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Evaluation of selected metallic and nonmetallic mineral resources, West Mojave Management Area, southern California

by

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U.S. Geological Survey (USGS)

Executive summary

- The West Mojave Management Area comprises some 8.7 million acres in the western Mojave Desert, southern California, in which the U.S. Bureau of Land Management along with the U.S. Fish and Wildlife Service and California Department of Fish and Game are cooperating in a management planning effort focused on desert tortoise and Mohave ground squirrel habitat.

- This mineral-resource assessment, prepared in 6 months, is based upon published literature, various available geophysical and geochemical databases, and mineral-occurrence inventories. No field verification was possible. Conclusions of this report are preliminary and serve as guidelines for the U.S. Bureau of Land Management.

- Large areas of the management area contain abundant direct and indirect indications of metallic and nonmetallic mineralization.

- The estimated *mean* undiscovered metal and nonmetal content in 12 types of deposits in the management area is 22 million tonnes of borate (40% probability), 19 million tonnes of iron (35% probability), 710 tonnes of silver (30% probability), 100 tonnes of gold (25% probability), 652,000 tonnes of copper (20% probability), 14,900 tonnes of lead (15% probability), 15,700 tonnes of zinc (10% probability), 9,800 tonnes of molybdenum (10% probability), and 590 tonnes of tungsten (<10% probability). At lower probabilities, the estimates of undiscovered metals in the types of deposits evaluated will increase. Undiscovered metallic and nonmetallic resources are also reported for each of the deposits evaluated

- The estimates are only partial estimates of the undiscovered mineral endowment and do not include estimates for deposit types for which grade and tonnage models are not available. The estimates are based upon 12 types of metallic and nonmetallic deposits for which adequate information was available, including grade and tonnage models. An additional 30 metallic and nonmetallic deposit types are known or might be present in the management area. Of these, qualitative estimates are made for two metallic deposit types, but these estimates can not be compared in any simple way to the quantitative estimates. Of the remaining deposits, many are of nonmetallic commodities. The value of the additional nonmetallic deposits not included in the above estimates is probably greater than that of the metallic deposits.

- Of the mineral-deposit types evaluated, iron skarn, lacustrine borate, hot spring gold, polymetallic vein districts, and quartz-alunite gold are most likely to be present.

- The USGS assessment involved a core team of 6 geologists with expertise in geology, geochemistry, geophysics, mineral deposits, and resource analysis. An additional 10 geologists were involved in various capacities during the course of the assessment.

- Estimates of undiscovered mineral resources were made to a depth of 3,280 feet (1 kilometer), which is commonly accessible by known methods of underground mining.

- Details of the assessment follow.

SUMMARY

The West Mojave Management Area encompasses some 35,200 square kilometers (8,700,000 acres) in the western Mojave Desert of southern California (fig. 1). Within this region, the Bureau of Land Management (BLM), in cooperation with the U.S. Fish and Wildlife Service and California Department of Fish and Game, is coordinating a multiagency planning effort focused on the desert tortoise and the Mohave ground squirrel. This report contributes to the planning effort by evaluating selected undiscovered metallic and nonmetallic mineral resources of this region, and presenting the resulting quantitative estimates of the undiscovered mineral resources in the management area. Additional qualitative estimates are made for two metallic deposit types, and these deposits contribute to the overall undiscovered mineral resources in the management area.

The region that includes the West Mojave Management Area has been the site of mineral exploration and mining activity for a variety of minerals for much of this and the previous century. Deposits and occurrences of gold, silver, base metals (copper, lead, zinc) with associated precious metals (gold, silver), iron, tungsten, borate, zeolite, saline brines, geothermal power, and a wide variety of nonmetallic minerals and construction material have been developed, are being produced, or are known to be present within the study area. These mineral occurrences and ore deposits were classified by deposit type using existing deposit models (table 1). Only those deposits that were sufficiently like those that define the descriptive, grade, and tonnage models were classified by deposit types. These deposits types were grouped into larger categories based on common associations for the purposes of delineation of permissive terranes. The permissive terranes are for (I) epithermal precious-metal systems; (II) polymetallic systems; (III) tungsten and base-metal skarn; (IV) iron skarn; (V) porphyry copper deposits, (VI) evaporite and saline mineral deposits; and (VII) zeolites and hectoritic clay deposits. Of the deposits found in the permissive terranes, quantitative estimates are reported for 12 deposits types (table 2 and 3). The total estimated *mean* undiscovered mineral resources in the 12 evaluated deposits is 22 million tonnes of borate (40% probability), 19 million tonnes of iron (35 % probability), 710 tonnes of silver (30% probability), 100 tonnes of gold (25% probability), 652,000 tonnes of copper (20% probability), 14,900 tonnes

of lead (15% probability), 15,700 tonnes of zinc (10% probability), 9,800 tonnes of molybdenum (10% probability), and 590 tonnes of tungsten (<10% probability) (table 4). Undiscovered mineral resources in each of the 12 evaluated deposits are also reported.

An additional 30 metallic and nonmetallic deposit types are known to, or might, be present in the study area. Quantitative estimates are not reported for these 30 types of deposits because either there are no grade and tonnage models to form a basis for the estimate, or the deposits are too small be compared to the worldwide database that constitutes the grade and tonnage models, or the deposits are of marginal economic interest in today's market. However, for two of these types of deposits, qualitative estimates are made for their undiscovered mineral resources in the study area. Because these two types of deposits lack grade and tonnage model, no probability levels could be assigned to estimates. Thus, the qualitative estimates cannot be compared readily to those based upon a probability distribution. Many of the remaining unevaluated deposits, of which most are of nonmetallic commodities, generally are of greater value than the metallic deposits.

In addition to reporting the *mean* estimated undiscovered mineral resources for the entire area, the *mean* and *median* undiscovered resources for the 12 evaluated deposit types are reported individually (table 3) and the probability distribution of the estimates are shown graphically in order that the estimated tonnage of undiscovered metals and nonmetals and their probability of occurrence can be applied appropriately by users of this report. Regardless of how the information is presented, it is clear that borate, iron, gold, and silver are the most important commodities in the study area of those commodities evaluated. For example, the potential value of undiscovered borate is probably larger than all the metals combined. Iron might also be present in appreciable amounts. The amount of undiscovered additional resources of base metals, molybdenum, and tungsten is probably not great. Additional undiscovered resources should be present in a variety of types of nonmetallic and a few metallic deposits which could not be evaluated using the methodology of the U.S. Geological Survey.

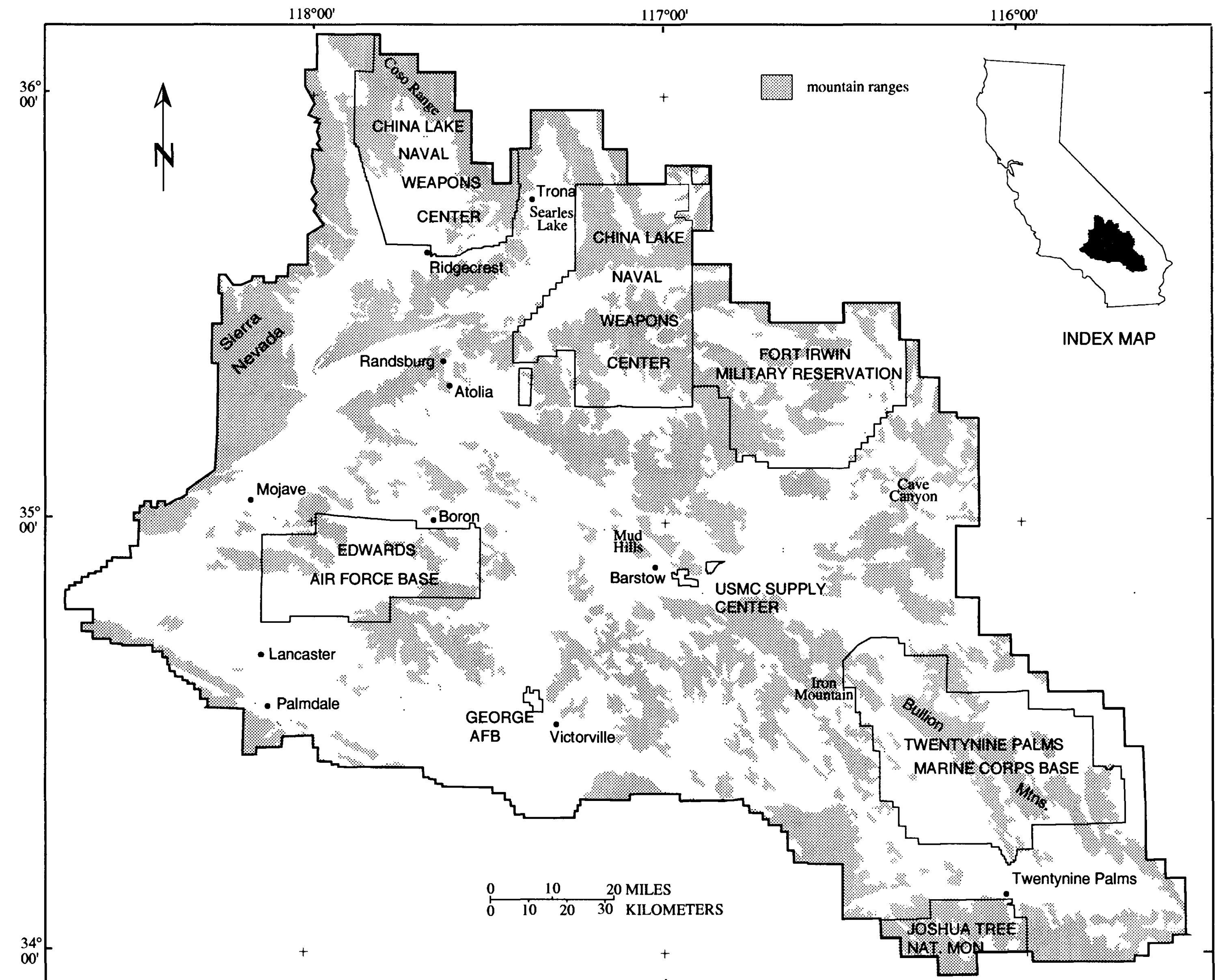

Figure 1. Location map of the West Mojave Management Area, southern California showing location of mountain ranges, military reservations, and national monuments

Table 1A. Ore deposit model and grade and tonnage models applicable to the West Mojave Management Area, California.

[Deposits are listed by model number found in Cox and Singer (1986, U.S. Geological Survey Bulletin 1693), Rytuba and Cox (1991, U.S. Geological Survey OFR91-116); Orris and Bliss (1991, U.S. Geological Survey OFR91-11A), Orris and Bliss (1992, U.S. Geological Survey OFR 92-437), and Bliss (1992, U.S. Geological Survey Bulletin 2004). *na*-deposit model or grade and tonnage model is not presently available. * denote deposit types for which quantitative probabilistic estimates have been made.]

Ore deposit group	**Deposit #**	**Grade-tonnage**
I: Epithermal precious metal systems		
Gold-rich types		
Quartz-alunite*	model 25e	Bulletin 1693
Sado-type, quartz-adularia*	model 25d	Bulletin 1693
Hot-spring Au-Ag*	model 25a	Bulletin 2004
Detachment-fault-related-polymetallic	model 40a	*na*
Barite veins	model 27e	OFR92-437
Epithermal manganese	model 25g	Bulletin 1693
Volcanogenic uranium	model 25f	Bulletin 1693
Placer Au	model 39a	Bulletin 1693
II. Polymetallic systems		
Polymetallic veins*	model 22c	Bulletin 1693
Polymetallic replacement	model 19a	Bulletin 1693
Tungsten veins*	model 15a	Bulletin 1693
III. Tungsten and base-metal skarns		
Copper skarns*	model 18b	Bulletin 1693
Zinc-lead skarns*	model 18c	Bulletin 1693
Tungsten skarns*	model 14a	Bulletin 1693
*IV. Iron skarn**	model 18d	Bulletin 1693
V. Porphyry copper		
Porphyry Cu*	model 17	Bulletin 1693
Porphyry Cu-Au*	model 20c	Bulletin 1693
Porphyry-gold	OFR91-116	*na*
VI. Evaporite and saline		
Lacustrine borate*	model 35b.3	OFR92-437
Bedded celestite	model 35a.1	OFR92-437
VII. Zeolite and hectoritic clays		
Zeolite	model 25oa	*na*
Hectoritic clays	model 25lc	*na*

Table 1B. Ore deposits in the West Mojave Management Area for which a permissive terrane was delineated but for which descriptive, grade, and tonnage models are not available.

[†-denotes deposits for which qualitative estimates of undiscovered resource are reported]

Epithermal precious metal system†
Silver-rich types--Waterloo-Langtry

Polymetallic systems†
Tungsten veins--Atolia-type

Evaporite and saline
Saline brines

Table 1C. Mineral deposits and other resources in the West Mojave Management Area for which permissive terranes were not delineated, but which either are represented by a mineral occurrence, deposit, mine, or that might be present in the study area.

Metallic mineral deposits	**Nonmetallic mineral deposits and other resources**
Tin skarns (model 14b)	Bentonitic clays
Mesquite-type epithermal gold	Construction material (including sand and gravel, cinders, pumice, perlite, and dimension stone)
	Expandible clays
	Feldspar
	Fluorite
	Gemstones
	Geothermal
	Gypsum
	Limestone
	Magnesite
	Monazite (Rare earth elements and thorium)
	Pyrophyllite and sericite
	Silica
	Talc
	Wollastonite

Table 2. Probabilistic estimates of the minimum numbers of undiscovered mineral deposits in the West Mojave Management Area, California.

[Deposit model numbers are in parentheses. X-mean expected number of deposits calculated from the probability distributions at the different confidence intervals by the computer program MARK3 (Root and others, 1992); Roman numerals -I, II, III - denote different terranes for gold-rich epithermal precious metal systems (see figure 4); MT-metric tons.]

Deposit group	Deposit type (number)	Estimated minimum number of undiscovered deposits at indicated probability levels					
		X	**0.9**	**0.5**	**0.1**	**0.05**	**0.01**
I	*Epithermal precious metal systems*						
	Quartz-alunite(25e)						
	II--Mojave area	0.36	0	0	1	2	2
	I, III--(other terranes combined)	0.32	0	0	1	1	2
	Quartz-adularia-Sado-type (25d)						
	I--Randsburg area	0.32	0	0	1	1	2
	Hot-spring gold (25a)						
	II--Mojave area	0.98	0	1	2	2	2
	I, III--(other terranes combined)	0.07	0	0	0	1	1
	Polymetallic systems						
II	Polymetallic veins(22c)						
	Jurassic	0.75	0	0	2	4	5
	Cretaceous	0.57	0	0	1	4	6
	Tungsten veins(15a)	0.03	0	0	0	0	1
	Tungsten and base-metal skarns						
III	Copper skarns(18b)	0.03	0	0	0	0	1
	Zinc-lead skarns(19c)	0.03	0	0	0	0	1
	Tungsten skarns(14a)	0.03	0	0	0	1	3
	Iron skarns(18d)						
IV	Tract 1- deposits <15 MT	4.4	1	2	10	12	18
	Tract 2- deposits < 200 MT	1.1	0	1	2	3	4
	Porphyry Cu						
V	Porphyry Cu-Mo (17)						
	Jurassic-Ord Mts.	0.11	0	0	0	1	2
	Pinto	0.03	0	0	0	0	1
	Porphyry Cu, Au-rich(20c)	0.30	0	0	1	1	1
	Evaporite and saline						
VI	Lacustrine borates(35b.3)	6.67	2	6	12	13	14

Table 3A. Mean estimated metal endowment for selected metallic and nonmetallic mineral deposits in the West Mojave Management Area.
[All metals are in thousands (x 1000) of tonnes. X-mean expected number of deposits; Roman numerals - I, II, III - denote different terranes for gold-rich epithermal precious metal systems; Arabic numeral - 1, 2- denote different tracts for iron skarns; (O)-permisive termane located around the Ord Mountains; (P)- permissive terrane located in the Pinto Mountains; (J)-Jurassic polymetallic veins; (K)-Cretaceous polymetallic veins.]

Deposit type	X	Cu	Mo	Au	Fe	W	Zn	Ag	Pb	B_2O_3
Epithermal										
Quartz-alunite II	0.36	7.37	-	0.012	-	-	-	0.070	-	-
Quartz-alunite I, III	0.32	6.41	-	0.011	-	-	-	0.061	-	-
Sado	0.32	0.42	-	0.003	-	-	0.02	0.066	0.001	-
Hot-Spring II	0.98	-	-	0.047	-	-	-	0.198	-	-
Hot-Spring I, III	0.07	-	-	0.003	-	-	-	0.014	-	-
Polymetallic										
Polymet. Vein(J)	0.75	0.10	-	0	-	-	3.91	0.081	6.26	-
Polymet. Vein(K)	0.57	0.06	-	0	-	-	3.17	0.065	4.69	-
W Veins	0.03	-	-	-	-	0.73	-	-	-	-
Skarn										
Cu Skarn	0.03	1.70	-	0	-	-	-	0	-	-
Zn-Pb Skarn	0.03	0.54	-	0	-	-	8.40	0.006	3.72	-
W Skarn	0.03	-	-	-	-	5.18	-	-	-	-
Iron skarn										
Fe Skarn (1)	4.4	-	-	-	8,930	-	-	-	-	-
Fe Skarn (2)	1.1	-	-	-	10,800	-	-	-	-	-
Porphyry Copper										
Porphyry Cu (O)	0.11	272	5.91	0.003	-	-	-	0.054	-	-
Porphyry Cu (P)	0.03	87.5	1.80	0.001	-	-	-	0.019	-	-
Porphyry Cu-Au	0.30	276	2.06	0.022	-	-	-	0.076	-	-
Evaporite & saline										
Lacustrine Borate	6.7	-	-	-	-	-	-	-	-	21,600

Table 3B. Median estimated metal endowment for selected metallic and nonmetallic mineral deposits in the West Mojave Management Area.
[All metals are in thousands (x 1000) of tonnes. All abbreviations are listed in Table 3A.]

Deposit type	Cu	Mo	Au	Fe	W	Zn	Ag	Pb	B_2O_3
Epithermal									
Quartz-alunite II	0	-	0	-	-	-	0	-	-
Quartz-alunite I, III	0	-	0	-	-	-	0	-	-
Sado	0	-	0	-	-	0	0	0	-
Hot-Spring II	-	-	0.015	-	-	-	0	-	-
Hot-Spring III	-	-	0	-	-	-	0	-	-
Polymetallic									
Polymet. Veins(J)	0	-	0	-	-	0	0	0	-
Polymet. Vein(K)	0	-	0	-	-	0	0	0	-
W Veins	-	-	-	-	0	-	-	-	-
Skarn									
Cu Skarn	0	-	0	-	-	-	0	-	-
Zn-Pb Skarn	0	-	0	-	-	0	0	0	-
W Skarn	-	-	-	-	0	-	-	-	-
Iron skarn									
Fe Skarn (1)	-	-	-	5,630	-	-	-	-	-
Fe Skarn (2)	-	-	-	1,570	-	-	-	-	-
Porphyry copper									
Porphyry Cu (O)	0	0	0	-	-	-	0	-	-
Porphyry Cu (P)	0	0	0	-	-	-	0	-	-
Porphyry Cu-Au	0	0	0	-	-	-	0	-	-
Evaporite & saline									
Lacustrine Borate	-	-	-	-	-	-	-	-	14,800

Table 4. Mean and median estimated metal endowment for all metallic and nonmetallic deposit types evaluated in the West Mojave Management Area, California

[All values are in thousands (X 1000) of tonnes. See tables 1 and 3 for mean and median values of individual deposit types that were evaluated. Note that estimates are not made for all of the deposit types that might be found in the area; see text for explanation.]

Commodity	Median	Mean
Gold	0.061	0.10
Silver	0.290	0.71
Tungsten	0	0.59
Molybdenum	0	9.8
Lead	0.16	14.9
Zinc	0.001	15.7
Copper	3.5	652
Iron	13,500	19,800
Borate	14,800	21,600

INTRODUCTION

The West Mojave Management Area encompasses some 35,200 square kilometers (8,700,000 acres) in the western Mojave Desert of southern California (fig. 1). Within this region, the Bureau of Land Management (BLM), in cooperation with the U.S. Fish and Wildlife Service and California Department of Fish and Game, is coordinating a planning effort focused on habitats of the desert tortoise and the Mohave ground squirrel. The purpose of the planning efforts is to prepare land-management and land-use strategies that ensure the survival of these species, that preserve natural ecosystems, and that allow for appropriate uses of its resource. This report contributes to this planning effort by evaluating selected undiscovered metallic and nonmetallic mineral resources of this region, and presents quantitative estimates for these undiscovered mineral resources in the management area. This information was prepared at the request of the BLM for inclusion within the planning report. A companion report describing the identified mineral resources in the study area is the responsibility of the U.S. Bureau of Mines (USBM).

The region that includes West Mojave Management Area has been the site of mineral exploration and mining activity for a variety of minerals for much of this and the previous century. Deposits of gold (e.g. Mojave and Randsburg Mining Districts near the towns of Mojave and Randsburg respectively), silver (e.g. Calico Mining District near the town of Barstow), base-metals (copper, lead, zinc) with associated precious metals (gold, silver) (e.g. Stedman Mining District in the Bullion Mountains), iron (Iron Mountain and Cave Canyon), tungsten (e.g. near the town of Atolia), borate (e.g. near Boron), zeolite (e.g. Mud Hills near the town of Barstow), saline brines (e.g. Searles Lake), and geothermal power (Coso Range) have been developed, are being produced, or are known to be present within the region. Active mines producing construction materials and other nonmetallic commodities are widespread in the management area, particularly in the southwestern part of the study area near Los Angeles.

This report expands upon an earlier administrative report (U.S. Geological Survey, 1992) submitted to BLM on March 15, 1992. Permissive terranes for the potential occurrence of selected metallic and nonmetallic mineral resources were delimited in that report. The terranes in that report were, for the most part, restricted to bedrock areas in the mountain ranges and were useful in predicting areas where undiscovered mineral deposits might be present. Herein, those permissive terranes are extended to include areas covered by younger deposits less than 1 km thick. The arbitrary thickness of 1 km was chosen because it is unlikely that deeper deposits could be discovered and explored using presently available technologies (Singer and Jachens, 1990). In addition, quantitative estimates for undiscovered resources in selected deposit types are also included in this report. Estimates were not made for all of the possible metallic and nonmetallic mineral deposits in the management area. No estimates were made for some small types of deposits, or for deposits that are permissive but for which the potential was judged to be negligible, or for metallic deposit types that do not have a descriptive model nor a grade and tonnage model, or for most of the nonmetallic deposits in the area because they also lack the necessary grade and tonnage models.

Work on this report began in mid-May, 1992, by a team of following individuals: (1) Richard M. Tosdal coordinated preparation of this report and wrote sections on procedures, epithermal precious metal systems--base and precious metal systems, polymetallic systems, base-metal and tungsten skarns, iron skarn, and zeolites and hectoritic clays; (2) James J. Rytuba prepared sections on epithermal precious metal systems--gold- and silver-rich, Tertiary porphyry copper-gold and porphyry gold, and borates; (3) Ted. G. Theodore wrote section on Jurassic porphyry copper, (4) James P. Calzia wrote section on salines, and (5) Steve Ludington prepared graphs showing probability versus estimated tonnes of metal and wrote discussion of the total metal endowment. Robert C. Jachens prepared geophysical and depth-to-basement maps used in the assessment, devised the model used to evaluate iron skarns, and contributed to the section on iron skarn. Gary A. Nowlan prepared geochemical maps. Robert J. Miller digitized the permissive terranes and prepared the maps. Kenneth R. Bishop and William J. Keith prepared mineral occurrence maps from USBM and USGS mineral occurrence databases, respectively. Steve Ludington supervised preparation of quantitative estimates which were made by a team composed of most of the aforementioned individuals. Robert L. Hill of the California Division of Mines and Geology, Donald Carlisle of the University of California at Los Angeles, and P. Goeffry Feiss of the University of North Carolina at Chapel Hill provided knowledge regarding the mineral deposits in the West Mojave Management Area, but although they were present at meetings, are not responsible for the quantitative estimates of the undiscovered mineral resources. Unpublished information regarding the distribution or Jurassic and Cretaceous plutonic rocks in the study area was provided by J.S. Miller of the University of North Carolina at Chapel Hill, J.D. Walker of the University of Kansas, and K.A. Howard of the U.S. Geological Survey.

The West Mojave Management Area is hereafter referred to as the study area.

Procedures for delineating permissive terranes

For this report, we follow the definitions of Cox and Singer (1986, p. 1). Specifically, a "mineral occurrence is "a concentration of a mineral ... that is considered valuable by someone somewhere, or that is of scientific or technical interest". A mineral deposit is " a mineral occurrence of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have economic potential." Finally, an ore deposit is " a mineral deposit that has been tested and is known to be of sufficient size and grade, and accessibility to be producible to yield a profit." An undiscovered ore deposit, like those being estimated in the study area, is defined as an ore deposit that is believed to exist, but that does not have published grade and tonnage data (D.A. Singer, oral commun., 1992). These term are used in the following sections.

