CHAPTER 12

DELINEATION OF MINERAL RESOURCE ASSESSMENT TRACTS AND ESTIMATES OF NUMBERS OF UNDISCOVERED DEPOSITS IN NEVADA

Dennis P. Cox, Steve Ludington, Byron R. Berger, Barry C. Moring, Maureen G. Sherlock, Donald A. Singer, and Joseph V. Tingley

INTRODUCTION

In this chapter, we apply the data on geology, geophysics, and mineral occurrences presented in the first part of this report to an assessment of the undiscovered mineral resources of Nevada following the three-part resource assessment process outlined in chapter 1. We assess undiscovered deposits, as opposed to reserves or resources in extensions to known deposits, in order to provide information that is useful in predicting the possible future supply of mineral raw materials from Nevada. Because the assessment process is based on mineral deposit models, our discussion of the mineral resources will be organized in accordance with the deposit types in which they are found.

The first part of the assessment is the delineation of areas in which the geology is permissive for the existence of deposits of one or more type. These areas, called permissive tracts, are based on geologic criteria derived from deposit models which are themselves based on studies of known deposits within the study area and worldwide. Tracts may or may not contain known deposits. Areas are excluded from these tracts when they are judged to have a negligible probability of occurrence. This judgment is based on geology, knowledge about exhaustion of discovery possibilities by thorough exploration, or, in this report, burial by more than 1 km of overlying barren rocks or sedimentary deposits (chapter 2). All lands, both public and private, in Nevada were considered in delineating the tracts; as were lands that are developed or withdrawn from mineral entry. Designation of a tract as permissive does not imply any special favorability for the existence of a deposit, nor does it address the likelihood that a deposit will be discovered if it exists. The probability of discovery of deposits involves a large number of uncertainties such as future economic conditions, development of new exploration methods, depth and type of cover, and the motivation of the explorationist, all of which are beyond the scope of this study.

In delineating permissive tracts, we have been as inclusive as possible, that is, where two possible interpretations of the geology were available to guide the delineation of a tract boundary, the choice was made that would provide the larger tract. Where the permissive rocks for a deposit type are not related to plutons, the tracts exclude areas underlain by plutons greater than 100 km^2 in area, thick parts of the Humboldt gabbro complex, metamorphic core complexes in the Ruby Mountains, and areas underlain by Jurassic volcanics of the Pony Trail assemblage. Where the permissive rocks are older than Tertiary, we have excluded areas that are within a Tertiary caldera (chapter 5), where permissive rocks are likely to be covered by more than 1 km of volcanic rock.

For some deposit types, smaller areas, considered to be more favorable for the deposit type were delineated within the permissive tract. These favorable areas, in which existence of deposits is more likely, may be based on the distribution of known deposits, or on a combination of geologic, geophysical or geochemical features known to be associated with the deposit type.

The second part of the assessment, the estimate of the number of undiscovered deposits within the delineated tracts, is done to show explicitly how favorable the tract is for the occurrence of deposits (Singer, 1993). The deposits are defined by the grade and tonnage models that are the third part of the assessment. The definition of what is meant by a deposit and the application of grade-tonnage models to deposit types in the study area are discussed in chapter 1). In the case of deposit types for which the grade and tonnage data were obtained for districts rather than individual deposits, the estimates are for undiscovered districts. Throughout this report, the words "deposit" or "district" refer to a concentration of a mineral with sufficient tonnage and grade that they could be economic under some foreseeable conditions. All "deposits" or "districts" are expected to be consistent with the grade and tonnage distributions described in chapter 1. Other concentrations that appear to be too small or too low in grade to ever become economic are referred to as occurrences.

For a particular deposit type, there is a single number of undiscovered deposits in the permissive areas in Nevada. Because we do not know this number, we have made subjective estimates of the number of deposits present at the 90th, 50th, and 10th (and sometimes 5th and 1st) complementary percentiles. The 10th percentile, for example, is the number of deposits for which there is at least a 10% chance of that number of deposits or more. For details, see Root and others (1992). Frequently estimates of deposits in the 90th percentile are associated with deposits that are known to the estimators, but whose tonnage or grade has not been announced; deposits that are being actively explored by industry at the time of the estimate; or deposits that otherwise are almost certain to exist. Estimates of deposits in the 10th percentile can express the idea that many of the ore-forming processes and depositional environments have come together to form deposits in the area; that most of the surface indications, such as mineral occurrences, structural intersections, geochemical or geochemical anomalies actually represent hidden orebodies. A wide range between the high and low estimates indicates a paucity of relevant information about the area and/or the deposit model, and a consequent high degree of uncertainty. A narrow range indicate a high level of confidence in the estimates.

Estimates in this study were based on the information in this report and on the combined knowledge of a team, composed of the authors of this chapter. In all cases, team members were mindful of the grade and tonnage model for the deposit type (chapter 1) such that about half of the undiscovered deposits or districts estimated are likely to fall above the median grade or tonnage for that deposit type. After all aspects of the area and deposit type were discussed, each team member made an independent estimate based on personal beliefs about combinations of various criteria. A number of the six guidelines for making these estimates listed by Singer (1993) were used by the team. Some used the number of known deposits per unit area of exposed permissive rocks multiplied by the area of permissive rock concealed by less that 1 km of post-mineral rocks and sedimentary deposits. Others based their estimates on the number of deposits known in well studied areas of similar geology elsewhere in the world. Others depended on the number of occurrences that might become deposits as a result of more complete exploration and still others were influenced by the number of exploration "plays" that could be visualized for the deposit type in question.

These estimates were compared, and team members who made high or low estimates relative to the group were questioned about their reasons. In some cases a minority succeeded in influencing the team in raising or lowering their estimates. After several iterations, a consensus was reached that satisfied all team members.

Because the entire assessment process is dependent on models, we were able to evaluate only those mineral resources that occur in deposit types that are relatively well understood. Permissive tracts for some deposit types were not delineated separately because of insufficient knowledge or disagreement about the model or about the area. Estimates of undiscovered deposits were not made for some deposit types because of lack of grade and tonnage models, lack of information on controls of deposit formation, and/or lack of economic significance of the deposit type for the foreseeable future. In the sections that follow, the criteria for tract delineation and the number of undiscovered deposits estimates are given, along with a discussion of the critical factors upon which the delineation and the estimates were based. Table 12-1 summarizes the estimates.

For more information about mineral deposits in Nevada that are representative of the types discussed here, the reader is referred to the chapter on known deposits and occurrences (chapter 10).

PLUTON-RELATED DEPOSITS

Pluton-related deposits include all deposits for which a genetic relation with an igneous intrusion can be inferred. Deposits may occur within the related pluton as in porphyry deposits (Titley, 1982), at or near the intrusive contact as in skarn deposits (Einaudi and others, 1981), or at some distance from the contact as with replacement and vein deposits. Some deposits such as those of the distal disseminated silver-gold type (Cox and Singer, 1992) are formed at such a distance from the pluton that we have only indirect evidence of a genetic relationship. Although these different deposit types typically represent different parts of large plutonic-hydrothermal systems and are, therefore, genetically related, they are considered separately here because (1) the various types have different tonnage and grade distributions that affect the resource assessment and (2) every plutonic system does not exhibit all related deposit types.

Plutons of Triassic, Jurassic, Cretaceous, and Tertiary age are known in Nevada, emplaced at varying crustal levels. The association of mineral deposits to these plutons and to regional structures has been studied by numerous workers including Roberts (1966), Jerome and Cook (1967), Noble (1970), Silberman and others (1976), and Stewart and others (1977). Our tract delineations borrow from these reports but are also based on new geochronology, and mineral discovery as reported in other chapters in this report.

Some preferred relationships exist between pluton age and certain deposit types. For example, tungsten skarn and low-fluorine porphyry molybdenum deposits tend to occur with Cretaceous plutons, and most copper skarns and iron skarns occur with Jurassic plutons (Cox and others, 1991). On close study, however, these relationships are found to have important exceptions and, though useful as exploration guides, may not be used to exclude areas in tract delineation. Moreover, periods of intrusion of widely differing age, each with associated deposits of different types, are recognized in the same areas, such as the Battle Mountain district (Theodore and others, 1992).

Because of the underlying tendency for different types of pluton-related deposits to occur together, or to be found with plutons of a variety of ages, and because of the statewide scale at which the assessment was conducted, only one permissive tract could be delineated (tract 1, plate 12-1). The tract permissive for pluton-related deposits is defined as an area extending 10 km outward from the outcrop of a pluton, or, in the case that the pluton has a geophysical expression as discussed in chapter 7, from the inferred subsurface boundary of the pluton based on its geophysical expression. It also includes areas around plutons whose presence is inferred from geophysics (chapter 7) or from the occurrence of skarn mineralization (chapter 10). Some pluton-related deposit types such as skarns are known to occur less than 10 km from the pluton contact; however, we could not portray a more appropriate boundary at the published scales of our maps. Tract 1 covers about 41% of the area of the state.

In a few places, mineral occurrences that resemble polymetallic replacement or vein deposit types are situated in areas in which no outcrop or geophysical expression of a pluton is known. These occurrences are referred to as lead-zinc veins in chapter 10, and may be unrelated to igneous activity. Areas containing these occurrences are shown on plate 12-1 by an area of 10 km radius around the occurrence that is given a different color pattern indicating fewer reliable criteria on which they are considered permissive for pluton-related deposits.

Carbonate-bearing and calcareous sedimentary rocks are present in all sedimentary assemblages in Nevada (Stewart, 1980; chapter 4 in this report), hence, no areas were excluded from the permissive tract on the basis of age or composition of intruded country rock. In order to simplify the map,

Table 12-1. Estimated number of undiscovered deposits and districts in permissive tracts in Nevada. Estimates are presented as complementary percentiles. The 50th percentile, for example is the number of deposits for which there is approximately a 50% chance of at least that number of deposits.

Deposit type	Number of deposits at 5 different percentiles				
	90 th	50 th	10 th	5 th	1 St
W skarn districts	6 or more	10 or more	16 or more	18 or more	21 or more
W vein districts	0	0	1 or more	6 or more	10 or more
Porphyry Mo, low-F deposits	12 or more	18 or more	24 or more	25 or more	29 or more
Climax Mo	0	3 or more	6 or more	6 or more	8 or more
Jurassic porphyry Cu deposits	1 or more	3 or more	6 or more	9 or more	12 or more
Cretaceus porphyry Cu deposits	1 or more	2 or more	3 or more	5 or more	6 or more
Tertiary porphyry Cu deposits	1 or more	3 or more	4 or more	8 or more	10 or more
Cu skarn deposits	6 or more	10 or more	14 or more	16 or more	20 or more
Au skarn deposits	2 or more	4 or more	6 or more	8 or more	10 or more
Fe skarn deposits	1 or more	8 or more	18 or more		
Zn-Pb skarn deposits and polymetallic replacement districts	11 or more	15 or more	20 or more	22 or more	25 or more
Distal disseminated Ag-Au	6 or more	10 or more	15 or more	16 or more	19 or more
Quartz-adularia vein districts	14 or more	19 or more	25 or more	28 or more	31 or more
Quartz-alunite vein districts	2 or more	6 or more	12 or more	14 or more	16 or more
Hot-spring gold deposits	13 or more	18 or more	23 or more	26 or more	30 or more
Sediment-hosted Au	15 or more	21 or more	27 or more	30 or more	34 or more
Sierran kuroko deposits	1 or more	3 or more	6 or more	7 or more	8 or more
Cyprus massive sulfide deposits	1 or more	2 or more	5 or more	7 or more	8 or more
Besshi massive sulfide deposits	O or more	1 or more	2 or more	2 or more	3 or more
Sedimentary exhalative Zn-Pb deposits	O or more	O or more	1 or more	3 or more	5 or more

certain obvious exclusions from the tract were not made. The reader is asked to assume, for example, that pluton outcrop areas are excluded from the area permissive for replacement deposits, and that porphyry deposits are largely restricted to areas of intrusive rock.

About 72% of the permissive tract is covered by 1 km or less of upper Tertiary and Quaternary rocks and sedimentary deposits. Areas covered by more than 1 km are excluded as are areas that are within a Tertiary caldera (chapter 5). In these latter areas, permissive pre-Tertiary host rocks are likely to be covered by more than 1 km of volcanic rock. Where the pluton is Tertiary in age, however, the enclosing Tertiary volcanic rocks are delineated as permissive.

For some pluton-related deposit types, it was possible to delineate parts of the tract having greater likelihood of occurrence of undiscovered deposits. The criteria on which these areas were delineated as favorable are discussed in the following sections.

Tungsten Skarn Districts

A tungsten skarn district as defined in the grade and tonnage model (Menzie and Jones, 1986) includes all orebodies situated on the contact of a single intrusion or, lacking other information, within 10 km of each other. Four such districts in Nevada, Tempiute, Mill City, Osgood Mountains (Potosi), and Regent, all associated with Cretaceous plutons, fall within the grade and tonnage distributions. Other occurrences are distinctly smaller. Of a total of 55 districts and occurrences in Nevada, 39 are of Cretaceous age, eight are Tertiary, five are Jurassic, one is Triassic, and two are associated with core-complex granites of Cretaceous and Tertiary ages. Because of this strong preference for Cretaceous plutons, a favorable area for tungsten skarn (fig. 12-1) was delineated within tract 1 that includes all areas within 10 km of mesozonal Cretaceous plutons. This area, mainly situated in western Nevada, has a higher likelihood of undiscovered tungsten skarn deposits than other parts of tract 1.

Undiscovered districts probably exist within the 51 known clusters of tungsten skarn occurrences that are, at present levels of exploration, too small to fall on the tonnage distribution for the model, but which, if explored more fully, might prove to be larger. Other districts probably exist in covered areas, which exceed the areas of exposed pre-Tertiary rock. Although our estimate was influenced by the belief that the number of undiscovered tungsten skarn districts is related in some way to the number of concealed plutons, we recognize that some tungsten skarns are associated with nonmagnetic (ilmenite series) granites that might not be detected and counted in concealed parts of the tract. We estimate (table 12-1) that there is a 90% chance of 6 or more undiscovered districts, a 50% chance of 10 or more, and a 10% chance of 16 or more undiscovered districts in the delineated area that are comparable in grade and tonnage to the tungsten skarn grade and tonnage model of Menzie and Jones (1986).

Tungsten Vein Districts

The known quartz-huebnerite and quartz-scheelite vein systems in Nevada occur in and near peraluminous granites that commonly contain primary muscovite. The distribution of these two-mica granites (from Barton and Trim, 1991; Abbott and others, 1991; David John, oral commun., 1992) is closely related to regional metamorphism of Cretaceous age (Barton and Trim, 1991), and in central and eastern Nevada to uplifts exposing Precambrian and Lower Paleozoic rocks. Areas within tract 1, extending 10 km out from the outcrop of these granites (fig. 12-2), are favorable for tungsten vein deposits. Tungsten vein occurrences that fall outside of this favorable area such as those in and northeast of the Patterson district (fig. 12-2) may reflect the presence of buried or otherwise unrecognized peraluminous intrusions.

