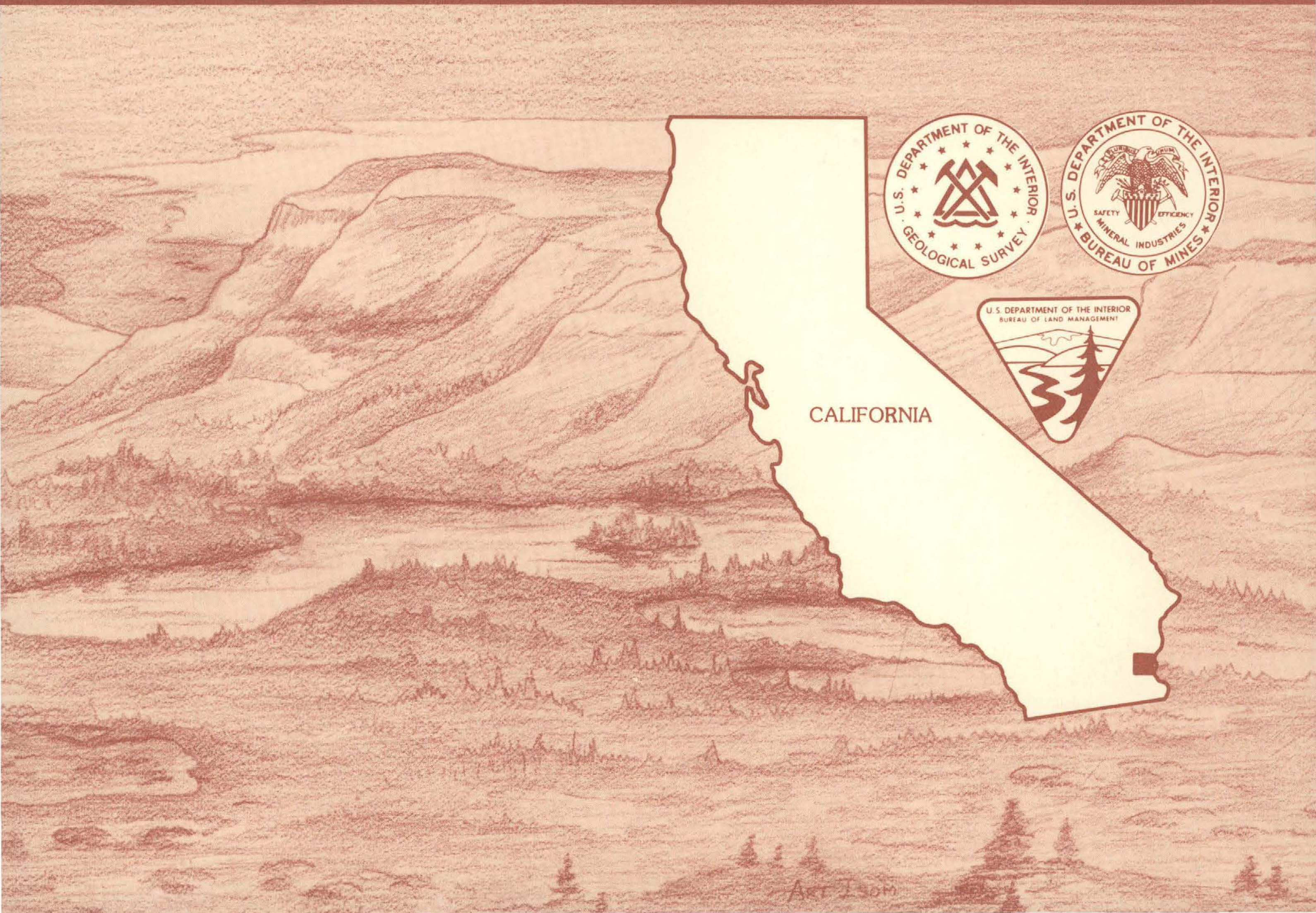
Mineral Resources of the Orocopia Mountains Wilderness Study Area, Riverside County, California

U.S. GEOLOGICAL SURVEY BULLETIN 1710-E



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Chapter E

Mineral Resources of the Orocopia Mountains Wilderness Study Area, Riverside County, California

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U.S. GEOLOGICAL SURVEY BULLETIN 1710

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
SOUTH-CENTRAL CALIFORNIA DESERT CONSERVATION AREA, CALIFORNIA

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Area

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys of certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of part of the Orocopia Mountains Wilderness Study Area (CDCA-344), Riverside County, California.

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By Gordon B. Haxel, David B. Smith, Charles L. Whittington, Andrew Griscom, Denny V. Diveley-White, *and* Robert E. Powell
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SUMMARY

Abstract

At the request of the U.S. Bureau of Land Management, approximately 34,172 acres of the Orocopia Mountains Wilderness Study Area (CDCA–344) were evaluated for mineral resources (known) and mineral resource potential (undiscovered). In this report, the area studied is referred to as the "wilderness study area" or simply "the study area". Any reference to the Orocopia Mountains Wilderness Study Area refers only to that part of the wilderness study area for which a mineral survey was requested by the U.S. Bureau of Land Management.

The Orocopia Mountains Wilderness Study Area is located in southeastern Riverside County, California, about 25 miles southeast of Indio. Fieldwork for this report was conducted between 1982 and 1986. In 1982, there were about 20 unpatented mining claims within or adjacent to the wilderness study area. Identified resources in the Orocopia Mountains Wilderness Study Area include low-grade talc deposits of moderate size and a small, low-grade, low-tonnage quartz-vein gold deposit. Active exploration for gold, including geochemical sampling and exploratory drilling, was underway in the late 1980's, and a tract with high resource potential for disseminated gold in crystalline rocks is delineated in the central part of the Orocopia Mountains Wilderness Study Area. One small area in the southeast corner of the wilderness study area has moderate resource potential for gold in quartz veins associated with propylitically altered mafic dikes cut by fault zones. Other small tracts within the wilderness study area have low resource potential for gold in quartz veins, moderate resource potential for gold in placer deposits, moderate resource potential for talc and fluorite, and moderate resource potential for gypsum and borates in evaporite strata. There is low resource potential for gold, copper, lead, zinc, and manganese in volcanogenic massive-sulfide deposits and for copper and molybdenum in porphyry deposits. Moderate potential for geothermal energy resources is assigned to the southwestern two-thirds of the study area. There is no energy resource potential for oil and gas in the study area.