Mineral and ore deposits within the study area were classified using the deposit models listed in Cox and Singer (1986), and supplemental publications (e.g. Rytuba and Cox, 1991; Orris and Bliss, 1991; Bliss, 1992). Only those deposits that were sufficiently like those that define the descriptive, grade, and tonnage model were classified. Permissive terranes in the study area could be drawn for the more common metallic mineral deposit types and a few nonmetallic mineral deposit types (borates, salines, zeolites, clays). A permissive terrane is an area that can contain a certain type of mineral occurrence or ore deposit, or in this report, a group of deposits. Thus, any terrane that is geologically similar to a terrane elsewhere that contains these types of mineral deposits can be considered permissive within the scope of this definition regardless of whether there are specific indications of mineralization (Menzie and Singer, 1990). Deposit types for which permissive terranes are delineated in the study area are listed on tables 1A and 1B. Deposit types that are not evaluated in this report for various reasons are shown on table 1C. These latter deposits are mostly the nonmetallic commodities and construction materials, though there are a few types of metallic deposits that were not evaluated. Metallic and nonmetallic deposits considered in the study area were grouped into larger categories based on common associations for the purposes of discussion and clarity of presentation. These larger categories of mineral deposits are: (I) epithermal precious-metal systems; (II) polymetallic systems; (III) tungsten and base-metal skarns; (IV) iron skarns; (V) porphyry copper deposits, (VI) evaporite and saline mineral deposits; and (VII) zeolites and hectoritic clay deposits.

Many different sources of information were used to classify the mineral occurrences and to delineate permissive terranes in the study area. Published sources of information are listed in the list of references. The Los Angeles, San Bernardino, Needles, Salton Sea, Trona, Bakersfield, Death Valley, and Fresno 1° by 2° geologic quadrangle maps published by the California Division of Mines and Geology form the geologic base. The mineral information databases of the USGS (Mineral Resources Data System) and the USBM (Minerals Availability System) provided inventories of mineral occurrences. Geophysical maps generated by members of the project include maps of gravity and aeromagnetic fields and depth-to-basement. Geochemical maps, including maps of stream sediment, rock, and heavy-mineral concentrate data, were derived from the National Uranium Resource Evaluation (NURE) program and past mineral-resource assessment projects of the USGS.

With respect to this report of the West Mojave Management Area, the following caveats must be kept in mind as this document is used for planning purposes. Many of these caveats are noted in other mineral-resource assessment reports (see Hodges and Ludington, 1991).

1. The delineation of permissive terranes in this report is based on the current understanding of mineral-deposit types and our knowledge of them is continuously subject to change, improvement, and revision. New deposit types may be discovered and described in the future that can not be easily accommodated in the groupings used herein. As such, additional permissive terranes may be indicated with the future work.
2. Permissive terranes are not drawn for all the possible deposits known to, or that might, be present in the study area. Specific permissive terranes were not drawn for deposits that are peripheral to and associated with deposits that are characteristic of the groups used herein (table 1A). In these cases, the permissive terranes for a group of deposits include these other types of deposits; the association of vein barite with the gold-rich epithermal systems is an example. Still other deposits cannot be classified within the framework of the groups used herein, and these lack any delineated permissive

terranes (table 1C). Generally, deposits for which we did not delineate permissive terranes include mineral occurrences or deposits that (1) lack a descriptive model, or (2) lack information regarding the occurrence of that particular type of deposit within the study area, or (3) were judged by the group to be of extremely limited economic potential in the study area based upon the information available, or (4) were of construction material and other nonmetallic mineral commodities.

3. As much as 65 percent of the study area is covered by deposits of sedimentary rock, alluvium, and volcanic rock that are younger than many of the deposits evaluated herein. These rocks thus could conceal existing mineral deposits. Of the remaining area, 10 percent consists of outcrops of Tertiary volcanic and sedimentary rock which are the host to significant known resources. The remaining 25 percent includes Mesozoic and older rocks. The large area of cover hampers the precision of the delineation of permissive terranes in these areas without adequate geophysical data. The permissive terranes delineated herein should be considered approximate in those areas where geophysical data are inadequate. The terranes were prepared originally at a scale of 1:250,000, the scale of the available geologic maps, but are shown herein at a scale of approximately 1:1,250,000.

4. Large parts of the study area (about 20 percent) lie within the jurisdiction of the Department of Defense in various military installations (fig. 1). Access to these installations has been generally restricted since their establishment, and little modern geologic and mineral resource information is available for these reservations. Large reservations include China Lake Navel Weapons Center (1,490 square km within study area), Edwards Air Force Base (1,255 square km), Twentynine Palms Marine Corps Base (2,409 square km), and Fort Irwin National Training Center (3,950 square km). Delineation of permissive terranes in these installations relied almost entirely on the available geologic maps.

5. Aeromagnetic and gravity data coverage is not uniform over the study area. Available aeromagnetic coverage consists of different surveys that were flown under different parameters (see discussion in section "Iron skarn"). As such, the quality of the data is variable. Although these data are generally adequate to define broad-scale features, they are not sufficiently detailed to identify individual sites of mineralization. Likewise, the gravity data are not uniformly distributed, though they too are adequate to define broad-scale features in areas of availability.
6. Gravity data were used to defined the 1-km depth to basement isopach, which in turn controlled much of the outline of the permissive terranes under cover (see Blakely and Jachens, 1991). This 1-km isopach outlines the area where pre-Tertiary rocks lie beneath 1 km or more of Tertiary and Quaternary volcanic and sedimentary rocks. The computer generated 1-km isopach was adjusted locally to account for areas of known outcrop. Despite these local problems in the 1-km isopach, the deep basins coincide reasonably well with known areas of Tertiary and younger sedimentary and volcanic rock accumulation based upon water well data and oil well test holes (Dibblee, 1967).
7. Geochemical data are not available for the entire study area (Fig. 2). There are notable areas where no data are available. In addition, the detection limits of important elements in the available database are in many cases inadequate for most of the study area. As a result, some areas containing anomalous concentrations of elements may have been undetected. This lack of data hinders delineation of permissive terranes where there are no known mineral occurrences (see also John and others, 1992).
8. Proprietary information held by companies presently involved either in active mining or exploration activities in the management area was generally not available to us. Only publicly available data were used.
9. This report was not accompanied by field work to check the veracity and reliability of information. We relied almost entirely on published literature, mineral-resource

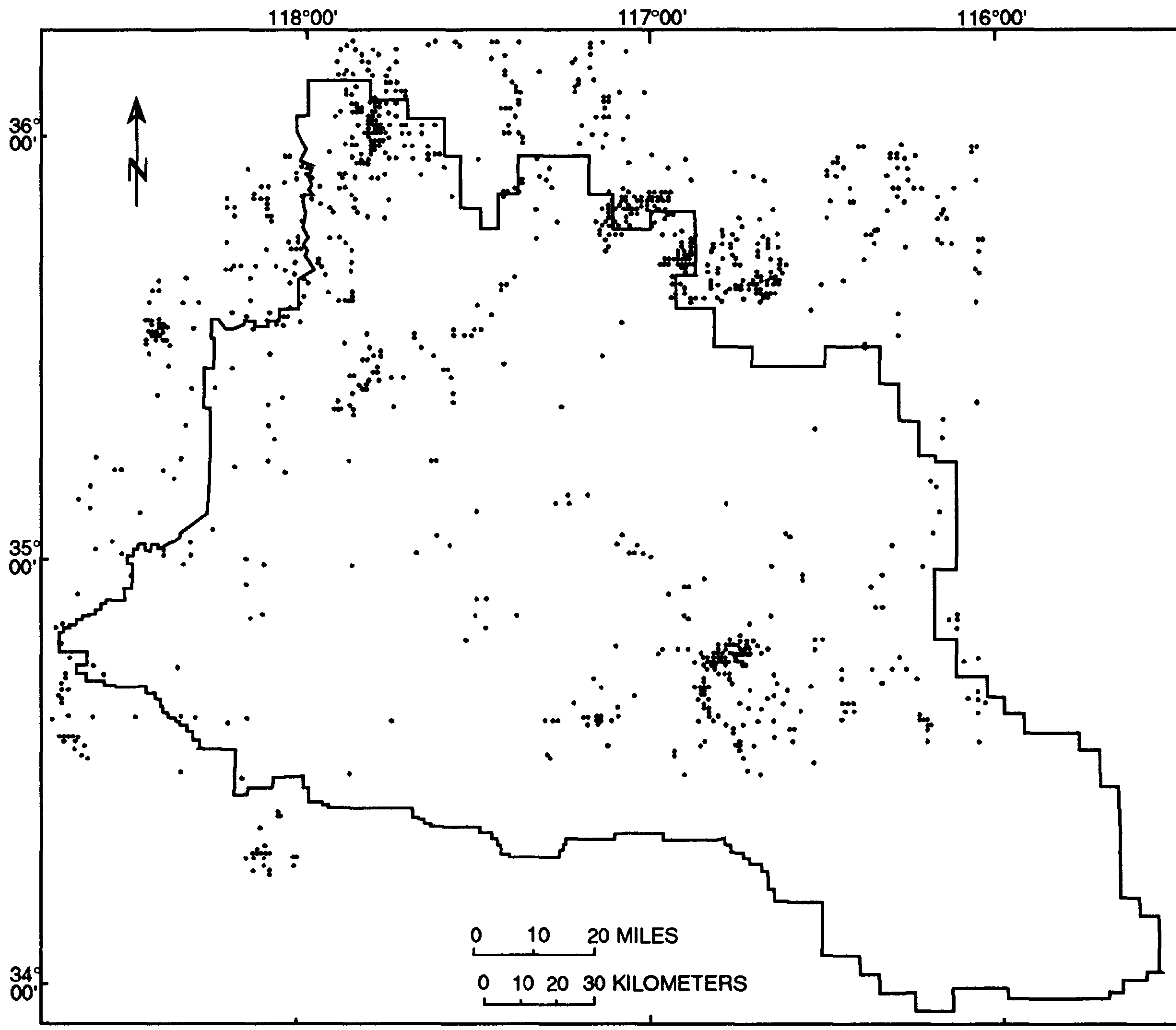

Figure 2A. Geochemical sample location map for rocks in the West Mojave Management Area, southern California. Samples are those that are included in USGS geochemical databases. Outline of the study area is shown.

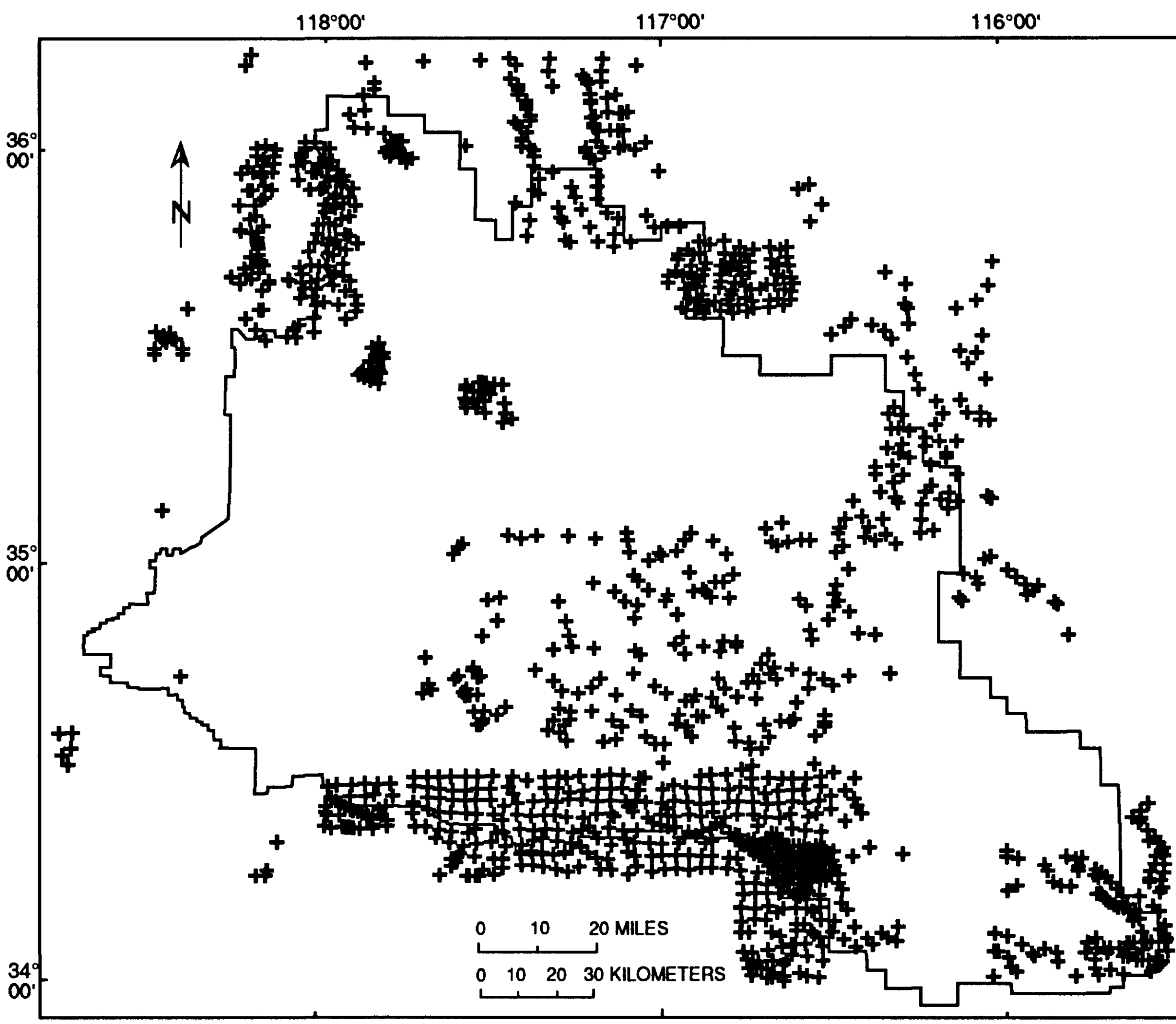

Figure 2B. Geochemical sample map for stream sediment and heavy-mineral concentrate samples in the West Mojave Management Area, California. Samples are those that are included in USGS geochemical databases. Outline of the study area is shown.

databases, the various geophysical and geochemical databases available to the USGS, as well as limited first-hand knowledge that was available to the project members.

Procedures for quantitative estimates of undiscovered mineral resources

The procedure and basis for the probabilistic methods of estimating the undiscovered mineral resources in a terrane have been outlined by Drew and others (1986), Singer and Cox (1988), Menzie and Singer (1990), Root and others (1992), Brew and others (1991), Root and others (1992), and Singer (1992) among others. Recently, Bultman and others (1992) have described limitations and pitfalls with the three-part methodology as practiced in the Office of Mineral Resources of the USGS. Several of these limitations were encountered in this study, and they are noted herein where appropriate.

There are two approaches to a quantitative mineral resource assessment. Estimates can be arrived at through either (1) comparison of the permissive terranes to those in well-explored regions that are geologically similar, or (2) identifying potential exploration targets for the type of deposit being evaluated. The first approach was largely used in this assessment, and several factors are taken into account before arriving at an estimate of the undiscovered mineral resources (Singer, 1992). These are: (1) geologic setting of particular types of ore deposits; (2) frequency of deposits in well explored areas and in the study area; (3) efficiency of exploration in the study area; (4) size of the ore deposit or mining district relative to a permissive terrane; (5) clustering of ore deposits; (6) restrictions afforded by the ore forming process; and finally, (7) whether known examples of deposits in the study area appear to have similar grades and tonnages to worldwide data that compose the deposit models listed in table 1A.

Estimates for the undiscovered mineral resources were made for most of the metallic deposits that are permissive in the study area. Critical to these estimates is the availability of a grade and tonnage model that is based on worldwide data (Cox and Singer, 1986; Singer and Cox, 1988; Bliss, 1992; Orris and Bliss, 1992). Deposits that are included in grade and tonnage models are those that have been, or are being, mined, or prospects that were not mined but were explored in sufficient detail to determine a grade and tonnage. Not all of the deposits in these models were mined, and many of them are not economic. The models are the basis for quantitative estimates of the undiscovered resources in the study area. Grade and tonnage models are, however, not available for most of the nonmetallic commodities. Estimates were made for most of the deposit types that are present in study area and for which grade and tonnage models are available (see tables 1A, 2 and 3). No estimates were made for a few deposit types that are either small, or are rarely found in the study area, or are of marginal economic interest today. These include tin skarn, vein manganese, placer gold, vein barite, and bedded celestite. In addition, the worldwide grade and tonnage models for iron skarn needed modification during this study in order to be applicable to southern California; this is described below. For still other deposit types that either did not fit a descriptive model or did not have a descriptive, grade, or tonnage model, a qualitative estimate was made on the basis of known occurrences in the study area. This step in the mineral resource assessment deviates from recent assessments (e.g. Brew and others, 1991; Ludington and Hodges, 1991). It was judged that qualitative estimates for some of these deposits were necessary because either their known resources are quite large (Waterloo-type barite-silver deposits) or they represented a significant resource in the study area in the past (tungsten veins-Atolia type).

Two meetings were held to estimate the undiscovered mineral resources in the study area. For the most part, the same group of USGS geologists participated in each meeting. The second meeting was also attended by the geologists from outside of the USGS that were mentioned in the introduction. Initial estimates were made at the first meeting, held in June, 1992. A month later, in July, 1992, these initial estimates were reevaluated and revised. These estimates are reported here.

Estimates of the undiscovered mineral resource for a particular deposit type were derived through discussion and consensus by project members regarding the probability of a certain number of undiscovered deposits. Generally, resulting estimates are influenced strongly by the individual(s) most knowledgeable about that particular deposit type and about the distribution of that type of mineralization within the study area. For each deposit type, estimates of the number of undiscovered deposits were made at the 90, 50, 10, 5, and 1 percent confidence level (table 2). Critical to the estimates is the expectation that half the undiscovered deposits should exceed the *median* grades and tonnages of those types of deposits on a worldwide basis. In cases where the worldwide *median* grade and tonnages are larger, or smaller, than the size of a deposit that might reasonably be expected in the study area based on known deposits and occurrence, the estimates of undiscovered resources are based on grade and tonnage models that are appropriate to the region under study, or the estimates are adjusted in order to apply the worldwide curve to the smaller study area. For this study, local grade and tonnage models were, for the most part, not developed because of the lack of data necessary to produce them. Thus, worldwide models were used throughout this report, and where necessary, were adjusted to fit the circumstances in the study area. These adjustments clearly are not rigorous nor uniquely defensible. However, they represents an attempt by the group to reflect the collective opinion regarding the potential for that particular type of deposit in the study area even though the validity of the quantitative estimates based upon these types of adjustments to the grade and tonnage models have been questioned (Bultman and others, 1992).

Estimates for individual deposit types at different levels of confidence (table 2) are processed by MARK3, a computer program that uses a Monte Carlo simulation (Root and others, 1992). The computer program combines the estimates of the types and numbers of undiscovered deposits (table 2) with historical grade and tonnage data. This simulation produces a probability distribution of contained metal for each of the undiscovered deposit types evaluated and for the study area. Commonly, a *mean* value is calculated and that value has been converted to a Gross-in-Place-Value (GIPV) using the extant or a 5-year-average metal prices and the estimated undiscovered mineral resources are reported as a *mean* dollar value (e.g. Brew and others, 1991; McCammon and others, 1991; Hodges and Ludington, 1991). For this report, the undiscovered mineral resources in the study area are not reported as GIPV, but rather as *median* (50th percentile) and *mean* metal contents (table 3) following Ludington and Hodges (1991). They are so reported in this manner for five reasons. (1) We are not able to judge the economic viability of the undiscovered resources; this is currently under study by the USBM. (2) Commodity prices vary with economic conditions, whereas the estimated metal content by this group will remain constant with respect to price variation, although it is clearly subject to future changes required by new information or by reevaluation by a different group. (3) Any single expression of the probabilistic estimates, such as *mean* or *median*, could be very far from the truth by an order of magnitude or more, thus leading the user to form misleading impressions of the mineral resource potential. (4) The *median* deposit played an important role in the estimation of the undiscovered resources. (5) The *mean* of any grade and tonnage model can be strongly influenced by a few giant deposits that may not be located anywhere close to the study area. Thus, *mean* metal content in an undiscovered deposit may range from several times to as much as an order of magnitude larger than the *median* metal content and, as such, the *mean* may not represent a useful portrayal of the metal endowment in the study area (compare tables 3A and 3B). This is shown graphically on figure 3 by plotting the tonnes of gold in various deposit types versus their probability of occurrence (Root and others, 1992). The graph is generated directly from the output from the MARK3 program. The reported *mean* metal content is the mean value of the tonnage distribution and is also shown on the graphs. The *median* is the amount of undiscovered resources at the 50th percentile.

As is evident from figure 3, only one terrane has a 50 percent (*median*) probability of having any gold, whereas the *means* of the distribution would suggest that there can be significant gold present in a wide variety of deposit types. As pointed out below in the section on "Estimate of total metal endowment" for the case shown on figure 3, the probability of having the *mean* value of gold in many of these deposits is fairly low. Thus, reporting the metal content as a *median* and *mean* value in tabular form and graphically showing the probability distribution for the estimated undiscovered metal contents in the various deposit types more accurately reflects the estimates of undiscovered resources and also presents a range of metal contents that might be present in the study area (see further discussion in section below "Estimate of Total Endowment"). Graphical presentation of the data also allows the users of the assessment to gauge the possible metal contents

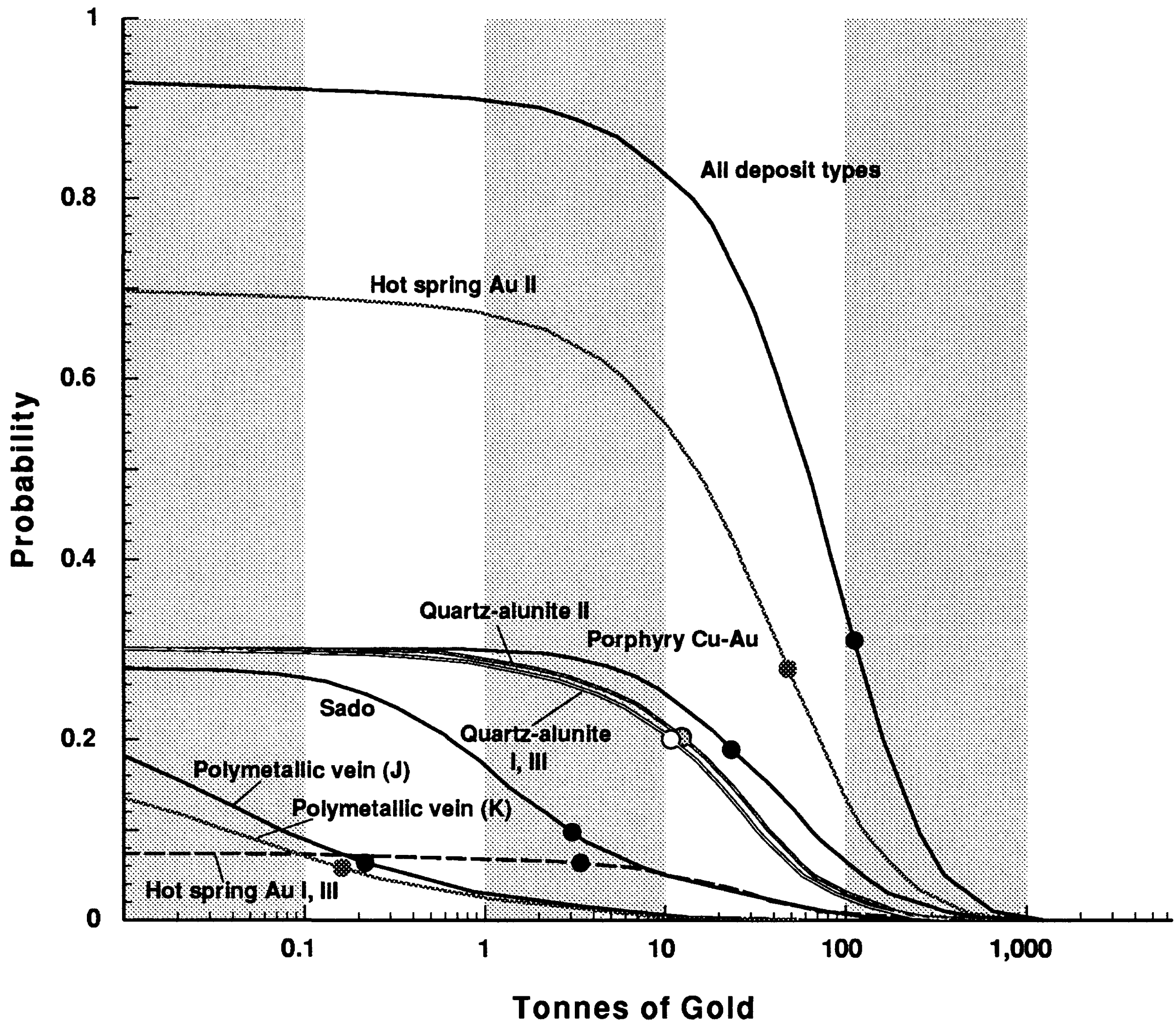

Figure 3. Graph showing probabilistic estimates for the amount of gold in individual deposit types, and in all deposit types, West Mojave Management Area, California. Circles indicate mean estimate for individual deposit types (see tables 1–3). Gold in porphyry copper deposits, Zn-Pb skarns, and Cu skarns is not shown because there is less than a 5 percent chance that any exists, even though, on average, together they contribute somewhat more than 4 percent of the estimated undiscovered gold*.

