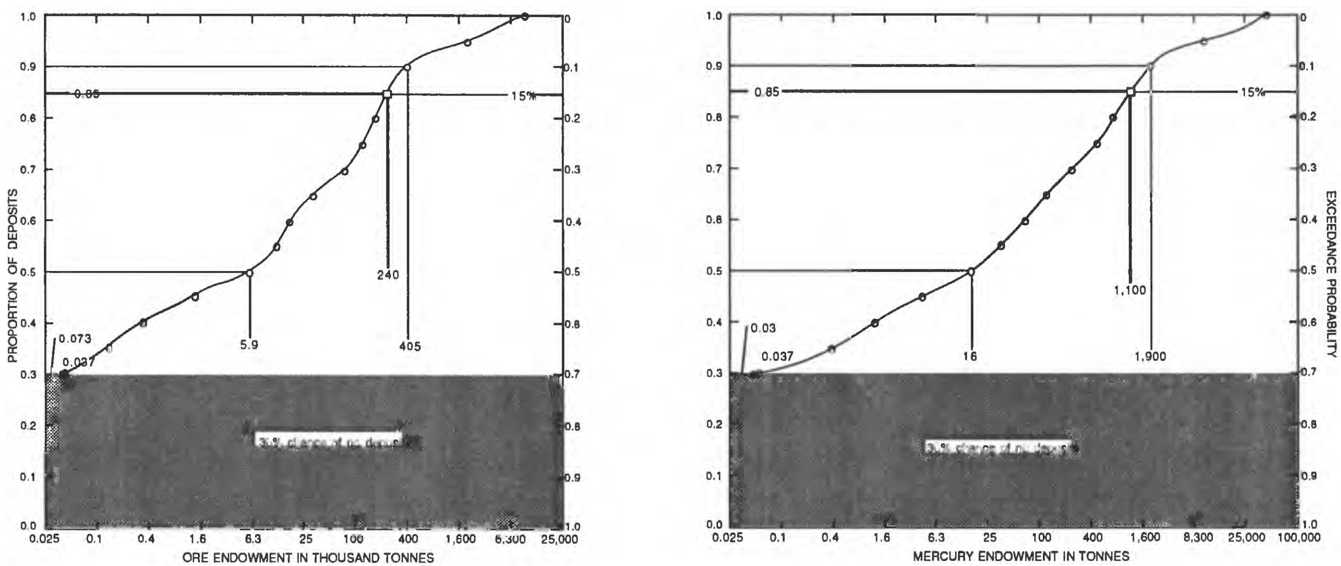
Percentile	Ore
0	0
0.05	0
0.10	0.00027
0.15	0.0034
0.20	0.012
0.25	0.02
0.30	0.034
0.35	0.059
0.40	0.096
0.45	0.13
0.50	0.17
0.55	0.21
0.60	0.25
0.65	0.29
0.70	0.35
0.75	0.47
0.80	0.87
0.85	1.7
0.90	2.6
0.95	3.3
1.00	12



Percentile	Hg
0	0
0.05	0
0.10	0.83
0.15	11
0.20	35
0.25	70
0.30	130
0.35	200
0.40	320
0.45	440
0.50	600
0.55	770
0.60	970
0.65	1,200
0.70	1,500
0.75	2,000
0.80	3,300
0.85	6,100
0.90	10,000
0.95	16,000
1.00	49,000

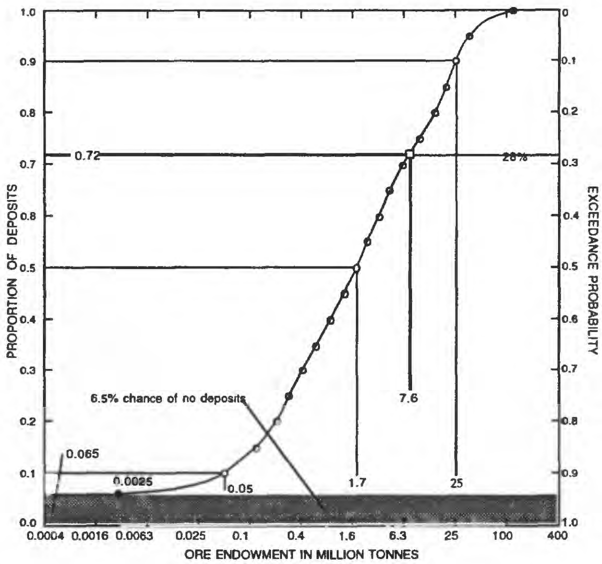
Figure B.14—Hot spring Hg deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 1, 3, 5, 8, 12 estimated to be present in the southern zone of the Winnemucca District, Nevada

Percentile	Ore
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0.039
0.35	0.14
0.40	0.37
0.45	1.3
0.50	5.9
0.55	12
0.60	18
0.65	33
0.70	75
0.75	120
0.80	180
0.85	240
0.90	410
0.95	2,000
1.00	9,000

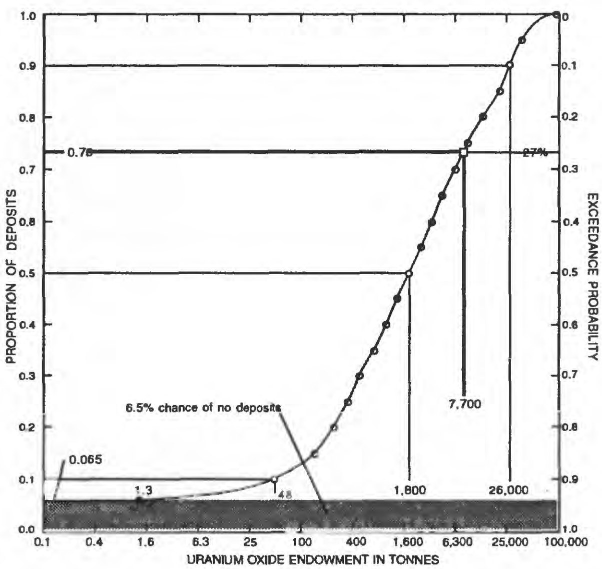


Percentile	Hg
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0.052
0.35	0.38
0.40	1.2
0.45	4.4
0.50	16
0.55	36
0.60	68
0.65	120
0.70	240
0.75	460
0.80	700
0.85	1,100
0.90	1,900
0.95	7,900
1.00	43,000

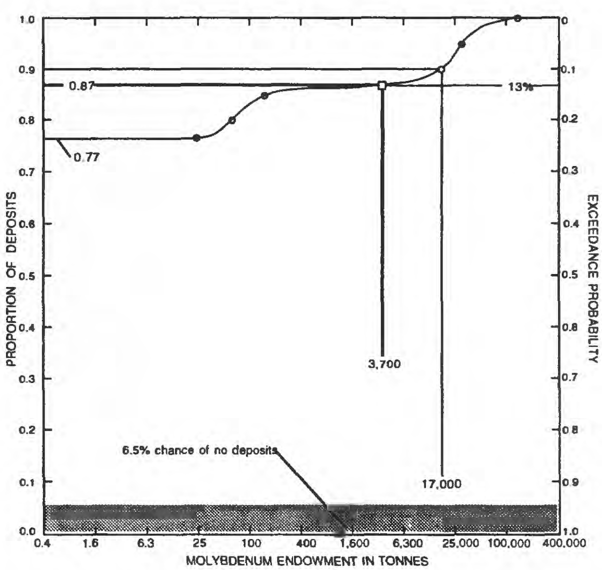
Figure B.15—Hot spring Hg deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 0, 1, 2, 4, 7 estimated to be present in the Surprise Resource Area, California-Nevada