The largest tungsten vein districts in Nevada produced on the order of 10,000 tonnes of ore each (estimated from data in Stager and Tingley, 1988). These fall well below the tonnage distribution for tungsten veins according to worldwide data of Jones and Menzie (1986b), a fact which greatly decreases the probability of undiscovered districts in Nevada that are consistent with the grade and tonnage model. Our estimate of the number of undiscovered districts is influenced positively by the belief that some of the known vein systems are incompletely explored, and that undiscovered veins exist in covered areas. The peraluminous granites with which these veins are associated are typically nonmagnetic and, because our knowledge about plutons under cover is based mainly on their magnetic expression, it is possible that deposits could occur beneath cover anywhere in Nevada. We estimate that there is a 10% chance of 1 or more undiscovered districts, a 5% chance of 6 or more, and a 1% chance of 10 or more undiscovered districts in the delineated area that are comparable in grade and tonnage to the tungsten vein grade and tonnage model (Jones and Menzie, 1986b).

Porphyry Molybdenum, Low-fluorine-type Deposits

Mineral occurrences classified as porphyry molybdenum, low-fluorine-type (Theodore, 1986; granodiorite molybdenite systems of Mutschler and others, 1981) are related to porphyritic, epizonal plutons and are widely scattered in Nevada. Because epizonal plutons are not consistently distinguished from more deep-seated ones in geologic maps of Nevada, we were not able to delineate a geologically favorable area within tract 1. The four deposits that are part of the grade and tonnage distribution (Menzie and Theodore, 1986) are in Cretaceous plutons as are 10 of the other 15 occurrences. Most deposits and occurrences are located in western Nevada on the east flank of the discontinuous belt of large Cretaceous batholiths trending NNE of Reno (fig. 12-1).

Our estimate of the number of undiscovered deposits was influenced by the large number of occurrences that were discovered and drilled during a very short period of intense exploration (1978-1981) fomented by high molybdenum prices. Grades and tonnages for many of these deposits were published, but most deposits were abandoned in 1981 when prices returned to lower levels. The deposits discovered during this period of exploration make up a large part of our grade and tonnage models although most are presently uneconomic. Our estimates also reflect the fact that 72% of

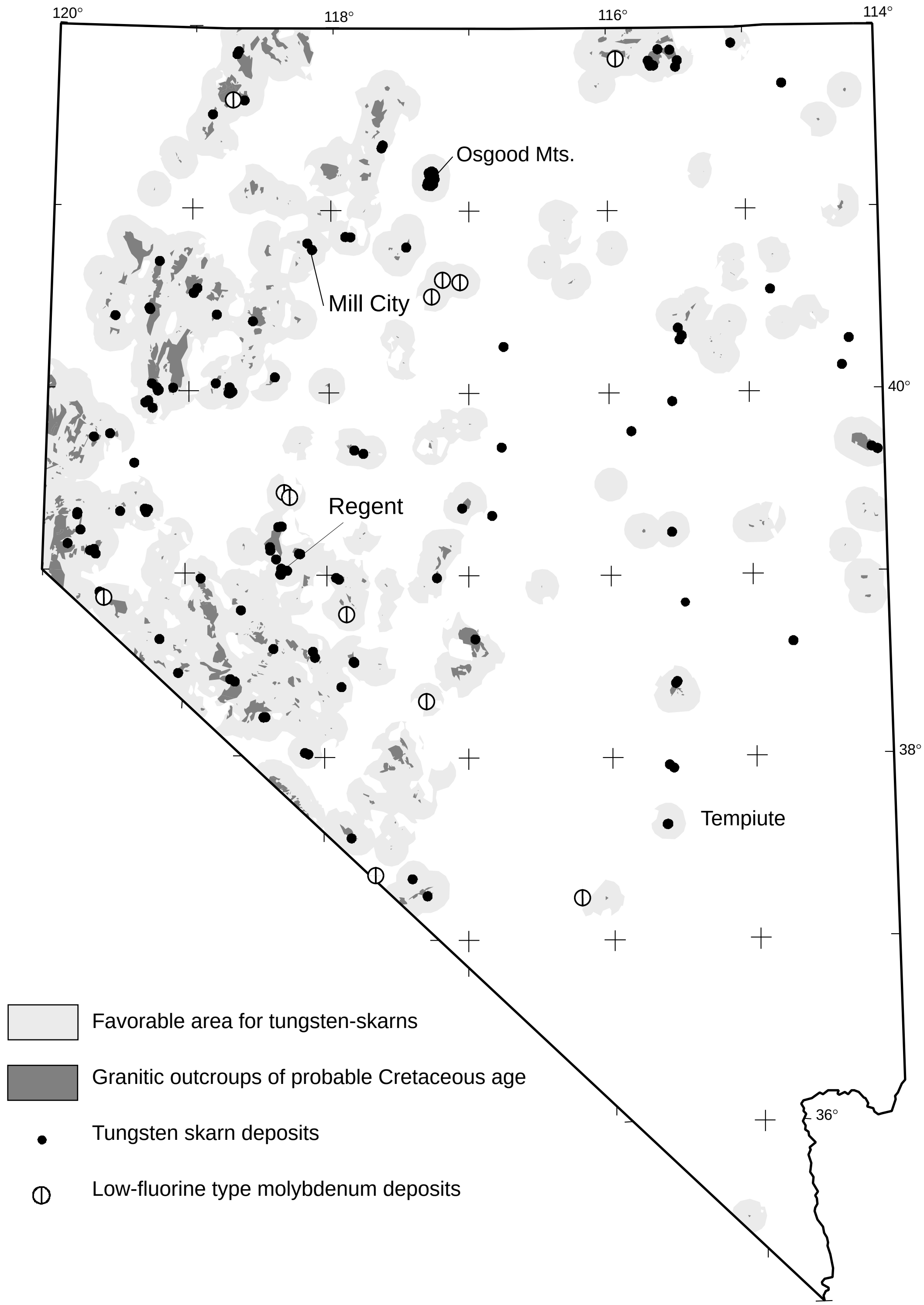

Figure 12-1. Areas favorable for W-skarn deposits within permissive tract 1 (see plate 12-1). W-skarn deposits are shown by dots, low-fluorine type porphyry Mo deposits and occurrences are shown by split circles. W-skarn deposits outside of the favorable area are associated with Jurassic and Tertiary plutons.

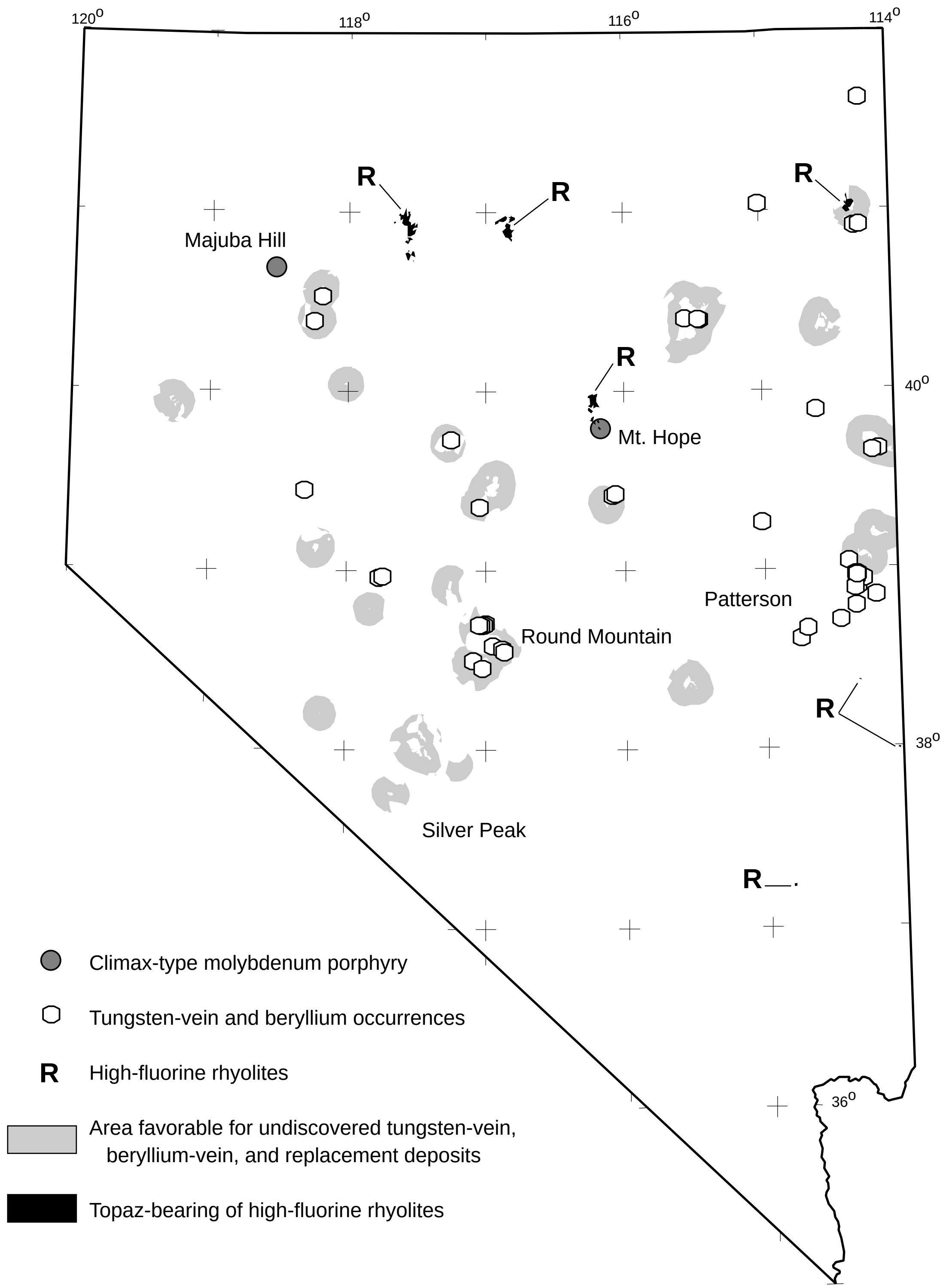

Figure 12-2. Areas around known peraluminous granite plutons within permissive tract 1. These are favorable for undiscovered W-vein deposits and beryllium vein and replacement deposits. Indicated by the letter R are areas of topaz-bearing or high-F rhyolites (from Christiansen and others, 1986) favorable for Climax Mo deposits.

tract 1 is concealed and unexplored. We estimate that there is a 90% chance of 12 or more undiscovered deposits, a 50% chance of 18 or more, and a 10% chance of 24 or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the porphyry molybdenum, low-fluorine model (Menzie and Theodore, 1986).

Climax Molybdenum Deposits

Among porphyry molybdenum deposits, the Climax type differs from the low-fluorine type in its strict association with high-silica granite or rhyolite, its higher grade, and generally higher fluorine content (White and others, 1981). Climax deposits included in the grade-tonnage model all have three or more superimposed orebodies, formed by repeated porphyry intrusion, but included as one deposit in each case. Considering this fact and the restricted permissive environment, the occurrence of a Climax deposit should be considered an uncommon event. Only one deposit, Mount Hope (Westra, 1982), is known in Nevada, and a second, Pine Grove, is situated in western Utah. Majuba Hill may be a second Nevada example, but data on its fluorine geochemistry are not available. Both occur within Tertiary rhyolite stocks. Topaz rhyolite flow-dome complexes, because of their high silica and fluorine content, are indicative of Climax molybdenum deposits and both Mount Hope and Pine Grove are situated near such complexes. Eight topaz rhyolite complexes are shown on figure 12-2 (Christiansen and others, 1986), but they are too widely scattered to enable us to draw a favorable area within tract 1. We estimate that there are zero undiscovered deposits at the 90th percentile, a 50% chance of three or more, a 10% chance of six or more and a 1% chance of eight or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the Climax porphyry molybdenum model (Singer and others, 1986b).

Porphyry Copper Deposits

A generalized model for porphyry copper deposits (Cox, 1986b) was used for this resource assessment. It includes such variants as copper-molybdenum and copper-gold porphyries, as well as porphyry copper, skarn-related deposits such as are found in the Robinson district. Porphyry copper deposits tend to form in and around epizonal plutons rather than deep-seated batholiths, but, because we lack such paleodepth information for many plutons in Nevada, no part of tract 1 could be excluded on this basis. The three known districts in the State contain deposits of three distinct ages: Yerington, Jurassic; Robinson, Cretaceous; and Copper Canyon, Tertiary. In addition, a porphyry copper prospect, not shown on plate 12-1, is associated with a Late Triassic to Early Jurassic pluton (Seedorff, 1991b) 22 km NW of Tonopah. Different areas are favorable for deposits of Jurassic, Cretaceous, and Tertiary ages (fig. 12-3). Deposits of Jurassic age are most likely to occur in a discontinuous belt extending from Yerington northeast to the Contact and Dolly Varden districts. The most favorable area for deposits of Early Cretaceous age is a belt including the Eureka, White Pine and Robinson districts. An area of Late Cretaceous plutons and associated copper skarn deposits near Luning is also favorable for porphyry copper deposits; and a Cretaceous stock at Crescent Peak in Clark County (Double Standard mine, no. 559; chapter 10 in this report) exhibits alteration and mineralization suggestive of a porphyry copper system (Longwell and others, 1965). The favorable area for Tertiary deposits is very broad and was not specifically delineated within tract 1. Many of the small epizonal plutons of Tertiary age scattered across northern and eastern Nevada are associated with small base- and precious-metal deposits and are favorable for porphyry copper systems. In addition, porphyry copper deposits are probably associated with quartz-alunite gold districts and Tertiary plutons accompanied by areas of widespread alunite alteration (Wallace, 1979; Hudson, 1983) within the western andesite belt (tract 2, plate 12-2; fig. 12-3). This area is not considered to be favorable for porphyry copper deposits because the porphyry environment is believed to exist more than 1 km below the alunite alteration environment. It is possible that some alunite alteration areas are associated with low-fluorine porphyry molybdenum or porphyry gold systems.

In our estimate of undiscovered deposits, we were guided by the fact that the area of concealed permissive bedrock that is unexplored is about 2.5 times larger than the area of exposed permissive rock. Thus if four deposits are known in exposed areas (Yerington, MacArthur, Copper Canyon, and the Robinson district system), about 10 deposits would be expected to exist in the covered areas if they occur there with equal density, and if all exposed deposits have been found. Two concealed deposits have already been discovered (Bear and Ann Mason), thus eight deposits might remain to be found. On the negative side, we noted that during the period of intensive exploration for porphyry copper deposits in the 1960s and ’70s, only a small number of deposits were found in Nevada, and that most of these were in the Yerington area.