Character and Setting

The Orocopia Mountains Wilderness Study Area is in southeastern Riverside County, about 25 mi southeast of Indio (fig. 1). The Orocopia Mountains comprise a small, rugged range on the northeast side of the northern Imperial Valley. The main part of the range lies about 6 mi northeast of the San Andreas fault zone.

Major lithologic units in the Orocopia Mountains Wilderness Study Area are Early and Middle Proterozoic (see appendixes for geologic time chart) gneiss and migmatite; a Middle Proterozoic anorthosite-syenite complex; Proterozoic(?), Jurassic, and (or) Cretaceous granitoid rocks; the late Mesozoic Orocopia Schist; the Eocene marine Maniobra Formation (Crowell and Susuki, 1979); and the Oligocene(?) and early Miocene nonmarine Diligencia Formation (Crowell, 1975) (fig. 2). The principal structural features of the study area are the Late Cretaceous Orocopia thrust, which places the Proterozoic and Mesozoic plutonic and gneissic rocks over the Orocopia Schist, and the late Tertiary Clemens Well fault, a major right-slip fault. Both faults trend northwestward through the central part of the Orocopia Mountains. The Orocopia thrust was

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modified by middle to late Tertiary low-angle-normal and strike-slip faulting.

Identified Mineral Resources

Identified resources in the Orocopia Mountains Wilderness Study Area include low-grade talc deposits of moderate size and a small, low-grade, low-tonnage quartz-vein gold deposit. Active exploration for low-grade, high-tonnage disseminated gold deposits was underway during preparation of this report.

Mineral Resource Potential

In the central part of the study area, a northwest-trending strip, approximately 12 mi long and 0.75 to 1 mi wide, between the Orocopia thrust and the Clemens Well fault has high potential for disseminated gold in crystalline-rock-hosted deposits. Geochemical sampling by industry indicates that rocks with anomalously high abundances of gold and arsenic (an alternative elemental indicator of gold mineralization) are widespread within this strip. A small area in the southeastern part of the study area between the Clemens Well fault and the Diligencia Formation has moderate potential for disseminated gold in quartz veins and fault zones associated with propylitically altered mafic dikes (fig. 2). This area is underlain by Proterozoic gneiss.

Small veins and pods of metamorphogenic white quartz are common in the late Mesozoic Orocopia Schist. Some of these veins are gold bearing; the Orocopia mine is developed in an unusually large gold-bearing quartz vein. The potential for gold in quartz veins within the Orocopia Schist is low.

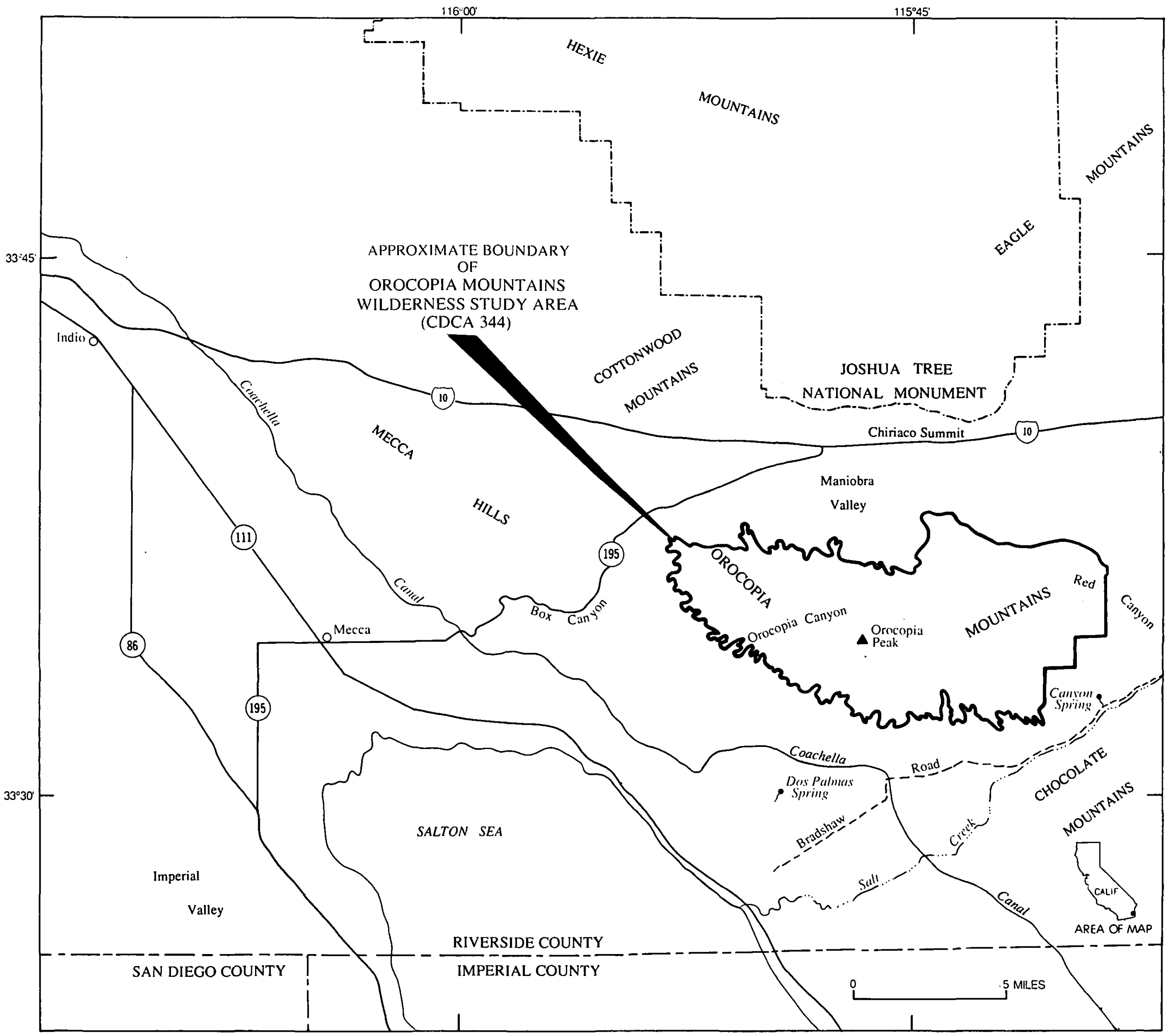

Figure 1. Index map showing location of the Orocopia Mountains Wilderness Study Area, Riverside County, California.