* A tract for Tertiary polymetallic vein deposits was originally included in this study, and the estimate for this area (0 0 0 0 1) is included in the figures used to plot the total gold for all deposit types in this figure. The tract, and its estimated undiscovered deposits were subsequently dropped from the assessment because we realized the deposits had been misclassified; they are now believed to be detachment fault-related polymetallic deposits, which lack a tonnage and grade model. The calculations were not adjusted because these deposits contributed, on average less than 0.01 percent of the total gold.

at different levels of probability, and apply the quantitative estimates derived herein to the appropriate situation.

As with the delineation of permissive terranes, there are caveats that must be recognized while examining the estimates of the undiscovered mineral endowment in the study area.

1. Estimates were made despite lack of critical data, such as uniform geochemical and geophysical surveys. Both these databases are critical to assessing areas that have been either closed to, or have not been subject to, mineral exploration under present economic and mining conditions. This lack of data clearly limits the robustness of the quantitative estimate of undiscovered resources in these areas (John and others, 1992).
2. The estimates assume that worldwide grade and tonnage models are applicable to smaller areas. This assumption is limited as ore deposits of identical size, grade, and tonnage are not uniformly distributed throughout the world. For example, the range in size of porphyry copper deposits is larger in Chile than it is in the United States. Thus, a simple application of a grade and tonnage model to a relatively small area such as the study area may overestimate or underestimate any remaining undiscovered mineral endowment. Where additional information is available, some modifications to the grade and tonnage curves are necessary. Modifications can take the form (1) of local grade and tonnage curves developed specifically for the region under consideration, or (2) truncation of the worldwide grade and tonnage curve where information is available to justify this case, or (3) a change of the probability distribution to reflect the small, or large, sizes of expected deposits in the study area. The last two modifications were applied in this study, and their applications are discussed where appropriate.
3. In the estimated mineral endowment of the study area, nonmetallic mineral deposits are severely underrepresented. Quantitative estimates are provided only for borates. No estimates were made for either vein barite or bedded celestite, both of which have grade and tonnage models and are also found in the study area. We made no estimates for these deposits because (1) the grade for barite veins are strongly biased toward high economic

grade (Orris, 1992a) and thus the use of this model would not have been appropriate in the study area, and because (2) the economic interest in strontium in bedded deposits is presently not great. In addition, no estimates were made for other nonmetallic resources found in the study area because these deposits do not have grade and tonnage models (table 1C). The general lack of estimates for nonmetallic deposits in this report is indeed unfortunate, because these commodities in the study area are important from an economic viewpoint (Anderson, 1989; Goerold, 1989). Thus, the estimate of the mineral endowment in the study area must be considered a minimum and incomplete until this deficiency is rectified.

4. No quantitative estimates were made for a few metallic deposit types that are known in the study area (see tables 1A and 2). Most known occurrence of these deposits in the study area are small, and they probably do not add much to the overall metal endowment. However for other metallic deposit types that lack grade and tonnage models, qualitative estimates were made. The qualitative estimates are only reported in the text below. Thus, mineral endowment in the study area is also underestimated for metallic commodities.
5. The quantitative estimates for undiscovered resources should be regarded as preliminary. Uncertainties in addition to those implied by the probability distributions for contained metals are inherent in the estimates of the metal endowment. Some of these uncertainties stem from the lack of appropriate information, time constraints, and changes in the dynamics of the individuals that were responsible for the estimates. Where appropriate, these uncertainties are mentioned in the report.
6. The estimates reflect the collective opinion of the two groups that prepared this report. During this study, it was our experience that slightly different panels and availability of additional information can change the estimates substantially. Thus, another panel might reach conclusions that differ from our conclusions. Regardless, this evaluation presents broad generalities that the BLM can use in the preparation of the environmental impact statement. It, furthermore, can serve as a guide for future work in the area. Additional

work, especially field studies, are required to corroborate and refine the conclusions in this report.

MINERAL RESOURCES OF THE WEST MOJAVE MANAGEMENT AREA

Following is a brief discussion of the types of deposits and the terranes in which they may be present, the median grades and tonnages of the deposit types based upon worldwide data where available, a brief summary of the criteria used to define terranes, and the probabilistic or qualitative estimates of undiscovered mineral deposits where possible. Graphical presentations of the metal contents in the evaluated deposit types are included and the reader is referred to them throughout the following discussion.

Epithermal precious-metal systems

Epithermal precious metal deposits in the study area consist of (1) gold-rich deposits with subordinate silver, (2) deposits which contain silver but almost no gold, and (3) base- and precious-metal deposits. Each deposit formed in a different geologic environments, and permissive terranes are delineated for each type (fig. 4). Associated deposit types are also included within the permissive terranes (table 1A). These are vein barite (model 27e; Clark and Orris, 1991), epithermal manganese (model 25g; Mosier, 1986a), mercury, fluorite, and uranium veins and disseminations. Small placer gold deposits (model 39a; Yeend, 1986) are also present.

Gold-rich types

Gold-rich epithermal deposits within the study area are of two general types: quartz-adularia and quartz-alunite gold. Known deposits of these types are associated with Tertiary felsic volcanic and subvolcanic rocks and represent ancient geothermal systems. Modern geothermal systems also are present region (e.g. Coso Range), and young epithermal deposits may be associated with these systems (Fraser and others, 1942; Williams, 1991). The distribution of known deposits coupled with the geologic literature allows the delineation of three terranes located in the northern part of the

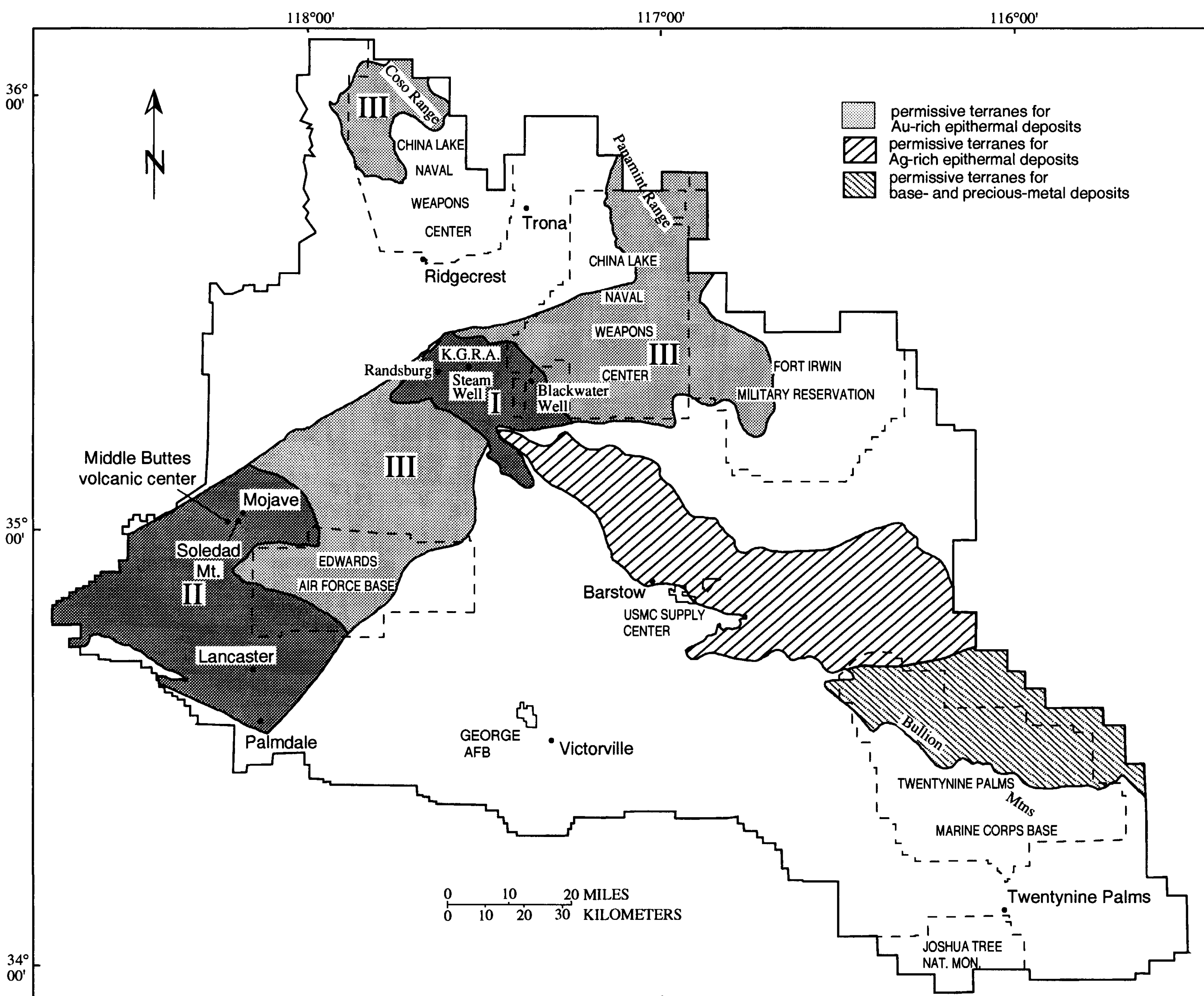

Figure 4. Permissive terrane for epithermal precious metal systems in the West Mojave Management Area, southern California.

study area (fig. 4). Terrane I makes up the area around and extending to the south of Randsburg; terrane II include the area around and to the west of the town of Mojave; whereas terrane III includes the remaining area in the northern parts of the study area where these types of deposits might be present. The following discussion refers to the three terranes.

Quartz-alunite gold

Quartz-alunite gold deposits (model 25e; Berger, 1986) are present in volcanic domes and associated flows and more rarely in adjacent nonvolcanic rocks. These deposits have a median tonnage of 1,600,000 tonnes with a median gold grade of 8.4 grams per tonne (g/t) and silver grade of 18 g/t (Mosier and Menzie, 1986a). In the study area, four of the seven deposits at the Middle Buttes volcanic center located immediately west-southwest of the town of Mojave are examples of this deposit type (fig. 4). These deposits had a pre-mining reserve of about 77,000 troy oz (~0.25 tonne) of gold (Blaske and others, 1991).

The two terranes for quartz-alunite deposits in study area are defined on the basis of the extent of Miocene volcanic centers and adjacent covered areas, the known presence of deposits, and the distribution of acid-sulfate alteration. One terrane (terrane II, fig. 4) encompasses the volcanic center in the Middle Buttes-Soledad Mountain area and adjacent covered areas. The other permissive terrane (terranes I and III combined, fig. 3) consists of the other known volcanic centers in the study area as well as the covered areas adjacent to these volcanic centers. Known quartz-alunite deposits are present in terrane II but a large area of alunite alteration occurs in terrane I at Blackwater Well. The four known deposits in terrane II are treated as one district and their published reserves place them on the lower part of the grade and tonnage curves established for the quartz-alunite districts.

In terrane II, the intensity of alteration at the Middle Buttes volcanic center and continuation of alteration to the border of covered areas implies that alteration and mineralization extend into the covered area. In particular, the covered area between the deposits at Middle Buttes and those at Soledad Mountain has a very high probability for the occurrence of a quartz-alunite deposit. For this terrane, the initial panel estimated a mean of 2.7 undiscovered quartz-alunite gold deposits having a *median* size of 400,000 troy oz (~12 tonnes) of gold in the entire terrane, based on a range of estimates from one deposit at the 90 percent confidence level to nine deposits at the 1 percent confidence level. A *mean* quartz-alunite gold deposit contains 1,240,000 oz (~39 tonnes) of gold and is about 3 times larger than the *median* deposit. The initial mean estimate of undiscovered deposits was, therefore, inflated by a factor of about 3 because the panel was estimating deposits having a much smaller grade and tonnage. A second estimate based upon a *mean* quartz-alunite gold deposit ranged from one or more deposit at the 10 percent confidence level to two or more deposits at the 1 percent confidence level with a mean expect number of deposits of about 0.4 (tables 2 and 3). This number represent a *mean* content of about 12 tonnes (397,000 troy oz) of gold and about 70 tonnes (2,300,000 troy oz) of silver in the terrane at about a 15 to 20 percent probability (fig. 5A). The estimates along with the worldwide grade and tonnage model also predicts a *mean* content of about 7,370 tonnes of copper at about a 10 percent probability (fig. 5A). As terrane II is largely covered by unconsolidated Quaternary and Tertiary(?) gravel, it is likely that an undiscovered district is present in the covered area. Drilling into the basins indicates that the Tertiary felsic volcanic rocks are present in the covered areas (Dibblee, 1967).

The estimated number of undiscovered quartz-alunite gold deposits has an uncertainty of at least 0.5 *mean* expected deposits because the panel in its second estimate should have reduced the estimate to only 33 percent of the original estimate (to 0.9 deposits) to take into account the change from *median* to *mean* size of the estimated deposit. Thus, the difference between two estimates of undiscovered deposits reflects an uncertainty introduced by changing the size of the deposit and composition of the panel. As similar adjustments to the estimates of undiscovered resources were made for each of the deposit types evaluated in this study, uncertainties of this magnitude accompany all of the estimates for undiscovered deposits reported herein. It should be also pointed out that in the case of the quartz-alunite gold deposits in terrane II, the undiscovered metal contents implied by the uncertainty of 0.5 mean expected deposits is taken into account in the probability distribution of the metals on figure 5A. However, the probability of larger, or smaller, metal tonnages being present is distinct from the case where the estimates for undiscovered deposits at the different confidence level were based on a different size deposit.

The *mean* silver and gold contents of quartz-alunite deposits are based on the grade and tonnage distributions for each element and are not independent variables. Because the panel assessed for undiscovered quartz-alunite deposits without regard to the total silver contained in the *mean* deposit, the silver resource estimate is overstated. Furthermore, it is inappropriate to use a silver to gold ratio of 5.5 implied by the silver and gold content of the *mean* deposit because the known deposits in the study area are not rich in silver. We believe any quartz-alunite deposits that may exist in the study area are less silver-rich than those in the world wide model. We would expect these deposits to have silver to gold ratios of 1-2 and thus the silver resource estimate would be reduced by 50-80 percent (table 3A, fig. 5A and 5B). It should be further noted that some quartz-alunite deposits with high-silver-content do not have high-gold-content and that high-gold-content deposits do not always have high-silver-contents. The grade and tonnage models overstate the silver content of the undiscovered deposits and would need to be modified if they were to be used to calculate the metal endowment of silver.

Other permissive terranes (terranes I and III, fig. 3) are composed of all the areas outside of terrane II (fig. 3) that are known to contain Miocene volcanic centers or are adjacent to such centers. The potential in these areas is considered to be less than in the terrane II because no large production has been documented from quartz-alunite type deposits in this tract. Two large areas of acid-sulfate alteration, however, are present in terrane I. The largest is present at Blackwater Well, about 30 kilometers east of Randsburg. There, quartz-alunite alteration in a Miocene flow dome complex covers an area 6 by 3.5 km and several zones of vuggy silica alteration occur within this broad zone of acid-sulfate alteration (Jenkins, 1989). This area of alteration is comparable in size to that present at Middle Buttes but no quartz-alunite gold mineralization is known to be present in this area. There is a high potential for undiscovered quartz-alunite deposits in and adjacent to this volcanic center. Immediately to the northwest of the Blackwater system is the Golden Valley

Known Geothermal Resource Area (KGRA). A large deposit of natroalunite estimated to contain 2,700,000 tonnes is present near Steam Well (Smith, 1964). It is likely that this alteration represents steam-heated alunite formed from near-surface oxidation of hydrogen sulfide related to the active geothermal system.

The estimate for the expected number of undiscovered quartz-alunite gold deposits in the permissive terranes I and III is slightly less than that in terrane II. A mean expected number of deposits in terranes I and III is 0.32, based on estimates that range from one or more deposit at the 10 percent confidence level to two or more deposits at the 1 percent confidence level (table 2). Thus, there is about a 20 percent, or less, probability that the *mean* gold (11 tonnes), silver (61 tonnes), and copper (6,410 tonnes) is present in the terrane (table 3A, fig. 5B).

Quartz-adularia

There are four types of quartz-adularia epithermal deposits in the U. S. Geological Survey descriptive, grade, and tonnage models (Cox and Singer, 1986; Bliss, 1992). There is a gold-rich type, known as the Sado-type (model 25d; Mosier and others, 1986a), and a silver-rich type known as the Comstock-type (Mosier and others, 1986f). A third quartz-adularia type, known as the Creede-type (model 25b; Mosier and others, 1986c) is similar to the other two deposits but is accompanied by significant base metals (copper, lead, and zinc). The fourth type is the hot-spring type gold-silver deposits (model 25a; Berger, 1986) that also can be considered to include all of the above mentioned deposit types. All deposits are typically veins or stockworks in volcanic rocks, in associated shallow intrusive rocks, and in non-volcanic country rock. The major difference between the first three and the fourth is size but more important is the mining method. Whereas the first three were generally mined in the past by underground workings, the fourth is presently developed by open-pit bulk mineable methods. Thus, hot spring deposits are larger than the others, although the grades are usually lower. Modern bulk-tonnage deposits are generally assigned to the hot spring type (Berger and Singer, 1992), whereas many of the past-producing mines that were worked underground could be assigned to one of the other types of deposits. A

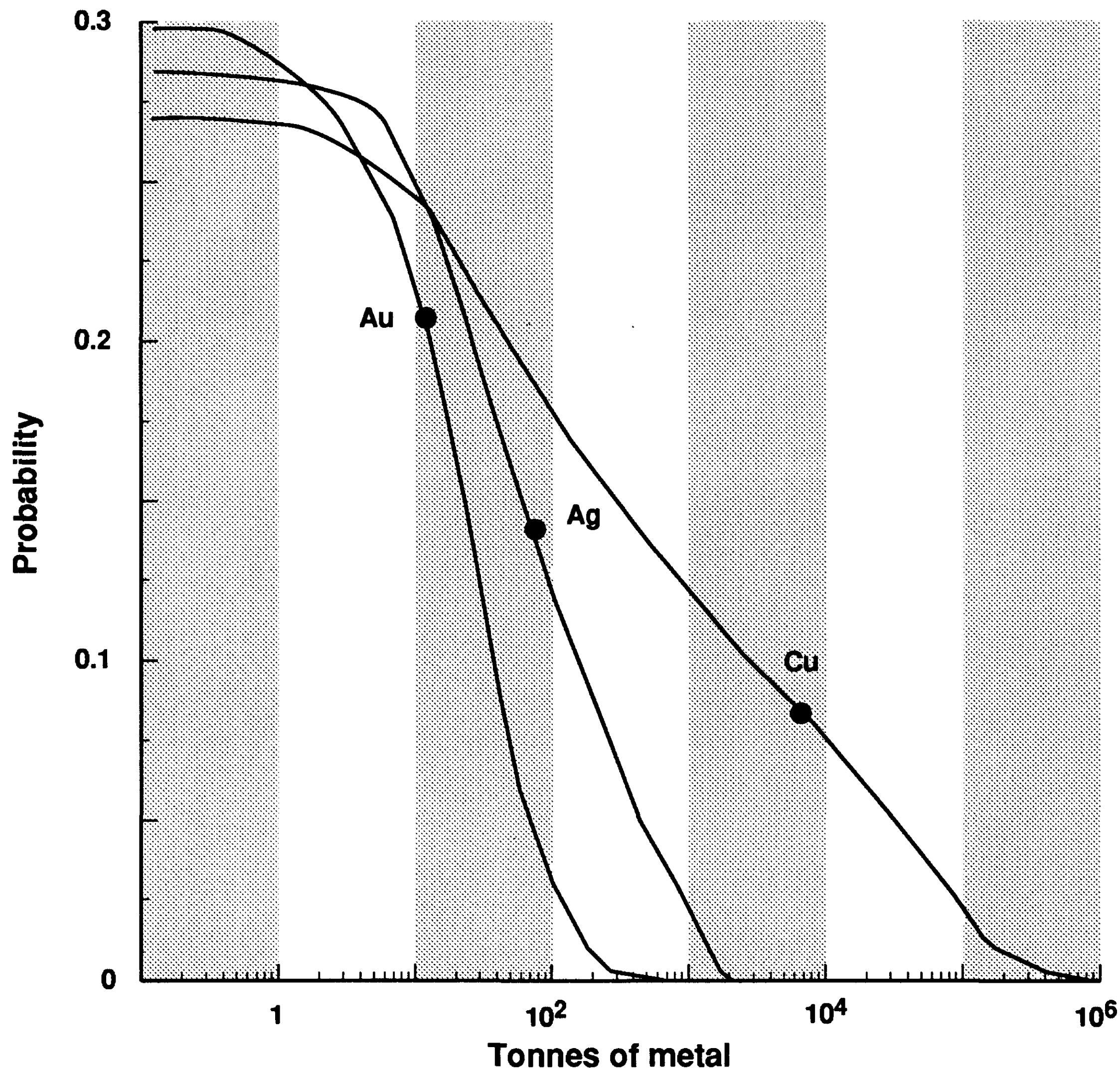

Figure 5A. Graph showing probabilistic estimates for the amount of gold (Au), silver (Ag), and copper (Cu) in quartz-alunite gold deposits in terrane II in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values. See figure 4 for location of terranes.

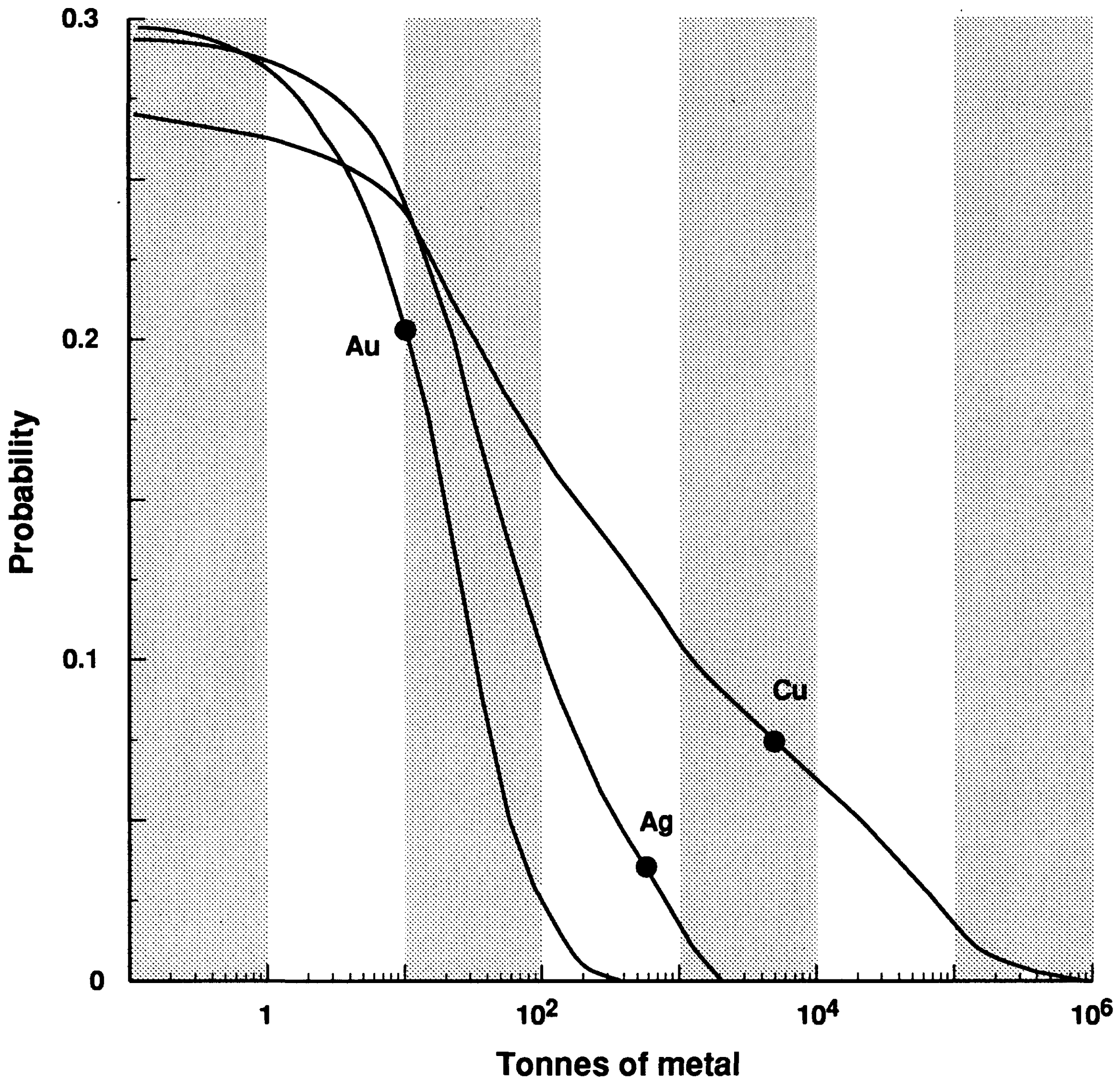

Figure 5B. Graph showing probabilistic estimates for the amount of gold (Au), silver (Ag), and copper (Cu) in quartz-alunite gold deposits in terranes I and III in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values. See figure 4 for location of terranes.

good example is the Rawhide deposit in Nevada where the present deposit is classified as a hot-spring type and the deposit that was mined in the early 1900 was classified as a Comstock-type even though they are part of the same mineralizing system (John and others, 1992)

Grades, tonnages, and contained metal vary amongst the four types. Sado-type epithermal deposits have a median tonnage of 600,000 tonnes with a median gold grade of 6.0 g/t and silver grade of 38 g/t (Mosier and Sato, 1986); 10 percent of the deposits have copper grades in excess of 1.9 weight percent. Comstock-type epithermal deposits have a median tonnage of 770,000 tonnes with a median gold grade of 7.5 g/t and a median silver grade of 110 g/t; 10 percent of the deposits have copper grades of that exceed 0.071 weight percent, zinc grades that exceed 0.025 weight percent, and lead grades that exceed 0.11 weight percent (Mosier and others, 1986d). Creede-type epithermal deposits have a median tonnage of 1,400,000 tonnes with a median gold grade of 1.5 g/t, silver grade of 130 g/t, copper grade of 0.16 weight percent, lead grade of 2.5 weight percent, and zinc grade of 1.7 weight percent (Mosier and others, 1986e). Hot spring gold-silver deposits have a median tonnage of 13,000,000 tonnes with a median gold grade of 1.6 g/t, and silver grade of 2.9 g/t (Berger and Singer, 1992).