Percentile	Ore
0	0
0.05	0
0.10	0.05
0.15	0.12
0.20	0.2
0.25	0.29
0.30	0.42
0.35	0.59
0.40	0.87
0.45	1.3
0.50	1.7
0.55	2.3
0.60	3.2
0.65	4.3
0.70	6.1
0.75	9.5
0.80	15
0.85	19
0.90	25
0.95	35
1.00	120

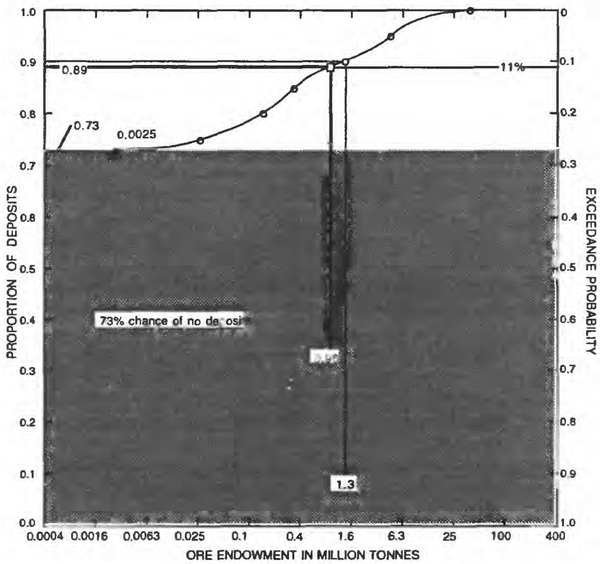


Percentile	U oxide
0	0
0.05	0
0.10	48
0.15	140
0.20	240
0.25	350
0.30	480
0.35	710
0.40	950
0.45	1,300
0.50	1,800
0.55	2,400
0.60	3,200
0.65	4,400
0.70	6,200
0.75	8,600
0.80	13,000
0.85	20,000
0.90	26,000
0.95	36,000
1.00	99,000

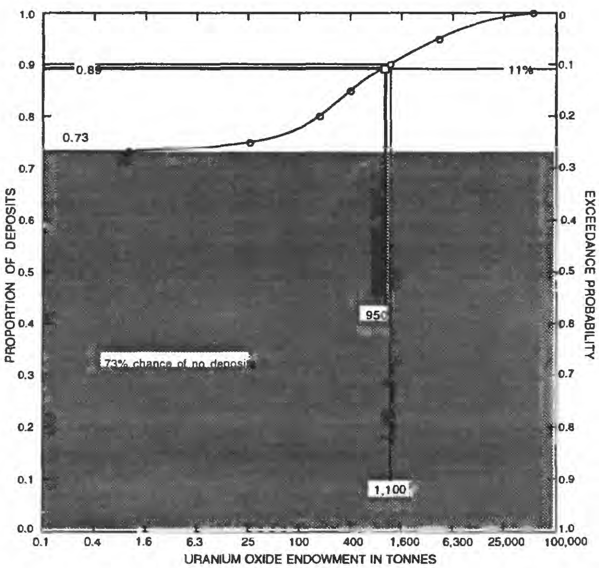


Percentile	Mo
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0
0.80	63
0.65	150
0.90	17,000
0.95	29,000
1.00	130,000

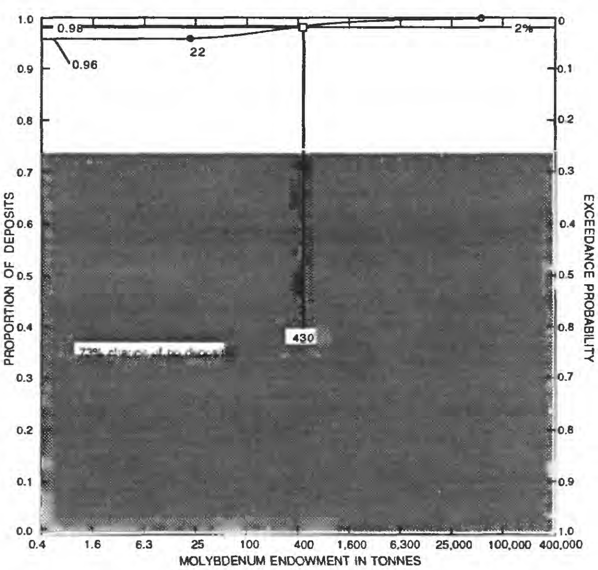
Figure B.16—Volcanogenic uranium deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 1, 2, 5, 8, 10 estimated to be present in the Winnemucca District, Nevada



Percentile	Ore
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0.027
0.80	0.15
0.85	0.33
0.90	1.3
0.95	4.4
1.00	38

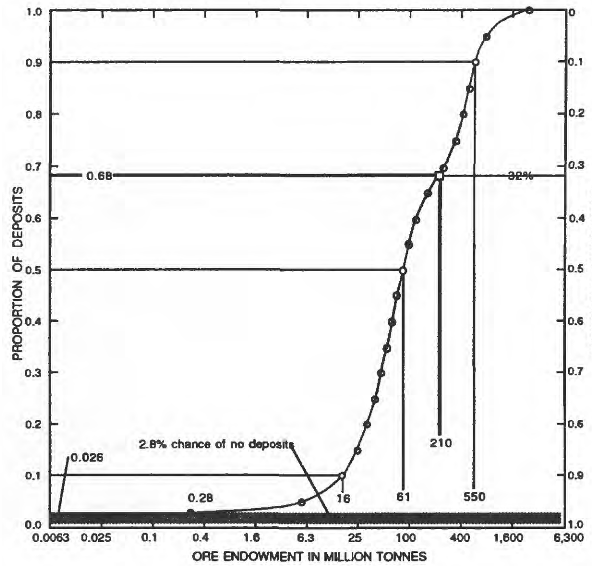


Percentile	U oxide
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	26
0.80	170
0.85	390
0.90	1,100
0.95	4,300
1.00	53,000

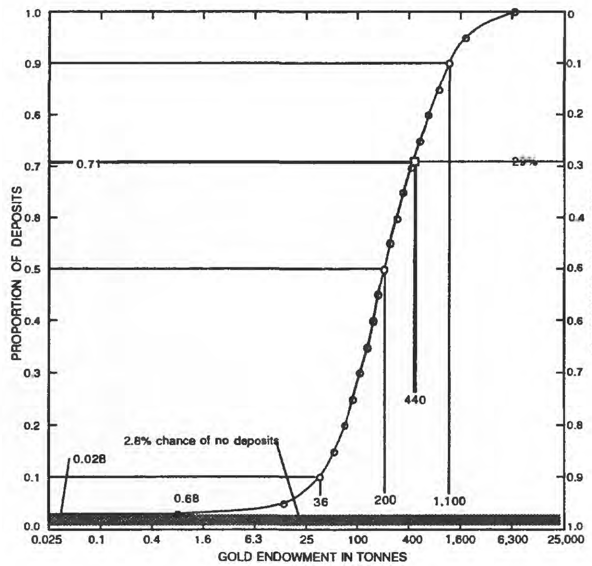


Percentile	Mo
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0
0.65	0
0.70	0
0.75	0
0.80	0
0.85	0
0.90	0
0.95	0
1.00	53,000