The Orocopia Schist is largely metagraywacke but includes minor metabasalt and ferromanganiferous metachert and siliceous marble. This oceanic assemblage is permissive for volcanogenic massive-sulfide deposits, including copper, lead, zinc, manganese, and possibly gold. However, regional and areal geologic and geochemical data indicate that the potential for such resources in the Orocopia Schist is low.

Metamorphosed ultramafic bodies in the Orocopia Schist are composed of antigorite or actinolite and talc. A few are largely talc, and one of these contains low-grade talc of commercial quality. The Orocopia Schist has moderate potential for talc.

There is moderate potential for fluorite in small veins in Mesozoic granitoid rocks. These granitic rocks are present only in the northernmost and central part of the study area. One such mineralized area is present about one-half mile north of the study area boundary at the Orcopia Fluorospar mine.

Certain parts of the Oligocene(?) and early Miocene Diligencia Formation contain lacustrine evaporite beds; stream-sediment concentrates from these areas contain high boron, barium, and strontium. The evaporite-bearing parts of the Diligencia Formation (southeastern part of study area) have moderate potential for gypsum and borates in evaporitic deposits.

Porphyry copper-molybdenum deposits in southern Arizona and adjacent regions are associated with Jurassic and, much more commonly, Late Cretaceous to early Tertiary granitoids. Although late Mesozoic granites crop out in the Orocopia Mountains, no geologic or geochemical evidence of porphyry copper mineralization or alteration is known; the potential for such copper and molybdenum is considered low.

Drainages downstream from the strip having high potential for disseminated gold in crystalline-rock-hosted deposits are areas that have moderate potential for placer gold. No gold was detected in stream-sediment concentrates from this area.

Two hot springs are known near the study area. Dos Palmas Spring, 2.5 mi south of the study area, has water temperature of 84 °F. Canyon Spring, about 0.5 mi east of the study area, has a water temperature of 97 °F. The southwestern two-thirds of the Orocopia Mountains Wilderness Study Area has moderate potential for geothermal energy.

The high grade of metamorphism precludes oil and gas accumulation. There is no potential for oil and gas resources in the study area.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is a joint effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to the system modified from that described by McKelvey (1972) and U.S. Bureau of Mines and U.S. Geological Survey (1980). Studies by the U.S. Geological Survey are designed to provide a reasonable scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Mineral assessment methodology and terminology as they apply to these surveys are discussed by Goudarzi (1984). See appendixes for the definition of levels of mineral resource potential, certainty of assessment, and resource/reserve classification.

Location and Physiography

The part of the Orocopia Mountains Wilderness Study Area (CDCA–344) requested for study encompasses 34,172 acres in Riverside County, California, about 25 mi southeast of Indio and approximately 9 to 30 mi east of Mecca (fig. 1). The Orocopia Mountains are a small, rugged range on the northeast side of the northern Imperial Valley, about 6 mi northeast of the San Andreas fault zone, which runs along the northeastern side of the Imperial Valley. The highest peak of the Orocopia Mountains is 3,815 ft and the range rises about 4,000 ft above the adjacent Salton Sea and Imperial Valley and about 3,000 ft above the southwestern base of the range. The Orocopia Mountains comprise two principal ridges. The larger of these ridges trends east-southeastward about 16 mi between Box Canyon and Salt Creek. The smaller ridge extends eastward about 11 mi from a point south of Chiriaco Summit. On some maps, this smaller ridge is considered a separate range—the Hayfield Mountains. Between these two ridges is a lower, hilly area, the northwestern part of which adjoins the Maniobra Valley. The rugged Mecca Hills adjoin the Orocopia Mountains to the northwest. Southeast of the Orocopia Mountains are the northernmost Chocolate Mountains.

The Orocopia Mountains are surrounded by paved or maintained gravel roads. These roads are Interstate 10 to the north, the paved road (California Highway 195) in Box Canyon to the west, the gravel road along the Coachella Canal on the southwest, and the gravel road (Bradshaw road) in Salt Wash to the southeast and east. The low area between the two principal ridges of the Orocopia Mountains is accessible by several dirt roads or jeep trails that begin at Chiriaco Summit or branch off from the Bradshaw

Road. Numerous dirt roads or jeep trails, branching off from the various roads surrounding the range, ascend the pediments surrounding the two principal ridges that make up most of the Orocopia Mountains. However, the higher parts of the principal ridges are accessible only by walking.

The Orocopia Mountains Wilderness Study Area includes most of the area of the higher, southwestern ridge of the Orocopia Mountains and about the west half of the hilly area between the two principal ridges. The south, southwest, and northwest boundaries of the study area generally follow the base of the steep part of the range. The northeast boundary follows the main dirt road that connects Salt Creek and Red Canyon with Maniobra Valley. The east boundary follows several section lines west of Red Canyon.

Previous and Present Investigations

Early studies of the geology of the Orocopia Mountains and surrounding areas include those by Brown (1923), Darton (1933), Miller (1944), and Dibblee (1954); the latter two reports define several of the stratigraphic names used in the region. The first detailed studies of the Orocopia Mountains were by J.C. Crowell and colleagues. Crowell and Walker (1962) studied a suite of distinctive Proterozoic (see appendixes for Geologic Time Chart) anorthositic and syenitic rocks, and Crowell and Susuki (1959) studied nearshore marine Eocene strata. These Proterozoic and Eocene rocks, the Mesozoic Orocopia Schist (Crowell, 1974), and certain other geologic features and relations were important in Crowell's (1960, 1962) pioneering documentation of large strike-slip displacement along the San Andreas fault system. Proterozoic crystalline rocks in the Orocopia Mountains were included in regional uranium/lead geochronologic studies by Silver (1966, 1968, 1971). Most of the Proterozoic and Mesozoic crystalline rock units in the Orocopia Mountains are closely related to terranes studied by Powell (1981, 1982) in ranges to the east. The Orocopia Schist and Orocopia thrust are discussed in the summary of the Orocopia Schist and related schist units by Jacobson and others (1988). Samples from the Orocopia Mountains were included in geochemical studies of the Orocopia Schist by Dawson and Jacobson (1986) and Haxel and others (1987). The Eocene, Oligocene, and Miocene strata of the central Orocopia Mountains were investigated by Cole (1958), Woodburne and Whistler (1973), Arthur (1974), Spittler (1974), Spittler and Arthur (1973, 1982), Squires and Advocate (1982), and Bohannon (1975, 1976). Paleomagnetic data from these Paleogene and Neogene strata were determined and analyzed by Terres (1984) and Carter and others (1987). The geology of the Orocopia Mountains is summarized by Crowell (1975).