Quartz-adularia deposits (Sado and hot-spring type) are known in the Mojave and Randsburg Mining Districts. In the Mojave Mining District, quartz-sericite-adularia bonanza vein and stockwork deposits had pre-mining reserves of 236,000 troy oz (~7.3 tonnes) of gold and 2,200,000 troy oz (~68 tonnes) of silver in the Shumake, and 31,200 troy oz (~1 tonne) of gold and 800,000 troy oz (~25 tonnes) of silver in the Silver Prince, and production from the Cactus Queen bonanza vein deposit was 92,000 troy oz (~2.9 tonnes) of gold and 2,320,000 troy oz (~72 tonnes) of silver (Blaske and others, 1991). Total production from the quartz-sericite-adularia bonanza vein and stock work deposits in the Randsburg mining district was about 836,000 troy oz (26 tonnes) of gold (Koschmann and Bergendahl, 1968) with the majority of the gold coming from the Yellow Aster Mine. In addition, about 10,000,000 troy oz (~311 tonnes) of silver were produced from the California Rand Silver Mine, the largest silver mine in the district (Hulin, 1925).

At the first meeting, all of the quartz-adularia deposits were classified as Sado-type deposits. It was subsequently decided at the second meeting that most of known quartz-adularia deposits were more accurately described as hot spring type deposits because known deposits are presently being mined by bulk-tonnage methods. However, it was also decided that the quartz-adularia deposits in terrane I (fig. 4) were still best classified as Sado-type deposits because they are largely vein deposits found in the basement rocks. Admittedly, these deposits could equally well be classified as hot-spring-type deposits which would change the estimated metal content for gold and silver because a *median* hot spring-type deposit contains about 6 times more gold and about 2 times more silver than *median* Sado-type deposits.

In terrane I, there is a mean expected 0.32 Sado-type deposits with at least one or more deposit at the 10 percent confidence level and two or more deposits at the 1 percent confidence level (table 2). Based on these estimates, there is about a 10 percent probability that the *mean* content of gold (3 tonnes), silver (66 tonnes) and copper (420 tonnes), and a less than 5 percent probability of the mean content of zinc (18 tonnes) and lead (1 tonne) is present in the terrane (table 3A, fig. 6). The estimate for copper is considered dubious because there is no known production of copper from present or past mining operations and no copper bearing minerals have been reported in the gold mines (Hulin, 1925). However, minute amounts of copper sulfides are present in veins that produced silver (Hulin, 1925). According to Hulin (1925), gold-rich and silver-rich veins in the Randsburg district are distinct and it is likely that any future undiscovered deposits in terrane I will either be gold-rich or be silver-rich, but not both.

For terrane II (fig. 4), it was estimated that there is about 1 mean expected undiscovered hot spring type gold deposit, or a chance of one or more deposit at the 50 percent confidence level and at least two or more deposits at the 10 percent confidence level (tables 2 and 3). In this terrane, there is about a 25 percent probability that there is the *mean* content of gold (47 tonnes) and silver (198 tonnes) being present in the terrane (fig. 7). In terranes I and III combined, the estimates of undiscovered deposits were lower with there being only 0.07 mean expected hot spring-type deposit with one or more deposit at the 10 percent confidence level and two or more deposits

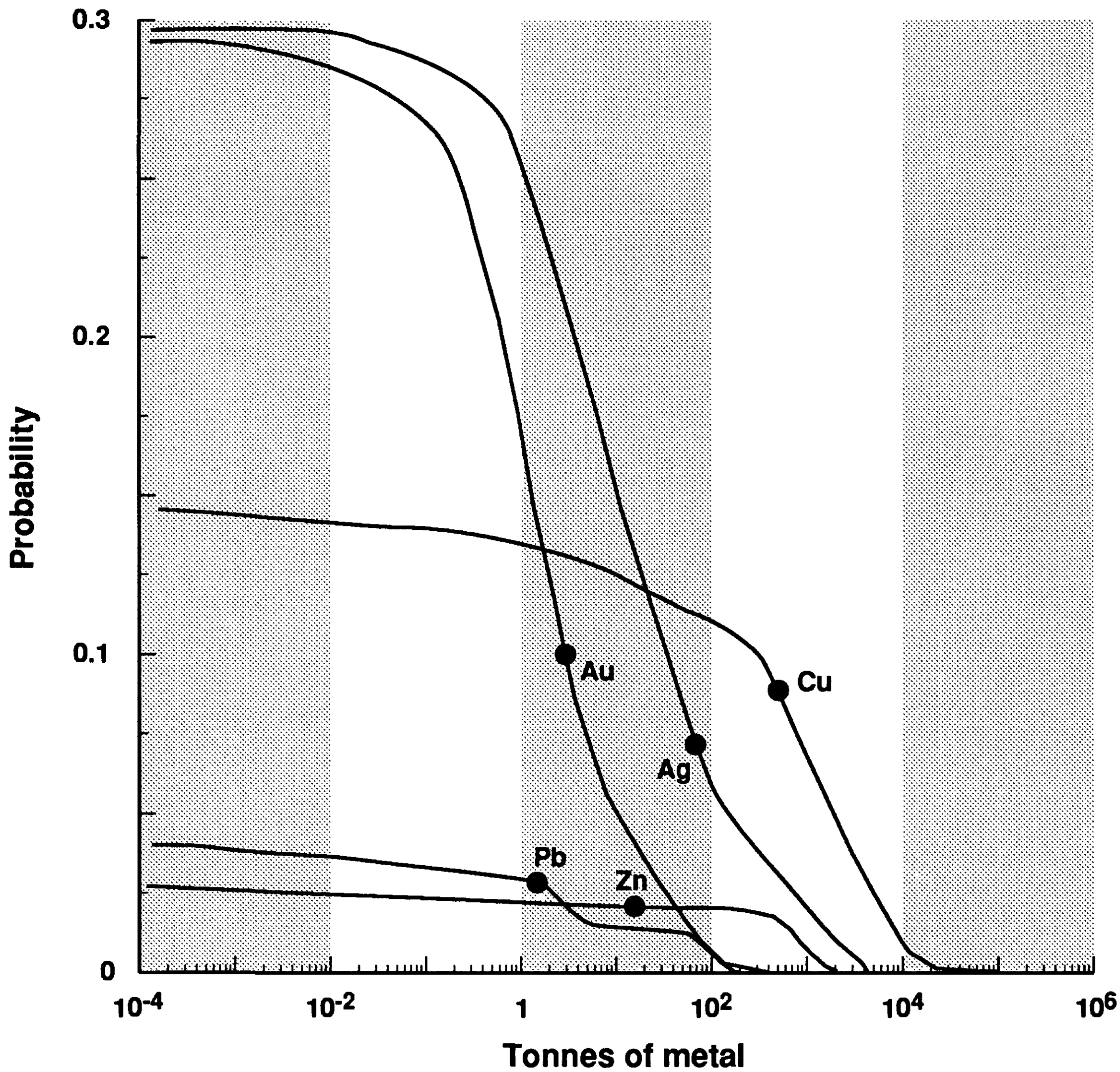

Figure 6. Graph showing probabilistic estimates for the amount of gold (Au), silver (Ag), copper (Cu), lead (Pb), and zinc (Zn) in Sado-type deposits in terrane I in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values. See figure 4 for location of terranes.

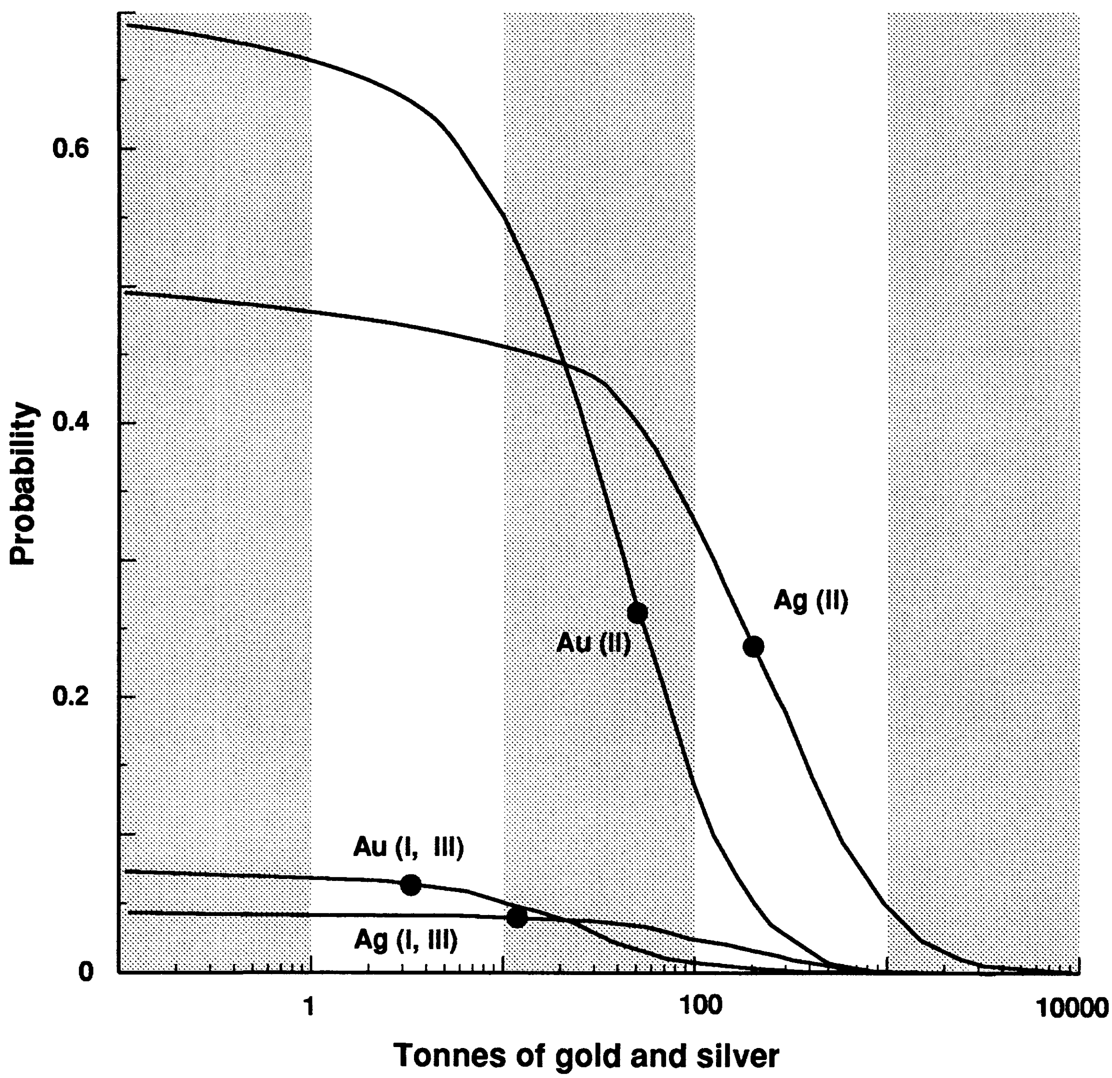

Figure 7. Graph showing probabilistic estimates for the amount of gold (Au) and silver (Ag) in hot spring-type deposits in three terranes (I, II, III) in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values. See figure 4 for location of terranes.

at the 1 percent confidence level (table 2). There is less than a 10 percent probability that there is the *mean* content of gold (3 tonnes) and silver (14 tonnes) being present in the terranes (table 3A, fig. 7).

The assessment for undiscovered hot spring gold deposits did not evaluate the potential for this type of deposit adjacent to borate deposits, and thus the estimate of undiscovered deposits underestimates the hot spring gold potential. See the discussion below under "borate deposits".

IB: Silver and barite rich types

Epithermal precious metal deposits in which silver is the dominant metal of economic interest are present in the study area. These deposits do not contain any gold, but do contain barite at grades that are economically significant in these deposits. The silver-rich deposits consist of vein deposits such as those in the Calico district near the town of Barstow and disseminated deposits such as those at Waterloo and Langtry, also in the Calico Mining District. The vein deposits in that mining district, classified by Mosier and others (1986d) to be of the Comstock epithermal vein type, are spatially and temporally related to the disseminated Waterloo and Langtry deposits (Feiss and others, 1991). No deposit model is available for these types of disseminated deposits. The disseminated deposits contain the largest reserves of silver and barite in the study area with the Waterloo and Langtry deposits near Barstow containing 24,500,000 tonnes averaging 105 g/t Ag and 11.8 weight percent barite and 13,600,000 tonnes averaging 85 g/t and 6.0 weight percent barite respectively (Fletcher, 1986).

In the study area, these deposits are present in Miocene lacustrine and fluvial sedimentary rocks that overlie volcanic rocks. Extensional tectonics and basin development accompanied their formation. Deposits of bedded evaporite minerals, such as borate, celestite and strontianite (strontium-bearing minerals), are associated with the silver-rich deposits. Locations of the Miocene volcanic and sedimentary rocks, areas of extensional deformation, and known mineral occurrences were the criteria used to delineate the permissive terranes for these deposits (fig. 4). No quantitative estimate could be made for these types of deposits because there are no grade and tonnage models available at this time (1992). However, it was estimated qualitatively that there is a potential for other deposits of this type that are equivalent in size to the two known deposits and the past production of the Calico Mining District.

Base- and precious-metal deposits

The region included within the study area has undergone varying amounts of extensional deformation in the Miocene (Dokka 1989; Bartley and Glazner, 1991). Volcanism preceded and was contemporaneous with this deformation. Base- and precious-metal, manganese, barite, borate, strontium, and other deposits also formed at this time. The largest metallic deposits are represented by the Waterloo and Langtry deposits of the silver-rich types described previously. Borate deposits are discussed below.

Base- and precious-metal deposits found in the extended terranes in the study area are classified as detachment-fault-related polymetallic deposits (model 40a; Long, 1992a). No grade and tonnage models are available for these deposits. These deposits contain either copper-gold or lead-zinc-silver minerals that are typically found along low-angle normal faults (detachment faults) or along high-angle faults in the hanging walls of the detachment faults (Spencer and Welty, 1989; Long, 1992a). Massive replacement bodies, breccias, and veins of specular hematite are characteristic of these deposits. In well-explored detachment fault terranes such as those in the Whipple and Buckskin Mountains, located some 140 km to the east, bedded manganese, epithermal manganese, and vein barite and fluorite deposits are spatially associated with the base- and precious-metal deposits (Spencer and Welty, 1989).

There is one and possibly two examples of these deposit types in the study area. One example might be the Briggs camp on the west slope of the Panamint Mountains (Schafer and others, 1990), although published information is too limited to classify the deposit unequivocally. The other deposit is the Bagdad-Chase Mine in the Stedman Mining District, located in the Bullion Mountains (Polovina, 1980, 1984). Some 291,000 troy oz (~9 tonnes) of gold, with additional amounts of silver and copper, have been produced from this district (Wright and others, 1953).

Exploration around the Bagdad-Chase Mine has identified an additional gold resource of 159,000 troy oz (~5 tonnes) of gold (870,000 tonnes of ore at a grade of 0.156 troy oz per ton) (California Mining Journal, 1987). Previously, the deposits in the Stedman Mining District have been included in the grade and tonnage models for quartz-alunite systems (Mosier and Menzie, 1986a), but the character and texture of the ore are clearly incompatible with that deposit model (Polovina, 1980).

In the study area, it appears that the detachment-fault-related polymetallic deposits are found in geologic settings slightly different from the silver-rich deposits. Whereas lacustrine environments are apparently important in generation of the silver-rich deposits, the base-and precious-metal deposits appear to be strongly structurally controlled and to be associated with volcanic rocks of approximately the same age. Thus, the permissive terrane for detachment-fault-related polymetallic deposits (fig. 4) include location of known types of deposits and areas of Miocene volcanic activity and extensional deformation. The permissive terrane lies in the southeastern part of the study area, immediately southeast of the permissive terrane for silver-rich epithermal deposits. Much of this terrane lies within the Twentynine Palm Marine Corps Base, and has not been investigated geologically in modern times. It seems likely that deposits like those in the Stedman Mining District might be found within this area, though we are unable to assign any probability to our conclusion.

Other epithermal precious metal systems with no delineated permissive terranes

Gold-bearing quartz-adularia veins in the Mesquite Mining District in southeastern California, some 130 km southeast of the study area, produce about 180,000 troy oz (~5.6 tonnes) of gold per year (Higgins, 1990). There is neither a descriptive deposit nor a grade and tonnage model available for these deposits. Gold-bearing veins in this district are similar in many ways to quartz-adularia deposits that are associated with felsic volcanic rocks (Manske, 1990, 1991), such as the Sado-type or hot-spring deposits. The most significant difference is that the epithermal deposits in the Mesquite Mining District are hosted by metamorphic rocks, whereas igneous rocks in the region of the same age as the deposit that could have acted as a heat source for the hydrothermal system are not hydrothermally altered nor are they present in the ore deposit (Manske, 1991; Tosdal and others, 1991). One other important factor is that the deposit formed within dextral strike-slip faults like those that are common throughout the study area. Though Mesquite-type deposits are hosted in metamorphic rocks, there is no reason to expect that these types of deposits are restricted to metamorphic rocks, and the deposits could just as likely form in volcanic and sedimentary rocks of any age given the appropriate structural environment and hydrothermal fluids.

It is, thus, possible that deposits similar to those in the Mesquite Mining District are present in the study area as the study area is cut by numerous strike-slip faults of many ages. It is, furthermore, possible that some of the small veins classified as epithermal or polymetallic deposits or occurrences may be the surface manifestation of a large epithermal system like that presently being mined in the Mesquite Mining District. Prior to the mining in the Mesquite Mining District, small high-grade gold-bearing quartz veinlets with only a small amount of reported production from them were the surface manifestation of the large orebodies (Morton, 1977). Additional production came from nearby small placer mines (Morton, 1977). Only after extensive exploration were the large orebodies defined.

No other information is available that would provide general criteria necessary for delineating permissive terranes for the epithermal deposits like those in the Mesquite Mining District. Permissive terranes for this type of epithermal deposits are not shown on figure 4.

Polymetallic systems

Deposit types included within this group are polymetallic replacement, polymetallic veins, and tungsten veins. These deposits are grouped largely because of their common association with granitic rocks. Skarns also are present in this environment (see below), but are discussed in separate sections because of (1) unique properties that make some of them amenable to geophysical exploration techniques (magnetite-bearing iron skarns) and (or) (2) their distinctive calc-silicate mineralogy which aids in identifying those deposits in the published literature.

Polymetallic replacement deposits

Polymetallic replacement deposits (model 19a; Morris, 1986) form at shallow depths where a stock or pluton has intruded carbonate rocks. Known occurrences in the study area are associated with granitic rocks of Mesozoic age. Carbonate rocks are present in the miogeoclinal sedimentary sequences of Proterozoic and Paleozoic age and are less common in the sedimentary sequences of Mesozoic age in the Mojave Desert. The carbonate rocks are generally located in the eastern and southern parts of the study area, but are volumetrically minor, except for areas in the San Bernardino Mountains on the southern margin of the study area, and in the Slate Range in the northern part of the study area. Small polymetallic replacement deposits are known in each of these ranges (Smith and others, 1968; Wattenberger, 1989).

Grade and tonnage models for polymetallic replacement deposits on a world-wide basis were compiled for entire districts, and these districts have a median tonnage of 1,800,000 tonnes with a median grade of 5.2 percent lead, 3.9 percent zinc, 0.094 percent copper, 150 g/t silver, and 0.19 g/t gold (Mosier and others, 1986b). Despite the permissive environment in the study area, neither permissive terranes nor quantitative estimates were made for these types of deposits because (1) known deposits in the area are too small to lie on the grade-tonnage curve, and (2) the general absence of carbonate rocks in the area.

Polymetallic veins

Polymetallic vein deposits (model 22c; Cox, 1986a) are widespread in the study area and are present in granitic, volcanic, and metamorphic terranes. Base and precious metals in varying abundances are produced from these deposits, which for the purposes defining a deposit model were grouped by district. Each district represents systems of veins where the veins are present within about 1 km of each other. The compiled districts have a *median* tonnage of 7,600 tonnes with a median grade of 2.1 weight percent zinc, 9 weight percent lead, 820 g/t silver, 0.13 g/t gold, and 10 percent of the deposits have copper grades that exceeds 0.89 weight percent (Bliss and Cox, 1986). Bliss and Cox (1986) note that data used to generate the grade and tonnage model reflect considerable complexity in the geologic and economic conditions under which the deposits produced or were evaluated. For this study, it is important to note that there are two types of polymetallic vein districts. One is a base-metal rich (base-metals with or without silver) vein and the second is a gold-silver type of polymetallic vein where the base-metals production is less important economically. The grade and tonnage models developed by Bliss and Cox (1986) are for the base-metal-rich veins, and an equivalent grade and tonnage model for the gold-silver rich polymetallic veins was not developed due to a lack of sufficient data.

Most polymetallic veins in the study area were worked primarily for their precious metal content, and to a lesser extent their base metal content (Wright and others, 1953; Carlisle and others, 1954; Troxel and Morton, 1962). The largest mining district in the study area is the Dale Mining District in the Pinto Mountains, which produced some 185,000 troy oz (~5.8 tonnes) of gold from numerous veins that covers an area about 9 km by 12 km (U.S. Bureau of Land Management, 1981, *in* Ruff and others, 1982). Other districts in the study area are the El Paso and Rademacher Mining Districts in the El Paso Mountains where small amounts of copper and gold also have been produced (Troxel and Morton, 1962). Still smaller districts are present in the San Bernardino, Ord, Rodman, and Alvord Mountains (Clark, 1970). Small gold placer mining districts are associated with some of these polymetallic veins, particularly those on the south flank of the El Paso Mountains (Troxel and Morton, 1962; Clark, 1970).

Polymetallic veins are associated with Jurassic and Cretaceous granitic rocks. In general, veins which produced gold and copper are associated with Jurassic plutons. These types of polymetallic veins are present near the porphyry copper system in the Ord Mountains (see below), and also in the Pinto and El Paso Mountains. The permissive terrane for Jurassic polymetallic veins is coextensive with the area of dominantly Jurassic plutonic and volcanic rocks (fig. 8). Only the

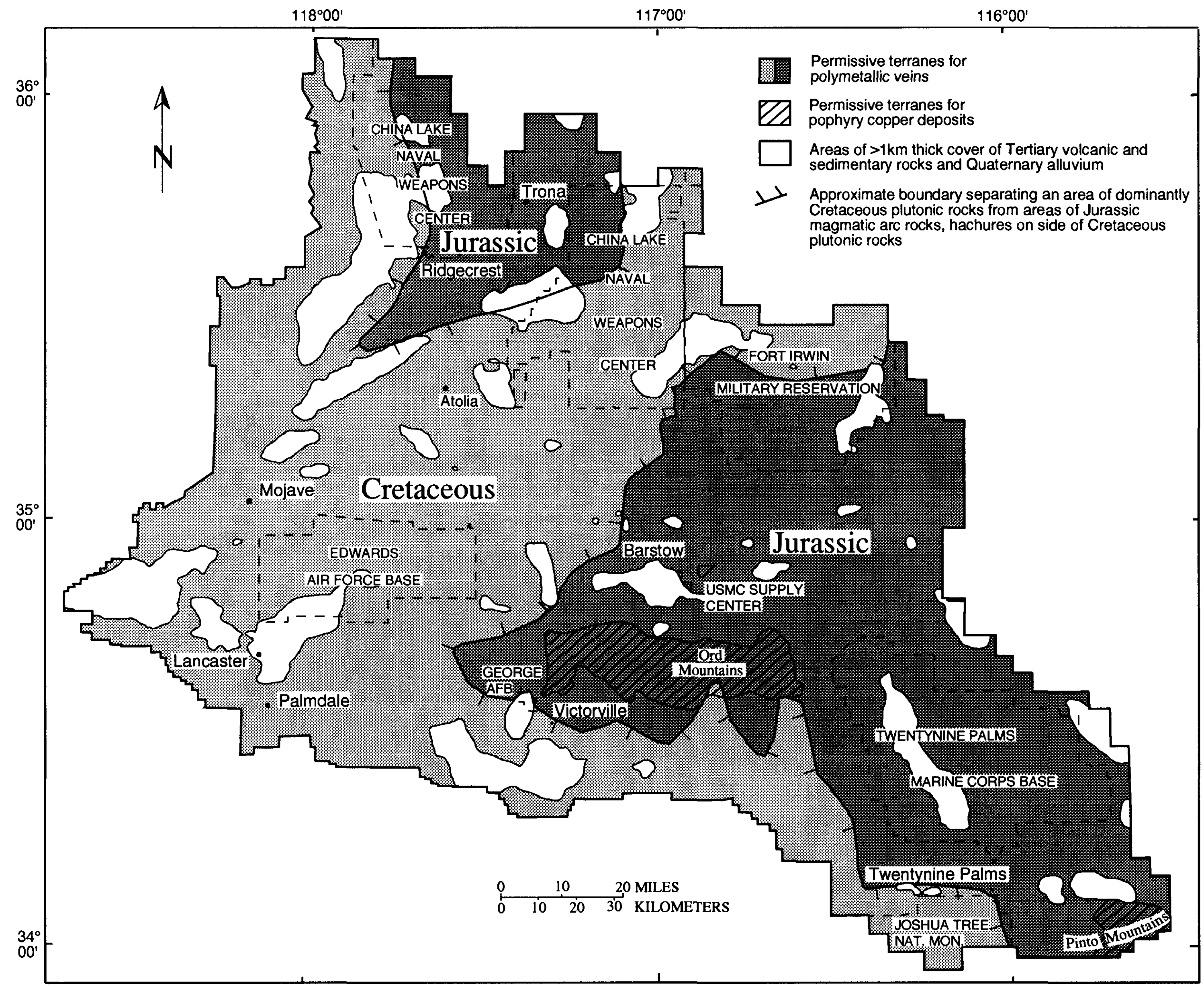

Figure 8. Permissive terranes for Jurassic and Cretaceous polymetallic vein districts and Jurassic porphyry copper deposits in the West Mojave Management Area, southern California.

areas of Jurassic plutonic and volcanic rocks where the younger cover exceeds 1 km thick are excluded from the permissive terrane.