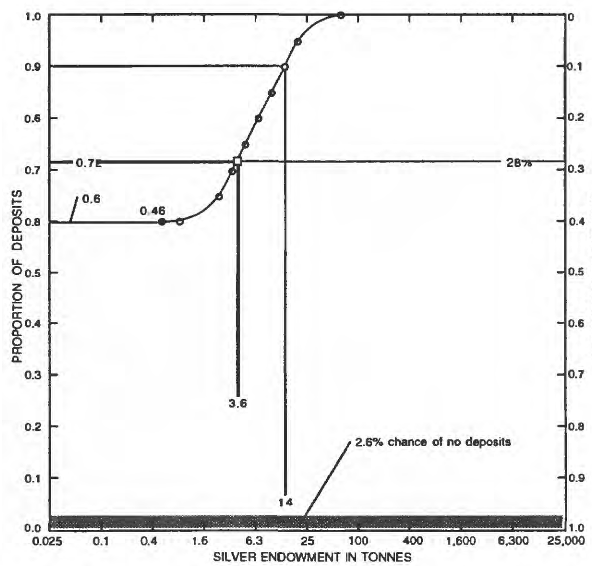
Figure B.17—Volcanogenic uranium deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 0, 0, 0, 1, 2 estimated to be present in the Surprise Resource Area, Nevada



Percentile	Ore
0	0
0.05	5.4
0.10	16
0.15	24
0.20	32
0.25	39
0.30	46
0.35	53
0.40	61
0.45	70
0.50	81
0.55	94
0.60	120
0.65	160
0.70	240
0.75	330
0.80	400
0.85	480
0.90	550
0.95	730
1.00	2,400

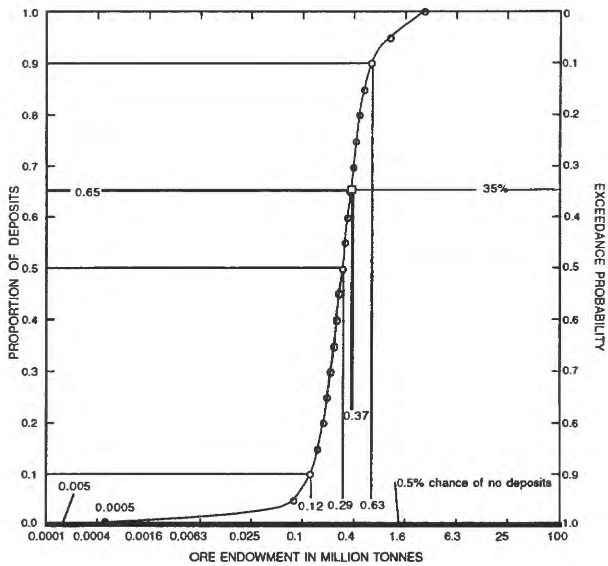


Percentile	Au
0	0
0.05	14
0.10	36
0.15	53
0.20	70
0.25	87
0.30	110
0.35	130
0.40	150
0.45	170
0.50	200
0.55	240
0.60	280
0.65	340
0.70	420
0.75	530
0.80	660
0.85	860
0.90	1,200
0.95	1,800
1.00	6,600

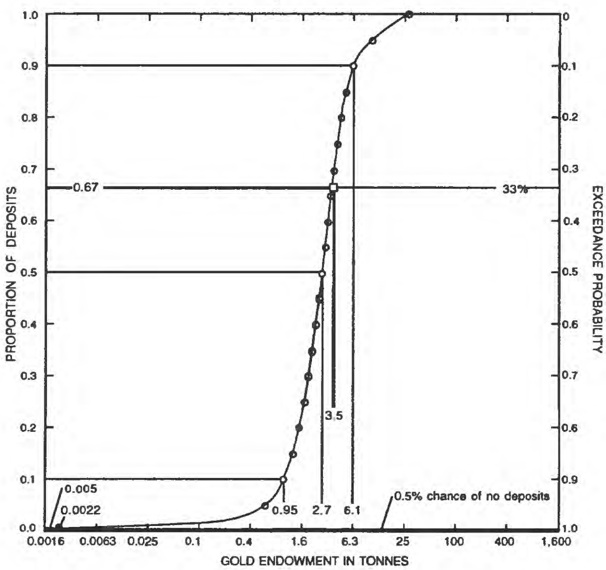


Percentile	Ag
0	0
0.05	0
0.10	0
0.15	0
0.20	0
0.25	0
0.30	0
0.35	0
0.40	0
0.45	0
0.50	0
0.55	0
0.60	0.8
0.65	2.3
0.70	3.4
0.75	4.6
0.80	6.7
0.85	9.6
0.90	14
0.95	19
1.00	61

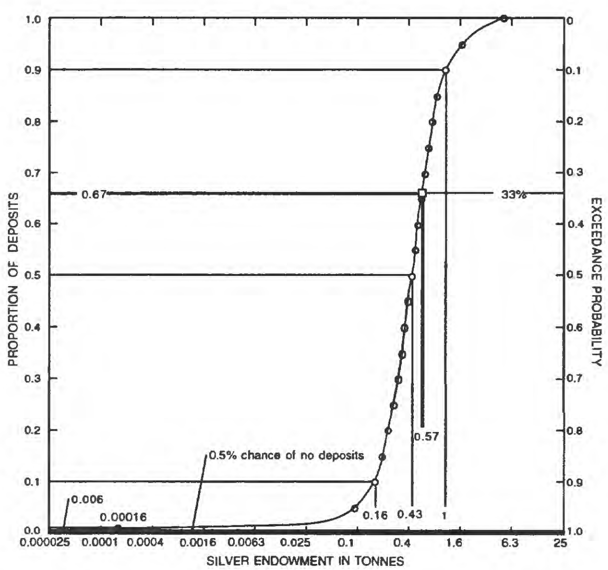
Figure B.18—Sediment-hosted Au-Ag deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 3, 6, 10, 20, 30 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California



Percentile	Ore
0	0
0.05	0.076
0.10	0.12
0.15	0.15
0.20	0.17
0.25	0.19
0.30	0.21
0.35	0.23
0.40	0.25
0.45	0.27
0.50	0.29
0.55	0.31
0.60	0.33
0.65	0.35
0.70	0.38
0.75	0.42
0.80	0.46
0.85	0.52
0.90	0.63
0.95	1.1
1.00	2.6