The geology of the Orocopia Mountains Wilderness Study Area and some adjoining areas was mapped by the U.S. Geological Survey during 1983–1986. Geochemical studies were conducted in 1982. Sieved and nonmagnetic heavy-mineral fractions were separated from samples collected from active stream channels. These separates were analyzed for 30 elements by semiquantitative emission spectroscopy and for gold by atomic-absorption methods. Previous geophysical investigations include an aerial radioactivity and magnetic survey by LKB Resources, Inc. (1980) for the U.S. Department of Energy, an aeromagnetic survey (U.S. Geological Survey, 1983), and gravity surveys (Mariano and others, 1986). These geophysical data were evaluated for this report.

The U.S. Bureau of Mines conducted surveys of the Orocopia Mountains Wilderness Study Area from 1982 to 1986, focusing on investigations of mines, prospects, and other mineralized areas. Mining files and claims were reviewed, large-scale maps of several mineralized areas were prepared, and samples of rocks and ores from mineralized areas were collected and analyzed by several methods.

APPRAISAL OF IDENTIFIED RESOURCES

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Methods of Investigation

The U.S. Bureau of Mines reviewed various sources of mineral information, including published and unpublished literature, U.S. Bureau of Mines' files, and mining claim records at the county courthouse in Riverside, Calif., and at the Bureau of Land Management state office in Sacramento, California. In addition, claimants, prospectors, and industry geologists that have knowledge of the mining activity in the area were interviewed. Mines, prospects, and mineralized areas within the wilderness study area and those as close as 2 mi from the Orocopia Mountains Wilderness Study Area boundary were examined, mapped, and sampled in February 1982.

U.S. Bureau of Mines personnel collected 35 samples in and near the study area. Accessible adits were sampled every 20 ft along their course and prospect pits and trenches were sampled across the mineralized structure. If no structure was present, or if a working was inaccessible, samples of the dump material were taken on a 10-ft-grid system.

Gold and silver were determined by fire assay, copper and manganese by atomic-absorption analysis, uranium by fluorimetric analysis, and calcium fluoride (fluorite) by atomic-absorption and wet-chemical analysis. Two samples were analyzed for talc content and quality by inductively coupled plasma analysis, optical emission spectrography, and wet-chemical analysis. Selected samples were analyzed for 40 elements by optical emission spectrography.

Complete sample data are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, P.O. Box 25086, Denver Federal Center, Denver, CO 80225.

Mining History

The earliest mining activity in the Orocopia Mountains was probably in the late 1880's. Miners, on their way to the La Paz gold field near Ehrenberg, Ariz., stopped at Dos Palmas spring and prospected in the nearby Orocopia Mountains. By 1894, two tunnels with nearly 300 ft of workings were located "6 mi northeast of Dos Palmas Spring" and were probably the Orocopia mine (Vredenburgh and others, 1981, p. 27). The main mining activity was between 1890 and 1920, and, except for some fluorspar and manganese mining in the 1940's and 1950's, very little mining or exploration occurred until the late 1980's.

No production records for mines within the Orocopia Mountains Wilderness Study Area are available; the only known mineral production near the study area was 10 tons of ore averaging 30 percent manganese from the Big Bullett claims in 1945 (Tucker and Sampson, 1945, p. 150) and about 50 tons of fluorite from the Orocopia Fluorspar mine in 1955 (Chesterman, 1957, p. 202) (fig. 2).

Appraisal of Sites Examined

Since late 1984, Utah International, Inc., Salt Lake City, Utah, and its joint venture partners, have been actively exploring for gold across the central part of the Orocopia Mountains Wilderness Study Area. As of November 1987, the company held a block of 583 valid mining claims and two prospecting permits. Exploration work to date has outlined four areas of anomalous gold concentrations (A.C. Ascencious, Utah International, Inc., written commun., 1986). Work for the winter of 1987–1988 and the fall of 1988 concentrated on a wedge of land in the northwestern part of the study area bounded by the Clemens Well fault on the north and the Orocopia thrust on the south and includes detailed geologic mapping and geochemical sampling and drilling. Data collected as of December 1987 suggest a mineralization model similar to that for the Mesquite mine in the Chocolate Mountains about 50 mi to the south (Leigh Freeman, Orvana, Inc., Denver, Colo., oral and written commun., 1987).

There are four other distinct mineralized areas, two within the study area and two within 2 mi of the boundary: manganese at the Big Bullett claims, talc at two areas southeast of Orocopia Canyon, gold at the Orocopia mine (within the wilderness study area) and fluorite at the Orocopia Fluorspar mine. Data on these mineralized areas and one other prospect are summarized in table 1.

Big Bullett Claims

Manganese was discovered near the west boundary of the study area (fig. 2, No. 1) sometime in the early 1940's. In 1945, 20 claims were located about 2.5 mi southeast of Shavers Well (Tucker and Sampson, 1945, p. 149) from which the previously mentioned manganese ore was produced.

The manganese is present as irregular lenticular masses as much as 3 ft thick in a 4- to 12-ft-thick quartzite layer in the Orocopia Schist. The ore was apparently deposited as masses of radiating pyrolusite crystals in vugs and fissures (Tucker and Sampson, 1945, p. 150). The quartzite layer is exposed for 500 ft, strikes N. 35° W., and can be projected into the study area.