We made separate estimates (table 12-1) for undiscovered deposits of different ages because of the differences in their favorable areas and because we believe that their probabilities of occurrence are different. The estimate for Jurassic deposits (including the possibility of undiscovered late Triassic to early Jurassic deposits) is the largest because of the large number of known Jurassic copper skarns deposits. The estimate for Tertiary deposits is second in ranking. The lowest estimate is given for Cretaceous deposits because we believe that, although Cretaceous plutons are numerous in Nevada, those of Early Cretaceous age are rare, and consequently, undiscovered systems like the Robinson district (110 Ma) are less likely to exist. These estimates, shown in table 12-1, are consistent in grade and tonnage with the porphyry copper model of Singer and others (1986a).

Porphyry Gold Deposits

Porphyry gold deposits (Vila and Sillitoe, 1991; Rytuba and Cox, 1991) contain gold, with low or negligible amounts of copper, in stockworks in shallow plutons. The deposits typically contain magnetite in stockwork veinlets and are associated with potassic hydrothermal alteration grading upward into acid sulfate (alunite) alteration.

No examples of this deposit type have been clearly demonstrated in Nevada. The Top deposit, mentioned by Sillitoe and Bonham (1990, p. 159) in the Bald Mountain

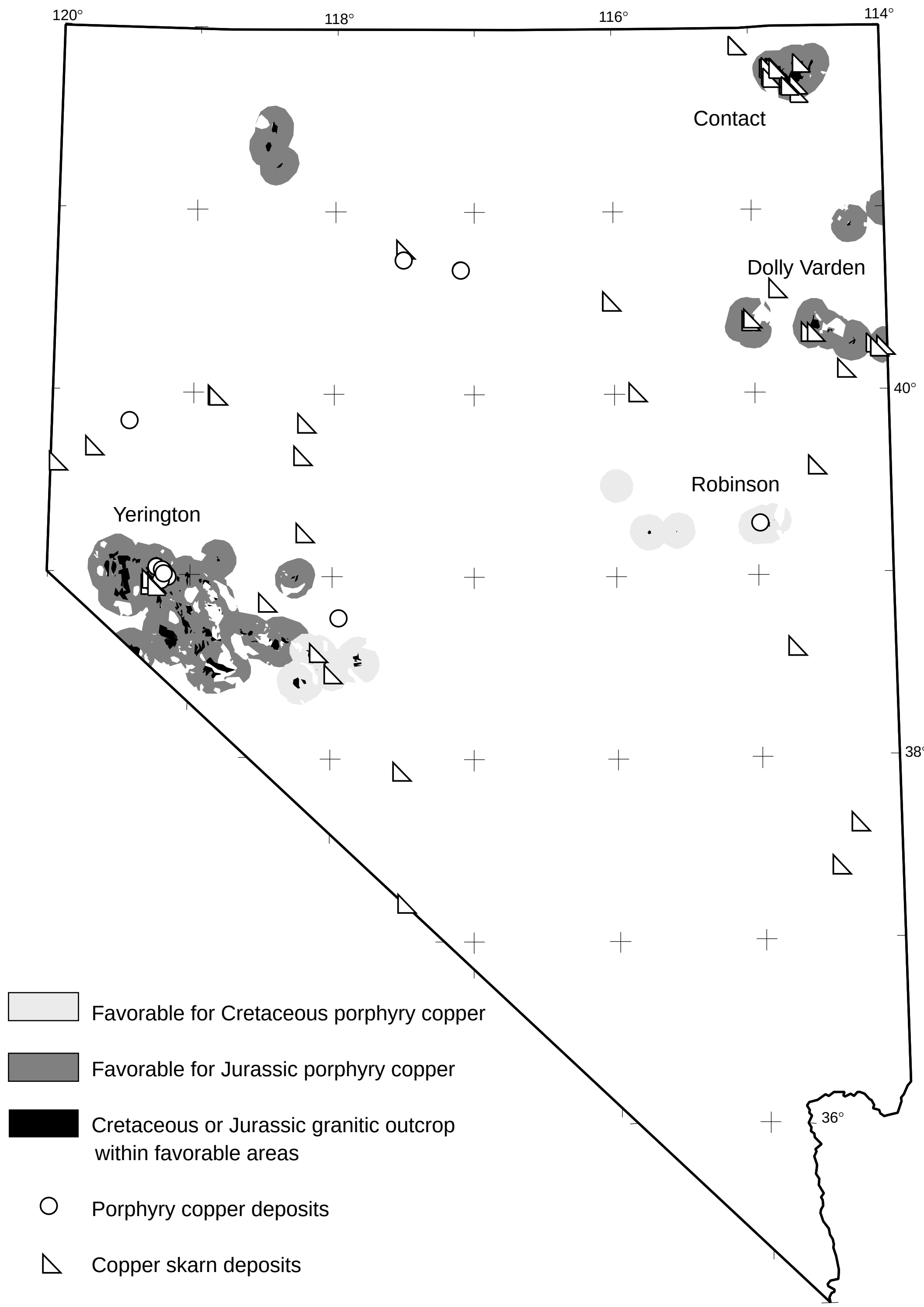

Figure 12-3. Areas favorable for undiscovered porphyry copper deposits of Jurassic age and Cretaceous age, within permissive tract 1 (see plate 12-1). Small skarns and porphyry copper deposits and occurrences outside the favorable area are mainly associated with Tertiary intrusions.

district, is a possible example. It is a pyritic stockwork within an intrusion of probable Eocene to Oligocene age. Possible deposits might be associated with similar intrusions in eastern Nevada, and can be expected to occur associated with other mineral deposits of Tertiary age in the Battle Mountain trend and elsewhere.

In western Nevada, it is possible that porphyry gold deposits exist beneath many of the larger alunite alteration zones in volcanic rocks of the western andesite assemblage in the Walker Lane. Thus the same tract delineated for quartz-alunite gold (discussed below) is permissive for porphyry gold deposits (plate 12-2, tract 2).

Because we lack grade and tonnage models for this deposit type, we do not estimate the number of undiscovered deposits. Deposits of this type are, however, of substantial tonnage and gold content and may become an important target for exploration in Nevada.

Copper Skarns

Copper skarns form near the contacts of plutons with reactive rocks, mainly limestone and dolomite. They are part of a genetically related group of deposits that range from porphyry copper deposits to zinc-lead skarns, polymetallic replacement, polymetallic veins, and distal disseminated silver-gold deposits. Copper skarns are numerous in Nevada with more than 50 occurrences listed in 20 localities in the MRDS records for the State (chapter 10). The seven deposits from Nevada included in the copper skarn grade and tonnage model of Jones and Menzie (1986a), are significantly lower in tonnage and higher in grade than the other deposits in the model. However, because these seven deposits are all located in the same general area near Yerington, and because we believe that undiscovered copper skarn deposits are, for the most part, located elsewhere in Nevada, we have relied on the original unmodified model. Skarns at Copper Canyon and in the Robinson district are included with the porphyry copper deposits.

The distribution of copper skarns with respect to porphyry copper deposits in Nevada is shown in figure 12-3. Most of the known deposits are in the Yerington district and are of Jurassic age. The Victoria deposit and other skarns in the Dolly Varden district are also Jurassic. The Contact district in northeastern Nevada contains many occurrences of unrecorded grade and tonnage associated with Jurassic plutons. Two deposits associated with Cretaceous plutons are in the Adelaide and Santa Fe districts. Tertiary copper skarn deposits occur in the Battle Mountain district. Other copper skarn occurrences near Tertiary plutons are numerous.

Because carbonate rock layers of sufficient thickness to host skarns may occur in all sedimentary units in Nevada, all areas within tract 1, permissive for porphyry copper deposits are also permissive for copper skarns (fig. 12-3). Parts of tract 1 that contain assemblages rich in carbonate rocks, however, are considered favorable for copper skarns (fig. 12-4).

Based on the belief that the number of concealed undiscovered deposits within 1 km of the surface is at least as large as the number of known deposits, we estimated that there is a 90% chance of six or more undiscovered deposits, a 50% chance of 10 or more, and a 10% chance of 14 or more undiscovered deposits in the delineated area that are consistent with the grade and tonnage model for copper skarn of Jones and Menzie (1986a).

Iron Skarns

Iron skarns are mainly associated with Jurassic and Cretaceous plutons in western Nevada and are hosted by carbonate rocks within the Pine Nut and Paradise volcanic assemblages and, to a minor extent, by the Mesozoic carbonate assemblage. With the exception of two occurrences in Paleozoic carbonates in eastern Nevada near Tertiary intrusions, known deposits are located in accreted terranes west of the Roberts Mountains thrust, but, because they occur in a number of assemblages, we do not delineate a favorable area for iron skarns.

Our estimate of the number of undiscovered deposits took into consideration that 19 deposits and occurrences are known in Nevada, of which four are deposits comparable to the iron skarn model of Mosier and Menzie (1986a). We also took note of the aeromagnetic survey carried out by U.S. Steel between 1953 and 1968 that covered more than 74,000 km^2 of western and north-central Nevada (Robert Jachens, written commun., 1990). We believe that it is unlikely that many concealed deposits were missed during this intensive survey. We estimate that there is a 90% chance of one or more undiscovered deposits, a 50% chance of eight or more, and a 10% chance of 18 or more undiscovered deposits in tract 1 that are comparable in grade and tonnage to the iron skarn model of Mosier and Menzie (1986a).

Zinc-lead Skarns and Polymetallic Replacement Deposits

These two types of deposits both consist of replacement lenses containing sphalerite and galena but differ mainly in that skarn deposits contain metasomatic calc-silicate minerals and generally occur closer to the associated pluton. Both types share the same geologic environment, and it is generally not possible to predict which type is more likely to occur in any one district. Singer (chapter 1) combined the two types, resulting in unimodal distributions of tonnage and grade. Thus no important information is lost in the assessment by combining the types.

Most major zinc-lead skarn and polymetallic replacement districts tend to be associated with plutons of Cretaceous age, but a few major districts and a large number of occurrences are known around Tertiary intrusive centers. A few occurrences are associated with Jurassic plutons in northeast and southwest Nevada. Most of the deposits and occurrences are situated in the part of Nevada underlain by Precambrian continental crust, and the host rocks for most deposits are the lower Paleozoic carbonate assemblage. The first carbonate beds above or within the thick Precambrian and lower Cambrian quartzite sequences have long been known to be the most productive (Woodward, 1972; Ivosevic, 1978). Some deposits are known in upper Paleozoic rocks and a few are found in the Luning Formation of Triassic age. The area within tract 1 with the greatest likelihood of deposits (fig. 12-4) is based on the intersection of tract 1 with the Precambrian clastic assemblage that contains important carbonate host rocks, the Lower and Upper Paleozoic

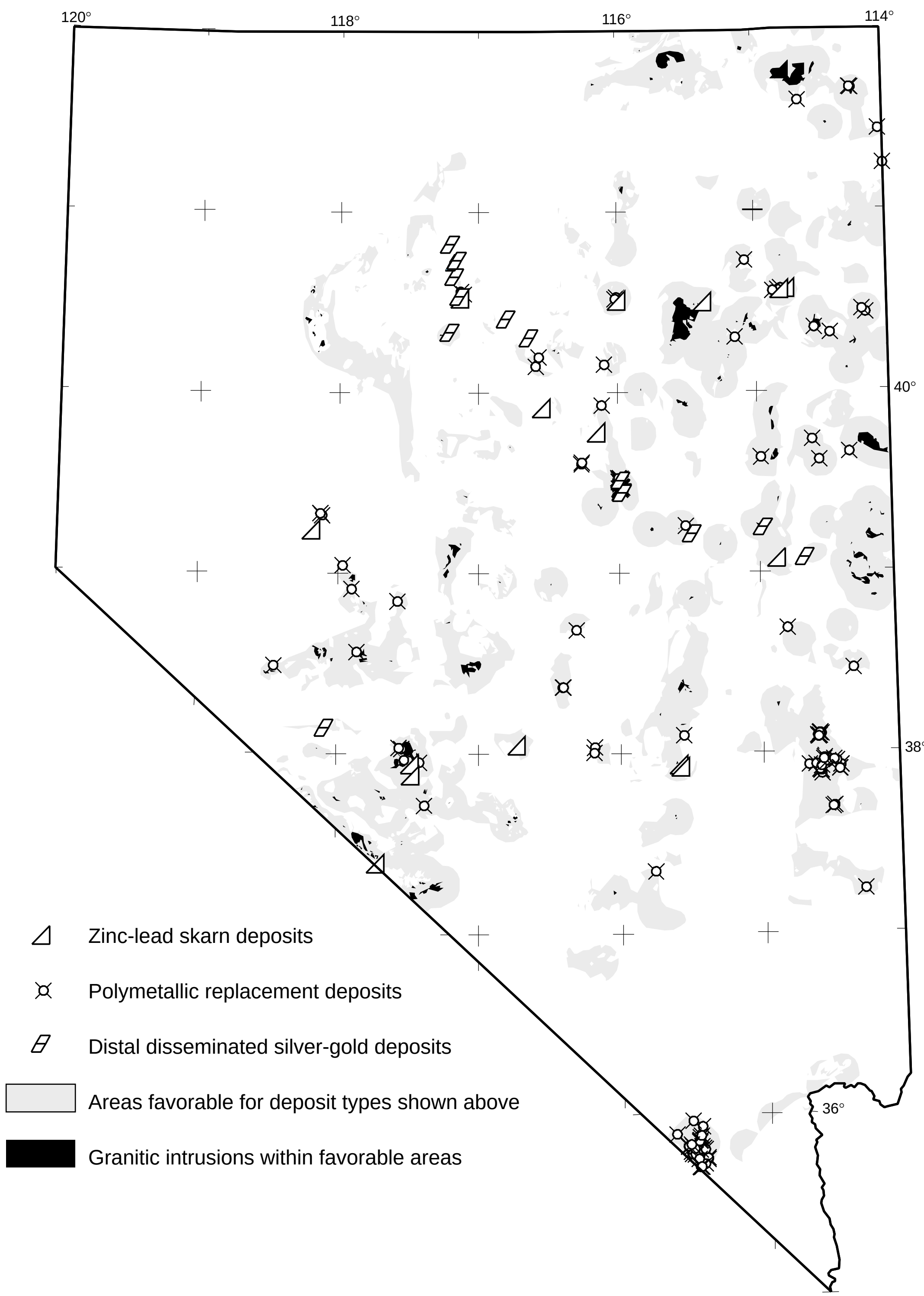

Figure 12-4. Parts of tract 1 that are underlain by Precambrian, lower and upper Paleozoic, and Mesozoic carbonate rocks. These areas are favorable for undiscovered zinc-lead skarns, polymetallic replacement, and distal disseminated silver gold deposits. Known deposits and occurrences of these types are shown by symbol. The area is also favorable for copper skarns shown in figure 12-3.

carbonate assemblages, and the Mesozoic carbonate assemblage.