The available literature is insufficient to conclude definitively that a different metal association is present in veins cutting Cretaceous granitic rock than those cutting Jurassic granitic rocks. However in the San Bernardino Mountains, Cretaceous polymetallic veins have produced, in addition to gold and silver, minor amounts of lead and zinc (Wright and others, 1953; Matti and others, 1982). Thus, Cretaceous veins may be representative of the base-metal-rich polymetallic veins. The permissive terrane for Cretaceous polymetallic veins is coextensive with the area of dominantly Cretaceous plutonic rocks (fig. 8). As with the Jurassic polymetallic veins, only the areas of Cretaceous plutonic rocks where the younger cover exceeds 1 km thick are excluded from the permissive terrane. We realize that the permissive terranes for both Jurassic and Cretaceous polymetallic veins are rather large, and recommend that additional field work be undertaken such that better terranes can be delineated.

The potential for polymetallic veins associated with the Jurassic plutonic rocks is considered to be greater than the potential for the Cretaceous veins. The panel estimated that for polymetallic vein districts of Jurassic age, there is a possibility of about 0.75 mean expected districts on the basis of two or more districts at the 10 percent confidence level, four or more districts at the 5 percent confidence level and 5 or more districts at the 1 percent confidence level (table 2). Based on this estimate, there is about a 10 percent probability that there is the *mean* content of gold (0.2 tonnes), silver (81 tonnes), copper (103 tonnes), lead (6,260 tonnes), and zinc (3,910 tonnes) present in the terrane (table 3A, fig. 9). Caution must be exercised with these estimates because Jurassic polymetallic veins are rich in gold and have produced copper, and the available grade and tonnage model is not generally applicable to this type of polymetallic vein (Bliss and Cox, 1986; Ludington and Hodges, 1991). Thus, the estimate of the metal content reported for these deposits probably over represents the silver, lead, and zinc resource and under represents the gold and copper contents (table 3A, fig. 9).

For Cretaceous polymetallic vein districts, there is the possibility of 0.57 mean expected deposits on the basis of one or more districts at the 10 percent confidence level, four or more districts at the 5 percent confidence level, and five or more districts at the 1 percent confidence level (table 2). Thus, there is about a 10 percent probability that there is the *mean* content of gold (0.1 tonne), silver (65 tonnes), copper (63 tonnes), lead (4,690 tonnes), and zinc (3,170 tonnes) present in the terrane (table 3A, fig. 10).

Tungsten veins

Tungsten veins include wolframite and base-metal sulfides in quartz veins that are commonly associated with peraluminous granitic rocks (model 15a; Cox and Bagby, 1986). Deposits in the western United States contain wolframite, and uncommonly scheelite, in veins cutting peraluminous granites that represent crustal melts (Ludington and Johnson, 1984; Barton, 1990). On a world-wide basis, vein systems that were used to construct the grade and tonnage models have a median tonnage of 560,000 tonnes with a median tungsten oxide (WO_3) grade of 0.9 weight percent according to Jones and Menzie (1986a). However in Nevada, productive tungsten veins rarely exceeded 10,000 tonnes of ore (D.P. Cox, oral commun., 1992). It is likely that such small tonnages are also representative of the types and sizes of deposits that remain to be discovered in the study area.

The permissive terrane for this type of deposit is restricted to areas of Cretaceous granites that crop out widely in the northwestern part of the study area (fig. 8). Small peraluminous granite bodies are known within this granitic terrane, although it is uncertain whether these granitic bodies represent differentiation products of metaluminous granite magmas or are individual peraluminous granite intrusions that are derived from melting of crustal sources (J. S. Miller, oral commun., 1992). Within this terrane, the potential for these types of veins is considered to be low (table 2) with 0.03 mean expected undiscovered deposit on the basis of at least 1 or more deposit at a 1 percent confidence level. Thus, there is less than a 5 percent probability that there is the *mean* content of tungsten (730 tonnes) present in the terrane (table 3A, fig. 11). This low estimate is

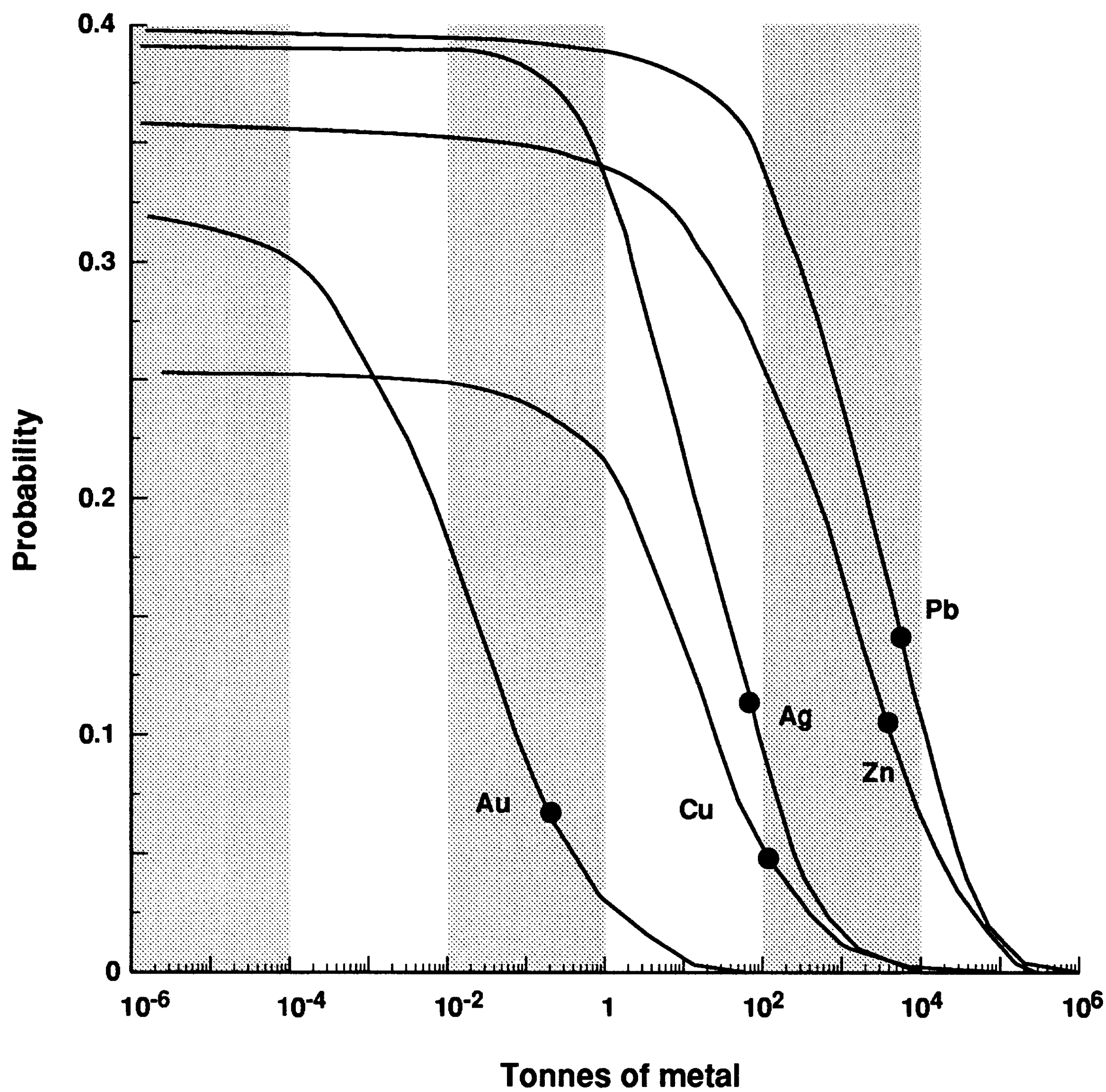

Figure 9. Graph showing probabilistic estimates for the amount of gold (Au), silver (Ag), copper (Cu), lead (Pb), and zinc (Zn) in polymetallic vein systems of Jurassic age in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values.

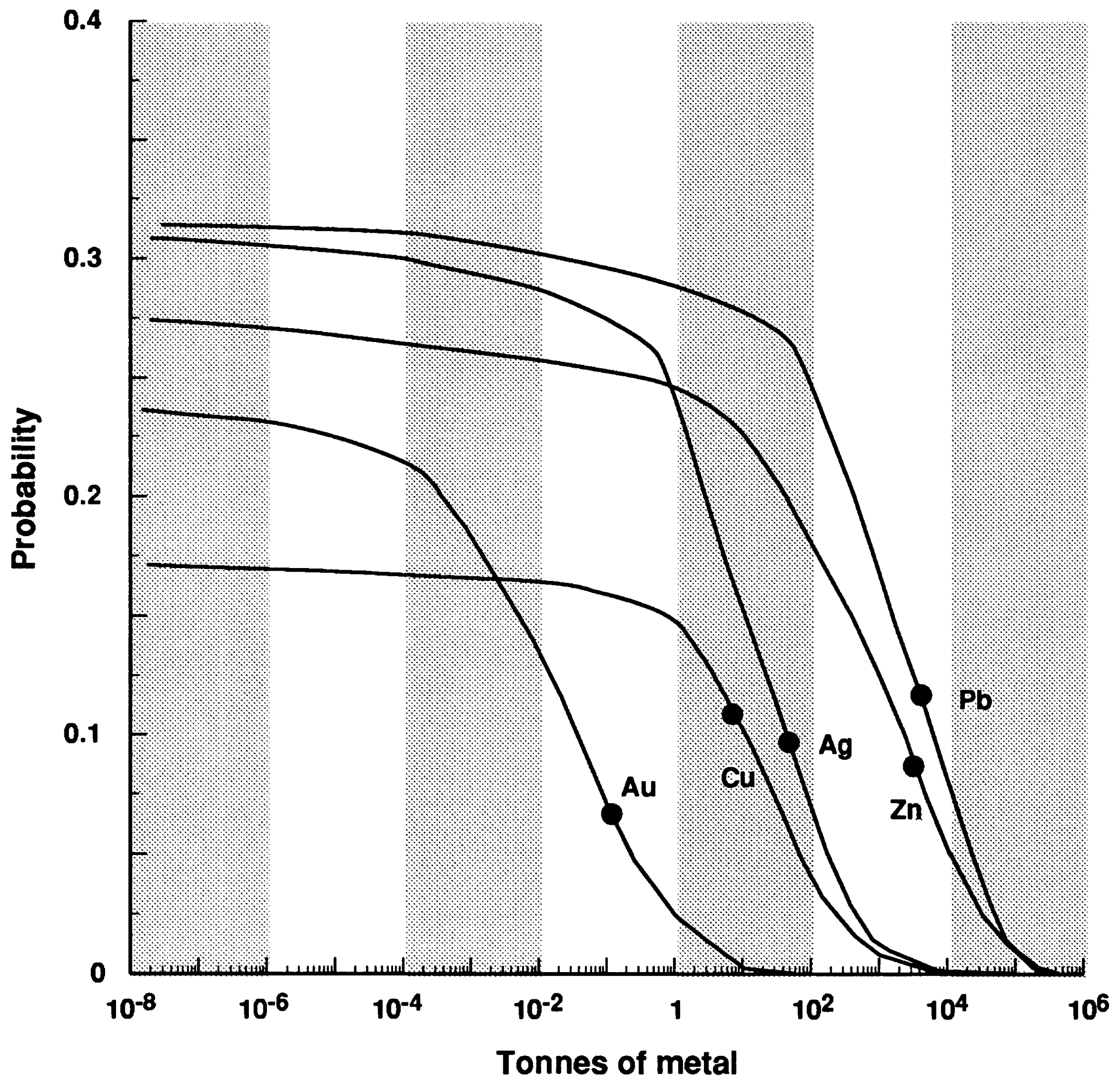

Figure 10. Graph showing probabilistic estimates for the amount of gold (Au), silver (Ag), copper (Cu), lead (Pb), and zinc (Zn) in polymetallic vein systems of Cretaceous age in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values.

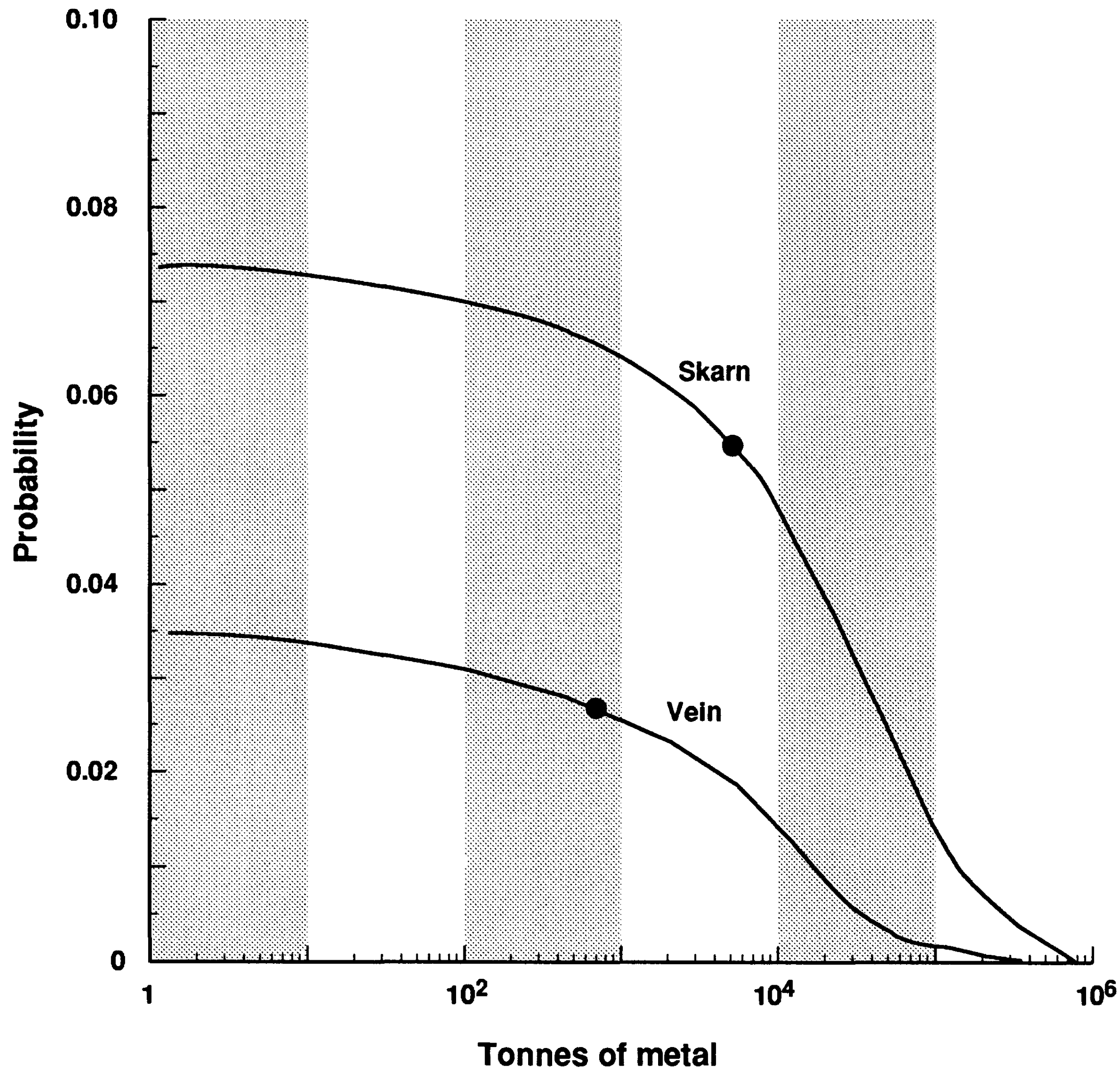

Figure 11. Graph showing probabilistic estimates for the amount of tungsten (W) in vein and skarn deposits in the West Mojave Management Area, California. Filled circles indicate mean estimates of metal for each deposit type. See table 3A for mean values.

justified because of the lack of evidence for these types of deposits in the exposed areas. Additional support for this conclusion stems from the apparent absence of peraluminous granites of the type that generally have associated tungsten veins, and the location of the permissive terrane west of the belt of peraluminous granite plutons that formed in the hinterland of the North American cordillera (Miller and Bradfish, 1980).

Tungsten veins-Atolia type

The largest tungsten-producing area in the study area was the Atolia Mining District immediately south of Randsburg. This district was a major producer of tungsten prior to the opening in 1938 of the Pine Creek tungsten skarn in the eastern Sierra Nevada, some 230 km to the north of the study area (Wright and others, 1953). Other small veins in the southern Sierra Nevada have had very minor production of tungsten (Troxel and Morton, 1962; Diggles and others, 1985a). Still another tungsten vein district in southern California is the Andrew Curtis Mine on the south flank of the San Gabriel Mountains, some 40 km south of the western boundary of the study area (Unruh and Graber, 1982).

In the study area, in excess of 1,000,000 units (8,000 tonnes) of tungsten oxide were produced from scheelite-bearing quartz veins that cut a Late Cretaceous metaluminous granite and from placer deposits in the Atolia Mining District (Lemmon and Dorr, 1940; Wright and others, 1953; Bateman and Irwin, 1954; Silver and Nourse, 1986). This deposit does not fit the tungsten vein model of Cox and Bagby (1986) in several important features, such as (1) the association with a metaluminous granite and not with a peraluminous granite, (2) the presence of scheelite rather than wolframite, and (3) the local presence of minor amounts of gold, cinnabar (mercury mineral), and stibnite (anitmony mineral) in the veins. Because of these differences with the model for tungsten veins, we treat the Atolia-style tungsten veins separately from those that are associated with peraluminous granites and that were used evaluated quantitatively in the previous section.

The permissive terrane for Atolia-type tungsten veins (fig. 8) is coextensive with Cretaceous plutonic rocks, and thus is the same as that for the tungsten veins. Within this large terrane, it was estimated that there is a chance of as many as two more mining districts of about the same size and type of as the Atolia Mining District. No probability was assigned to this qualitative estimate.

Tungsten and base-metal skarns

Skarns are deposits formed by metasomatic replacement of predominantly carbonate rocks, but also other sedimentary or igneous rocks, by calcium-iron-magnesium-manganese silicate minerals (Einaudi and others, 1981). Skarns in the study area are spatially and genetically related to Mesozoic granitic intrusions. Here, carbonate rocks are relatively common in the sedimentary sequences of Proterozoic and Paleozoic age, and are less common in the sedimentary sequences of Mesozoic age. Paleozoic carbonate rocks are common in the miogeoclinal sequences, which are present in the east and southern part of the study area. To the west and north, the rocks are generally of eugeoclinal character, and the volume of carbonate rocks is small. In the Mojave Desert, most carbonate rocks are present as small pendants in largely Jurassic and Cretaceous plutons. Tungsten skarns are apparently associated with Cretaceous plutons, whereas iron skarns are preferentially associated with the Jurassic plutons. Iron skarns will be discussed in a following section.

Tungsten skarns

Tungsten skarns (model 14a; Cox, 1986b) have a median tonnage of 1,100,000 tonnes at a median grade of 0.67 percent tungsten oxide (Menzie and Jones, 1986). In contrast, production data for 65 tungsten skarns in Nevada suggest a median tonnage of 920 tonnes at a median grade of 0.61 weight percent tungsten oxide (Stager and Tingley, 1988; D.A. John, written commun., 1992). This data suggest that tungsten skarns in the study area may be of equivalent size to those in Nevada and smaller than the world-wide grade and tonnage model of Menzie and Jones (1986).

Tungsten skarns in the study area are in the Sierra Nevada, near Goldstone, in the Shadow Mountains, and in the San Bernardino Mountains (Bateman and Irwin, 1954; Diggles and other, 1985a; Rapp and Vredenburgh, 1991). Most of these deposits are small and discontinuous, with the deposit in the Shadow Mountains reporting the largest production. About 1,000 units of tungsten oxide (about 8 tonnes) were produced from low-grade skarns in the Shadow Mountains (Bateman and Irwin, 1954). This mining district is smaller than the smallest deposit that makes up the grade and tonnage curve (Menzie and Jones, 1986) and would lie near the median tonnage for these deposits in Nevada, if we assume the smallest tonnage and the highest possible grade. Because the deposit in the Shadow Mountains was extensively worked, the group concluded that the other known tungsten skarns in the study area are of similar small size.

Criteria used to define permissive terranes (figs. 8 and 12) include the presence of carbonate rocks near Cretaceous plutons and evidence of skarn or vein type mineralization. Within the terrane, it is estimated that there is a possibility of 0.03 mean expect deposit on the basis of one or more deposit at the 1 percent confidence level. Thus, there is about a 5 percent probability that there is the *mean* content of tungsten (5,180 tonnes) present in the terrane (table 3A, fig. 11). This estimate is justified by the small sizes of known deposits in the study area.

Base-metal skarns

Copper skarns (model 18b; Cox and Theodore, 1986) have a median tonnage of 560,000 tonnes with a median copper grade of 1.7 weight percent; 10 percent of deposits have silver grades that exceed 36 g/t and 10 percent of the deposits have gold grades that exceed 2.8 g/t (Jones and Menzie, 1986b). Zinc-lead skarns (model 18c; Cox, 1986c) have a median tonnage of 1,400,000 tonnes with a median grade of 5.9 weight percent zinc, 2.8 percent lead, 0.09 weight percent copper, and 290 g/t silver; 10 percent of the deposits have gold grades that exceed 0.46 g/t (Mosier, 1986b).

Permissive terranes for copper and zinc-lead skarns in the study area are restricted to those small areas of limestone that are intruded by Mesozoic granitic rocks. These terranes are identical to those delineated for tungsten skarns (fig. 12). Because there are no known occurrences of copper or zinc-lead skarn within the study area, it is not known with which of the plutonic suites, Jurassic or Cretaceous, these types of deposits might be associated. However, judging from the

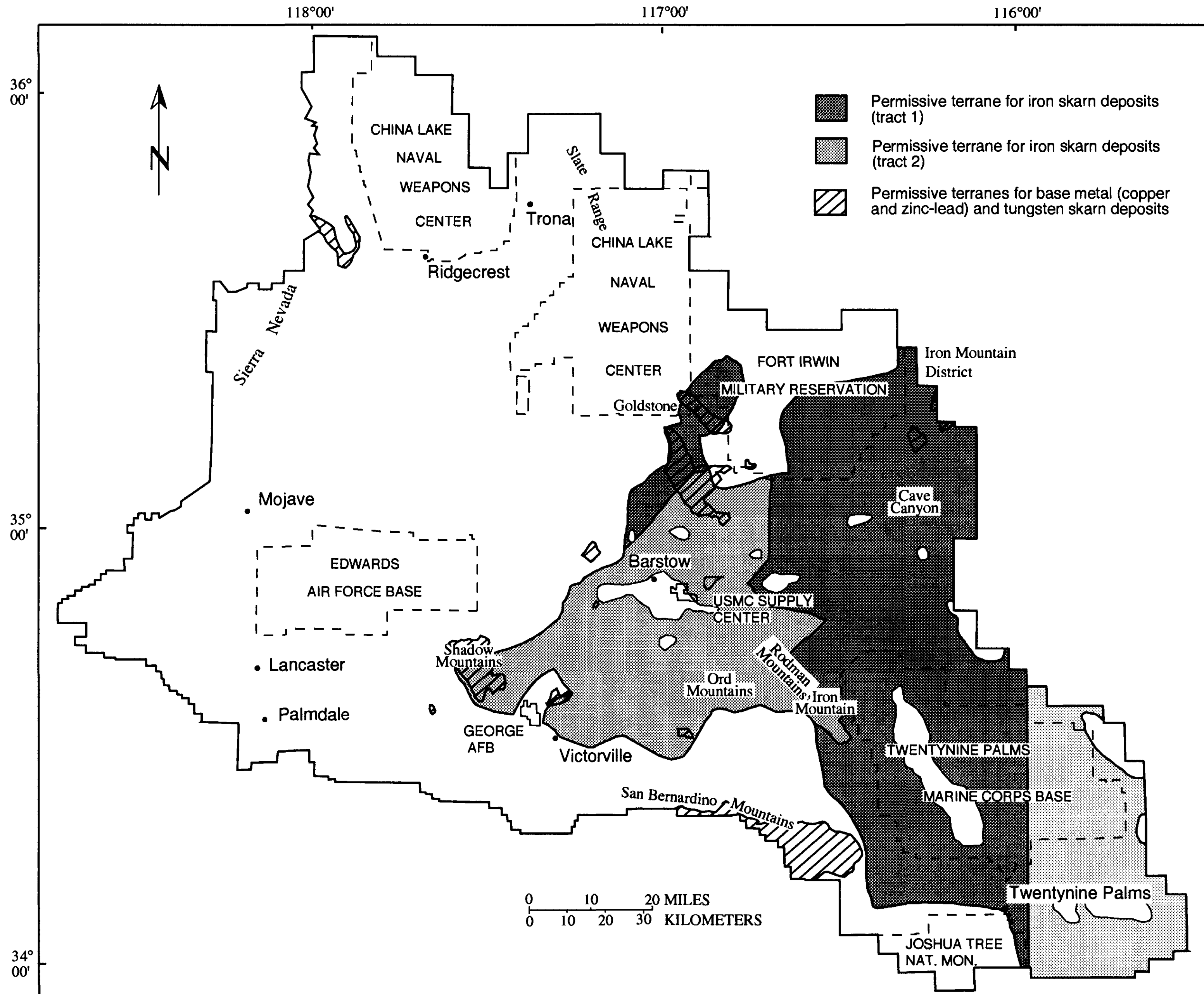

Figure 12. Permissive terrane for iron, basemetal, and tungsten skarn deposits in the West Mojave Management Area, southern California.