The workings consist of an opencut 20 ft long by 8 ft deep and scattered prospect pits on a northwest-facing hillside. No pyrolusite was observed in any of the workings and the samples taken in the opencut and one prospect pit did not contain manganese concentrations above the background levels found in samples from other localities within and near the study area (table 2 of Kreidler, 1984). Pyrolusite was not seen anywhere else along the quartzite outcrop, which thins to the southeast in the study area and is buried under alluvium to the northwest. The known deposit appears to be mined out, but other lenticular masses of pyrolusite may be concealed within the quartzite.

Talc Occurrences

Impure talc is present at two prospects along the south boundary of the study area: at the Goat claims, inside the wilderness study area, and at an unnamed prospect 3/4 mi south of the study area (fig. 2, No. 2, 3).

At the Goat claims, the talc occurs as a talcose chlorite-actinolite schist in a 50-ft-wide shear zone in the Orocopia Schist (R.B. Saul, C.H. Gray, and J.R. Evans, written commun., 1968). The shear zone trends N. 60° W., dips 34° SW., and is traceable on the surface for about 600 ft, beyond which it is buried by alluvium.

Workings consist of several opencuts stair-stepping up the canyon wall. The claimant reports that "large reserves of subsurface talc were defined by a drilling program run by the previous claim holder." Further details and the drilling data were not available to the U.S. Bureau of Mines for examination and talc was not exposed in the workings. However, the deposit was examined in the winter of 1982–1983 by two industrial minerals companies who found talc contaminated by serpentine, iron, and quartz (Jerry Stock, Cyprus Industrial Minerals Co., and Hans Ackerman, Pluess-Staufer Co., oral commun., 1982).

About 2.75 mi southeast of the Goat claims, talc is exposed in two opencuts along a ridge. The talc occurs as pods and lenses in a broad shear zone in Orocopia Schist. The vertical shear zone strikes N. 50° E. Alluvial cover prevents tracing the shear beyond the workings.

Table 1. Mineral deposits in and near the Orocopia Mountains Wilderness Study Area
[Numbers correspond to sample locations shown on fig 2. Mines or prospects labeled inactive have had no exploration or development work since 1980]

Map No. (fig. 2)	Name	Location	Commodity	Type of deposit	Development	Description	References
1	Big Bullett claims	NW. 1/4 sec. 31, T. 6 S., R. 11 E.	Manganese	Vug and fissure filling	Opencut; inactive	Pyrolusite in lenticular masses in fractured, contorted quartzite as thick as 3 ft.	Tucker and Sampson (1945).
2	Unnamed prospect	N. 1/2 sec.. 32, T. 7 S., R. 12 E.	Talc	Shear zone	Trenching and open-cut; inactive	Faulted Orocopia Schist with talc and actinolite in shear zone.	None.
3	Goat claims	SW. 1/4 sec. 13, SE. 1/4 sec. 14, S.E. 1/4 sec. 23 NW. 1/4 sec. 24, T. 7 S., R. 11 E.	Talc	Shear zone	Prospect; inactive	Talcose chlorite-actinolite schist in shear zone in Orocopia Schist.	None.
4	Orocopia mine	NW. 1/4 sec. 22 T. 7 S., R. 12 E.	Gold	Quartz veins	Three adits; inactive	Quartz vein in shear, exposed for several thousand feet; three adits connected by stopes.	Tucker and Sampson (1945).
5	Orocopia Fluorspar mine	NE. 1/4 sec. 25, T. 6 S., R. 12 E.	Fluorite	Vein	Trenching and shaft; inactive	Fluorite veins in shear zone in quartz monzonite cut by quartz-biotite schist.	Chesterman (1957).

The upper opencut is along the ridge crest and measures 50 ft by 15 ft. Pods of actinolite crystals are scattered through the talc body. The lower opencut is about 20 ft down the hillside and is about 30 ft by 15 ft. The talc pod exposed in the lower cut is brecciated and weathered, suggesting that talc formation preceded faulting.

Analyses of two talc samples from this prospect are compared to talc analyses from several producing areas in the United States (table 3 of Kreidler, 1984). Talc from the prospect compares most closely to, and could be similarly utilized as, talc from the Cohutta Talc Co., Georgia, which is used for roofing granules (Chidester and others, 1964, p. 30).

Orocopia Mine (Gold)

The Orocopia mine is within the wilderness study area about 4 mi west of Canyon Spring (fig. 2, No. 4), and has also been known alternately as the Dos Palmas mine or Fish mine (Larry Vredenburgh, U.S. Bureau of Land Management, oral commun., 1982). In February 1982, there were 462 ft of workings in three adits (upper, 66 ft; middle, 106 ft; lower, 290 ft); all that remained of the mill was a foundation and tailings pile. The three adits are connected by stopes and an ore chute, by which the ore was moved to the lower adit and then to the mill.

The adits were driven northeastward along a quartz vein that lies in a fault zone striking N. 55° E. and dipping 45°–55° NW. in chloritic schist. The fault is traceable on the surface for over 0.75 mi to the northeast; it is abruptly truncated by a wide shear zone a short distance to the southwest.

The vein is as much as 5 ft wide, is locally fractured and brecciated, and contains locally abundant limonite pseudomorphs of pyrite; no other minerals were observed. However, 10 of 24 samples taken along the vein on the three levels contain gold concentrations ranging from 0.022 to 0.250 troy oz/ton and averaging 0.125 troy oz/ton (table 4 of Kreidler, 1984) (1 troy oz/ton ≈ 34 ppm). An estimated 850 tons of ore averaging 0.107 troy oz/ton gold remain in the upper and middle adits; the lower adit is apparently mined out. More detailed work, including drilling and trenching would be needed to make an accurate estimate of resources.

Orocopia Fluorspar Mine

The Orocopia Fluorspar mine is north of the study area about 3.5 mi southeast of Chiriaco Summit (fig. 2, No. 5). The mine was opened in 1955 and has been worked intermittently since that time, although it was not worked in February 1982. In May 1983, four people held a single claim on the mine.

The workings consist of a shaft, 35 ft deep, centered in a trench 150 ft long, 10 ft wide, and as much as 5 ft deep along the strike of the main vein. The vein is exposed in prospect pits for another 75 ft beyond the ends of the trench. Several other prospect pits are scattered along smaller veins near the mine.