Zinc-lead skarn and polymetallic replacement districts are abundant in Nevada; at least ten districts large enough to be on the grade-tonnage distribution, three of which, Pioche, Eureka, and Ward, are above the median in tonnage. Many of the 25 smaller occurrences may be insufficiently explored, and little or no exploration has been carried out in covered areas. Of the 10 known districts, six have tonnages distributed around the median (three above and three below) and are situated in the exposed part of the permissive tract. The covered portion of the tract is 2.5 times greater in size, so the expected number of undiscovered deposits should about 15. Consistent with this expected number, we estimate: a 90% chance of 11 or more undiscovered districts, a 50% chance of 15 or more, and a 10% chance of 20 or more undiscovered districts in the delineated area that are comparable in grade and tonnage to the combined zinc-lead skarn and polymetallic replacement grade-tonnage model of Singer (chapter 1).

Gold skarns

Skarn deposits with gold as the principal product are important in Nevada, as illustrated by the gold production from the Copper Canyon and McCoy areas. Theodore and others (1991) found that the presence of gold is the only consistent difference between gold-bearing and other base-metal skarns. Meinert (1989) suggested that host rocks for gold skarns are typically carbonate-bearing sequences with an important clastic or volcaniclastic component. These rocks commonly represent parts of accreted terranes. Because the known examples in Nevada are related to Tertiary plutons, we have tentatively drawn a favorable area for gold skarns (fig. 12-5), within the permissive tract (tract 1). This area is based on the intersection of Tertiary plutons and accreted terranes of the Black Rock, Paradise volcanic, Pine Nut, Golconda, and Roberts Mountains assemblages and the overlying Mesozoic carbonate assemblage (shown on plate 3-1).

Grade and tonnage models for deposits in which gold is the major product are provided by Theodore and others (1991, figs. 1c and 2c) and eight deposits from Nevada are included in this model. Seven of these are in the Battle Mountain district; all are above the median tonnage; and only one deposit, Fortitude, is above the median gold grade (8.6 g/t).

Undiscovered deposits are believed to exist mainly in concealed parts of the permissive tract. Given that two known deposits are distributed around the median grade and that 2.6 times as much of the permissive tract is concealed as is exposed, then the expected number of undiscovered deposits should be about five. Consistent with this expected number, we estimate: a 90% chance of two or more undiscovered deposits, a 50% chance of four or more, and a 10% chance of six or more undiscovered deposits that are comparable in grade and tonnage to the gold skarn grade-tonnage model of Theodore and others (1991, figs. 1c and 2c).

Distal Disseminated Silver-gold Deposits

Distal disseminated silver-gold deposits (Cox and Singer, 1992) are low-grade, sediment-hosted, precious-metal deposits found in the same districts as copper and zinc-lead skarn and polymetallic replacement deposits. They occur in a wide variety of favorable host rocks including clastic sedimentary rocks. They show no apparent preference for plutons of any specific age, but they probably require the presence of a large, productive intrusive system. We were unable to define an area of special favorabilty for this deposit type within tract 1.

There are at least ten deposits known in the Nevada, six of which are part of the grade-tonnage model (Cox and Singer, 1992). Because they are low in metallic mineral content and thus difficult to detect by traditional prospecting methods, we believe that the number of undiscovered deposits is approximately equal to the number of known deposits. We estimate that there is a 90% chance of six or more undiscovered deposits, a 50% chance of 10 or more, and a 10% chance of 15 or more undiscovered deposits in the permissive tract that are comparable in grade and tonnage to the distal disseminated silver-gold model of Cox and Singer (1992).

Other Pluton-related Deposits

Many types of deposits occur in tract 1 for which no estimate of the number of undiscovered deposits has been made. Beryllium deposits, in the form of pegmatites, veins, replacements, and skarns, are associated with peraluminous granites and occur in the part of tract 1 that is delineated as favorable for tungsten veins (fig. 12-2). Little is known about these deposits and no grade-tonnage models are available.

A genetic association between peraluminous granite and gold quartz veins is suggested by the productive deposits in the Mineral Ridge district near Silver Peak, Nevada (Spurr, 1906; Bercaw and others, 1987; plate 10-1 in this report), and the Skidoo deposit in Inyo County California (Fife, 1987). These veins resemble low-sulfide gold-quartz veins, described below, but differ from these in that they occur in quartzofeldspathic rather than marine volcanogenic host rocks. Spurr (1906) noted the close association of the Mineral Ridge veins to dikes of muscovite-bearing alaskite, and hypothesized an ore magma, evolving from granite to pegmatite to gold-bearing quartz vein. Spurr's ideas were not widely accepted, but his observations suggest an uncommon process that warrants modern investigation. Questions to be addressed are what is the regional relationship of peraluminous granites to gold deposits? and, are there petrologic differences between peraluminous granites that host tungsten veins, on the one hand, and gold veins, on the other?

Polymetallic veins are the most abundant metallic mineral deposits in the state. They occur throughout tract 1 with every kind of deposit that is formed in association with felsic granitoid plutons. In some cases isolated occurrences were used as supporting evidence for concealed plutons. Because of the small tonnage of deposits in the existing model (Bliss and Cox, 1986) and because large, important deposits of this type are unknown in Nevada, undiscovered deposits were not estimated. For the same reasons, no estimates were made for

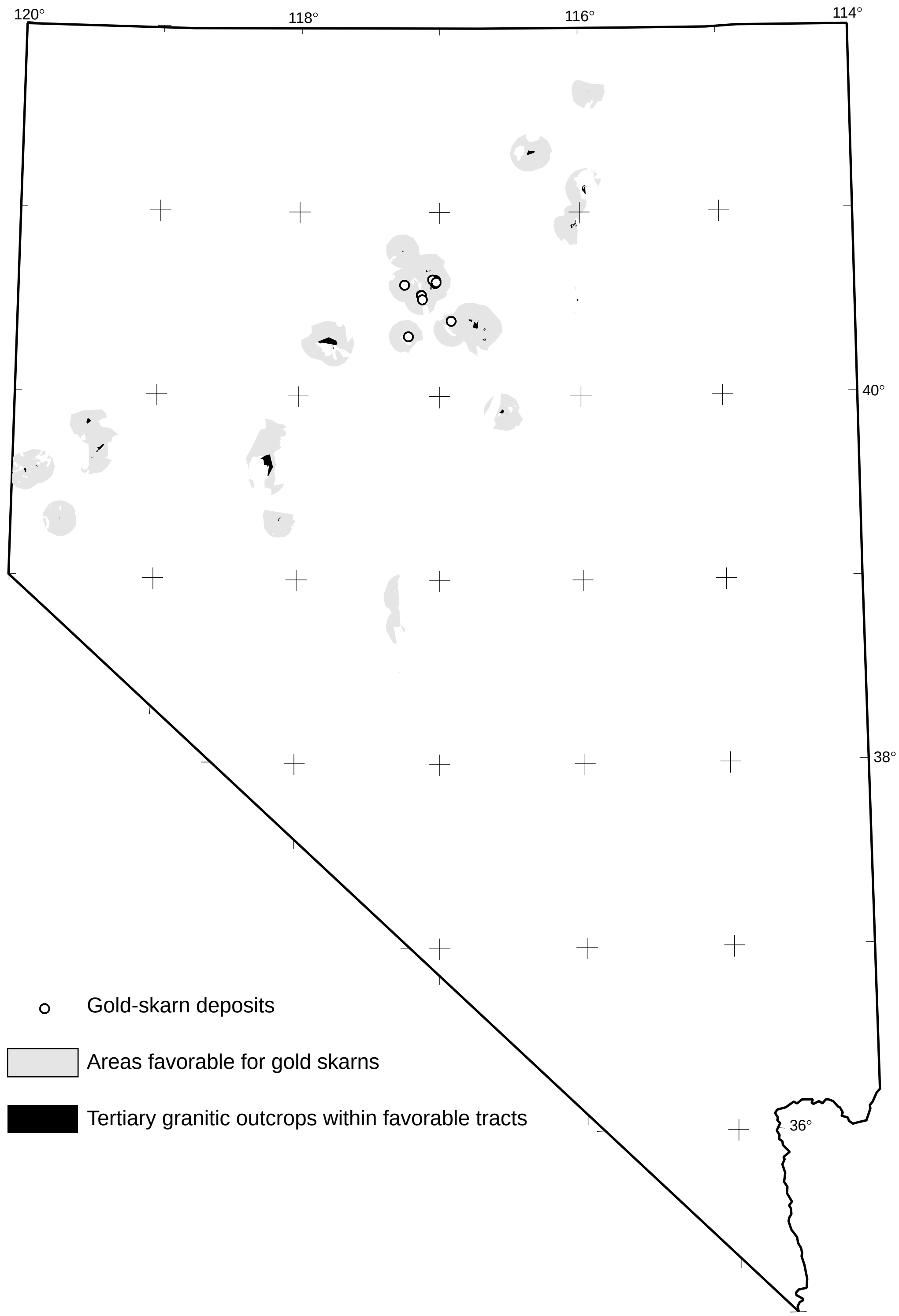

Figure 12-5. Parts of tract 1 favorable for gold skarn deposits based on the intersection of the 10 km area surrounding Tertiary plutons and areas of accreted terranes (Black Rock, Jungo, Paradise volcanic, Golconda, and Roberts Mountains assemblages) and the Mesozoic carbonate assemblage.

replacement manganese deposits, which occur in association with polymetallic replacement deposits in many districts in tract 1.

Areas of widespread alunite alteration within the western andesite belt (tract 2, plate 12-2) are permissive for volcanic-hosted copper-arsenic-antimony deposits, Cox (1986a). Deposits of this type are not known in Nevada, but occur in the nearby Monitor district in California (Clark, 1977). No grade-tonnage model has been prepared for this deposit type.

Volcanic-hosted magnetite deposits (Cox, 1986c) occur in felsic to intermediate volcanic rocks of Jurassic age in the Black Rock assemblage and in the Pony Trail volcanic assemblage in northwestern and north-central Nevada respectively. Because of the restricted environment of these deposits and the low probability that important deposits could have escaped discovery by magnetic exploration programs, no estimate of undiscovered deposits was made.

Iron deposits in the form of magnetite or hematite replacement of gabbro or mafic volcanic rocks are found in the Humboldt complex. No grade-tonnage model has been prepared for this deposit type and no estimates of undiscovered deposits were made.

Deposits of platinum-group metals related to plutonic activity but not included in tract 1 occur in or near amphibolite dikes in Precambrian gneissic rocks in southern Nevada (chapter 10). These deposits have not been classified, nor do we know of any analogs elsewhere. Lack of information on the regional controls for this type of mineralization made it impossible to delineate a permissive tract.

DEEP-SEATED DEPOSITS UNRELATED TO IGNEOUS INTRUSIONS

Low-sulfide Gold-quartz Vein Deposits

Low-sulfide gold-quartz veins, although not widely recognized as a deposit type in Nevada, may occur in the western part of the State. Permissive rocks for this type of deposit are regionally metamorphosed marine volcanic rocks and volcanogenic sediments. All of the allochthonous assemblages in Nevada are metamorphosed in part and contain these permissive rocks. If these deposits were to exist in Nevada, they would be found in the Black Rock, Paradise, Pine Nut, Golconda, and Roberts Mountains assemblages (chapter 4).

No major deposits of this type are known in Nevada, but a few occurrences of auriferous quartz veins with carbonate alteration haloes are known, mainly in metavolcanic rocks of the Black Rock assemblage (chapter 10). No major ductile shear structures comparable to those of the Mother Lode belt in California are known in Nevada. Undiscovered deposits in this tract are likely to have low tonnage according to Bliss (1992) who assembled data on low-sulfide gold veins in terranes without major through-going shear zones. Because of our uncertainty concerning the existence of low-sulfide gold-quartz veins in Nevada, and the low probability of deposits consistent with the grade-tonnage model of Bliss (1992), no estimate of undiscovered deposits was made.

Flat Fault Gold Deposits

Models for gold on flat faults (Bouley, 1986) or detachment-fault-related deposits (Long, 1992) are based on deposits in southwestern Arizona and southeastern California. These deposits are analogous to small deposits in the Newberry district south of Las Vegas (plate 10-1) where gold is associated with minor copper, specular hematite, and chlorite in low angle shear zones. The structures may be related to detachment faults separating uplifted Precambrian metamorphic rocks and Tertiary granitic plutons from overlying Tertiary volcanic rocks in southernmost Nevada. No grade-tonnage model exists for this deposit type, and no estimate of undiscovered deposits was made.

Quartzite-hosted Gold

Gold-bearing quartz veins, not easily explained by an association with igneous heat sources, occur in quartzite of late Precambrian and early Cambrian age in the Johnnie district (chapter 10). There are insufficient data to construct a grade-tonnage model for this deposit type in Nevada, and analogs are unknown elsewhere. No estimate of undiscovered deposits was made.

EPITHERMAL DEPOSITS

In Nevada, known epithermal deposits of gold, silver, and manganese (chapter 10) are distributed in a crescent-shaped area, concave to the east, that corresponds poorly with the overall distribution of Tertiary volcanic rocks (Silberman and others, 1976; Stewart and others, 1977; Cox and others, 1991; Seedorff, 1991a; Ludington and others, 1993). The crescent is most sharply defined by epithermal gold and silver deposits (fig. 12-6), whereas hot-spring mercury, volcanogenic uranium, and simple antimony deposits correspond largely to this pattern, but are somewhat more broadly distributed. This distribution of volcanic-hosted epithermal deposits cannot be explained by the absence of volcanic rocks inward from the crescent. On the contrary, eastern Nevada contains extensive outcrops of older interior andesite-rhyolite assemblage rocks (older than 27 Ma) in which epithermal vein type deposits are virtually unknown.

In addition to active volcanism, faulting and fracture permeability are important in controlling the distribution of epithermal deposits. The crescent-shaped area described above corresponds closely to those areas which were undergoing faulting in an extensional tectonic regime during active volcanism. The synvolcanic deformation is important because it provides fracture permeability at the same time that hydrothermal systems related to volcanism are active and circulating, thus facilitating the formation of veins and stockworks. Where Miocene volcanic rocks are not much faulted, for example in the Sierra Nevada of California and in the Cascade Range of Oregon and Washington, epithermal mineral deposits are rare or absent.