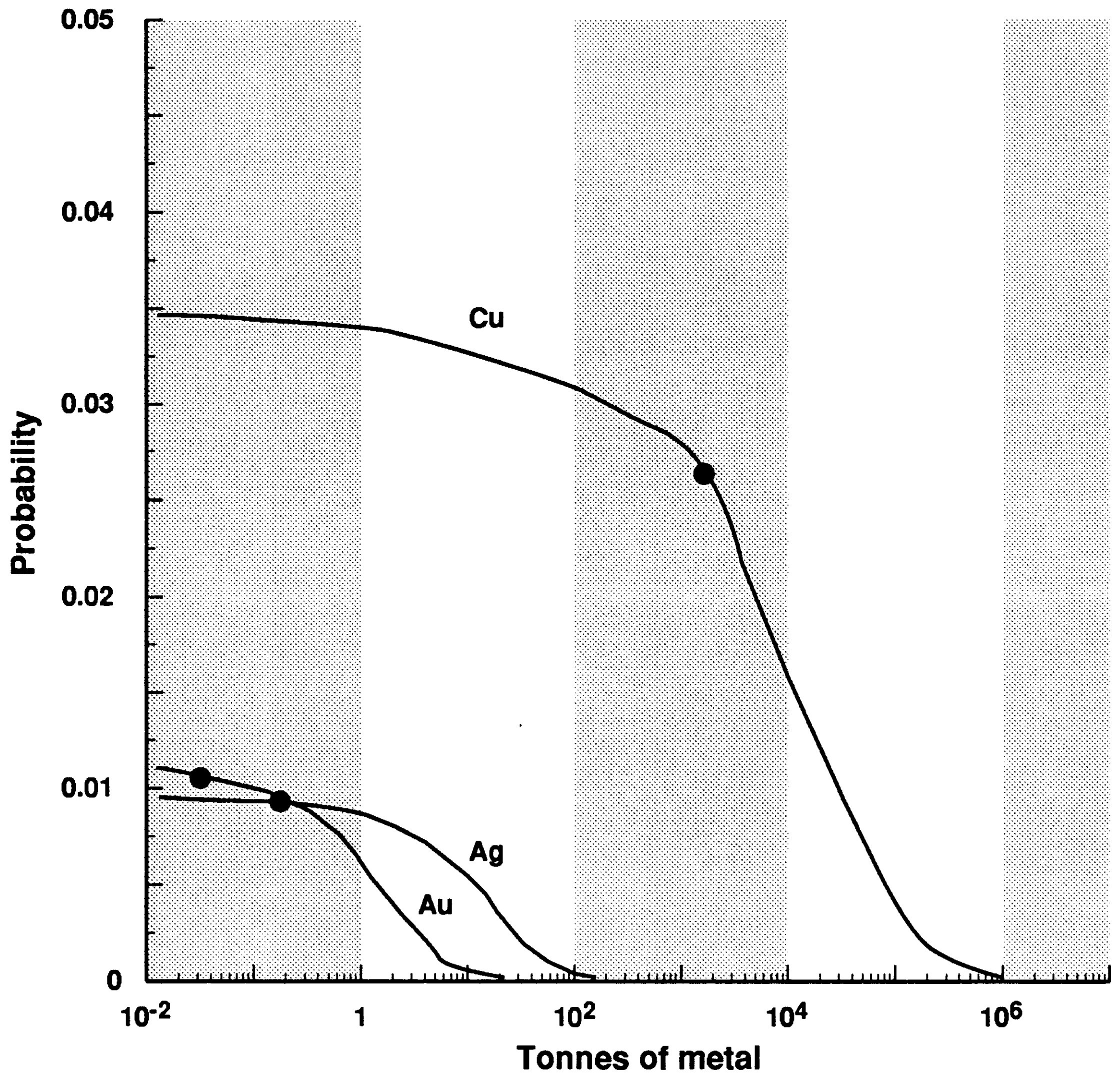

Figure 13. Graph showing probabilistic estimates for the amount of copper (Cu), gold (Au), and silver (Ag) in copper skarn deposits in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values.

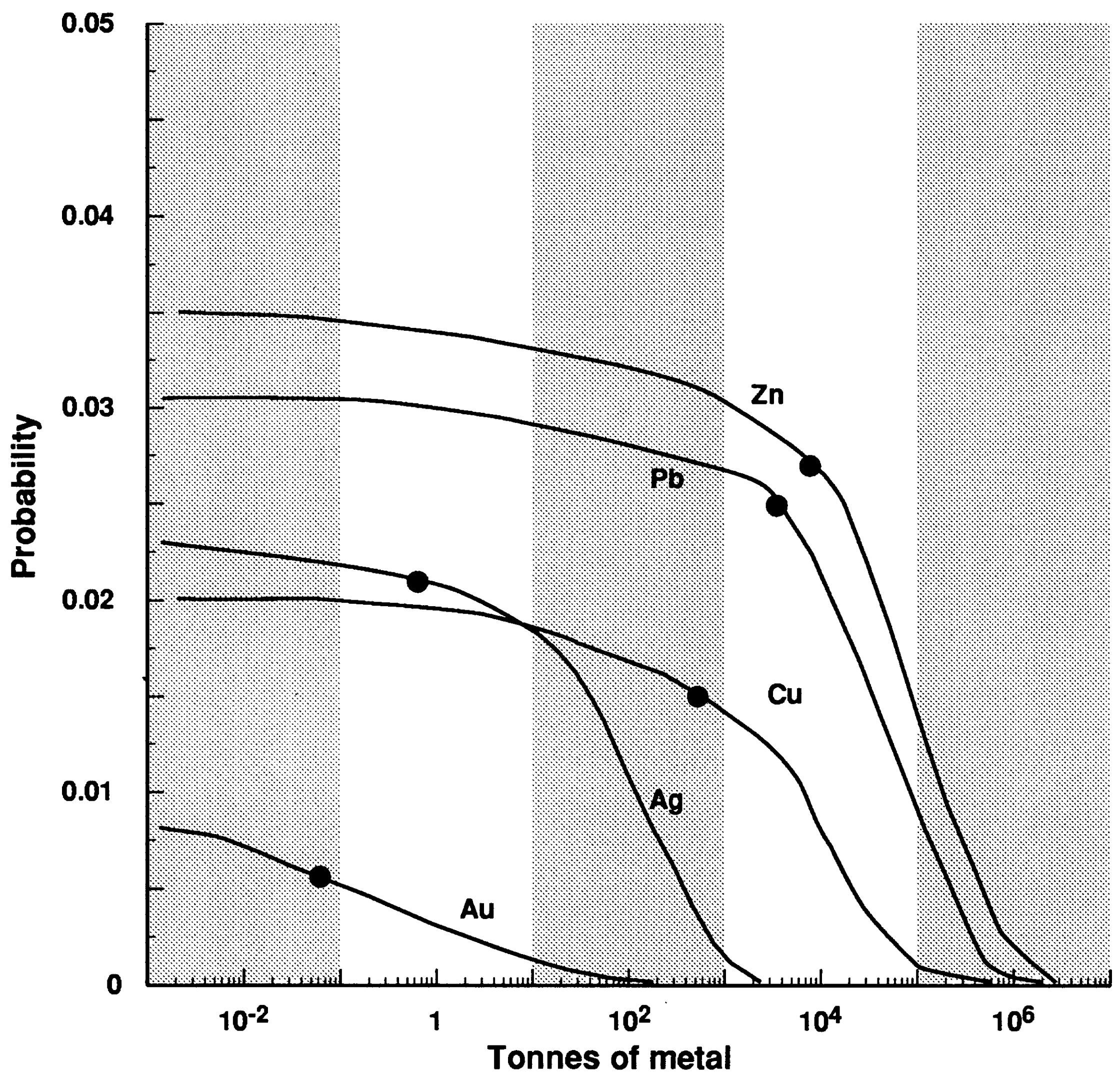

Figure 14. Graph showing probabilistic estimates for the amount of zinc (Zn), lead (Pb), copper (Cu), gold (Au), and silver (Ag) in zinc-lead skarn deposits in the West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean values. See figure 12 for location of terrane.

metal associations in the polymetallic and tungsten veins (see above) and the presence of at least one porphyry copper system (see below), it seems likely that the copper skarns might be associated with Jurassic plutons. The association of zinc-lead skarn is unknown, because there is little zinc-lead mineralization known in the study area except for small polymetallic replacement deposits in the southern Slate Range.

The possibility of these two types of skarns being present in the permissive terrane can not be zero. Thus, these two skarn types are assigned a low probability of at least one or more deposit at the 1 percent confidence level (table 2). Thus, there is less than a 5 percent probability that there is the *mean* metal content in the undiscovered copper (copper-1,700 tonnes; gold-0.02 tonne) and zinc-lead (zinc-8,400 tonnes; lead-3,720 tonnes; gold-0.08 tonne; silver-6 tonnes) skarn deposits in the permissive terrane (figs. 13 and 14).

Iron skarn

Iron skarn forms in a manner similar to base metal and tungsten skarns. For purposes of this report, these deposits are considered separately from other skarns because their typical magnetic properties are amenable to reconnaissance evaluation using aeromagnetic data. Iron skarns (model 18d; Cox, 1986d) have a median tonnage of 7,200,000 tonnes with a median grade of 50 weight percent iron (Mosier and Menzie, 1986b) on a worldwide basis. In the study area and in southern California in general, iron skarns are relatively common with deposits in the study area including the Bessemer deposits at Iron Mountain (1,633,000 tonnes), Cave Canyon Mining District in the Cave Mountains (3,600,000 tonnes), Iron Mountain Mining District in the southern Avawatz Mountains (Silver Lake Mining District; 5,400,000 tonnes), and several other small deposits that produce iron ore used in the portland cement industry (Lamey, 1948a, b, c; Rapp and Vredenburgh, 1991). Most of the deposits in the study area are smaller than the median size in the grade and tonnage model of Mosier and Menzie (1986b), with the bulk of the deposits having tonnages of less than 500,000 tonnes (Wright and others, 1953). In contrast, the Black Eagle Mine in the Eagle Mountains, the largest deposit in southern California and located about 20 km southeast of the southeast boundary of the study area, is larger than the median and contained, prior to mining, 135,000,000 tonnes of ore with an additional sizable deposit lying buried beneath 400 m of alluvium to the immediate west of the mine (Collins, 1982). The dominant mineral in the skarns in the study area is magnetite, though many of the small iron skarn deposits contain hematite with subordinate magnetite (Wright and others, 1953). Gold is a common by-product in some iron skarns and many of these deposits throughout the world are mined for the gold content, not for the contained iron (Theodore and others, 1991). Gold has not been reported from iron skarns in the Mojave Desert, though gold has been recovered from small replacement deposits near iron skarns in the Eagle Mountains (Ruff and others, 1982).

Iron skarn deposits in southern California are associated with Jurassic plutons which commonly have an associated aeromagnetic high (Jachens and others, 1986). This association, the presence of known iron skarn mineralization, and the parts of the Jurassic arc that are known or inferred to have formed at shallow (<10 km) depths (J.S. Miller, oral commun., 1992) were used to delineate permissive terrane (fig. 12) lying in the central and southern part of the study area. Exceptions to this association might be present in the northeastern part of the study area because outside of the study area to the north, small iron skarns are associated with Miocene stocks (J.P. Calzia, unpub. data, 1992). However, there is no evidence to suggest that Miocene iron skarn is present in the study area.

Two different aeromagnetic surveys cover the permissive terrane in the study area (fig. 12). Their different parameters allow the permissive terrane for iron skarns to be divided into two separate tracts. Tract 1, which lies in the central part of the study area around the Ord and Rodman Mountains and in the southeastern part of the study area, is covered by a survey with a 300-m drape with a 0.8-km flight spacing. Tract 2 includes the remainder of the permissive terrane and is covered by a survey with a 120-m drape and a 5-km flight spacing that was prepared as part of the NURE program. The survey flown as part of the NURE program includes the only aeromagnetic data that covers most of the military reservations in the study area. Utilizing the data and aerial coverage provided by these surveys, the permissive terrane was searched by computer for undiscovered deposits of various sizes and at varying depths of up to 1 km beneath cover. The search was based on a model where median grade of an iron skarn was converted to contained magnetite content and then to a magnetic susceptibility. A compact geometry, in this case a cube, was assumed for the various size deposits. Such a geometry was assumed to simplify the model even though iron skarns are more likely to be tabular bodies. Because tabular deposits are easier to find than compact deposits, it was also assumed that the surveys found almost all of the deposits above a certain size when the model results indicated that 50 percent of the volume had been searched perfectly. This allowed the determination of the maximum size of deposits that could lie within the permissive terrane and be undetected by the available aeromagnetic data.

Based upon this model, no deposit larger than 15,000,000 tonnes of magnetite ore could be present in tract 1 (fig. 12) and not have been detected by the available survey. For tract 2 (fig. 12), the maximum size was judged to be no larger than 200,000,000 tonnes of ore even though the parameters of the survey nowhere allowed 50 percent of the area to be effectively search. This maximum size is about 1.5 times the size of the Black Eagle Mine in the Eagle Mountains. Considering that this deposit is elongate over 8 km (5 mi.) and that the aeromagnetic flightlines are oblique to most geologic contacts in the study area, we decided that it is highly unlikely that a deposit of this size is not reflected by the NURE data. The NURE data with their 5-km spacing between flightlines did, however, miss the Cave Canyon and Iron Mountain (Silver Lake Mining District) iron skarn deposits in the region; these deposits are smaller than 6,000,000 tonnes.

The grade and tonnage curves for the worldwide data set were truncated at the maximum tonnages allowed by the aeromagnetic data for the purposes of estimating the endowment within the two tracts. Within tract 1, it was estimated that there was the possibility of about 4.4 mean expected deposits on the basis of one or more deposit at the 90 percent confidence level, two or more deposits at the 50 percent confidence level, ten or more deposits at the 10 percent confidence level, twelve or more deposits at the 5 percent confidence level, and eighteen or more deposits at the 1 percent confidence level (table 2). Thus, there is about a 40 percent probability that the *mean* content of iron (8,931,000 tonnes) is present in tract 1 (table 3A, fig. 15). Within tract 2, it was

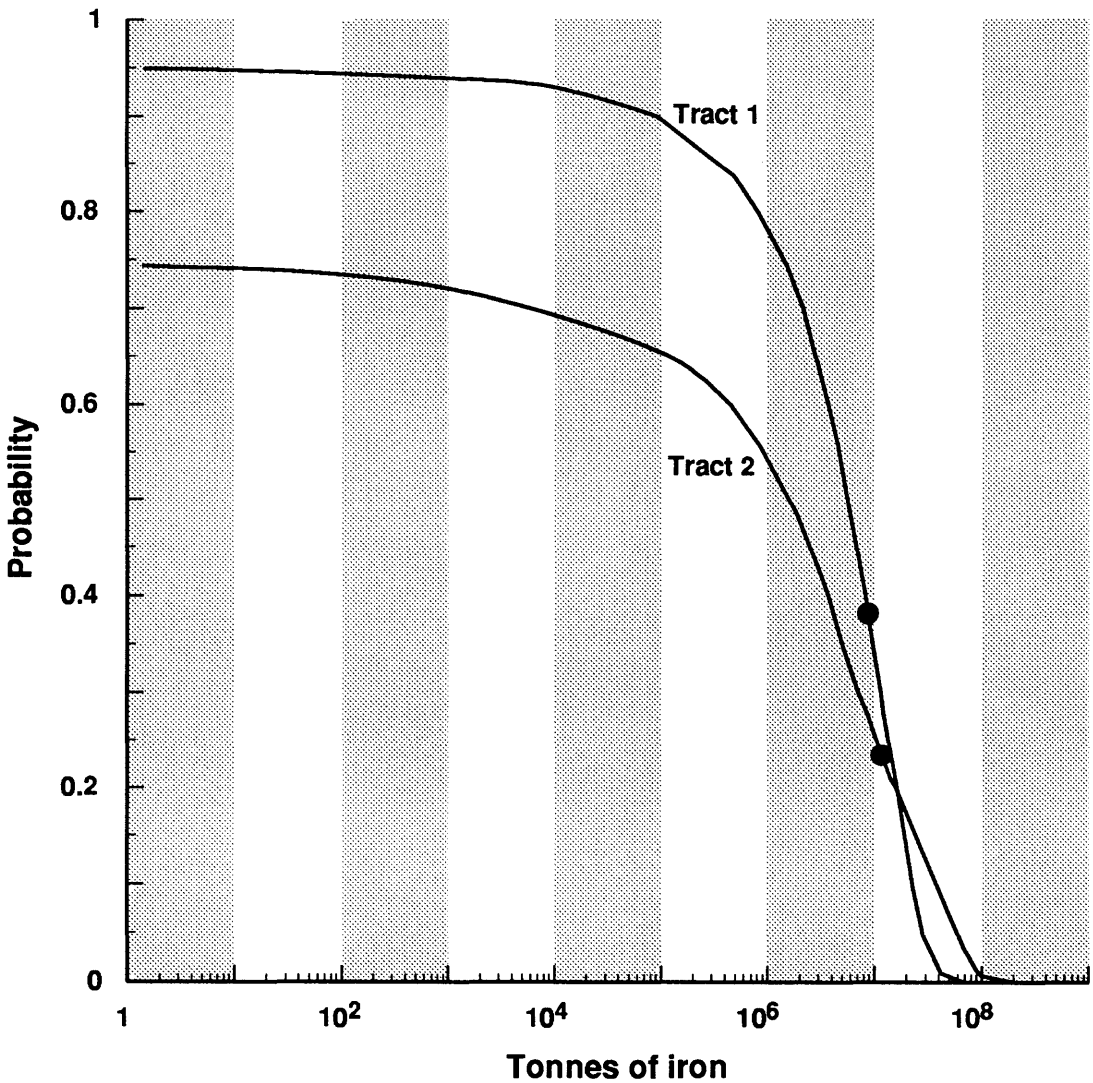

Figure 15. Graph showing probabilistic estimates for the amount of iron in iron skarn deposits in two tracts in the West Mojave Management Area, California. Filled circles indicate mean estimates for iron in each tract. See table 3A for mean values. See figure 12 for location of tracts.

estimated that there was the possibility of about 1.1 mean expected deposit on the basis of one or more deposit at the 50 percent confidence level, two or more deposits at the 10 percent confidence level, three or more deposits at the 5 percent confidence level, and four or more deposits at the 1 percent confidence level (table 2). Thus, there is about a 25 percent probability that there is the *mean* content of iron (10,832,000 tonnes) present in tract 2 (table 3A, fig. 15).

Porphyry copper

Porphyry copper deposits are associated with high-level felsic plutonic rocks that have intruded coeval volcanic rocks or older rocks. Large areas of hydrothermal alteration commonly are associated with porphyry deposits. Porphyry copper deposits (model 17; Cox, 1986e) have a median tonnage of 140,000,000 tonnes with a median copper grade of 0.54 weight percent; by-product molybdenum, silver, and gold are produced from many deposits (Singer and others, 1986a). This deposit type has been subdivided into three deposit types with different characteristics and metal contents. Porphyry copper-molybdenum deposits (model 21a; Cox, 1986f) have a median tonnage of 500,000,000 tonnes with a median copper grade of 0.42 weight percent copper, 0.016 weight percent molybdenum, 0.012 g/t gold, and 1.2 g/t silver (Singer and others, 1986b). Porphyry copper-gold deposits (model 20c; Cox, 1986g) are smaller with a median tonnage of 100,000,000 tonnes with a median grade of 0.5 weight percent copper, 0.38 g/t gold, 1.0 g/t silver, and 10 percent of the deposits have greater than 0.0072 weight percent molybdenum (Singer and Cox, 1986b). Porphyry copper, skarn-related deposits (model 18a; Cox, 1986h) constitute the last deposit type, but the lack of known copper skarns in the area and the scarcity of carbonate rocks in the permissive terranes seemingly precludes there being any of these deposits in the study area. The general porphyry copper and the porphyry copper-gold deposit models are applied in this report.

Porphyry copper deposits in the study area may be of two ages, Jurassic and Tertiary. These systems are discussed in the following sections.

Jurassic porphyry copper deposits

The permissive terrane for Jurassic porphyry copper deposits lies in the south-central part of the study area (fig. 8). The permissive terrane includes that part of the Jurassic magmatic arc where volcanic rocks and subvolcanic plutons are extensively preserved (e.g. Cox and others, 1987). The Jurassic arc in this part of the southern cordillera is oblique to the Cretaceous magmatic arc that also transgressed the region (Miller and Barton, 1990; Fox and Miller, 1990; Tosdal and others, 1989). As outlined, approximately 50 areal percent of the permissive terrane includes unconsolidated sands and gravels that cover bedrock in the valley floors.

In contrast to the Cretaceous granitoids, the Jurassic granitoids in the region commonly are more heterogeneous chemically and lithologically; they contain less quartz, commonly contain conspicuous sphene, and have high color index, contain lavender, gray, or pinkish alkali feldspar, contain clots of mafic minerals, and are more potassic showing a tendency toward alkalic compositions (Tosdal and others, 1989; Fox and Miller, 1990; U.S. Geological Survey, 1991). A small, probably Jurassic, granitoid body in the southern part of the Ord Mountains, not shown on the mining district-scale map of Weber (1963) but to be described below as being associated genetically with a porphyry copper system, has some notably alkalic facies. In some other places in the study area, as in the Pinto Mountains, Jurassic plutons are associated with magnetite skarn deposits or zones of extensive albitization (Fox and Miller, 1990; see above).

Specifically, the two permissive terranes for the Jurassic porphyry copper systems are in the Pinto Mountains (Dale Mining District) on the southeast and across the Ord and Rodman Mountains on the northwest (fig. 8). The Dale Mining District in the area of the Pinto Mountains includes a number of mineral occurrences that are classified as polymetallic veins, a type of mineral occurrence that is present on the fringes of many porphyry copper systems throughout the southwestern United States.

The permissive terrane for Jurassic porphyry copper systems in the Ord Mountains includes one known deposit of this type. This deposit is known as the Red Hill deposit and it is located on the southern flank of the Ord Mountains, approximately 3.2 km south of Ord Mountain itself, mostly in N 1/2 sec. 6, T. 6 N., R. 2 E., but some parts of the deposit also appear to be present in the adjoining section to the north, sec. 31, T. 7 N., R. 2 E. The mineralized system was explored in 1960 by a number of drill holes put down by Western Gold and Uranium, Inc., and it was also drilled during a subsequent round of exploration by American Exploration & Mining Co. during 1968 (L. Storey, written commun., 1992). As a result of these exploration activities, two nearly vertical shear zones near the contact of a largely non-porphyritic, alkalic quartz monzonite were found to contain an indicated sulfide reserve of 3,629,000 tonnes averaging 0.305 weight percent copper and 0.155 weight percent molybdenum and a somewhat deeper "prospective" sulfide reserve of 2,359,000 tonnes averaging 0.262 weight percent copper and 0.117 weight percent molybdenum below a depth of approximately 200 m (L. Storey, written commun., 1992). As further pointed out in the report provided by Storey, combined oxide reserves in the two mineralized shear zones include 444,000 tonnes that average 0.4 weight percent copper and 0.07 weight percent molybdenum. Thus, the total tonnage delineated in the two zones that constitute this mineralized system would plot at approximately the 3 percentile of the generalized porphyry copper tonnage model of Singer and others (1986), and the sulfide copper grade would plot at approximately the 10 percentile. If a factor of 2 times were used to convert the molybdenum grades to copper equivalency, in light of the approximately two-to-one present (1992) price ratio for molybdenum to copper, then the copper equivalent grade of this system be approximately 0.6 weight percent copper equivalent. In addition, nine of thirty-one rock samples analyzed from the exposed parts of the Red Hill system contain detectable concentrations of silver, that is, greater than 0.1 part per million, and all of these samples that contain detectable silver show highly elevated abundances of both copper and molybdenum (T.G. Theodore, unpub. data, 1992). Silver would constitute an important byproduct from the Red Hill system if it were ever put into production. As further noted in the report provided by Storey,

> Molybdenite, chalcopyrite, and lesser bornite and pyrite, were introduced contemporaneously or after the introduction of quartz. The molybdenite forms clusters and flakes in the quartz and along minor fractures. Chalcopyrite, bornite, and pyrite form veinlets in the quartz, silicified rocks, and kaolinized hybrid rocks, and occur as aggregates and grains disseminated in the kaolinized hybrid rocks.