The fluorite is in veins in fault and shear zones in Mesozoic quartz monzonite; at least nine veins were prospected. The quartz monzonite is cut by two well-developed joint sets and local, irregular massive quartz bodies. The veins are roughly parallel, strike N. 30° E., dip a few degrees from vertical, and are as much as 6 ft thick. The quartz monzonite is brecciated and silicified for several feet adjacent to the veins.

The fluorite is usually colorless to light gray and, rarely, pale purple. The veins comprise crystalline aggregates with individual crystals as much as 0.25 in. across and colloform masses resembling chert. Gangue minerals are quartz, calcite, and iron oxide. Chesterman (1957, p. 202) reported mine run ore of 91.7 percent CaF_2 and a select sample contained 97.8 percent CaF_2. Fluorite samples collected and analyzed by U.S. Bureau of Mines personnel ran as much as 94.9 percent CaF_2 (table 2 of Kreidler, 1984). The fluorite is of metallurgical grade and was shipped to Kaiser Steel Co. for use in their Fontana, Calif., blast furnaces. Assuming a depth equal to one-third the length of the outcrop of the largest vein, Chesterman estimated reserves of 5,000 tons of fluorite in 1955 (written commun., 1983).

The veins, although striking toward the boundary, cannot be traced into the study area due to surface cover.

Oil and Gas

In 1923, an oil and gas test well was drilled about 3.5 mi southwest of the wilderness study area boundary (fig. 1); no other information is available. No other oil and gas wells or leases are reported in the Orocopia Mountains area.

Geothermal Resources

The Salton Trough, west of the San Andreas fault, is a Known Geothermal Resource Area containing many hot-water springs and wells. East of the San Andreas fault, two hot springs are known near the study area. Dos Palmas Spring, about 2.5 mi south of the study area, has a water temperature of 84 °F and Canyon Spring, about 0.5 mi east of the study area, has a water temperature of 97 °F (Higgins and Martin, 1980).

No tracts of land are known to be leased for geothermal exploration in or near the study area; however, Calzia and others (1979) place the western part of the Orocopia Mountains Wilderness Study Area in a region designated as "prospectively valuable for geothermal resource." No heat flow data were included.

Conclusions

The Big Bullett manganese deposit appears to be mined out because no pyrolusite was seen in outcrop and no concentrations of manganese were found in any of the samples.

Low-grade talc of commercial quality occurs at the unnamed prospect outside the southwest boundary and on the Goat claims within the study area. Industry geologists who have examined the Goat claims report the talc is contaminated with serpentine, iron, and quartz. Extensive subsurface exploration is needed to adequately evaluate this report.

Along the Orocopia mine vein, gold concentrations are as high as 0.250 troy oz/ton and average 0.125 troy oz/ton in 10 of 24 samples. This constitutes a small-tonnage, low-grade gold resource.

An estimated 5,000 tons of fluorite is still in place at the Orocopia Fluorspar mine, about 1.5 mi north of the study area.

The Orocopia Mountains are not underlain by any rocks which are considered possible reservoir rocks for oil and gas. No land within the study area has been leased for oil and gas.

Although the westernmost part of the Orocopia Mountains Wilderness Study Area lies within an area designated as "prospectively valuable for geothermal resources," no known geothermal exploration or development has taken place.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

Two major faults divide the Orocopia Mountains into several structural blocks. These faults are the Late Cretaceous Orocopia thrust and the middle to late Tertiary Clemens Well fault system. The rocks of the Orocopia Mountains can be divided into three groups: (1) the Proterozoic and Mesozoic gneissic and granitoid rocks that form the upper plate of the Orocopia thrust; (2) the late Mesozoic Orocopia Schist, which forms the lower plate of the Orocopia thrust; and (3) unmetamorphosed Eocene to Miocene sedimentary and volcanic strata. The following summary of the geology of the Orocopia Mountains is based largely on Crowell (1975).

Lithologic Units

The oldest rocks in the Orocopia Mountains are Early Proterozoic (uranium-lead zircon age of about 1,670 Ma, million years ago; Silver, 1971) augen gneiss and migmatite exposed in the southeastern corner of the range. Most of these gneissic rocks are quartzofeldspathic; some quartzose and biotite-rich rocks are present. The next oldest group of rocks is Middle Proterozoic (about 1,420 Ma; Silver, 1971) banded gneiss that crops out in small bodies between the Orocopia thrust and the Clemens Well fault. The banded gneiss is characterized by distinctive blue or violet quartz.

Intruding the Middle Proterozoic gneiss is a Middle Proterozoic anorthosite-syenite complex that consists of anorthosite, gabbro, diorite, syenite, alkali granite, and other less common rock types (Crowell and Walker, 1962). The uranium-lead isotopic age of this intrusive suite is about 1,220 Ma (Silver, 1971). This anorthosite-syenite complex makes up most of the structural block between the Orocopia thrust and the Clemens Well fault.

Granitoid rocks of several compositions and ages are present in the Orocopia Mountains, and are most common in the hills south and southwest of Maniobra Valley and in the smaller, northern ridge of the Orocopia Mountains. The granitoid rocks intrude the Middle Proterozoic anorthosite-syenite complex and the older gneisses. By analogy with nearby areas (Powell, 1981), granitoid rocks of Proterozoic, Jurassic, and Cretaceous age probably are present. None of the granitoid rocks intrude the Orocopia Schist. Although Triassic granodiorite and related granitoid rocks are exposed in several nearby areas (Ehlig, 1981), they do not crop out in the Orocopia Mountains. Augen gneiss and migmatite in the Canyon Spring area, east of the Clemens Well fault and west of the unconformable contacts with the Diligencia Formation, are cross cut by a swarm of propylitically altered, highly chloritic Mesozoic mafic dikes, commonly foliated. These dikes are in turn disrupted by numerous small faults that would go largely unrecognized were it not for the offset of the mafic dikes.

The main (western), larger ridge of the Orocopia Mountains is underlain largely by the late Mesozoic Orocopia Schist. The structural thickness of the Orocopia Schist is more than 1 mi. The Orocopia Schist comprises chiefly quartzofeldspathic schist, derived from graywacke, and also includes minor interlayered metabasalt and ferromanganiferous metachert and siliceous marble (Haxel and Dillon, 1978; Ehlig, 1981; Haxel and others, 1987; Jacobson and others, 1988). Geochronologic data from elsewhere in southern California indicate that at least part of the protolith of the Orocopia Schist is Late Jurassic or older (Mukasa and others, 1984); and that metamorphism of the Orocopia Schist, and accompanying movement on the overlying Orocopia thrust, occurred in Late Cretaceous time (Haxel and Tosdal, 1986, p. 54).