The Walker Lane area contains well developed normal faults, and is probably the best studied region of epithermal mineralization in Nevada (Stewart, 1988). Northwest-striking high-angle faults that predominate in this area have been shown by John and others (1989) to be at least as old as the

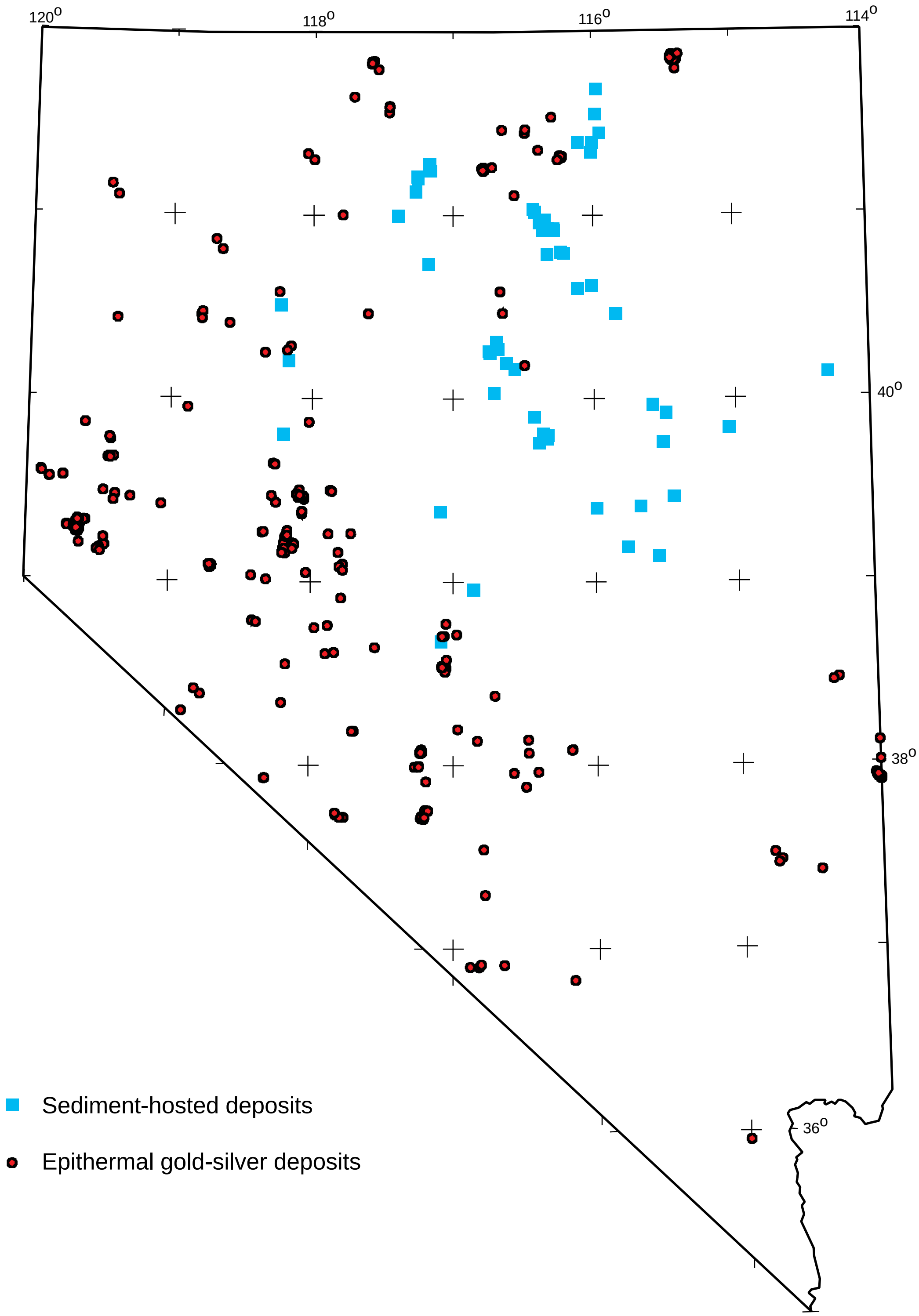

Figure 12-6. Distribution of sediment-hosted gold deposits in relation to epithermal gold-silver deposits.

earliest volcanic activity (22 Ma) in the Paradise Range.

This region is shown by Blakely and others (1988, and in chapter 3) to be characterized by a northwest trending grain in the pattern of magnetic anomalies that can be recognized about 50 km to the northeast of traditional boundaries of the Walker Lane that are based on topography and structure (fig. 12-7). This expanded area of characteristic magnetic fabric encompasses all of the volcanic-hosted epithermal districts in southwestern Nevada, some of which are as old as 26 Ma (Round Mountain) and several are 19-20 Ma in age (Tonopah, Goldfield, and Wonder districts). The northeastern boundary of this magnetic anomaly pattern coincides with a line separating calderas younger and older than 27 Ma (Best and others, 1989); the eastern boundary is the magnetic quiet zone (chapter 3). We believe that the Walker Lane deformation began locally at 27 Ma and continued during succeeding volcanic episodes until the beginning of Basin and Range deformation at about 11 Ma, thus controlling the distribution of epithermal precious-metal deposits in this portion of Nevada. A strong negative correlation exists between the magnetic quiet zone and the distribution of volcanic-hosted epithermal deposits. This is especially clear in the southern arm of the crescent where a gap exists between the deposits in the Walker Lane and the Atlanta and Stateline districts to the east in Lincoln County.

Two northwest-striking linear permissive areas in central Nevada were drawn to enclose basalt flows, dike swarms and linear magnetic anomalies associated with the northern Nevada rift (see chapter 3). The northern segment of this area contains the Fire Creek and Buckhorn hot-spring gold deposits. Basalt outcrops and magnetic anomalies die out at the southern end of this segment near Eureka, but shallow magnetic sources indicate a southern continuation that is slightly offset, but parallel to the northern one (see chapter 3). The Crown Point gold deposit near Currant may be related to this southern continuation, but Crown Point was not included in plate 10-2 or table 10-2 because of difficulties in classifying it. Gold occurs with limonite in fractures filled with quartz and calcite in silicified Mississippian limestone at the Crown Point Mine.

Tract 2 (plate 12-2), which outlines areas permissive for epithermal deposits, is based on the distribution of volcanic rocks, of epithermal mineral deposits, prospects, and occurrences, on the distribution of synvolcanic faults, and on the magnetic anomaly patterns described above. This tract covers 55% of Nevada; 47% of the tract is covered by superficial deposits younger than the mineralized rocks. The permissive tract is divided into two subtracts. Tract 2a is based on outcrop areas of volcanic rocks of the bimodal and western andesite assemblages and those parts of the interior andesite-rhyolite assemblage younger than 27 Ma, as well as areas where these rocks are covered, but are close enough to the surface to exhibit an aeromagnetic signature (chapter 3). Tract 2b includes sedimentary rocks within and between the volcanic rock areas that are permissive, but have a lower likelihood of undiscovered deposits. These areas are included because some epithermal deposits are known to occur in sedimentary rocks close to volcanic centers (Willard, Atlanta, Florida Canyon).

Epithermal Quartz-adularia Vein Districts

Quartz-adularia veins have been subdivided into three subtypes, Comstock, Sado, and Creede, based on their metal grades and the presumed character of the basement underlying the volcanic sequence in which they are found (Mosier and others 1986). The Comstock subtype, rich in silver and low in base metals, is generally found in volcanic rocks overlying low-grade metasedimentary basement rocks, and is, by far, the most abundant subtype in Nevada. The Creede type, rich in base metals, is not found in Nevada, and the Sado type, with low silver to gold ratio, makes up a very small proportion of the known deposits. Therefore the Comstock grade-tonnage model was applied to undiscovered quartz-adularia districts.

Quartz-adularia deposits occur with roughly the same frequency in all volcanic assemblages in Nevada. Statistical tests of grade, tonnage, and metal-ratio data from deposits in the three volcanic assemblages show no significant differences between the deposits in them, suggesting that local hydrologic, structural, or other conditions have greater influence on mineralization than type of volcanic host rock.

Our estimate of the number of undiscovered districts of the quartz-adularia type in tracts 2a and 2b was based on the following considerations:

1. A district is defined by the grade-tonnage model for Comstock epithermal veins (Mosier and others, 1986). Roughly 21 such districts are known in Nevada (chapter 10).
2. An additional eight districts are known that are too small in tonnage to fit the model. Some of these may be incompletely explored and present opportunities for the discovery of new districts.
3. Quartz-adularia vein systems will probably be found in the vicinity of some hot-spring gold deposits as exploration near these deposits proceeds. Where the hot-spring deposit is isolated from other known epithermal districts, these systems are considered to be evidence for undiscovered quartz-adularia districts.
4. Quartz adularia vein deposits can be detected by prospecting methods that have been employed in Nevada since the 1850s. Thus exploration for them in exposed permissive areas can be considered to be well advanced.
5. Known localities are mainly in areas of exposed permissive rock. Only one deposit, Sleeper, has been found beneath alluvium. Thus, the 47% of the permissive area under cover is likely to contain many undiscovered deposits.

We estimated that there is a 90% chance of 14 or more undiscovered districts, a 50% chance of 19 or more, and a 10% chance of 25 or more undiscovered districts that are consistent with the Comstock grade-tonnage model (Mosier and others, 1986).

Epithermal Quartz-alunite Gold Districts

The quartz-alunite deposit type requires the presence of extensive hypogene acid-sulfate alteration. The Goldfield district is the main example in Nevada and is one of the

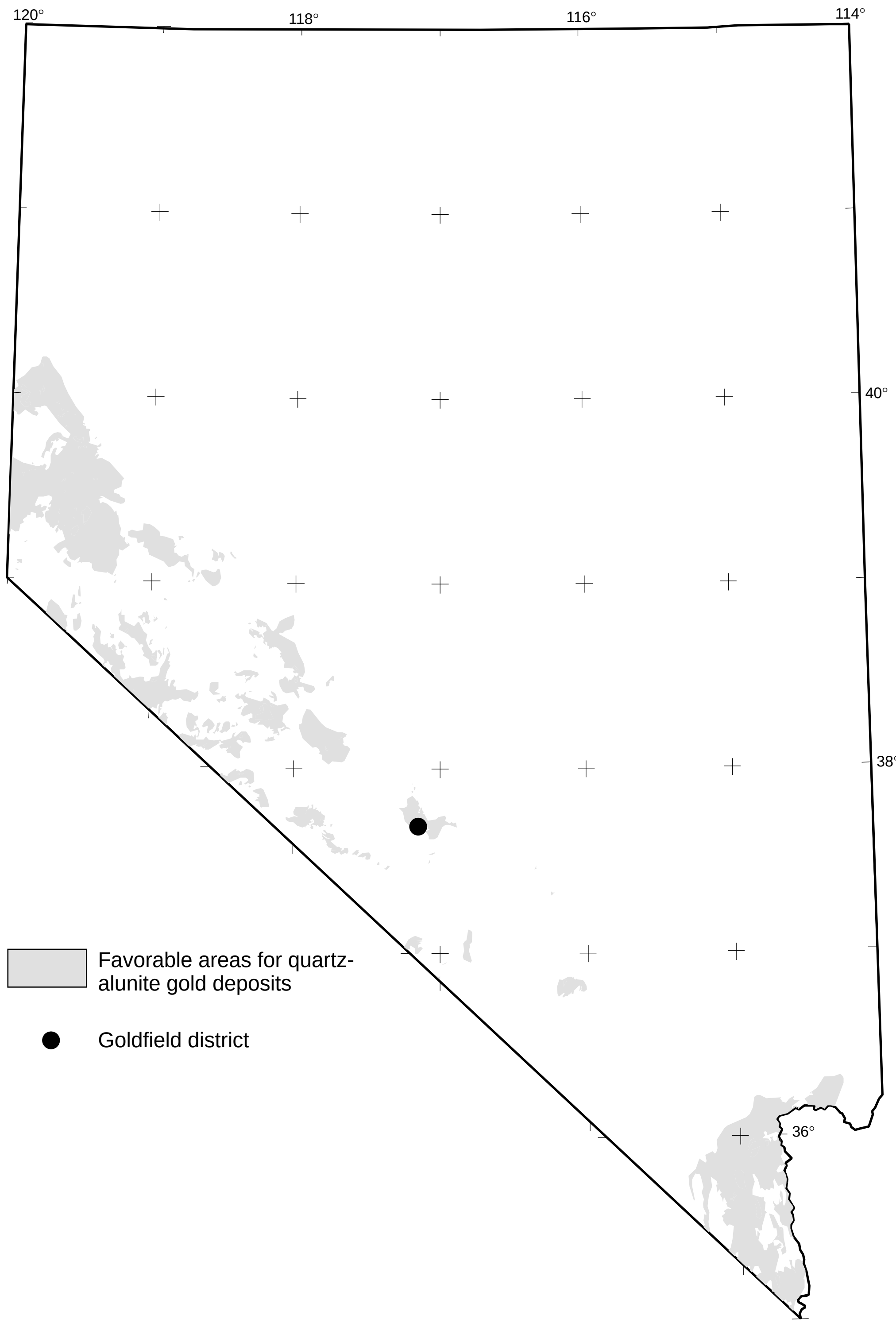

Figure 12-7. The favorable area for quartz-alunite gold deposits based on the distribution of volcanic rocks of the western andesite assemblage.

largest districts of this type in the world (Ransome, 1909; Ashley, 1990). At least six additional occurrences of hypogene alunite are known (chapter 10) in western Nevada, mainly in rocks of the western andesite assemblage. Alunite alteration locally affects pre-Miocene rocks but can be shown to be genetically related to western andesite assemblage volcanism (David John, written commun., 1993). Alunite alteration also occurs in the Alunite district near Las Vegas, in andesites that presumably belong to a southern extension of the western andesite assemblage.

Figure 12-7 shows the distribution of volcanic rocks of the western andesite assemblage disturbed by Tertiary faulting within the Walker Lane. This area, within permissive tracts 2 and 2b, is considered favorable for quartz-alunite deposits because nearly all of the occurrences of alunite alteration in Nevada are in andesitic rocks of the Walker Lane. As discussed previously, quartz-alunite districts may represent high-level extensions of porphyry copper systems and this favorable area is also considered permissive for that deposit type.

In our estimate of undiscovered districts, we considered the smaller area of tract 2b, and also our belief that these deposits form under special conditions of intense sulfidation, and are thus inherently less abundant than hot-spring and quartz-adularia deposits. We estimated that there is a 90% chance of two or more undiscovered districts, a 50% chance of six or more, and a 10% chance of 12 or more undiscovered districts in the delineated areas, consistent with the epithermal quartz-alunite grade-tonnage model (Mosier and Menzie, 1986b).

Hot-spring Gold-silver Deposits

Hot-spring Au deposits are disseminated or stockwork deposits that form near a paleosurface in volcanic rocks and, less commonly, in sedimentary rocks and alluvial sedimentary deposits (Berger, 1985). They are closely related to quartz-adularia and quartz-alunite gold deposits but we have tried to classify them separately because they are distinctly larger in tonnage and lower in grade. Because they grade downward into fissure veins, they are, in some cases, difficult to distinguish from the other types of epithermal gold deposits. Moreover, some epithermal deposits, mined by open pit methods, are more appropriately placed in the hot-spring category because of their reported tonnage and grade, even though evidence for a paleosurface is lacking.