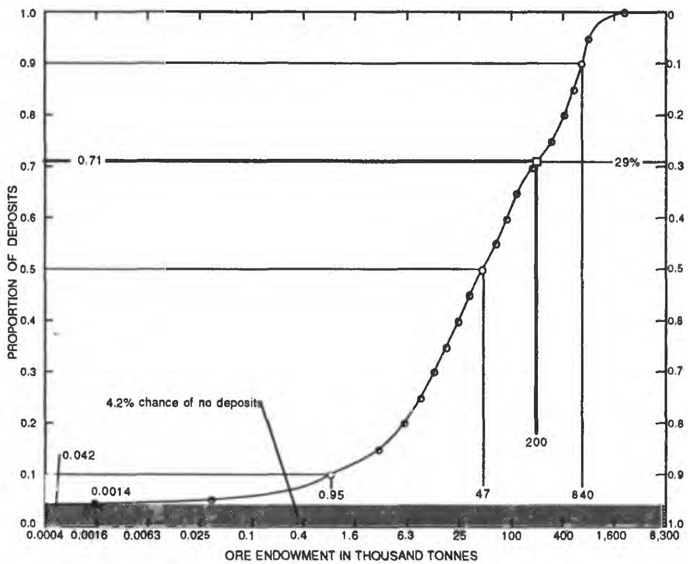
Percentile	Au
0	0
0.05	0.59
0.10	0.95
0.15	1.2
0.20	1.4
0.25	1.7
0.30	1.9
0.35	2.1
0.40	2.3
0.45	2.5
0.50	2.7
0.55	2.9
0.60	3.1
0.65	3.4
0.70	3.6
0.75	4
0.80	4.4
0.85	5
0.90	6.1
0.95	10
1.00	27

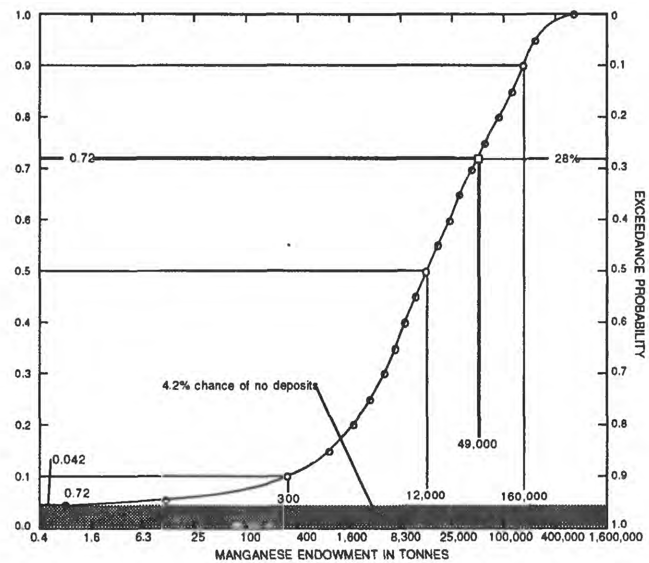


Percentile	Ag
0	0
0.05	0.093
0.10	0.16
0.15	0.19
0.20	0.23
0.25	0.27
0.30	0.3
0.35	0.33
0.40	0.36
0.45	0.4
0.50	0.43
0.55	0.47
0.60	0.51
0.65	0.55
0.70	0.61
0.75	0.66
0.80	0.74
0.85	0.85
0.90	1
0.95	1.7
1.00	5

Figure B.19—Chugach-type low-sulfide Au-quartz vein deposits: Simulated Mark3 endowment populations for an undiscovered deposit distribution of 20, 30, 50, 100, 200 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California

Percentile	Ore
0	0
0.05	0.034
0.10	0.95
0.15	3
0.20	5.9
0.25	9.1
0.30	13
0.35	18
0.40	25
0.45	33
0.50	47
0.55	68
0.60	90
0.65	120
0.70	180
0.75	290
0.80	420
0.85	530
0.90	650
0.95	790
1.00	2,100





Percentile	Mn
0	0
0.05	12
0.10	300
0.15	910
0.20	1,800
0.25	2,800
0.30	4,000
0.35	5,400
0.40	7,000
0.45	9,100
0.50	12,000
0.55	17,000
0.60	23,000
0.65	30,000
0.70	42,000
0.75	59,000
0.80	87,000
0.85	120,000
0.90	160,000
0.95	220,000
1.00	620,000

Figure B.20—Volcanogenic manganese (Franciscan-type) deposits: Simuated Mark3 endowment populations for an undiscovered deposit distribution of 2, 10, 15, 20, 30 estimated to be present in the Winnemucca District and Surprise Resource Area, Nevada-California

Table 1—Wilderness Study Areas and other areas in the Winnemucca District and Surprise Resource Area for which resource surveys were conducted by the U.S. Geological Survey and the U.S. Bureau of Mines.

NAME OF WILDERNESS STUDY AREA	IDENTIFIED RESOURCES	RESOURCE POTENTIAL[1]	REFERENCES
Black Rock Desert	none	**M:** gold, silver, mercury, lithium; **L:** oil & gas	Olson, 1985; Calzia and others, 1987
Blue Lakes	none	**L:** gold, silver, antimony, copper, lead, mercury, molybdenum, zinc, uranium	Willet, 1986; Bergquist and others, 1987
Charles Sheldon Antelope Range and Sheldon National Antelope Refuge	opal, ornamental stone, uranium	Probable: copper, gold, lead, mercury, silver, uranium, zinc	Cathrall and Tuchek, 1984; Cathrall and others, 1978
Disaster Peak	none	**H:** gold; **L:** gold, silver, mercury, uranium	Leszcykowski, 1987; Minor and others, 1988
East Fork High Rock Canyon	none	**M:** gold, silver, mercury, zeolites **L:** geothermal	Schmauch, 1986; Ach and others, 1988
High Rock Canyon	none	**H:** zeolites; **M:** gold, silver, mercury; **L:** uranium, lithium, geothermal, oil & gas	Scott, 1987; Turrin and others, 1988
High Rock Lake	geothermal	**L:** mercury, uranium, gold, geothermal	Neumann and Close, 1985; Noble and others, 1988b
Little High Rock Canyon	none	**M:** gold, silver; **L:** gold, silver, uranium, pozzolan, perlite, geothermal	Keith and others, 1988; Peters and others, 1987
Massacre Rim	none	**M:** gold, silver, mercury, uranium	Causey, 1987; Bergquist and others, 1988
Mount Limbo	none	**M:** gold, silver **L:** gold, silver, geothermal	Keith and others, 1986; Rumsey, 1986
North Fork Little Humboldt River	none	**L:** mercury	Leszcykowski, 1985; Peterson and Wong, 1986; Peterson and others, 1986
Pahute Peak	none	**H:** gold, silver, geothermal; **M:** gold, silver, copper, lead, zinc, molybdenum, tungsten; **L:** mercury, uranium	Olson, 1986; Noble and others, 1987
Pueblo Mountains	gold, copper, molybdenum, zeolites, diatomite, geothermal, sand, gravel, stone	**H:** silver, mercury; **M:** gold, silver, mercury, copper, molybdenum; **L:** silver, zinc, mercury, molybdenum, copper, lead, zeolites, diatomite, oil & gas, geothermal	Munts, and Willett, 1987; Roback and others, 1987
Sheldon Contiguous	none	**L:** mercury, gold, silver, natural gas	Cathrall and others, 1984; Tuchek and others, 1984; Esparza, 1986
South Jackson Mountains	none	**M:** gold, silver, copper, lead, zinc, iron; **L:** oil & gas, geothermal	Hamilton, 1987; Sorenson and others, 1987
South Warner, CA	calcite	**L:** geothermal	Duffield and Weldin, 1976

[1] as defined in Taylor and Steven (1983); **L**, low; **M**, moderate; **H**, high.

Table 2—Types of mineral deposits present in the Winnemucca District and Surprise Resource Area, northwest Nev. and northeast Calif.