The oldest unmetamorphosed supracrustal rocks in the Orocopia Mountains make up the Eocene Maniobra Formation (Crowell and Susuki, 1959), which crops out in the area around the head of Red Canyon and in Maniobra Valley. These are marine strata about 4,900 ft thick, consisting of brown shale, sandstone, and conglomerate. The Maniobra Formation rests nonconformably on granitic basement rocks and is unconformably overlain by the Oligocene(?) and early Miocene Diligencia Formation (Crowell, 1975). The Diligencia Formation crops out over a wide tract between the Clemens Well fault, the main area of the Maniobra Formation, and Red Canyon. The Diligencia Formation consists of about 4,900 ft of nonmarine conglomerate, breccia, sandstone, and mudstone; basaltic to andesitic flows, sills, and dikes; and limestone and evaporites (Spittler and Arthur, 1982; Squires and Advocate, 1982). Late Cenozoic clastic sedimentary rocks and deposits are widely exposed in the Mecca Hills, west-northwest of the Orocopia Mountains (Dibblee, 1954). Within and adjacent to the Orocopia Mountains Wilderness Study Area, the only strata younger than the Diligencia Formation are local accumulations of Pliocene to Quaternary fanglomerate and alluvium.

Structure

The Late Cretaceous Orocopia thrust places the Proterozoic gneiss and anorthosite-syenite complex and the Proterozoic and Mesozoic granitoid rocks atop the Orocopia Schist. The Orocopia thrust is synmetamorphic with respect to the Orocopia Schist. Where well preserved, the thrust is marked by a mylonitic zone, typically about 100 ft thick, developed largely from the granitic upper-plate rocks. Along much of its length, the Late Cretaceous Orocopia thrust was disrupted or modified by middle to late Tertiary low-angle normal (detachment) faulting characterized by cataclastic rocks. The Orocopia thrust may also locally have been affected by faulting related to the late Tertiary strike-slip Clemens Well fault system. Thus, the structure mapped as the Orocopia thrust evidently is actually a composite fault. This composite fault is exposed almost continuously for about 10 mi, along the northeastern margin of the outcrop area of the Orocopia Schist.

The foliation of the Orocopia Schist defines a broad, northwest-trending, doubly plunging anticline of Tertiary age. The Orocopia thrust and its upper-plate crystalline rocks crop out on the northeast flank of this anticline; the upper-plate rocks, but not the thrust itself, are exposed on the southwest flank of the anticline. The Maniobra and Diligencia Formations occupy a broad structural trough between the two basement-rock ridges of the Orocopia Mountains. The Diligencia Formation is folded into several broad synclines and anticlines. The Maniobra Formation crops out on the northeastern flank of the trough, and dips southwestward beneath the Diligencia Formation; the Maniobra Formation is not exposed on the southwest side of the trough, where the Diligencia Formation was deposited directly on crystalline basement rocks.

The late Cenozoic San Andreas fault zone (Crowell, 1979, 1981), which consists of numerous fault segments and splays, lies about 6 mi southwest of the main part of the Orocopia Mountains, and is well exposed in the Mecca Hills (Sylvester and Smith, 1976). The Clemens Well fault passes northwesterly through the central part of the Orocopia Mountains. Along much of its trace, the Clemens

Well fault separates the Diligencia Formation to the northeast from crystalline basement rocks to the southwest, but along the southeastern part, crystalline rock is present on both sides of the fault. Right slip along the Clemens Well fault is probably no more than few tens of miles (Crowell, 1975). The Clemens Well fault apparently is part of a major late Tertiary right-slip fault that has been fragmented by the San Andreas fault system in late Cenozoic time (Powell, 1981). The Maniobra and Diligencia Formations are cut by numerous subvertical faults that strike northwest or northeast. Several of the northeast-striking faults have minor left slip. South of the Orocopia Mountains, between the Orocopia Mountains and the northern Chocolate Mountains, the Salton Creek fault has uncertain but possibly substantial strike-slip displacement.

Geochemical Studies

A reconnaissance geochemical survey was conducted in the Orocopia Mountains Wilderness Study Area in 1982. The purpose of this type of survey is to evaluate a large area for evidence of mineralization. The survey was not designed to find individual mineral deposits; it was designed to delineate favorable geochemical provinces and mineralized districts that may be suitable for follow-up studies.

Minus-80-mesh (less than 0.01 in.) stream sediments and nonmagnetic heavy-mineral concentrates derived from stream sediments were selected as primary sample media because they represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Chemical analysis of sediments provides information useful in identifying those basins that contain unusually high concentrations of elements that may be related to mineral deposits.

Stream-sediment samples were collected from dry stream channels in and near the study area at 55 sites. At all these sites both a minus-80-mesh sample and a heavy-mineral concentrate sample were collected. Samples were composited from what appeared to be the most recently active alluvium along 30 to 50 ft of channel length.

After sieving, the minus-80-mesh fraction was ground to approximately minus-150-mesh in a vertical pulverizer with ceramic plates. The fraction coarser than 80 mesh was discarded.

To produce the heavy-mineral concentrate, bulk stream sediment was first passed through a 10-mesh (0.08-in.) screen. Approximately 10 to 15 lb of the minus-10-mesh sediment were panned to remove most of the quartz, feldspar, organic materials, and clay-sized material. The panned concentrate was then separated into light and heavy fractions using bromoform (heavy liquid, density 2.8 g/cm^3). The light fraction was discarded. The material of density greater than 2.8 g/cm^3 was further separated into three fractions (highly magnetic, weakly magnetic, and nonmagnetic) using a Frantz Isodynamic Separator. The nonmagnetic fraction, or a split of it, was hand ground and saved for analysis. Whenever possible, an unground split was saved for visual examination to determine mineralogy. These preparation procedures result in a concentrated mineral assemblage that may be rich in ore-forming or ore-related minerals such as pyrite, galena, cassiterite, sphalerite, chalcopyrite, stibnite, free gold, barite, and scheelite. This selective concentration of ore-related minerals permits determination of elements that are not easily detected in bulk stream-sediment samples.