The high-level environments permissive for hot-spring deposits are difficult to separate from those for other epithermal deposits using published geologic data. Thus, we did not delineate separately for the hot-spring gold deposits, and they share tracts 2a and 2b with the other epithermal deposits.

Of the 15 deposits classified as hot-spring gold deposits in Nevada, Round Mountain, the largest, is related to the interior andesite-rhyolite volcanic assemblage, and lies near the inner, eastern edge of the expanded Walker Lane belt. Borealis and Paradise Peak are associated with western andesite assemblage rocks, and the rest are in rocks of the bimodal basalt-rhyolite assemblage (e.g., Hog Ranch) and nearby sedimentary rocks or sedimentary deposits (e.g., Lewis). Seven deposits are located within 5 km of a rhyolite intrusion close in age to the time of mineralization. Buckhorn and Fire Creek are hosted in basaltic andesite and presumably lie above mafic dikes related to the Northern Nevada magnetic anomaly described by Blakely (1988).

Our estimate of the number of undiscovered deposits in these areas was influenced by the following considerations:

1. About 15 deposits are known and prospecting was in progress at seven or more additional localities at the time of preparing the estimate (1989-92).
2. MRDS records (chapter 10) contain 19 additional occurrences that have descriptions suggestive of hot-spring gold mineralization.
3. There is a common association of gold and hot-spring mercury deposits. Roughly 75 hot-spring mercury deposits and occurrences are described in the MRDS records for Nevada.
4. Most of these deposits and occurrences are in areas of exposed permissive rock. Additional permissive area, roughly equal to the exposed area, is covered by younger sedimentary deposits, and could conceal undiscovered deposits.
5. Because of their low grade and fine grain size of contained gold, hot-spring gold deposits are more difficult to detect by traditional exploration methods than vein deposits and most of the known deposits have been discovered since 1960. There has been no exploration during this period in the large portion of the permissive area within the Nevada Test Site.

We estimated that there is a 90% chance of 13 or more, a 50% chance of 18 or more, and a 10% chance of 23 or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the hot-spring gold grade and tonnage model (Berger and Singer, 1992).

Several other types of epithermal deposits occur in the tracts outlined above but, for various reasons, no estimates of numbers of undiscovered deposits were made.

Other Epithermal Deposits

Hot-spring mercury deposits occur in and near volcanic rocks of the bimodal and western andesite assemblages and in the younger (post-27 Ma) rocks of the interior andesite-rhyolite assemblage, sharing this area with quartz-adularia veins and hot-spring gold deposits (Rytuba and Heropoulos, 1992). Areas permissive for mercury deposits are the same as the tracts outlined for quartz-adularia and hot-spring deposits (tracts 2a, and b). The largest mercury district in Nevada, Mc Dermitt, is related to peralkaline rhyolites (Rytuba and Glanzman, 1979), but not enough is known about the chemical petrology of volcanic rocks in Nevada to draw a favorable area based on the distribution of peralkaline volcanic rocks.

Veins of stibnite belonging to the simple antimony model (Bliss and Orris, 1986a) are abundant in Nevada. Many of the deposits are concentrated in the crescent-shaped pattern along with other epithermal deposits suggesting a similar origin. However, some simple antimony deposits in Nevada are found associated with other deposit types in other environments of deposition, associated with sediment-hosted gold deposits, polymetallic vein and replacement deposits, and, locally, with tungsten skarn deposits. Because of these diverse associations, tracts permissive for simple antimony deposits cannot be delineated separately. This deposit type may occur in tracts delineated as permissive for quartz adularia veins and hot-spring gold deposits, sediment-hosted gold deposits, and in other tracts permissive for various skarn, replacement, and other pluton-related deposits. The simple antimony deposit model of Bliss (1986b) contains deposits dissimilar to those in Nevada and was not considered to be representative of known occurrences in the state. Thus, no numerical estimate of undiscovered deposits was made.

Epithermal manganese deposits have the same spatial pattern as quartz-adularia vein deposits. Of the 13 well described deposits in the State (chapter 10), 11 are in volcanic rocks of tract 2. Volcanogenic uranium deposits have a wider, less well defined distribution. Many deposits occur in sedimentary rocks of tract 2b.

Rhyolite-hosted tin deposits require a highly evolved rhyolite with a high fluorine content (often demonstrated by the presence of topaz) for their formation. Six areas of topaz rhyolite are shown in figure 12-2 that suggest the occurrence rhyolite-hosted tin as well as a possibility for Climax porphyry molybdenum deposits. Because this deposit type has no value as a source of tin in the United States, no estimate of undiscovered deposits was made.

SEDIMENT-HOSTED GOLD DEPOSITS

Delineation of tracts permissive for sediment-hosted gold deposits is the least constrained part of this statewide analysis of mineral resources. This is true because (1) the deposits occur in a wide variety of types and ages of host rock, (2) structures believed to control the distribution of deposits are not shown on published geologic maps, (3) direct determination of mineralization age by isotopic analysis is restricted by the lack of suitable minerals in the deposits, and (4) there is a lack of agreement about the genetic association of mineralization with igneous rocks, primarily because of the lack of age constraints.

During the last two decades of intensive exploration for gold, sediment-hosted gold deposits have not been found in significant numbers outside of the Great Basin. If these deposits are unique to this region, then, as pointed out by Seedorff (1991a), their origin must be related to some unique feature of the region. Speed and others (1988) show that this region is distinctive among other forelands in its great width, lack of extensive uplift and unroofing, and absence, on the oceanward side, of a colliding basement terrane. Berger and Henley (1989) point to the overthickening of the crust by thrust faulting as an important characteristic of the part of the Great Basin occupied by known sediment-hosted gold deposits, adding that tectonic stacking of marine sedimentary deposits could have created large reservoirs of connate water. Existence of such a fluid reservoir is suggested (Rose and Kuehn, 1987; Hofstra and others, 1988) by the geochemistry and isotopic composition (elevated $d^{18}O$, CO_2, H_2S, and Cl^-) in ore-stage fluid inclusions from sediment-hosted gold deposits.

Large parts of the crust in Nevada have been overthickened by crustal shortening along the active western margin of North America during the late Paleozoic and Mesozoic (Speed and others, 1988). The Roberts Mountains and Golconda assemblages (chapter 4) were thrust eastward during the Late Paleozoic Antler, and Triassic Sonoma orogenies, respectively. In the Cretaceous, several allochthons within the Paradise volcanic assemblage were thrust southeastward and stacked east of the Pine Nut fault and behind and atop the Golconda assemblage; thrust faulting resulted in thickening of Triassic rocks of the Jungo assemblage; eastern assemblage rocks were thickened by east-directed thrusting during the Elko and Sevier orogenies in much of northeastern Nevada (Thorman and others, 1991).

Based on the assumed relationship between crustal thickening and sediment-hosted gold deposits, all sedimentary and metasedimentary rocks within the area of tectonically thickened crust are delineated as permissive for sediment-hosted gold deposits (tract 3, plate 12-3). Tract delineation was based on distribution of the allochthons mentioned above, and, in the Sevier orogenic belt in eastern Nevada by patterns of folding and thrust faulting on the geologic map of Stewart and Carlson (1978). Tract 3 encompasses 62% of the area of Nevada; 77% of the tract is covered by Tertiary and Quaternary rocks and sedimentary deposits less than 1 km thick. We believe that sediment-hosted gold deposits are possible anywhere within tract 3. Known sediment-hosted gold deposits, however are concentrated in a more restricted area of north-central Nevada that is, in large part, distinct from the area in which Tertiary-age volcanic-hosted epithermal gold-silver deposits are known (fig. 12-6). During the Tertiary, the two deposit types were being formed at different times and in different places. We suggest that, after the beginning of synvolcanic faulting (about 27 Ma), conditions were no longer favorable for the formation of sediment-hosted gold deposits. Thus, unequivocal examples are not found southwest of the 27 Ma timeline (fig. 12-8).

In drawing a favorable area within this broad permissive tract we chose to ignore the traditional Carlin and Getchell trends (critically reviewed by Seedorff, 1991a) and to examine the favorability of features that have well understood geologic origins. Within tract 3, one area, containing 72% of the sediment-hosted deposits shown on plate 10-2, is delineated empirically as being more favorable for this deposit type (fig. 12-8). It includes sedimentary rocks of the Roberts Mountains and Paleozoic carbonate assemblages within 5 km, measured horizontally from the Roberts Mountains thrust and its extension along strike in the subsurface. The 5-km radius was selected to include rocks above and below the thrust that may have had increased fracture permeability due to deformation during thrust faulting. This tract extends southwestward into the area of volcanic activity younger than 27 Ma, but only two deposits (White Caps and Shale Pit) have been discovered there.

In the permissive tract and its extent downward to a depth of 1,000 m, we estimate that there is a 90% chance of 15 or more undiscovered deposits, 50% chance of 21 or more, and a 10% chance of 27 or more deposits that are consistent with the grade-tonnage model of Mosier and others (1992). Our estimate was mainly influenced by the high density of known deposits in exposed areas, and the large proportion of the permissive area that is concealed by less than 1 km of cover.

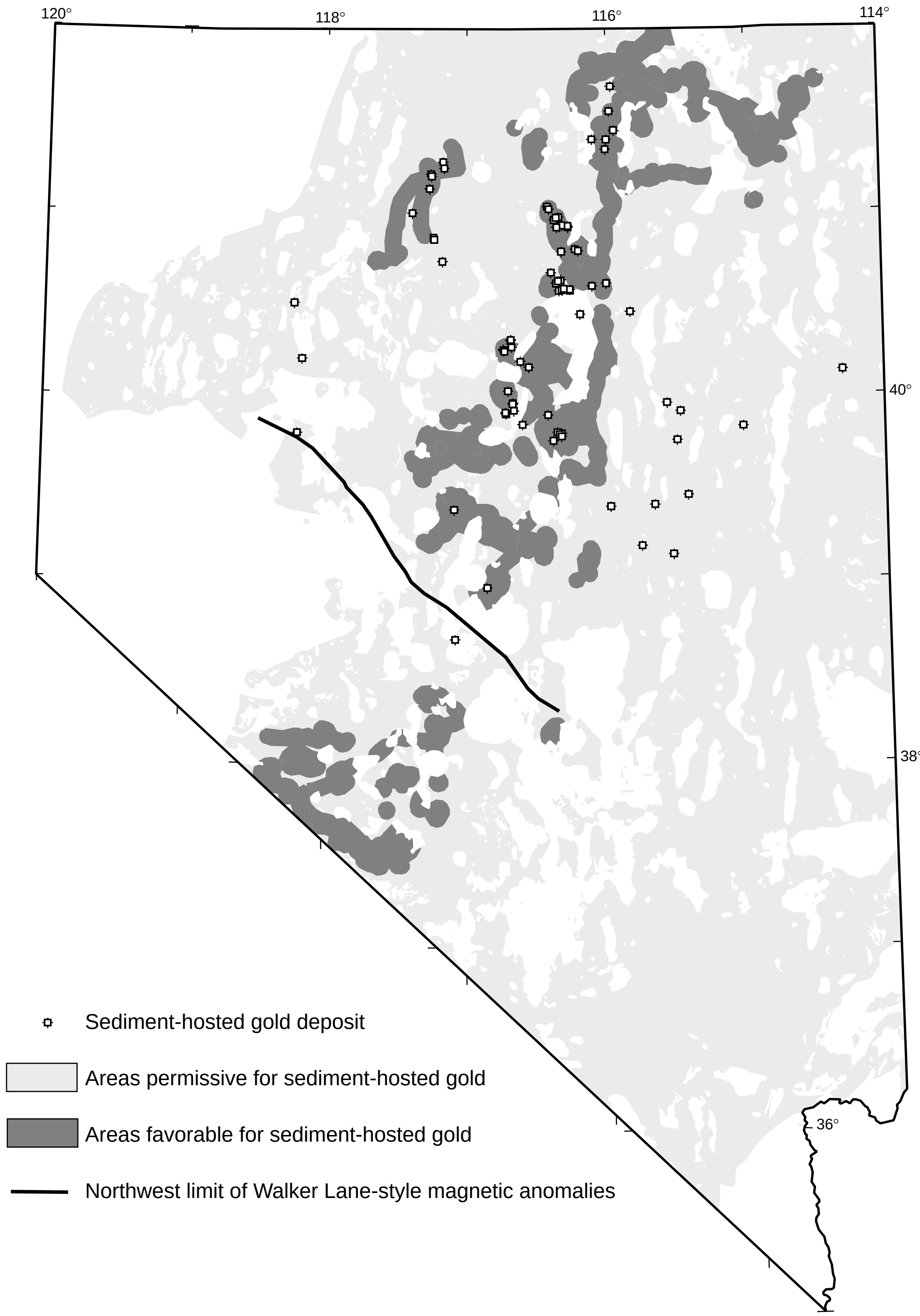

Figure 12-8. The permissive area for sediment-hosted gold deposits. Within this permissive area, the favorable area contains 70% of the known deposits. It is underlain by sedimentary rocks within 5 km of the Roberts Mountains thrust (see text for discussion). The heavy line is drawn through 27-Ma calderas and is the northeast limit of Walker Lane-style magnetic anomalies and abundant volcanic-hosted epithermal gold-silver deposits. Large sediment-hosted deposits are unknown southwest of this line.

DEPOSITS RELATED TO MARINE VOLCANIC ROCKS

Kuroko Massive Sulfide Deposits

Kuroko massive sulfide deposits contain massive iron, copper, zinc, lead sulfides and are found in island-arc volcanic rocks. The Black Rock assemblage (chapter 5) is delineated (plate 12-3, tract 4) as permissive for kuroko massive sulfide deposits because of the occurrence of intermediate to felsic marine volcanic rocks in many localities within it. Examples of kuroko deposits are rare and not well documented in Nevada. Sorensen and others (1987, p. B12) briefly described the Red Boy and other prospects that probably belong to this type in the South Jackson Mountains. Singer (1992) has shown that kuroko deposits of Triassic and Jurassic age as typified by deposits in the western foothills of the Sierra Nevada, tend to have lower tonnage than other kuroko deposits. A grade and tonnage model called Sierran kuroko is believed to better represent undiscovered deposits in tract 4.

Based on these occurrences, we estimate that there is a 90% chance of one or more undiscovered deposits, a 50% chance of three or more, and a 10% chance of six or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the Sierran kuroko massive sulfide model of Singer (1992).

Cyprus Massive Sulfide Deposits

Cyprus-type deposits contain mainly iron, copper, and minor zinc sulfides and occur in basinal oceanic or back-arc basalts (Constantinou, 1980). The Roberts Mountains and Golconda allochthons are believed to contain remnants of oceanic crust (chapter 5). Parts of these assemblages that contain volcanic rocks form a tract permissive for Cyprus massive sulfide deposits (plate 12-3, tract 5). The Golconda allochthon includes thick pillow basalt, chert, and turbidite, as well as scattered bodies of serpentine indicating an oceanic environment of deposition (Jones and Jones, 1991). Rye and others (1984) concluded from textural and isotopic studies that the Big Mike copper deposit, which occurs in basalt of the Golconda assemblage, is probably a Cyprus type deposit formed near a sea floor spreading center. The Roberts Mountains assemblage contains chert, argillite, and greenstone that also suggest an oceanic environment permissive for Cyprus-type deposits. The eastern part of the Roberts Mountains assemblage that is composed chiefly of shales of the Vinini Formation is considered less favorable for Cyprus-type deposits.