Pluton-related hydrothermal

(1)porphyry copper, (2) porphyry copper-molybdenum, (3) porphyry copper, skarn related, (4) gold skarn, (5) polymetallic replacement, (6)polymetallic vein, (7)distal-disseminated silverr-gold, (8) low-F stockwork molybdenum, (9) Climax-type molybdenum (?), (10) tin greisen, (11) tungsten skarn, (12) polymetallic skarn/replacement, (13) mesothermal polymetallic veins

Epithermal environment

(1) Comstock-type gold-silver veins (± Creede-type base metal--silver-gold veins)
(2) hot-spring gold-silver, mercury
(3) deep hot spring gold-silver veins
(4) hot-spring manganese vein
(5) uranium deposits

Areas of regionally elevated heat flow

(1)sediment-hosted (Carlin type) gold-silver
(2) hot-spring gold-silver, mercury
(3) deep hot spring gold-silver veins
(4) hot-spring manganese veins

Deposits found in areas of accreted terranes

(1) kuroko/Cyprus/Besshi-type massive sulfide deposits
(2) exhalative sedimentary lead-zinc
(3) volcanogenic manganese, volcanic-hosted magnetite
(4) low-sulfide, gold-quartz veins

Deposits associated with Tertiary sedimentary rocks and basins

(1) placer deposits
(2) sedimentary uranium deposits

Table 3—Examples of mineral deposits in the Winnemucca District and Surprise Resource Area, northwest Nev. and northeast Calif.

Porphyry Cu and related deposits
Battle Mountain Mining District, Buffalo Valley area, Kennedy area, Fireball Ridge, Guonami (west of area)

Low-F stockwork molybdenum
Battle Mountain Mining District, Ashdown Mining District, Guonami(?)

Climax-type Mo(?) and related deposits
Majuba Hill (?)

W skarn, polymetallic replacement/skarn
Osgood Mountains area, Mill City, Selenite Range

Polymetallic silver-gold vein
Rochester, Arabia, Central, Washiki, Rose Creek, Sierra, Desert, Unionville, Star, and Battle Mountain Mining Districts

Epithermal
Creede/Comstock type - Jessup, Desert(?), Leadville, Sierra distr., Seven Troughs(?)
Hot spring related - Sleeper, National, Hog Ranch (just o/s area to W), Rosebud/Lantern, Farrell, Seven Troughs(?), Scossa, Sulphur, Florida Canyon, Wind Mountain
Hot spring Hg - Antelope Springs(?), Black Knob(?), Bottle Creek(?), Disaster(?), Dutch Flat, Goldbanks, Lake, Mount Tobin, Opalite, Poverty Peak, Red Butte(?), Lantern, Wind Mountain, Spring Valley(?), Tobin/Sonoma

Sediment hosted (Carlin type) gold-silver
Osgood Mountains (Preble, Pinson, Getchell), as well as possible district in Hot Creek Range

Massive sulfide deposit in mafic volcanic rock
Big Mike (Sonoma Range)

Franciscan-type manganese
Many occurrences, for example Black Diablo, Washiki, Tobin/Sonoma, Buffalo Mountain

Metamorphic-hosted low-sulfide, gold-quartz
Many occurrences north of Jessup, Sierra, Donelly

Table 4—Deposit types, examples, and tract rationale used for permissive, favorable, and prospective tracts in the Winnemucca District and Surprise Resource Area, northwest Nev. and northeast Calif.

DEPOSIT TYPE	EXAMPLES	TRACT RATIONALE
Porphyry Cu	Copper Canyon, Elder Creek, Adelaide, Fireball,	**Permissive:** Areas adjacent to known, outcropping plutons, their subsurface extensions, inferred subsurface plutons, and known mineral deposits that infer a pluton's presence; a 10–km buffer was used. **Favorable:** Areas that contain most prospects and occurrences; also influenced by conceptual metallogenic trends that transcend Tertiary structures. **Prospective:** Areas close to important known deposits and prospects, and that have received substantial exploration activity.
Lo-F Mo	Buckingham, Trenton Canyon, Granite Point, Mill City, Leonard, Gregg Canyon, Kennedy	same as for Porphyry Cu
W skarn	Mill City, Potosi, Nightingale, Toy	**Permissive:** same as for Porphyry Cu; virtually all stratigraphic units contain permissive carbonate strata. **Favorable:** Areas closely adjacent to known, outcropping plutons, their subsurface extensions, inferred subsurface plutons, or known mineral deposits that infer a pluton's presence; a 5-km buffer was used. **Prospective:** Areas close to known deposits and prospects, and that have received substantial exploration activity.
W vein	New York Canyon, prospects adjacent to Rocky Canyon stock	**Favorable** (only): Areas adjacent to known prospects and occurrences associated with peraluminous granite.
Distal diss Au, polymetallic replacement, replacement Mn, Cu, Fe, and Au skarn	Marigold, Lonetree, Fortitude	**Permissive:** same as porphyry Cu, with the addition of areas north and northwest of I-80 and Battle Mountain **Favorable:** Areas that contain most prospects and occurrences; also influenced by conceptual metallogenic trends that transcend Tertiary structures. **Prospective:** Areas close to important known deposits and prospects, and that have received substantive exploration activity.

Polymetallic vein	Leadville, Battle Mountain, and Kennedy Mining Districts	**Permissive**: Any rock that can fracture; all areas not containing Cenozoic cover > 1 km. (similar to tracts for hot spring and epithermal deposits) **Favorable**: Zone of occurrences of porphyry-related deposits and deep epithermal districts. Similar to porphyry tracts except buffered wider due to distal aspects of deposits. **Prospective**: Zone around known occurrences and deposits.
Hot spring Au	Crowfoot-Lewis, Florida Canyon, Hog Ranch, Sleeper, Wind Mountain	**Permissive:** The entire area where bedrock is within 1 km of the surface. **Favorable:** Areas that contain most prospects and occurrences; also influenced by areas of hydrothermal alteration interpreted from Landsat imagery, areas that exhibit anomalous geochemical concentrations, and conceptual metallogenic trends that transcend Tertiary structures. **Prospective:** Areas close to important known deposits and prospects, and that have received substantial exploration activity; also includes hydrothermally altered areas that have been verified on the ground.
Epithermal Mn		Same as hot spring Au
HS Hg	Mc Dermitt, Opalite, Goldbanks	Same as hot spring Au
Volcanogenic U	Moonlight Mine, Buckhorn	**Permissive:** Areas of outcropping Tertiary volcanic rocks, and volcanic rocks buried by shallow surficial deposits. **Favorable:** Areas that contain most prospects and occurrences, areas with high radioactivity defined by aerial surveys, and areas that exhibit anomalous geochemical concentrations of uranium. **Prospective:** Areas that exhibit a favorable depositional environment, especially moat sediments associated with calderas.
Sed-hosted Au-Ag	Twin Creeks, Pinson, Preble, Getchell, (Turquoise Ridge)	**Permissive:** Areas underlain by overthickened continental crust due to Paleozoic and (or) Mesozoic overthrusting. **Favorable**: Presence of Paleozoic platformal carbonate strata or carbonate strata of overlap assemblage. **Prospective:** Presence of known deposits. Structural windows through the Roberts Mountains allocthon that contain anomalous contents of Au, As, Hg, Sb, Hg, and Tl, as well as evidence of decalcification reactions. Presence of gold placers near windows.