> Small amounts of specular hematite and magnetite are also present, associated with the copper minerals. Brown garnet-epidote aggregates occur as small masses along the contact between felsite and quartz monzonite at several locations. ***Strong kaolinization and the development of secondary biotite and K-feldspar are evident in close proximity to the shear zones.

As a comparison, the Jurassic porphyry copper system at Yerington, Nev., produced approximately 162,000,000 tons of ore at a copper grade of 0.55 weight percent between 1953 and 1978 when the mine was shut down (Einaudi, 1982). It is highly probable that the permissive terrane for Jurassic porphyry copper deposits in the study area does not contain a porphyry copper deposit as large as the one at Yerington. This is reflected in the estimated tonnages of copper that remain undiscovered in the permissive terrane (table 3, figs. 16A and 16B).

Additional clusters of polymetallic veins are present elsewhere in the Ord Mountain Mining District, especially along a series of north-south-striking mineralized structures or ledges that define the approximately 5-km-long Ord Mountain fault zone (Weber, 1963). One of these polymetallic vein occurrences is at the Moly Prospect. Small amounts of molybdenite are reported to be present at the Moly Prospect, also known as the Molly claims, in the NW 1/4 sec. 30, T. 7 N., R. 2 E., approximately 2.5 km north of the Red Hill deposit, and approximately 0.8 km southwest of Ord Mountain (L. Storey, written commun., 1992; Weber, 1963). Principal underground exploration work at these claims was conducted in the late 1950s (Weber, 1963), and these workings explore a north-south striking, steeply east-dipping mineralized fault, containing copper- and gold-bearing hydrothermal assemblages, that is surrounded by an area of altered metavolcanic rocks that is about 0.3 km^2 in size at the surface. The copper mineralization along the mineralized fault at the Moly prospect is mostly in the form of chalcocite, although disseminated chalcopyrite and bornite have been reported from the underground workings (L. Storey, written commun., 1992). Somewhat farther to the north, near the north end of the Ord Mountains, there is another cluster of largely copper-bearing polymetallic veins in the general area of the Copper Junction workings, the Josephine ledge, the Brilliant ledge, and the Gold Banner Mine (Weber, 1963). As pointed out by Weber (1963), all of these latter occurrences have had only a minor amount of recorded production.

The permissive terrane for Jurassic porphyry deposits in the general area of the Ord Mountains (fig. 8) is defined on the basis of the wide extent of apparently Jurassic-age polymetallic veins in the area, some areas of widespread hydrothermal alteration, and the known presence of at least one of these mineralized porphyry systems therein that, incidentally, does fall on both the grade and tonnage curves established for the general type of porphyry copper deposits as discussed above. The mean expected number of undiscovered Jurassic porphyry copper deposits in this terrane is 0.11, based on an estimate of one or more deposits at a 5 percent confidence level and two or more deposits at the one percent confidence level (table 2). Thus, there is about a 6 percent probability that there is the *mean* content of copper (272,000 tonnes) and about a 4 percent probability that there is *mean* content of molybdenum (5,910 tonnes), gold (3 tonnes), and silver (54 tonnes) present in the terrane in the Ord Mountains (table 3A, fig. 16A).

The permissive terrane for Jurassic porphyry copper deposits in the general area of the Pinto Mountains (fig. 8) is estimated to contain 0.03 mean expected deposits based on the estimate of one or more porphyry system at the 1 percent confidence level (table 1). Thus, there is less than a 4 percent probability that there is the *mean* content of copper (87,500 tonnes), molybdenum (1,800 tonnes), gold (1 tonne), and silver (19 tonnes) in the terrane (table 3A, fig. 16B). Support for the lower estimate comes from the lack of a known porphyry copper system in the outlined permissive terrane.

The difference in the expected numbers of porphyry copper deposits between Ord Mountains and the Pinto Mountains terranes is primarily a reflection of a clustering effect (Slichter, 1962; Harris, 1984; Carlson, 1991; Bultman and others, 1992) in the subjective estimate that results principally from the known presence of one of these types of deposits in the area of exposed bedrock in the Ord Mountains. This conclusion also results from the fact that a much greater percentage of the outlined Ord Mountains permissive terrane is covered by gravel than the permissive terrane at Pinto Mountain. Therefore, the likelihood is greater that in the Ord Mountains terrane there may be an undiscovered Jurassic porphyry copper deposit below the gravels there simply because the covered areas are more widespread than those in the terrane in

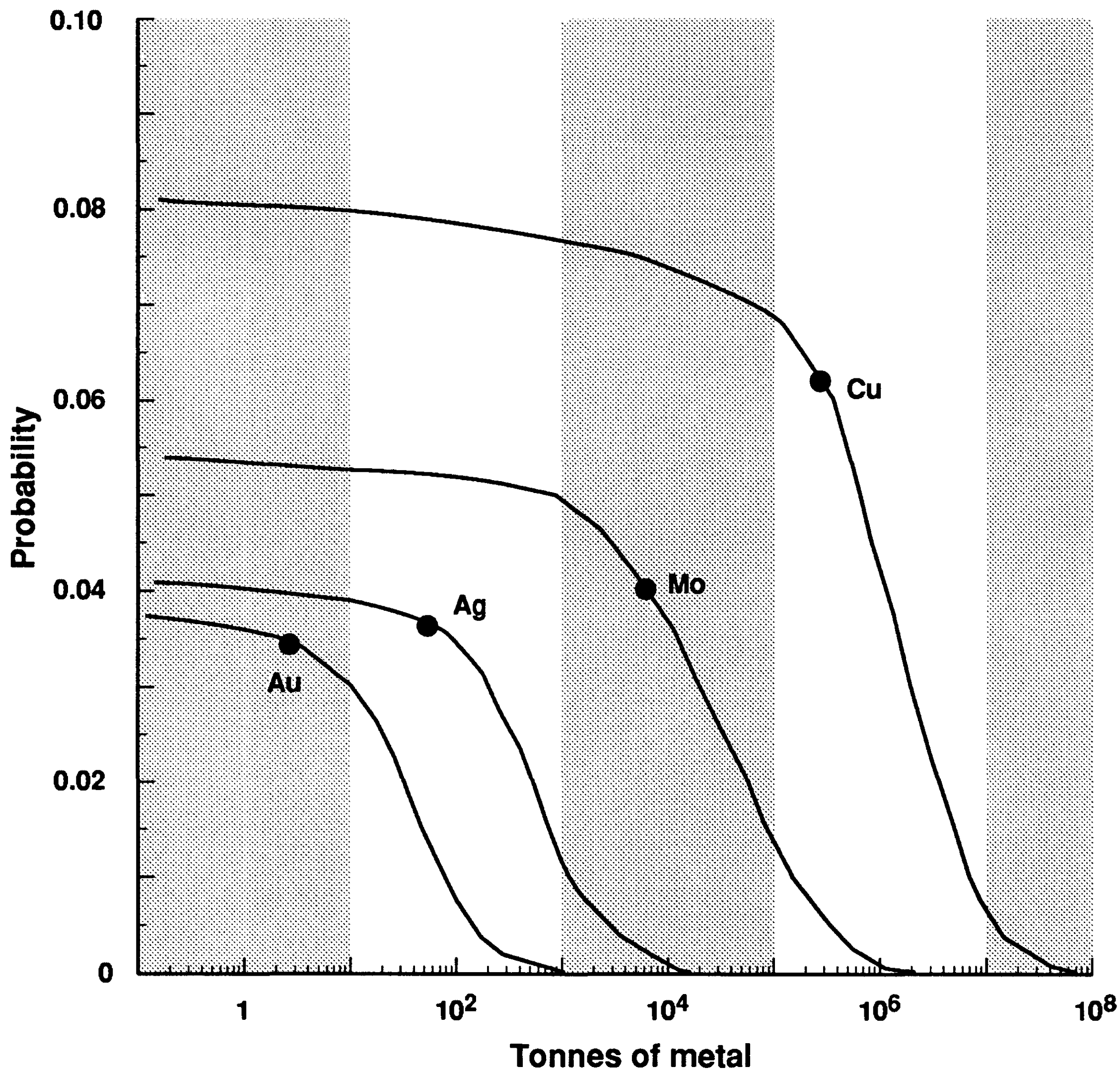

Figure 16A. Graph showing probabilistic estimates for the amount of copper (Cu), molybdenum (Mo), gold (Au), and silver (Ag) in porphyry copper deposits of Jurassic age in the Ord Mountains area, West Mojave Management Area, California. Filled circles indicate mean estimates for each metal. See table 3A for mean value. See figure 8 for location of terrane.

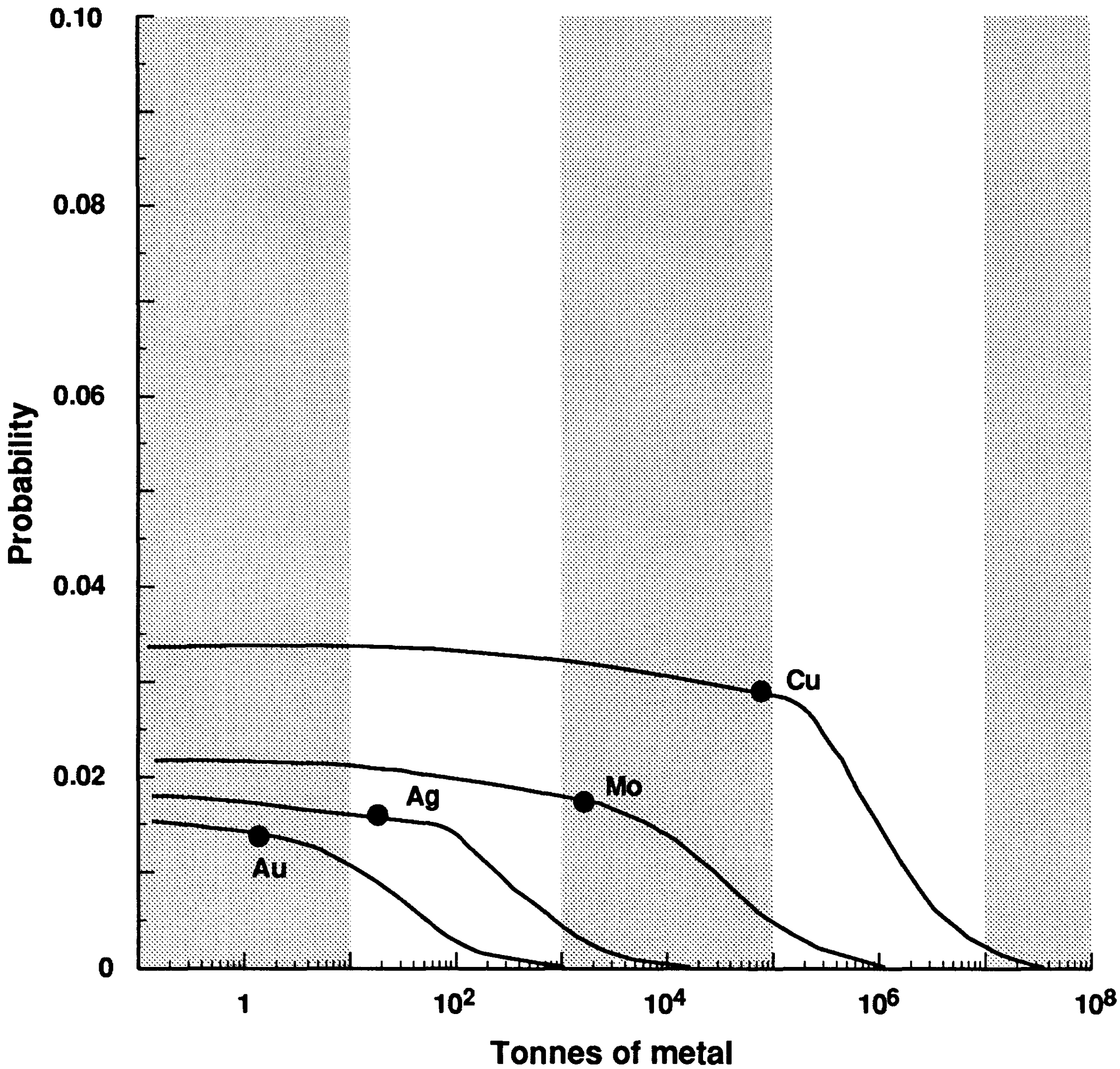

Figure 16B. Graph showing probabilistic estimates for the amount of copper (Cu), molybdenum (Mo), silver (Ag), and gold (Au) in porphyry copper deposits of Jurassic age in the Pinto Mountains area, West Mojave Management Area, California. Filled circlees indicate mean estimates for each metal. See table 3A for mean values. See figure 8 for location of terrane.

Pinto Mountains. Such a judgment is valid only if the geology of bedrock in the covered areas is generally the same as that in each of the two exposed bedrock areas. We have no geologic evidence to conclude that such an inference is not valid for these two terranes.

Tertiary porphyry copper deposits

Gold-rich porphyry copper deposits can be associated with quartz-alunite gold deposits and may be present at a depth of less than 1 kilometer (the depth limit of this assessment) below those deposits (Stoffregen, 1987). In particular, the area below the large alteration zone associated with the Miocene Cactus Queen deposits in the Mojave Mining District and the covered area between the Cactus Queen deposits and those at Soledad Mountain have a high probability of the presence of an undiscovered porphyry copper-gold deposit of Miocene age (fig. 4). The panel estimated that in terrane II (fig. 4) there are 0.3 mean expected deposits based on one or more deposit at the 10, 5, and 1 percent confidence level (table 2). Thus, there is about a 20 percent probability that there is the *mean* content of copper (276,000 tonnes) and gold (22 tonnes) and about a 10 percent probability that there is *mean* content of molybdenum (2,060 tonnes) and silver (76 tonnes) in this terrane (table 3A, fig. 17).

Porphyry gold deposits

Porphyry gold deposits are commonly associated with quartz-alunite gold deposits and typically are deeper than or lateral to the quartz-alunite deposits, occurrences, and areas of extensive acid-sulfate alteration (Rytuba and Cox, 1991). Porphyry gold deposits have much larger resources of gold than quartz-alunite deposits and typically contain very large tonnages of ore averaging 0.5-1.5 g/t gold; however, no grade and tonnage model is available for this deposit type. Porphyry gold deposits in the Maricunga segment of the Chilean volcanic arc contain 2.3 to 6.0 million oz of gold (Vila and Sillitoe, 1991). No porphyry gold deposits are known in the study area. However, the large areas of acid sulfate alteration in the Middle Buttes in the Mojave Mining District and at Blackwater Well (fig. 4) suggest a potential for occurrence of this deposit

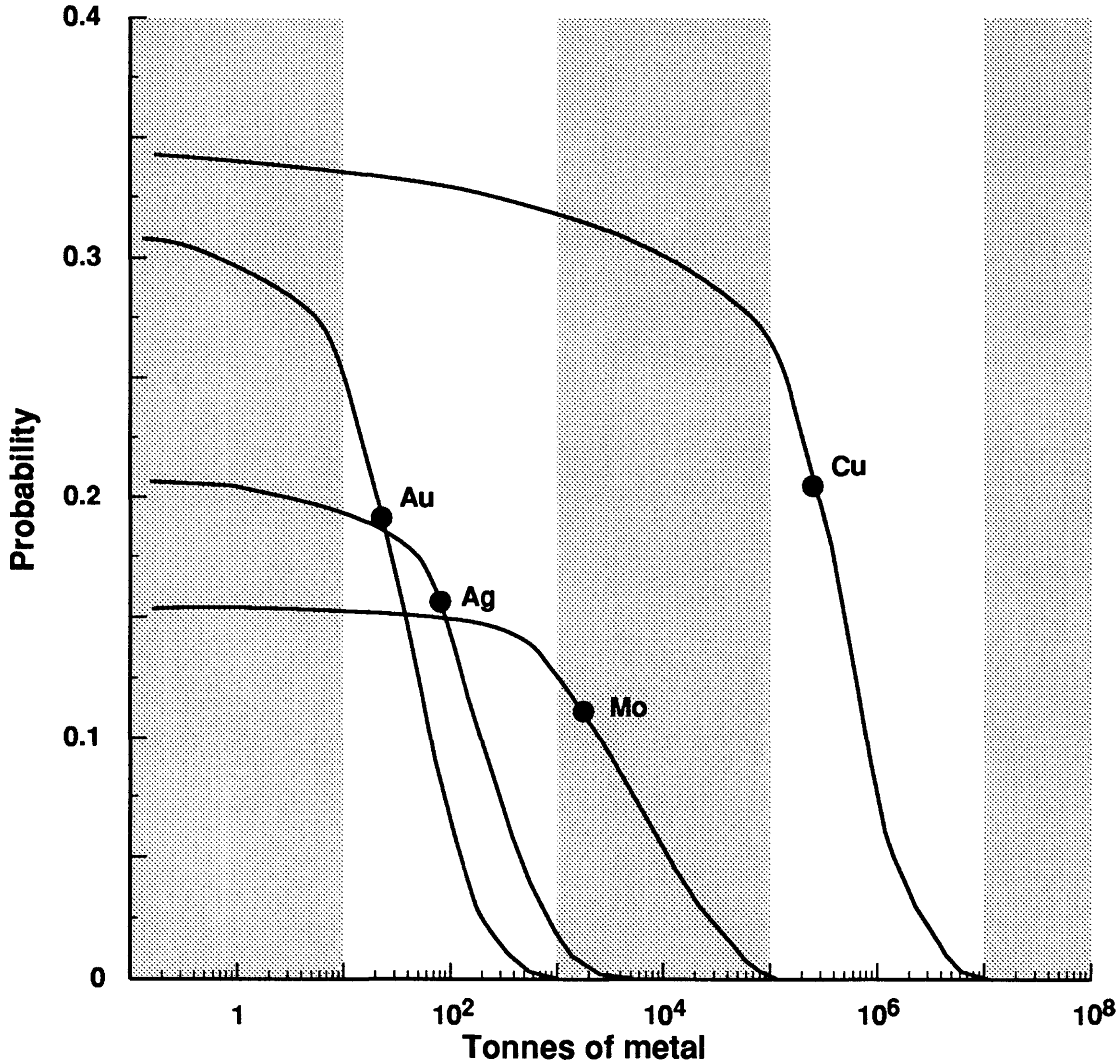

Figure 17. Graph showing probabilistic estimates for the amount of copper (Cu), molybdenum (Mo), gold (Au), and silver (Ag) in porphyry copper-gold deposits in the West Mojave Management Area, California. Filled circlees indicate mean estimates for each metal. See table 3A for mean values.

type at depth. No quantitative estimates were made for these deposits because of the lack of a grade and tonnage model. However, they represent a possible resource which has, to our knowledge, never been recognized in the study area.

Evaporite and saline deposits

Evaporite and saline deposits are present as bedded deposit of Tertiary age or as playa deposits and lake brines in Quaternary basins. Of the varied types of deposits only borate and saline deposits are discussed here because of their present economic importance. Other bedded deposits such as barite and strontium, as celestite (model 35a.1; Orris, 1992b) or strontianite, are present in the study area (Durrell, 1953). These deposits have been mined in the past and they represent additional resources not evaluated herein.

Borate deposits

Borate deposits are of major economic importance within the study area. On a worldwide basis, lacustrine borate deposits (model 35b.3, Orris, 1992c) have a median tonnage of 1,100,000 tonnes with a median grade of 22 weight percent boron oxide (B_2O_3). Twenty out of the twenty-three deposits that define the worldwide grade and tonnage model are located in southern California, and thus this grade and tonnage model is, in essence, a local grade and tonnage model applicable largely to the study area.

The Kramer sodium borate deposit at Boron, located in the west-central part of the study area, constitutes the largest resource of this type in North America (fig. 18). These deposits consist of stratiform beds of borate minerals interbedded with lacustrine sedimentary rocks that were deposited in basins formed during Miocene extension (Smith, and others 1979; Siefke, 1991). Small-volume basalt flows and plugs were emplaced at initiation of extensional deformation and typically are present at the base of the lacustrine sequence. Fluids from hot springs venting near margins of the basins are the presumed source for the boron. Minor amounts of arsenic sulfides, realgar and orpiment, are characteristic of these deposits. Miocene sedimentary rocks are present at

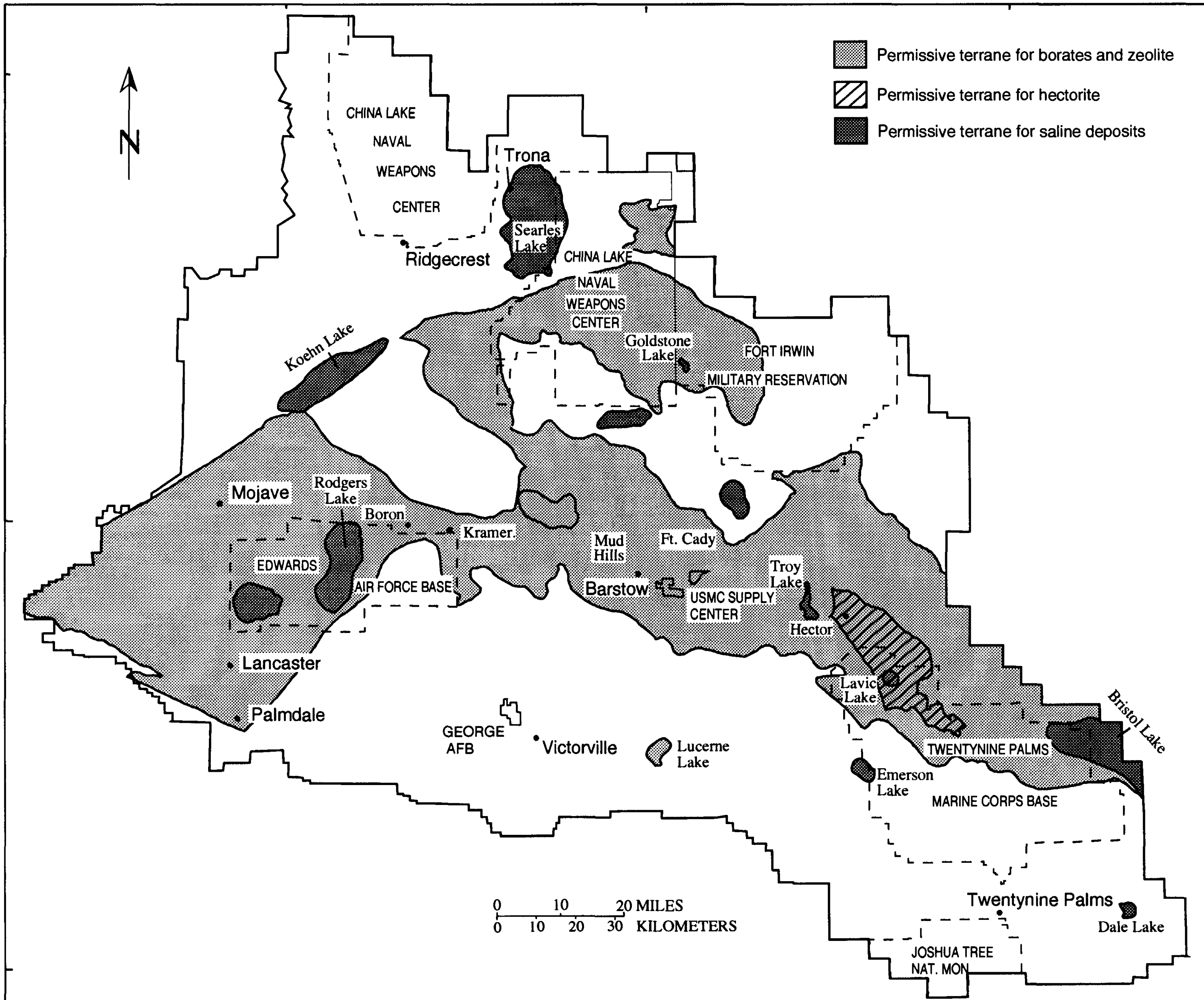

Figure 18. Permissive terranes for borate, saline, zeolite, and hectorite deposits in the West Mojave Management Area, southern California.

depth in present-day basins of the western Mojave and are covered by Pliocene and younger sediments (Dibblee, 1976). In the east part of the study area, the Miocene sedimentary rocks also crop out in the mountain ranges. The sedimentary rocks within these Miocene basins also host bedded deposits of barite, celestite (strontium sulfate), and strontianite (strontium carbonate) (Durrell, 1953).