Based on the broad extent of the permissive area, and on the presence of one known deposit and one occurrence that might belong to this model (chapter 10), we estimate that there is a 90% chance of one or more undiscovered deposits, a 50% chance of two or more, and a 10% chance of five or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the Cyprus massive sulfide model of Singer and Mosier (1986).

Franciscan-type Volcanogenic Manganese

Tract 5 is also permissive for volcanogenic manganese deposits of the Franciscan type (Mosier and Page, 1987). Small deposits of stratiform manganese oxides are found in the Golconda allochthon. The Black Diablo Mine is the largest of this type in Nevada. Black Diablo's production of about 55,000 tonnes of ore places it in the upper 10% of Franciscan-type deposits. No estimate of undiscovered deposits was made because of the small tonnage and low economic value of deposits of this type. This tract is also permissive for Besshi-type deposits discussed below.

Besshi Massive Sulfide Deposits

Besshi deposits are stratabound, tabular bodies of massive iron, copper, and minor zinc sulfides found in sedimentary rocks in mafic volcanic environments (Fox, 1984). The Rio Tinto copper deposit at Mountain City (Coats and Stephens, 1968) occurs in graphitic shale of the Valmy Formation in the Roberts Mountains allochthon and has some similarity to Besshi deposits worldwide. It lacks a close association with mafic flow rocks, which are present in the best examples of the Besshi model in Japan, eastern U.S.A, and Norway. Tract 6 (plate 12-3), based on the distribution of rocks of the Roberts Mountains assemblage (chapter 4) is permissive for Besshi massive sulfide deposits. We estimate that there is a 50% chance of one or more undiscovered deposits, a 10% and 5% chance of two or more, and a 1% chance of three or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the Besshi massive sulfide model of Singer (1986).

DEPOSITS RELATED TO SEDIMENTARY ROCKS

The existence of the following types of deposits in Nevada is unsupported by known examples, and the presence of possible resources in them is therefore highly speculative. Artillery-type manganese deposits are an exception, but no grade-tonnage model exists for this type. Except for sedimentary exhalative deposits, no estimates of undiscovered deposits were made, and no permissive tracts were drawn.

Sedimentary Exhalative Zinc-lead (Sedex) Deposits

Sedimentary exhalative zinc-lead deposits, more conveniently referred to as sedex deposits are stratabound tabular bodies of massive zinc and lead sulfides in black shales, siltstones or carbonate rocks (Large, 1980). Turner and others (1989) noted similarities between the Roberts Mountains allochthon and lower Paleozoic strata in the northern Canadian Cordillera that host numerous large sedex deposits. Bedded barite deposits, which occur in close association with sedex deposits in some areas, are widespread in the allochthon. Ketner (1991) described stratabound gossans containing high values of lead, zinc, and silver in lower Middle Ordovician and Lower Silurian units of the Roberts Mountains assemblage in northeastern Nevada that are strongly suggestive of sedex deposits. We conclude that tract 6 (the Roberts Mountains assemblage) is permissive for sedex deposits. The eastern part of the tract, underlain by shale and chert of the Vinini Formation probably has a higher probability of deposits because these rocks are most similar to host rocks described for the deposit model. Sedex deposits are large and high grade (Menzie and Mosier, 1986), and a discovery of such a deposit would have a major effect on Nevada's mining economy. We estimate that there is a 90% chance of zero or more undiscovered deposits, a 50% chance of zero or more, a 10% chance of one or more, a 5% chance of three or more, and a 1% chance of five or more undiscovered deposits in the delineated area that are comparable in grade and tonnage to the sedimentary exhalative Zn-Pb deposits of Menzie and Mosier (1986).

Mississippi Valley Deposits

Thick, regionally extensive carbonate rocks are permissive for Southeast Missouri Pb-Zn and Appalachian Zn subtypes of Mississippi Valley type deposits, but no clearly defined examples of such deposits are known in the Basin and Range. Callahan (1977) pointed to similarities in geologic environments between the Cordilleran region and the Mississippi Valley and Appalachian miogeosyncline. Others noted similarities in mineralization patterns between deposits of the Mississippi Valley type and deposits in the Goodsprings district (Hewett, 1931, p. 100) and near Pioche (James and Knight, 1979), suggesting that parts of some polymetallic replacement districts in the Great Basin were formed by early diagenetic processes and later modified by igneous-related hydrothermal events.

As reviewed by Leach and Rowan (1986), Mississippi Valley deposits are believed to result from the deposition of metals carried in basinal brines that have migrated outward from fold belts containing deformed and uplifted sedimentary basins. In applying such a process model to Nevada, Late Paleozoic and Mesozoic orogenies could be expected to have driven mineralizing fluids through much of the basal clastic, and lower and upper carbonate assemblages of eastern and southern Nevada. Appalachian Zn deposits are formed where fluid flow intersects with karsted terrane beneath regional unconformities. At least two such unconformities are believed to exist in Nevada: one during the early Devonian and another preceding the Pennsylvanian Period (Matti and McKee, 1977; Augustus Armstrong, written commun., 1992). Existing geologic maps make it difficult, however, to delineate tracts in Nevada containing unconformities in carbonate rocks of these ages.

Artillery Manganese Deposits

Artillery-type manganese deposits are formed in lacustrine sedimentary rocks deposited in conditions of extreme crustal extension and volcanism. The Miocene Horse Spring and Muddy Creek Formations that host two examples of this deposit type in Nevada represent this environment and are permissive for the deposit type.

Sediment-hosted Copper and Kipushi-type Deposits

Stratabound and pipelike bodies of copper, silver and other metal sulfides with high metal to sulfur ratios occur in sedimentary strata associated with evaporites (Kirkham, 1989; Cox and Bernstein, 1986). Evaporite environments may be considered to be sources of brine capable of leaching and transporting copper and other metals in oxidized sedimentary rocks. These metals may be deposited as sulfides where brines interact with reduced sedimentary beds. The presence of evaporites in Nevada is indicated by two clusters of gypsum deposits; one in Clark County in strata of Pennsylvanian-Permian and Triassic age and another in west-central Nevada in Jurassic rocks (Papke, 1987). Permian redbeds in Clark County (Longwell and others, 1965) could serve as sources of copper, and the overlying Kaibab Formation could have formed traps for sediment-hosted Cu deposits. No occurrences of this deposit type are known in Nevada, but a silver-rich variant of the type, known as the Silver Reef district occurs in redbeds of the Triassic Chinle Formation in southwest Utah (Proctor, 1953).

Sediment-hosted copper deposits may also exist in the Jungo, Pine Nut, and Mesozoic carbonate assemblages in west-central Nevada. The presence of gypsum deposits indicates that evaporite basins were present. Brines derived from these evaporites could have acted as scavengers of copper and other metals from any oxidized sedimentary rocks in the vicinity and deposited copper in overlying marine sediments.

Dolomites of Pennsylvanian age in southeast Nevada are permissive for Kipushi copper-lead-zinc deposits based on the occurrence of a deposit of that type, the Apex copper-germanium-gallium deposit, in southwest Utah (Bernstein, 1986).

CONCLUSIONS

Table 12-1 shows the predicted number of undiscovered deposits or districts for 18 deposit types. These numbers reflect the fact that a 1 km thickness of crust is being considered and that more than half the area of the permissive tracts of Nevada is covered by less than 1 km of postmineral rock or sediment.

This analysis of the mineral resources of Nevada is based on mineral deposit models, and is limited to the kinds of mineral concentrations that are well recognized, the kinds that we can model. For base and precious metals, these models account for 78 to 92% of all of these metals discovered throughout the world to date (Singer, 1995). Deposit models are not fixed entities. Old models will be discarded, and new models will emerge in the constantly changing ambience of earth science, mining technology, and economic demand. If this analysis had been carried out a century ago, many important deposit models including porphyry copper would not have been included, resulting in totally different conclusions about the mineral wealth of Nevada. Forty years ago our analysis would have failed to recognize the sediment-hosted gold deposits which would have resulted in a serious underestimation of Nevada's gold resources.

As pointed out by McKelvey (1959) mineral resources result from the combination of geologic endowment and human ingenuity. Continued application of this ingenuity to Nevada with its rich variety of geologic environments will yield new mineral discoveries and a growing list of deposit models to aid in further exploration.

REFERENCES

Abbott, E.W., Laux, D.P., and Keith, S.B., 1991, Geochemistry and ore deposits—Influence of magma chemistry; Field trip 8, *in* Buffa, R.H, and Coyer, A.R., eds., Geology and ore deposits of the Great Basin field trip guidebook compendium: Reno, Geological Society of Nevada, April 1990, p. 401-590.

Anderson, E.R., 1981, Structural ties between the Great Basin and Sonoran Desert sections of the Basin and Range Province: U.S. Geological Survey Open-File Report 81-503, p. 4-6.

Ashley, R.P., 1990, The Goldfield district, Esmeralda and Nye Counties, p. 1-7, *in* Shawe, D.R. and Ashley, R.P. eds., Epithermal gold deposits—part 1, Geology and resources of gold in the United States: U.S. Geological Survey Bulletin 1857-H, 31 p.

Barton, M.D. and Trim, H.E., 1991, Late Cretaceous two-mica granites and lithophile-element mineralization in the Great Basin, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 1, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 529-538.

Bercaw, L.B., Atinson, W.W., and Nielson, R.L., 1987, Geology and gold deposits of central Mineral Ridge, Esmeralda County, Nevada: Geological Society of America Abstracts with Program, v. 19, no. 5, p. 260.

Berger, B.R., 1985, Geologic-geochemical features of hot-spring precious metal deposits, *in* Tooker, E.W., ed., Geologic characteristics of sediment- and volcanic-hosted disseminated gold deposits—search for an occurrence model: U.S. Geological Survey Bulletin 1646, p. 47-48.

Berger, B.R. and Henley, R.W., 1989, Advances in the understanding of epithermal gold-silver deposits, with special reference to the western United States *in* Keays, R.R., Ramsay, W.R.H., and Groves D.I., eds., The Geology of Gold Deposits: the Perspective in 1988: Economic Geology Monograph 6, p. 405-423.

Berger, B.R., and Singer, D.A., 1992, Grade and tonnage model of hot-spring Au-Ag, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 23-25.

Bernstein, L.R., 1986, Geology and mineralogy of the Apex germanium-gallium mine, Washington County, Utah: U.S. Geological Survey Bulletin 1577, 9 p.

Best, M.G., Christiansen, E.H., Deino, A.L., Grommé, C.S., McKee, E. H., and Noble, D.C. 1989, Excursion 3A: Eocene through Miocene volcanism in the Breat Basin of the western United States: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 91-133.

Blakely, R. J., 1988, Curie temperature isotherm analysis and tectonic implications of aeromagnetic data from Nevada, Journal of Geophysical Research, v. 93, p. 11,817-11,832.

Bliss, J.D., 1992, Grade and tonnage model of Chugach-type low-sulfide Au-quartz veins, in Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 44-46.

Bliss, J.D., and Cox, D.P., 1986, Grade and tonnage model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125-129.

Bliss, J.D., and Orris, G.J., 1986a, Descriptive model of simple antimony deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 183.

Bliss, J.D., and Orris, G.J., 1986b, Grade and tonnage model of simple antimony deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 184-188.

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

Callahan, W.H., 1977, Some thoughts regarding premises and procedures for prospecting for base metal ores in carbonate rocks in the North American Cordillera: Economic Geology, v. 72, p. 71-81.

Christiansen, E.H., Sheridan, M.F., and Burt, D.M., 1986, The geology and geochemistry of Cenozoic topaz rhyolites from the western United States: Geological Society of America Special Paper 205, 82 p.

Coats, R.R., and Stephens, E.C., 1968, Mountain City Copper Mine, Elko County, Nevada, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933-1967 (Graton Sales Volume), v. 2: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 1074-1101.

Chung, C.F., Singer, D.A., and Menzie, W.D., 1992, Predicting the sizes of undiscovered mineral deposits: an example using mercury deposits of California: Economic Geology, v. 87, p. 1174-1179.

Clark, W.B., 1977, Mines and mineral resources of Alpine County, California: California Division of Mines and Geology County Report 8, 48 p.

Constantinou, G., 1980, Metallogenesis associated with Troodos ophiolite, *in* Panayoutou, A., ed., Ophiolites, Proceedings International Ophiolite Symposium, Nicosia, Cyprus 1979: Cyprus Geological Survey Department, p. 663-674.

Cox, D.P., 1986a, Descriptive model of Cu-As-Sb deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 110.

Cox, D.P., 1986b, Descriptive model of porphyry copper deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76.

Cox, D.P., 1986c, Descriptive model of volcanic-hosted magnetite, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 172.

Cox, D.P., and Bernstein, L.R., 1986, Descriptive model of Kipushi Cu-Pb-Zn, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 227.

Cox, D.P., Ludington, Steve, Sherlock, M.G., Singer, D.A., Berger, B.R., and Tingley, J.V., 1991, Mineralization patterns in time and space in the Great Basin of Nevada, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 2, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 193-198.

Cox, D.P., and Singer, D.A., 1992, Descriptive and grade and tonnage models of distal-disseminated Ag-Au, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 19-22.

Einaudi, M.T., Meinert, L.D., and Newberry, R.J., 1981, Skarn deposits, p. 317-391, *in* Skinner, B.J., ed., Seventy-fifth anniversary volume, 1905-1980, Economic Geology: New Haven, Connecticut, The Economic Geology Publishing Co., 964 p.

Fife, D.L., 1987, Mesothermal gold mineralization—Skidoo-Del Norte mines, Death Valley, Inyo County: California Geology, v. 40, April 1987, p. 86-93.

Fox, J.S., 1984, Besshi-type volcanogenic sulphide deposits—a review: Canadian Mining and Metallurgical Bulletin, v. 77, p. 57-68.

Gans, P.B., Mahood, G.A., and Schermer, E. 1989, Synextensional magmatism in the Basin and Range Province; a case study from the eastern Great Basin: Geological Society of America Special Paper 233, 58 p.

Hammarstrom, J.M., Orris, G.J., Bliss, J.D., and Theodore, T.G., A deposit model for gold-bearing skarns, *in* Schindler, K.S., ed., USGS Research on Mineral Resources-1989, Program and abstracts Fifth Annual V. E. McKelvey Program on Mineral and Energy Resources: U.S. Geological Survey Circular 1035, p. 27-28.