Low-sulfide (Chugach) Au-quartz veins	Humboldt Range occurrences, which are notably enriched in silver relative to the worldwide model (see text)	**Permissive:** All pre-Tertiary rocks that exhibit metamorphic fabrics. **Favorable:** Areas that contain most prospects and occurrences, as well as inferred regional shear zones. **Prospective**: Areas close to important known deposits and prospects, and that have received substantial exploration activity.
Massive sulfide and SEDEX	Big Mike	**Permissive**: Paleozoic terranes containing submarine volcanic rocks. **Favorable**: Areas known to contain widespread, small, massive sulfide occurrences, as well as presence of manganese and bedded barite occurrences. **Prospective**: Areas close to known important deposits and prospects that have received substantial exploration. Presence of copper-bearing gossans in association with above listed favorable criteria.
Franciscan Mn	Black Rock	**Permissive**: Paleozoic terranes containing ophiolitic or basalt-shale sequences. **Favorable**: Stratigraphic units known to contain occurrences of manganese. **Prospective**: Areas close to known important deposits and prospects that have received substantial exploration.

Table 5. Characteristics of permissive terranes and favorable tracts for Mesozoic and Tertiary porphyry copper deposits and Mesozoic stockwork molybdenum, low fluorine deposits; Mesozoic tungsten skarn, and other types of deposits in the Winnemucca District and Surprise Resource Area, northwest Nev. and northeast Calif.

[------do.------, same as above; --, not available; n.a., not applicable]

Deposit type	Permissive terrane (inferred to depths of 1 km)	Favorable tract	Prospective tract	Criteria used to delineate favorable or prospective tract[1]	Worldwide Characteristics[2] Median tonnage (million tonnes)	Median grade
			Mesozoic and Tertiary			
Porphyry copper (plate 2)	Areas adjacent to exposed plutons, their subsurface extensions, inferred subsurface extensions and mineral occurrences that suggest a pluton's presence; 10-km buffer used	Areas that contain most prospects and occurrences; also influenced by conceptual metallogenic trends that predate late Tertiary structures	Areas close to important known deposits and prospects and that have received substantial exploration activity		[3]140	[3]0.48 percent Cu
Stockwork molybdenum, low fluorine (plate 2)					94	0.085 percent Mo
		Tract A		1, 2, 3, 4, 5, 6, 7, 9, 10, 14		
		Tract B		1, 2, 8, 9, 10, 12, 14		
		Tract C		1, 2, 4, 6, 11, 13		
		Tract D		1, 2, 9, 10		
		Tract E		1, 2, 7, 9, 10, 23		
		Tract F		1, 2, 7, 9, 10		
		Tract G		1, 2, 9, 10		
		Tract H		1, 2, 9, 10		
			Mesozoic			
Tungsten skarn (plate 3)	------do.------ In addition, virtually all pre-Mesozoic strata contain carbonate-bearing host rocks, permissive for the formation of skarn	Areas closely adjacent to known plutons, their subsurface extensions, inferred subsurface plutons, known mineral deposits that suggest a pluton's presence; a 5-km buffer was used	------do.------		1.1 [4]0.69	0.67 percent WO_3 [4]0.65 percent WO_3
Tungsten vein (plate 3)	------do.------	Areas adjacent to known prospects and occurrences associated with peraluminous granite	n.a.		0.56	0.9 percent WO_3
		Tract A		1, 15		
		Tract B		1, 15		
		Tract C		1, 15		
			Mesozoic and Tertiary			
Porphyry copper, skarn related (plate 4)	------do.------ Includes large area north of the Battle Mountain Mining District	Areas that contain most prospects and occurrences; also influenced by conceptual metallogenic trends that predate late Tertiary structures	Areas close to important known deposits and prospects and that have received substantial exploration activity	.	80	0.98 percent Cu
Copper skarn (plate 4)	------do.------	------do.------	------do.------		0.56	1.7 percent Cu
Lead-zinc skarn (plate 4)	------do.------	------do.------	------do.------		1.4	5.9 percent Zn 2.8 percent Pb
Iron skarn (plate 4)	------do.------	------do.------	------do.------		7.2	50 percent Fe
Gold skarn (plate 4)	------do.------	------do.------	------do.------		[5]0.213	[5]8.6 g Au/tonne
Iron skarn (plate 4)	------do.------	------do.------	------do.------		7.2	50 percent Fe
Distal-disseminated, silver-gold (plate 5)	------do.------	------do.------	------do.------		[6]1.7	[6]1.2 g Au/tonne
			Tract A	1, 2		
Polymetallic vein (plate 5)	------do.------ Includes any rock that can fracture and all areas <1 km of the surface	------do.------ Buffered occurrences of pluton-related deposits and deep epithermal mining districts	------do.------		0.0076	820 g Ag/tonne 9 percent Pb 2.1 percent Zn
Polymetallic replacement (plate 5)	------do.------	------do.------	------do.------		1.8	5.2 percent Pb 3.9 percent Zn
Replacement manganese (plate 5)	------do.------	------do.------	------do.------		0.022	36 percent Mn
			Tertiary			
High level hot-spring gold-silver deposits (plate 6)	Entire area where bedrock is within 1 km of the surface	Areas that contain most prospects and occurrences; also influenced by areas of hydrothermal alteration interpreted from Landsat imagery, areas that exhibit anomalous metal concentrations, and conceptual metallogenic trends that transcend late Tertiary structures	Areas close to important known deposits and prospects, and that have received substantial exploration activity; also includes hydrothermally altered areas that have been verified on the ground		[7]13	[7]1.6 g Au/tonne
Vein epithermal deposits (Comstock epithermal vein, quartz-sericite-adularia) (plate 6)	------do.------	------do.------	------do.------		n.a.	n.a.
Epithermal quartz-alunite,	------do.------	------do.------	------do.------		n.a.	n.a.