The Kramer deposit is the largest active producing mine in the study area and the sodium borate ore minerals, kernite and borax, are the main producing ore minerals. Here, the sodium borate ore zone is successively enveloped by calcium borates consisting of ulexite-bearing claystone, colemanite-bearing claystone, and finally, barren claystone at its outer edge (Siefke, 1991). The deposit is present in a 130-m thick sequence of claystone and shale that overlies the Miocene Saddleback basalt. The ore-bearing sedimentary section has a maximum thickness of 100 m and is 3.2 km in length and 1.6 km in width (Siefke, 1991). It is buried by as much as 260 m of arkosic sandstone and as much as 60 m of alluvium. Three additional deposits similar to the Kramer deposit were discovered in the late 1950s but none of these has been mined although they contain a very large tonnage of calcium borate. The Rho A and B deposits are located 11 km east of the Kramer deposit and 2.4 km north of Kramer Junction. These ore bodies include the calcium borate mineral, colemanite, and minor amounts of the arsenic sulfide minerals, realgar and orpiment (Evans and Anderson, 1976). The deposits are present in lake beds of the Miocene Tropico Group and are likely correlative with the lacustrine section which hosts the sodium borate deposit at Kramer (Dibblee, 1967). Both Rho A and B deposits have an upper and lower ore zone that is present in a 145 m interval at a depth from 240 to 385 m below the surface (Evans and Anderson, 1976). The dimensions of the Rho A deposit are 300 by 800 m, and the Rho B deposit is 700 by 430 m (Evans and Anderson, 1976). The combined reserves of the lower ore zone of both deposits is 42,600,000 tonnes of 9 weight percent B_2O_3 (Evans and Anderson, 1976). The upper zone of the Rho A deposit contains 21,700,000 tonnes of 14 weight percent B_2O_3 and 11,890,000 tons of 17 weight percent B_2O_3 in the subzone of the upper zone, and the upper zone of the Rho B deposit contains 9,980,000 tons averaging 5 weight percent B_2O_3 (Evans and Anderson, 1976).

The Sunray Mid-Continent Oil deposit is located 6.4 km north of Kramer Junction and about 3.25 km north of the Rho deposits. At this deposit the ore mineral is the calcium-bearing borate, colemanite, and the ore zone has a minimum thickness of 12 to 30 m and an average grade of about 3.7 weight percent B_2O_3 (Evans and Anderson, 1976). The Ft. Cady deposit, northeast of Barstow, is still another borate deposit with a estimated reserve of 132,450,000 tons of borate ore averaging 6.4 weight percent B_2O_3 (Burnett, 1990).

The permissive terranes delineated for borate deposits (fig. 18) are based on the distribution of Tertiary or Quaternary basins and the distribution of known deposits and occurrences in these basins. In addition, these terranes are also permissive for epithermal precious-metal deposits and other bedded evaporate deposits. A good example of the borate-precious metal association is the presence of bedded barite, celestite or strontianite, and borate in the same sedimentary sequence that contains the large disseminated silver deposits at Waterloo and Langtry near the town of Barstow (see section on "Epithermal Precious-metal Systems" above).

It was estimated at the first meeting that in the study area there was potential for at least one additional borate deposit the size of Kramer, that is 18,000,000 tonnes of B_2O_3. Using the grade and tonnage model for lacustrine borate deposits (Orris, 1992c), the consensus estimate may be expressed in the terms that there are between 2 and 14 undiscovered borate deposits in the study area (table 2) with a *mean* size of 5 million tonnes and *mean* grade of 25 weight percent B_2O_3. The *mean* deposit contains about 1,250,000 tonnes of B_2O_3 and is slightly less than one tenth the size of the Kramer deposit. Therefore, using the grade and tonnage models to express the statement that "there is at least one additional undiscovered deposit the size of Kramer" requires that there is the possibility of 6.7 mean expected deposits in the study area. Thus, there is about a 40 percent probability that there is *mean* content of borate (21,600,000) in the terrane (table 3A, fig. 19).

Although we believe our estimate to accurately reflect the range in size of the expected borate resource, local conditions in the study area suggest to us that this resource is more likely to be found in a much smaller number of larger deposits than those in the grade and tonnage model. This is because lacustrine borate deposits are characterized by beds of borate which extend

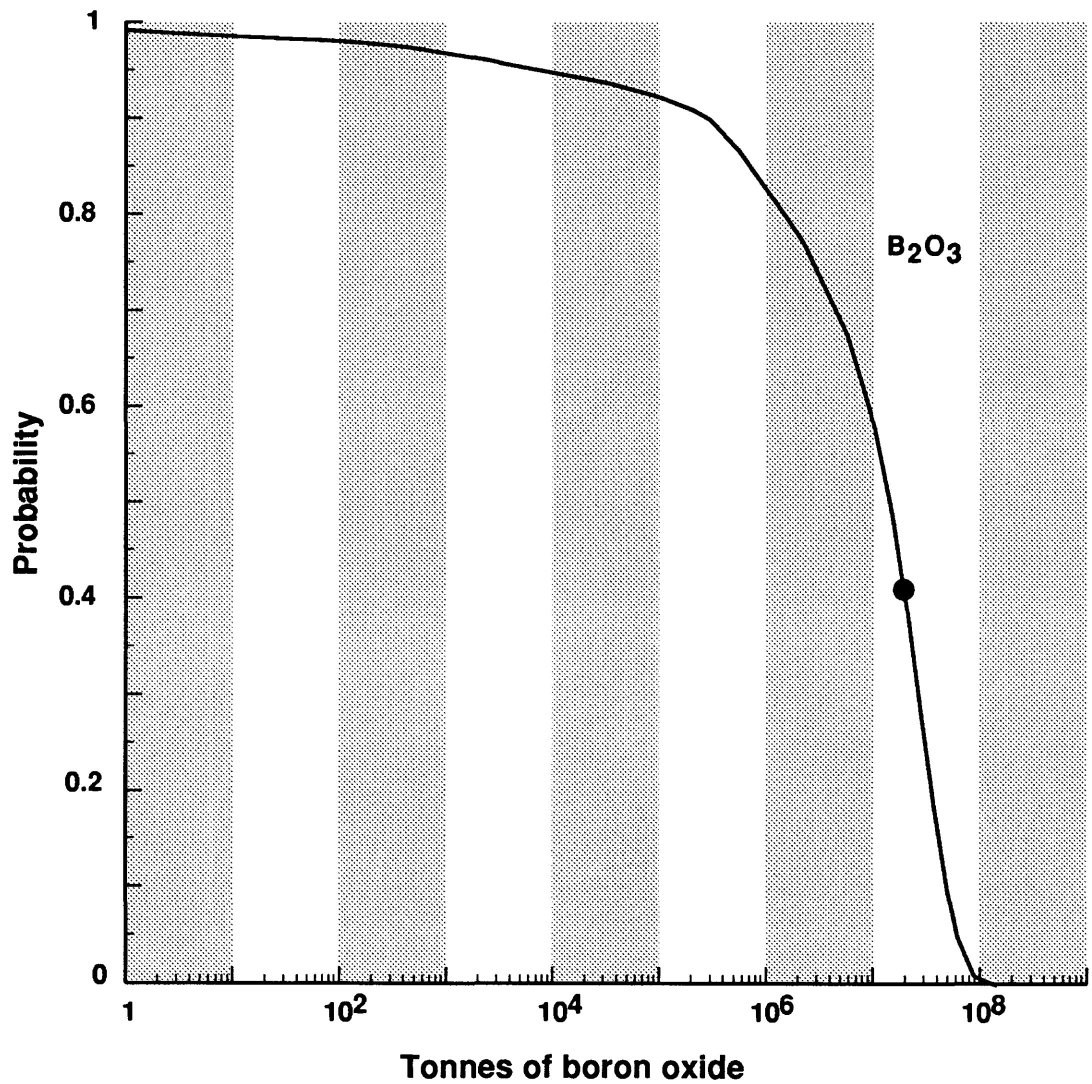

Figure 19. Graph showing probabilistic estimates for the amount of boron oxide (B_2O_3) in lacustrine borate deposits in the West Mojave Management Area, California. Filled circle indicates mean estimate of boron oxide. See table 3A for mean value.

throughout the basin to form a single large deposit rather than several, small, distinct ore bodies. In the study area, it is unlikely to have several small deposits primarily because structural disruption of a single large stratiform ore body into smaller individual deposits has not occurred to the extent that the ore beds could not be considered a single large deposit or district. It should also be noted that the grade and tonnage model of Orris (1992c) as presently constructed contains both districts and single deposits. If the curve is considered to represent only districts, then the Kramer, Rho A and B, and Sunray Mid-Continent Oil deposits represent a single district. The estimated one undiscovered deposit represents a district for purposes of this report.

The presence of large amounts of arsenic sulfides, rare occurrences of stibnite, and low, but geochemically anomalous concentrations of gold in the Kramer deposit indicate that the hot-spring systems, which provided the source of the boron, have a high potential for gold. It is possible that lacustrine sedimentary rocks which host the borate deposits may also host hot spring-type gold deposits. The potential for this type of mineralization would be highest near the structures along which hot spring fluids were localized. In the Kramer deposit, vent areas have not been located and this is true as well for the Rho A and B deposits and the other stratiform borate deposits and occurrences in the study area. The immense resource of borate and arsenic sulfides in the study area indicates that the hot-spring systems were long lived and that the flux of hydrothermal fluids vented was very large. It is thus possible that large precious metal systems are present near the hot spring vent areas of the borate deposits. Because no example of gold deposits like those postulated here are known to exist, the assessment for undiscovered hot spring gold deposits did not evaluate this environment of the vent regions in the lacustrine beds, and thus necessarily underestimates significantly the potential for hot spring gold deposits.

Salines

Saline mineral resources are present on five of the seventeen dry lakes within the study area that are outside of the military reservations (fig. 18). Very large and well-developed deposits of crystalline saline minerals and saturated brines are known to exist at Searles, Koehn, Bristol, and

Dale Dry Lakes; concentrated brines also are known at Lucerne, Emerson and Troy Dry Lakes (Calzia and others, 1979). Resources of sodium, potassium, carbonate and borate compounds in these lakes are present in the bedded crystalline deposits and also in the brines. No evidence of brines or bedded salt deposits are known at the other dry lakes in the study area (Calzia and others, 1979). Goldstone, Lavic, and Rogers Dry Lakes are present within military reservations and the saline mineral resources of these three dry lakes are unknown.

Searles Lake and Koehn and Bristol Dry Lakes (fig. 18) are located at the low end of large alluviated valleys and are underlain by thick (>100 m) accumulations of lacustrine sediments interbedded with crystalline saline deposits. Regional Bouguer gravity data indicate that these valleys coincide with sedimentary basins 1 to 2 km deep (Calzia and others, 1979). Lucerne and Emerson Dry Lakes contain relatively dilute brines (≤100,000 ppm total dissolved salts) in thin (≤45 m thick) lacustrine sequences. Searles Lake and Bristol, Koehn, and Dale Dry Lake (fig. 18) contain known reserves of crystalline saline minerals (Gale, 1951; Calzia and others, 1979). Searles Lake represents the largest resource containing, in 1985, a reserve of 440,000,000 tonnes of bedded salts, carbonates, and borates (Long, 1992b). Searles Lake and Bristol Dry Lake (fig. 18) also contain an extremely large, and relatively untapped, reserve of Cl-rich brines in addition to the bedded deposits.

The study area clearly contains very large and very valuable saline mineral resources. As no grade and tonnage model is available for these types of deposits, no estimates were made of the undiscovered saline resources in the study area. However, because of past mining activity and because of investigations of the resource potential for the various dry lakes (e.g. Calzia and others, 1979), it is probably unlikely that new undiscovered resources are present at those dry lakes outside of military reservations.

Zeolite and hectoritic clays

Zeolite and hectoritic (lithium-bearing bentonite) clay deposits are present in the Mojave Desert region of California, particularly near Barstow (Stinson, 1984, 1988) (fig. 18). Zeolite deposits (model 25oa; Sheppard, 1991) are primarily formed by the alteration of rhyolitic tuff and tuff breccia in hydrologic basins. Hectorite (model 25lc; Asher-Bolinder, 1991) also forms from the alteration of rhyolitic tuff, and in the study area replaces ash beds that are interbedded with lacustrine sedimentary rocks and cherty travertine limestone deposited from hot springs (Sweet, 1980). Similar tuff beds at a higher stratigraphic level have been altered to zeolite, and borate deposits are present at depth in an evaporite section (Sweet, 1980). Hectorite is being mined at Hector in the study area, and deposits of zeolite are present in the Mud Hills.

Permissive terranes (fig. 18) for hectoritic clays are delineated on the basis of the location of known deposits and areas of fine-grained Miocene sedimentary rocks rich in tuffaceous material. As the fine-grained sedimentary and tuffaceous rocks that host zeolite deposits are interbedded with volcanic rocks and with borate deposits and occurrences, the permissive terranes for zeolites are coincident with those for borates and also for epithermal precious-metal systems (figs. 4 and 18). The zeolite deposits in Mud Hills and their geologic association with the barite, borate, and disseminated silver deposits in the adjoining Waterman Hills and Calico Mountains are a good example of this relationship.

Estimate of total endowment

A summary of the results of this assessment, in terms of the amount of contained metal (and borate) in the 12 deposit types that were evaluated is presented in table 4. In this discussion, we will commonly use the terms "metals" or "all metals" to include borate, B_2O_3, even though, in chemical terms, it is not a metal. Although table 4 is a convenient summary, it does not convey a complete answer to the question, "What is the magnitude of undiscovered resources in the study area?" The *mean* and *median* values in tables 3 and 4 are a products of a computer program called MARK3, which is described in Root and others (1992). The program combines estimates of the types and numbers of undiscovered mineral deposits with historical worldwide grade and tonnage information to produce a probability distribution of quantities of contained metals in undiscovered deposits. Because MARK3 produces probability distributions, **the amount of undiscovered resource, for any given metal, cannot be properly represented by a single number.**

Nature of distributions

The probability distributions that result from the computer simulations are rather different from the ones most people are accustomed to thinking about. This results primarily from the marked asymmetry of tonnage distributions used in production of contained metal distributions. In all the deposit types considered in the study area, a few large deposits in the model account for a very large proportion of the contained metal. Logarithmic standard deviations representing nearly an order of magnitude or more are common among the tonnage models compiled by Cox and Singer (1986). This is one reason why, in figure 3 for example, the *mean* amounts of gold are so much larger than the *medians*, and why amounts as large as the *mean* are unlikely to exist. For example, with reference to figure 20, the *median* (50th percentile) zinc estimate is 9.4 tonnes, whereas the *mean* estimate is 15,700 tonnes, more than three orders of magnitude larger. For this zinc estimate, there is less than a 15 percent probability of occurrence of an amount as large as the *mean*. The other reason contributing to this phenomenon is the high probability that no deposits containing zinc exist.

In addition, the proportion of this undiscovered metal that can be recovered at a profit is not determined here. The estimated undiscovered metal is that present *in deposits like those in the associated grade and tonnage models* (see table 1). Some deposits in the models are economic, and some are not.

Alternative presentations

The most informative form of presentation is probably purely graphical, such as those shown throughout this report for each of the deposit types for which a quantitative estimate was made. Figure 20 shows the probability distributions for each metal in all of the undiscovered deposits that were evaluated in this study. The probability distributions were constructed using the results from MARK3. Curves for gold, silver, iron, and borate are much steeper than for the other metals, indicating relatively greater certainty. This is because the number of deposit types that contain these commodities is higher (see table 2), and the probability of zero deposits (and thus, zero tonnes) is very low (well under 0.1 for all four commodities).

Another way to show variability is generally termed the use of "error bars." This terminology is not appropriate in this instance, because what we are attempting to show is not related to mistakes; we are attempting to communicate the uncertainty associated with the estimates shown on table 2. Figure 21 shows the same information as figure 20, but in a more abbreviated form. The filled circles represent the mean number of tonnes. The upper and lower horizontal bars represent 90 and 10 percent probabilities of that tonnage or more. Thus, the intervals shown are larger than the more commonly used amounts of one standard deviation.

Finally, it may also be helpful to report the results as a confidence interval. There is an 80 percent chance that the true value will lie between the 90th and 10th percentile. Thus, using an 80 percent confidence interval, the amount of undiscovered gold is between 2 and 253 tonnes, the amount of undiscovered silver is between 5 and 1,800 tonnes, the amount of undiscovered tungsten is between 0 and 27,000 tonnes, the amount of undiscovered molybdenum is between 0 and 11,000 tonnes, the amount of undiscovered lead is between 0 and 32,700 tonnes, the amount of undiscovered zinc is between 0 and 20,400 tonnes, the amount of undiscovered copper is between 0 and 1,420,000 tonnes, the amount of undiscovered iron is between 1,730,000 and 49,800,000 tonnes, and the amount of undiscovered borate is between 676,000 and 103,000,000 tonnes.

Meaning of the estimates

Whatever form is used to communicate the results of these estimates, it is well to remember that they reflect a large uncertainty in the number and sizes of undiscovered deposits of the types evaluated. Furthermore, not all types of deposits known to be present in the study area could be

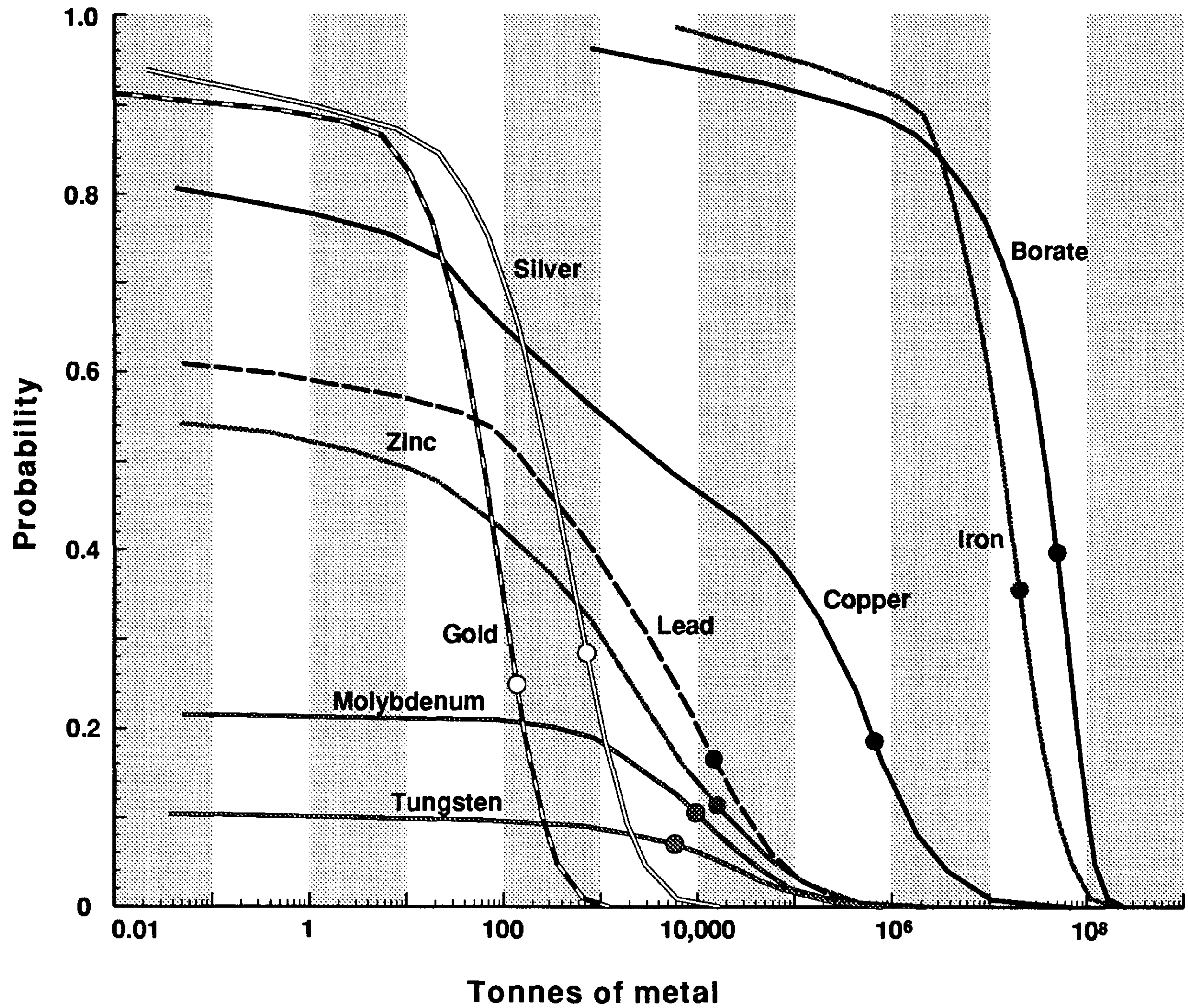

Figure 20. Graph showing probabilistic estimates for total metal in all undiscovered deposits in the West Mojave Management Area, California. Circles indicate mean estimate for each metal*.

* In addition to the Tertiary polymetallic vein tract mentioned in the footnote to figure 3, there was originally a third iron skarn tract with a very small number of estimated deposits; this tract was subsequently dropped from the assessment because it was based only on a geophysical anomaly that was no different than other anomalies that were located in areas outside of the permissive terranes. The figures for iron used to construct this figure were not recalculated because this tract contributed, on average, less than 6 percent of the total iron.

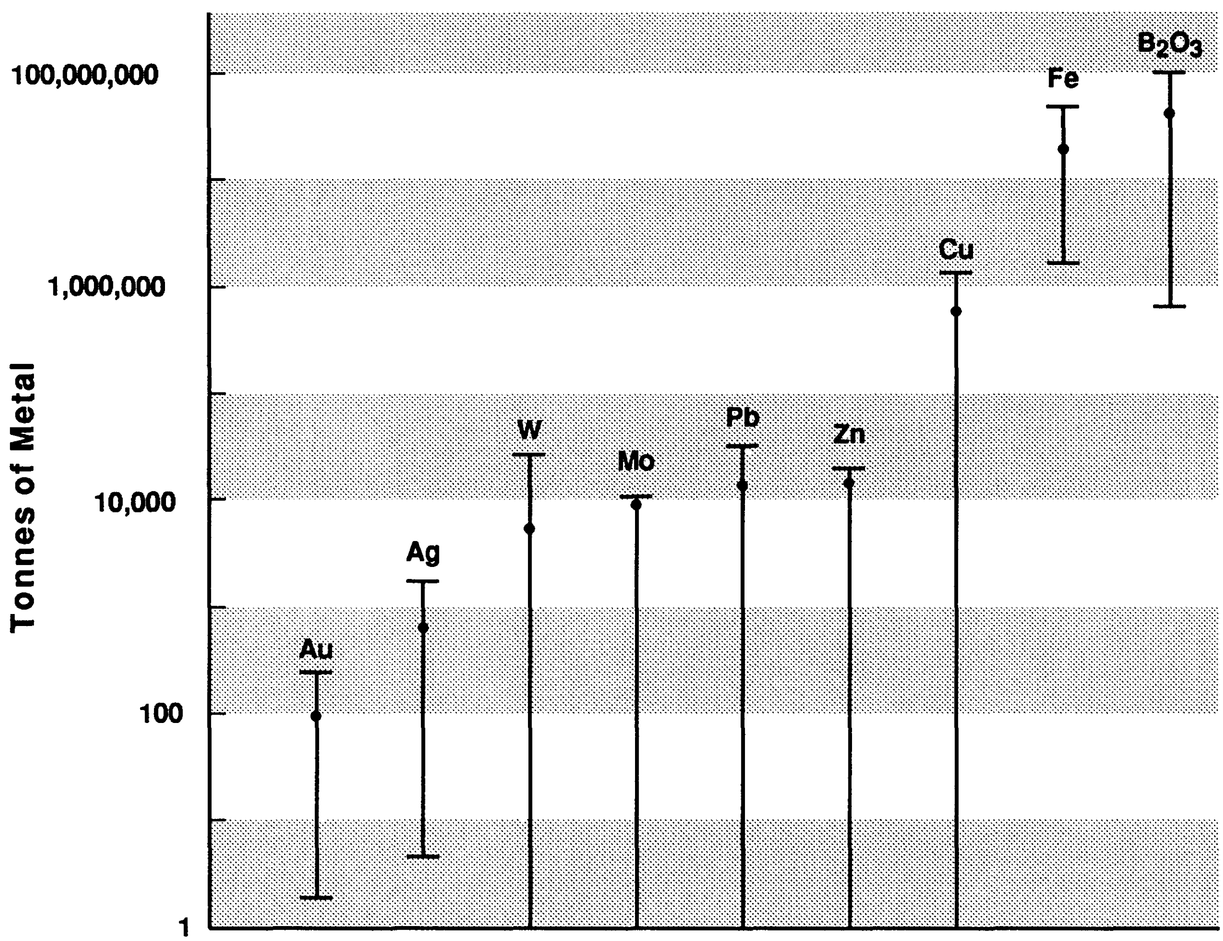

Figure 21. Graph showing the estimated amount of total contained metal in twelve undiscovered deposit types in the West Mojave Management Area, California. Filled circles represent the mean estimates. Upper and lower bounds (horizontal bars) represent 10th and 90th percentile. Because the vertical scale is logarithmic, W, Mo, Pb, Zn, and Cu do not have lower bounds displayed; for these metals, the probability is high that there are no undiscovered deposits which contain the metals, and thus, the probability is at least 0.9 that there are zero undiscovered tonnes of metal.

evaluated (see above). Undiscovered deposits are, by their very nature, not known with a high degree of certainty.

The most important conclusion that can be drawn from the probability distributions represented in tables 2, 3, and 4, and figures 20 and 21, is the dominant role played by borate in the region. The value of undiscovered borate implied by these estimates is probably larger than all of the metals combined. Of similar importance but of less total value, is gold. These two commodities are both currently produced by the major mines in the study area. Iron, which might also be present in appreciable amount, will continue to play a role in the portland cement industry (Rapp and Vredenburg, 1991). The possibility of significant additional resources of base metals and tungsten is probably low.

It is also important to remember that not all of the possible metallic or nonmetallic resources known to be present, or that might be present, in the study area were quantified in this study. We did not evaluate most of the nonmetallic deposits, as well as a few metallic deposits such as those like the Waterloo barite-silver deposits. Until sufficient information is available regarding these deposits, the estimates of resources presented herein should be considered tentative by the users of this report.

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