Hewett, D.F., 1931, Geology and ore deposits of the Goodspings quadrangle, Nevada; U.S. Geological Survey Professional Paper 162, 171 p.

Hofstra, A.H., Landis, G.P., Leventhal, J.S., Northrop, H.R., Rye, R.O., Doe, T.C.,and Dahl, A.R.., 1991, Genesis of sediment-hosted, disseminated gold deposits by fluid mixing and sulfidation of iron in the host rocks—chemical reaction path modeling of ore depositional processes at Jerritt Canyon, Nevada, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 1, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 235-238.

Hudson, D.M., 1983, Alteration and geochemical characteristics of the upper parts of selected porphyry systems, Western Nevada [Ph.D. dissert.]: University of Nevada, Reno, 229 p.

Ivosevic, S.W., 1978, Johnnie gold district, Nevada, and implications on regional stratigraphic controls: Economic Geology, v. 73, p.100-105.

James, L.P., and Knight, L.H., 1979, Statabound lead-zinc-silver ores of the Pioche district, Nevada—unusual "Mississippi Valley deposits, *in* Newman, G.W. and Goode, H.D., eds. Basin and Range Symposium: Denver, Rocky Mountain Association of Geologists, p. 389-395.

Jerome, S.E., and Cook, D.R., 1967, Relation of some metal mining districts in western United States to regional tectonic environments and igneous activity: Nevada Bureau of Mines and Geology Bulletin 69, 35 p.

John, D.A.,Thomason, R.E., and McKee, E.H., 1989, Geology and geochronology of the Paradise Peak Mine and the relationship of pre-Basin and Range extension to early Miocene precious metal mineralization in west-central Nevada: Economic Geology, v. 84, p. 631-649.

Jones, A., E., and Jones, D.L., 1991, Paleogeographic significance of subterranes of the Golconda allochthon, northern Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin—Symposium proceedings, Geological Society of Nevada, Reno, Nevada, p. 21-23.

Jones, G.W. and Menzie, W.D., 1986a Grade-tonnage model of Cu skarns, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 86-89.

Jones, G.W. and Menzie, W.D., 1986b Grade-tonnage model of W veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 65-66.

Ketner, K.B., 1991, Stratigraphy and strata-bound, lead-zinc-barium mineralization of lower Paleozoic rocks in northeastern Nevada, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 2, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 539-551.

Kirkham, R.V., 1989, Distribution, settings, and genesis of sediment-hosted stratiform copper deposits, *in* Boyle, R.W., Brown, A.C., Jefferson, C.W., Jowett, E.C., and Kirkham, R.V. eds., Sediment-hosted Stratiform Copper Deposits: Geological Association of Canada Special Paper 36, p. 3-38.

Large, D.E., 1980, Geologic parameters associated with sediment-hosted, submarine exhalative Pb-Zn deposits: An empirical model for mineral exploration, *in* Stratiform Cu-Pb-Zn deposits: Geologisches Jahrbuch, series D, v. 40, p. 59-129.

Leach, D.L., and Rowan, E.L., 1986, Genetic link between Ouachita foldbelt tectonism and Mississippi Valley lead-zinc deposits of the Ozarks: Geology, v. 14, p. 931-935.

Long, K.R., 1992, Preliminary descriptive deposit model for detachment-fault-related mineralization, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004.

Longwell, C.R., Pampeyan, B.B., and Roberts, R. J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines and Geology Bulletin 62, 218 p.

Ludington, Steve, Cox, D.P., Sherlock, M.G., Singer, D.A., Berger, B.R.,and Tingley, Joe, 1993, Spatial and Temporal analysis of precious-metal deposits for a mineral resource assessment of Nevada, *in* Kirkham, R.V., Sinclair, R.V., Thorpe, W.D., and Duke, J.M., eds., Mineral deposit modeling: Geological Association Canada Special Paper 40, p. 31-40.

Matti, J.C., and McKee, E.H., 1977, Silurian and Devonian paleogeography of the outer continental shelf of the cordilleran miogeocline, central Nevada, *in* Stewart, J.H., Stevens, G.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States, Pacific Paleogeography Symposium I: Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, Calif., p. 181-215.

McKee, E. H., and Coats, R. R., 1975, K-Ar age of ore deposition, Tuscarora mining district, Elko County, Nevada: Isochron/West, no. 8, p.11-12.

McKelvey, V.E., 1959, Resources, population growth and level of living: Science, v. 129, p. 875-881.

Meinert, L.D., 1989, Gold skarn deposits—geology and exploration criteria, *in* Keays, R.R., Ramsay, W.R.H., and Groves D.I., eds., The Geology of Gold Deposits: the Perspective in 1988: Economic Geology Monograph 6, p. 537-552.

Menzie, W.D. and Jones, G.M., 1986, Grade-tonnage model of W-skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 55-57.

Menzie, W.D., and Mosier, D.L., 1986, Grade-tonnage model of sedimentary exhalative Zn-Pb, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 212-215.

Menzie, W.D., and Theodore, T.G., 1986, Grade-tonnage model of porphyry Mo, low-F, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 120-122.

Mosier, D.L., and Menzie, W.D., 1986a, Grade-tonnage model of Fe skarns, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 94-97.

Mosier, D.L., and Menzie, W.D., 1986b, Grade-tonnage model of epithermal quartz-alunite veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 159-161.

Mosier, D.L., and Page, N.J, 1987, Descriptive and grade-tonnage models of volcanogenic manganese deposits in oceanic environments—a modification: U.S. Geological Survey Bulletin 1811, 63 p.

Mosier, D.L., Sato, Takeo, and Singer, D.A., 1986, Grade-tonnage model of Comstock epithermal veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 151-153.

Mosier, D.L., Singer D.A., Bagby, W.C., and Menzie, W. D., 1992, Grade and tonnage model of sediment-hosted Au, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 26-28.

Mutschler, F.E., Wright, E.G., Ludington, Steve, and Abbott, J.T., 1981, Granite molybdenite systems: Economic Geology, v. 76, p. 874-897.

Noble, J.A., 1970, Metal provinces in western United States: Geological Society of America Bulletin, v. 81, p. 1607-1624.

Page, B.M., 1959, Geology of the Candelaria mining district, Mineral county, Nevada: Nevada Bureau of Mines and Geology Bulletin 56, 67 p.

Papke, K.G., 1987, Gypsum deposits in Nevada: Nevada Bureau of Mines and Geology Bulletin 103, 26 p.

Proctor, P.D., 1953, Geology of the Silver Reef (Harrisburg) district, Washington County, Utah: Utah Geological and Mineralogical Survey Bulletin 44, 169 p.

Proffett, J.M., 1977, Cenozoic geology of the Yerington district, Nevada, and implications for the nature of Basin and Range faulting: Geological Society of America Bulletin, v. 88, p. 247-266.

Ransome, F.L., 1909, Geology and ore deposits of Goldfield, Nevada: U.S. Geological Survey Professional Paper 66, 258 p.

Roberts, R.J., 1966, Metallogenic provinces and mineral belts in Nevada: Nevada Bureau of Mines Report 13 Part A, p. 47-72.

Rose, A.W., and Kuehn, C.A., 1987, Ore deposition from highly acidic CO_2-enriched solutions at the Carlin gold deposit, Eureka County, Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 19, no 7, p. 824.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Nonrenewable Resources, v. 1, p. 125-138.

Rye, R.O., Roberts, R.J., Snyder, W.S., Lahusen, G.L., and Motica, J.E., 1984, Textural and isotopic studies of the Big Mike cupriferous volcanogenic massive sulfide deposit, Pershing County, Nevada: Economic Geology, v. 79, p. 124-140.

Rytuba, J.J. and Cox, D.P., 1991, Porphyry gold: a supplement to U. S. Geological Survey Bulletin 1693: U. S. Geological Survey Open File Report 91-116, 5 p.

Rytuba, J.J., and Glanzman, R.K., 1979, Relation of mercury, uranium, and lithium deposits to the McDermitt caldera complex, Nevada-Oregon,in Ridge, J.D., ed., Papers on mineral deposits of western North America: Nevada Bureau of Mines and Geology: Nevada Bureau of Mines and Geology, Report 33, p. 109-117.

Rytuba, J.J., and Heropoulus, Chris, 1992, Mercury in epithermal gold systems—an important by-product: U.S. Geological Survey Bulletin 1877, p. D1-D8.

Seedorff, Eric, 1991a, Magmatism, extension, and ore deposition of Eocene to Holocene age in the Great Basin—mutual effects and preliminary proposed genetic relationships, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 1, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 133-178.

Seedorff, Eric, 1991b, Royston district, western Nevada—a Mesozoic porphyry copper system that was tilted and dismembered by Tertiary normal faults, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 1, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 359-391.

Silberman, M.L., Stewart, J.H., and McKee, E.H., 1976, Igneous activity, tectonics and precious metal mineralization in the Great Basin during Cenozoic time: Society of Mining Engineers, AIME Transactions, v. 260, p. 253-263.

Sillitoe, R.H. and Bonham, H.F., 1990, Sediment-hosted gold deposits: distal products of magmatic-hydrothermal systems: Geology, v. 18, p. 157-161.

Singer, D.A., 1986, Grade-tonnage model of Besshi massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 136-138.

Singer, D.A., 1992, Grade and tonnage model of Sierran kuroko deposits, *in* Bliss, J.D., ed., Developments in deposit modeling: U.S. Geological Survey Bulletin 2004, p. 29-32.

Singer, D.A., 1993, Basic concepts in three-part quantitative assessments of undiscovered mineral resources: Nonrenewable Resources, v. 2, no. 2, p. 69-81.

Singer, D.A., 1995, World class base and precious metal deposits—a quantitative analysis: Economic Geology, v. 90, p. 88-104.

Singer, D.A. and Mosier, D.L., 1981, The relation between exploration economics and the characteristics of mineral deposits, *in* Ramsey, J.B., ed., The Economics of Exploration for Energy Resources: Greenwich, Connecticut, JAI Press, p. 313-326.

Singer, D.A., and Mosier, D.L., 1986, Grade-tonnage model of Cyprus massive sulfide, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 131-135.

Singer, D.A., Mosier, D.L., and Cox, D.P., 1986a, Grade-tonnage model of porphyry copper, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 77-81.

Singer, D.A., Theodore, T.G., and Mosier, D.L., 1986b, Grade-tonnage model of Climax Mo, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 73-75.

Sorensen, M.L., Plouff, Donald, and Turner, R.L., 1987, Mineral resources of the South Jackson Mountains Wilderness Study Area, Humboldt County, Nevada: U.S. Geological Survey Bulletin 1726, 12 p.

Speed, R.C., Elison, M.W., and Heck, F.R., 1988, Phanerozoic tectonic evolution of the Great Basin, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States (Rubey Volume VII): Englewood Cliffs, New Jersey, Prentice Hall, p. 572-605.

Spurr, J.E., 1906, Ore deposits of the Silver Peak Quadrangle, Nevada: U.S. Geological Survey Professional Paper 55, 174 p.

Stager, H.K. and Tingley, J.V., 1988, Tungsten deposits of Nevada: Nevada Bureau of Mines and Geology Bulletin 105, p.105 and 206.

Stewart, J.H., 1980, Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

Stewart, J.H., 1983, Cenozoic structure and tectonics of the northern Basin and Range Province, California, Nevada, and Utah: Geothermal Resources Council, Special report n. 13, p. 25-40.

Stewart, J.H., 1988, Tectonics of the Walker lane belt, western Great Basin—Mesozoic and Cenozoic deformation in a shear zone, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States (Rubey Volume VII): Englewood Cliffs, New Jersey, Prentice Hall, p. 683-713.

Stewart, J.H., and Carlson, J.E., 1978, Geologic map of Nevada: U. S. Geological Survey, scale 1:500,000.

Stewart, J.H., Moore, W.J., and Zietz, Isidore, 1977, East-west patterns of Cenozoic igneous rocks, aeromagnetic anomalies, and mineral deposits, Nevada and Utah: Geological Society of America Bulletin, v.88, p. 67-77.

Theodore, T.G., Orris, G.J., Hammarstrom, J.M., and Bliss, J.D., 1991, Gold-bearing skarns: U.S. Geological Survey Bulletin 1930, 61 p.

Theodore, T.G., 1986, Descriptive model of porphyry Mo, low-F, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 120.

Theodore, T.G, Blake, D.W., Louks, T.A., and Johnson, C.A., 1992, Geology of the Buckingham stockwork molybdenum deposit and surrounding area, Lander County, Nevada: U.S. Geological Survey Professional Paper 798-D, 307 p.

Thorman, C.H., Ketner, K.B., Brooks, W.E., Snee, L.W., and Zimmermann, R.A., 1991, Late Mesozoic-Cenozoic tectonics in northeastern Nevada, *in* Raines, G. L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, v. 1, Symposium Proceedings: Reno, Geological Society of Nevada, April 1990, p. 25-46.

Titley, S.R., 1982, The style and progress of mineralization and alteration in porphyry copper deposits, *in* Titley, S.R., ed. Advances in geology of the porphyry copper deposits—southwestern North America: Tucson AZ, Univ. of Arizona Press, p. 93-116.

Turner, R.J.W., Madrid, R.J., and Miller, E.L., 1989, Roberts Mountains allochthon: comparison with lower Paleozoic outer continental margin strata from the northern Canadian Cordillera: Geology, v. 17, p. 341-344.

Vikre, P.G., 1981, Silver mineralization in the Rochester district, Pershing County, Nevada: Economic Geology, v. 76, p. 580-609.

Vila, Tomás and Sillitoe, R.H., 1991, Gold-rich porphyry systems in the Maricunga belt, northern Chile: Economic Geology, v. 86, p. 1238-1260.

Wallace, A.B. 1979, Possible signatures of buried porphyry copper deposits in middle to late Tertiary volcanic rocks of Western Nevada, *in* Ridge, J.D., ed., Proceedings of the fifth quadrennial IAGOD symposium: Reno, University of Nevada, Mackay School of Mines, v. 2, p. 69-76.

Westra, Gerhard, 1982, The Mount Hope stockwork molybdenum deposits: Geology Society of America Abstracts with Programs, v. 14, p. 646.

White, W.H., Bookstrom, A.A., Kamilli, R.J., Ganster, M.W., Smith, R.P., Ranta, D.E., and Steininger, R.C., 1981, Character and origin of Climax type molybdenum deposits, *in* Skinner, B.J., ed., Economic Geology, 75th Anniversary Volume: Economic Geology Publishing Company, p. 270-316.

Wilkins, Joe, Jr., 1984, The distribution of gold and silver-bearing deposits in the Basin and Range Province, western United States, *in* Wilkins, Joe, Jr., ed, Gold and silver deposits of the Basin and Range Province, western U.S.A.: Arizona Geological Digest, v. 15, p 1-27.

Woodward, L. A., 1972, Upper Precambrian strata of the eastern Great Basin as potential host rocks for mineralization: Economic Geology, v. 67, p. 677-681.