gold-silver (plate 6)						
Hot-spring mercury (plate 6)	------do.------	------do.------	------do.------		0.0095	0.35 percent Hg
Epithermal manganese (plate 6)	------do.------	------do.------	------do.------		0.025	31 percentMn
Volcanogenic uranium (plate 7)	Areas where Tertiary volcanic rocks crop out, and where they are buried by shallow surficial deposits; areas of hot-spring activity	Areas that contain most prospects and occurrences, areas with high radioactivity defined by aerial surveys, and areas that exhibit anomalous concentrations of uranium	Areas that exhibit a favorable depositional environment, especiaslly moat sediments associated with calderas		0.34	0.12 percent U_3O_8
			Tract A	1, 5, 6, 16		
Sandstone uranium (plate 7)	--	Not delineated, but all alluvial basins adjacent to favorable tracts for volcanogenic uranium are favorable	--		--	--
			Mesozoic and Tertiary			
Pluton-related vein-uranium (plate 7)	Areas adjacent to exposed plutons, their subsurface extensions, inferred sub-surface extensions and mineral occurrences that suggest a pluton's presence;	Areas that contain most prospects and occurrences; also influenced by conceptual metallogenic trends that predate late Tertiary structures	Areas close to important known deposits and prospects and that have received substantial exploration activity		--	--
		Tract B		1, 2, 4, 17		
		Tract C		1, 2, 4, 10, 17		
		Tract D		1, 2, 4, 10, 12, 18		
		Tract E				
		Tract F				
Sediment-hosted gold-silver deposits (Carlin type) (plate 8)	Areas underlain by overthickened continental crust due to Paleozoic and Mesozoic thrusting	Areas thast contain most prospects and occurrences; also influenced by conceptual metallogenic trends that predate late Tertiary structures; areas within 10 km of known sediment-hosted gold-silver deposits, and, in the western WSRA, within 10 km of the western projection of the Roberts Mountains allochthon beneath the sole of the Golconda thrust	------do.------		6.6	2.3
			Tract A	1, 4, 6, 9, 10, 12,		
			Tract B	1, 4, 5, 9, 14		
			Tract C	1, 2, 4, 6, 9, 14		
			Mesozoic			
Low-sulfide (Chugach) gold-quartz vein (plate 9)	All pre-Tertiary rocks that contain metamorphic fabrics	Areas thast contain most prospects and occurrences; also includes regionally inferred shear zones	------do.------		[8]0.0032	[8]6.2 g Au/tonne
			Tract A	1, 4, 7, 14, 19		
			Tract B	------do.------		
			Tract C	------do.------		
			Tract D	------do.------		
			Tract E	------do.------		
			Tract F	------do.------		
			Tract G	------do.------		
			Tract H	------do.------		
			Tract I	------do.------		
			Tract J	------do.------		
			Paleozoic			
Cyprus-type massive sulfide (plate 10)	All ophiolite-related mafic lava sequences; rocks of the Roberts Mountains and Golconda allochthons	Areas that contain most prospects and occurrences; including Cu, Zn, or gold geochemical anomalies and Mn-rich interflow sedimentary strata	Areas close to important known deposits and prospects and that have received substantial exploration activity		1.6	1.7 percent Cu
		Tract G		1, 6, 20, 21		
Besshi-type massive sulfide (plate 10)	Mixed siliciclastic and mafic volcanic strata of the Roberts Mountains and Golconda allochthons	------do.------	------do.------		0.22	1.5 percent Cu
Sierran-type kuroko massive sulfide (plate 10)	Areas proximal to deep water felsic domes; rocks of the Black Rock terrane	Areas that contain most prospects and occurrences; geochemical anomalies in base and precious metals and Ba	------do.------		1.5	1.3 percent Cu
		Tracts B, C		1, 4		
Sedimentary exhalative zinc-lead (copper, barite) (plate 10)	Areas underlain by autochthonous lower Paleozoic rocks and (or) allochthonous rocks of the Roberts	------do.------	------do.------		15	5.6 percent Zn 2.8 percent Pb

	Mountains allochthon					
	Tracts F, H			1, 22		
Volcanogenic manganese (Franciscan-type) (plate 10)	All ophiolite-related mafic lava sequences; rocks of the Roberts Mountains and Golconda allochthons	Areas that contain most prospects and occurrences; including Cu, Zn, or gold geochemical anomalies and Mn-rich interflow sedimentary strata	Areas close to important known deposits and prospects and that have received substantial exploration activity		[9]0.00045	[9]36 percent Mn
			Tertiary and Quaternary			
Placer Au–PGE (plate 11)	All Tertiary basins to a depth of 1 km	3–km buffer around all prospective areas	Delineated by 2–km buffer around all placer Au–PGE occurrences		--	--

[1]Criteria: 1, Presence of mines and prospects; 2, presence of numerous metal occurrences petrogenetically linked to a pluton-related environment (shallow-seated magmatic hydrothermal); 3, anomalous concentrations of As, Sb, Au, Ag, Cu, Pb, Mo, and Zn in numerous stream-sediment and soil samples (King, 1996); 4, geochemical anomalies of base and precious metals in various sample media; 5, presence of major premineralization structure; 6, widespread hydrothermal alteration of host igneous phase and wallrocks; 7, widespread presence of quartz-sulfide mineral stockworks or veins; 8, anomalous concentrations of Sb, As, Au, Ag, and Pb in numerous stream-sediment and soil samples (King, 1996); 9, presence of reactive, premineralization rocks; 10, skarn alteration in carbonate rocks together with widespread occurrences of polymetallic veins; 11, aeromagnetic data suggesting presence of elevated concentrations of pyrrhotite and (or) other magnetic minerals in shells surrounding the central intrusion(s); 12, clusters of widespread presence of tungsten skarn; 13, presence of anomalous concentrations of Cu and Mo in altered rock; 14, presence of nearby gold placers; 15, presence of nearby peraluminous granite; 16, areas proximal to caldera margin, nearby hot-spring mercury deposits. airborne radiometric anomalies; 17, large areas of low-grade uranium-mineralized rock; 18, uranium localities. airborne radiometric anomalies associated with plutons; 19, presence of numerous mineral occurrences related to the metamorphic environment.; 20; presence of Mn–rich sedimentary strata; 21, ophiolitic basalt; 22, presence of bedded barite occurrences; 23, anomalous concentrations of Au in stream-sediment and soli samples (King, 1996).
[2]From Cox and Singer (1986), except as noted.
[3]North American porphyry copper model of Hammarstrom and others (1993).
[4]Nevada tungsten skarn model of John and Bliss (1994).
[5]From Theodore and others (1991).
6From Appendix A, this report.
[7]From Berger and Singer (1992).
[8]From Bliss (1992b).
[9]From Mosier and Page (1987).

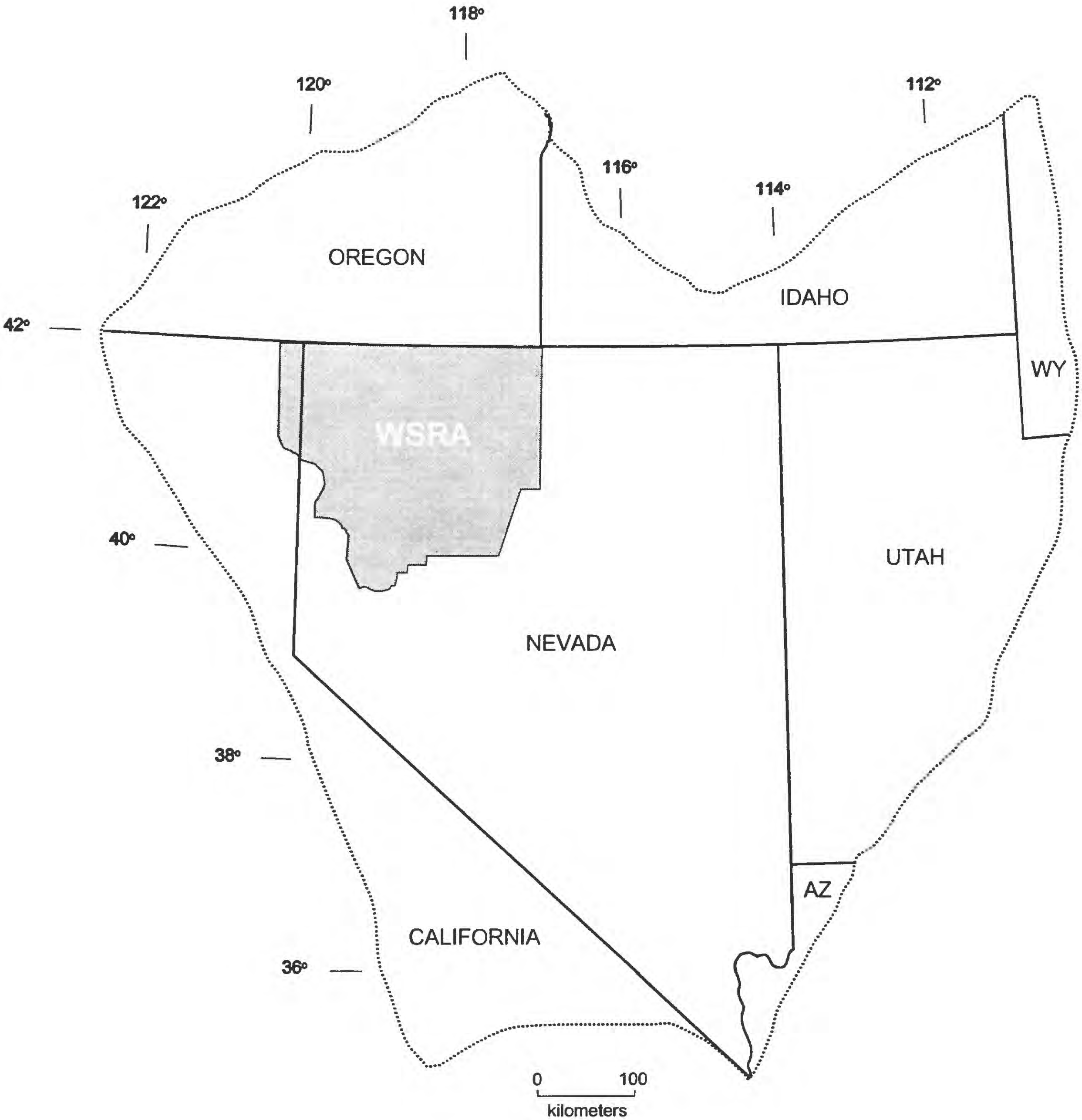

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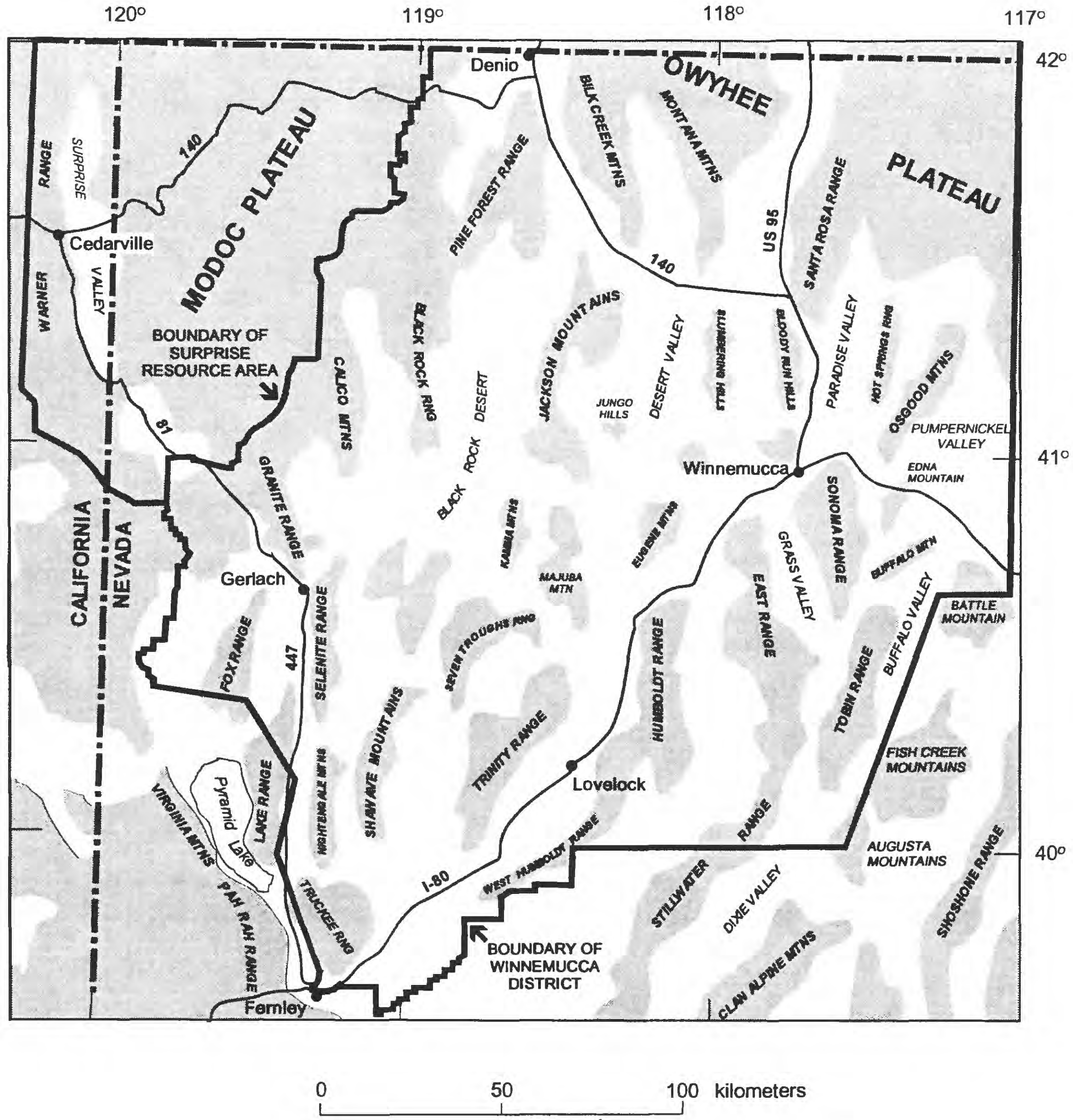
Figure 1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140
SURPRISE
RANGE
WARNER
VALLEY
Cedarville
BOUNDARY OF SURPRISE RESOURCE AREA
81
CALIFORNIA
NEVADA
PINE FOREST RANGE
BILK CREEK MTNS
MONTANA MTNS
US 95
SANTA ROSA RANGE
BLACK ROCK RNG
JACKSON MOUNTAINS
DESERT VALLEY
JUNGO HILLS
BLOODY RUN HILLS
PARADISE VALLEY
HOT SPRINGS RNG
OSGOOD MTNS
PUMPERNICKEL VALLEY
EDNA MOUNTAIN
Winnemucca
BLACK ROCK DESERT
CALICO MTNS
GRANITE RANGE
Gerlach
SONOMA RANGE
GRASS VALLEY
BUFFALO MTN
MAJUBA MTN
EAST RANGE
BATTLE MOUNTAIN
BUFFALO VALLEY
SELENITE RANGE
FOX RANGE
447
SEVEN TROUGHS RNG
HUMBOLDT RANGE
TOBIN RANGE
SHAWAVE MOUNTAINS
TRINITY RANGE
FISH CREEK MOUNTAINS
Lovelock
Pyramid Lake
LAKE RANGE
VIRGINIA MTNS
PAH RAH RANGE
TRUCKEE RNG
I-80
WEST HUMBOLDT RANGE
RANGE
AUGUSTA MOUNTAINS
STILLWATER
DIXIE VALLEY
SHOSHONE RANGE
BOUNDARY OF WINNEMUCCA DISTRICT
CLAN ALPINE MTNS
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50
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Figure 2