Samples were analyzed by a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968) for 29 elements in the heavy-mineral concentrates and for 31 elements in the minus-80-mesh sediments. Minus-80-mesh stream sediments were also analyzed for gold by an atomic-absorption method (Hubert and Chao, 1985). A complete listing of all analyses was provided by B.M. Adrian and others (written commun., 1987).

The reconnaissance geochemical survey delineated three anomalous tracts within the study area. The first tract consists of the northwest-trending band of gneiss, migmatite, and anorthosite-syenite complex that forms the upper plate of the Orocopia thrust. Nonmagnetic heavy-mineral concentrates from the southeastern part of this belt contain anomalous silver (as much as 2 ppm, parts per million), arsenic (as much as 1,000 ppm), bismuth (as much as 100 ppm), and tungsten (as much as 1,000 ppm). Rock samples collected during a current gold-exploration program along the northwestern part of the belt contain high values of gold (usually ranging from 10–800 ppb, parts per billion, with some values as high as 6 ppm) and arsenic (as much as 150 ppm) (Leigh Freeman, Orvana Resources Corp., oral and written commun., 1987). Eight rotary drill holes, each collared in crystalline rocks of the upper plate, were drilled in the summer of 1987. These holes intercepted zones containing anomalously high concentrations of gold (80–100 ppb), but did not penetrate any ore-grade material (Leigh Freeman, Orvana Resources Corp., oral and written commun., 1987).

The second geochemically anomalous tract is the western part of the study area where one sample of nonmagnetic heavy-mineral concentrate contains 100 ppm gold and 30 ppm silver. The geochemical anomaly may indicate gold-bearing quartz veins within the schist.

The third anomalous tract encompasses outcrops of the Diligencia Formation. Nonmagnetic heavy-mineral concentrates from this tract contain anomalous amounts of barium (greater than 10,000 ppm) and strontium (greater than 10,000 ppm). The nonmagnetic fraction of the concentrate contains 50–85 percent barite ($BaSO_4$). Minus-80-mesh stream sediments from the tract contain anomalous abundances of boron (300–2,000 ppm). The chemistry and mineralogy of the samples may reflect the presence of evaporites as previously reported by Crowell (1975).

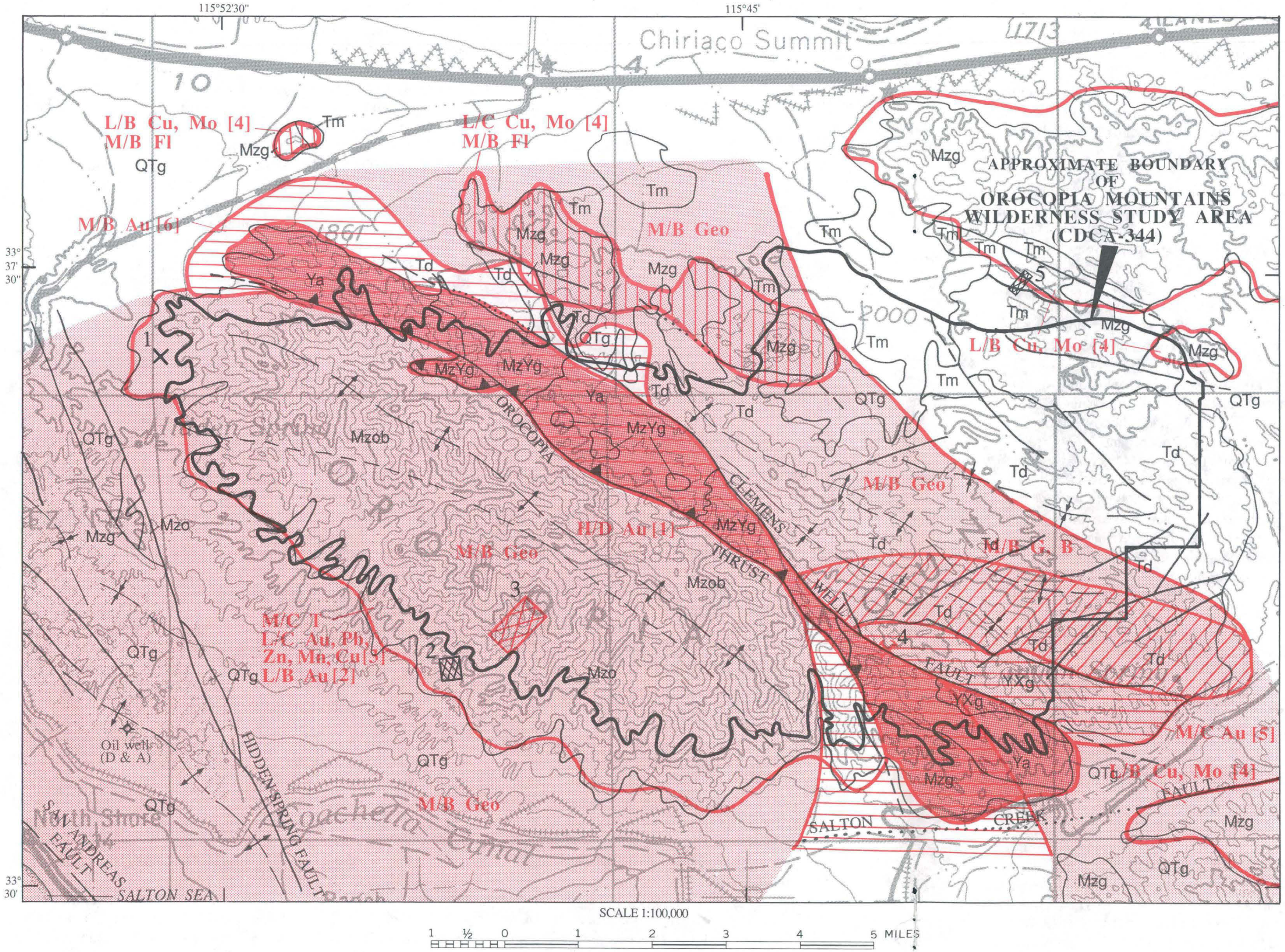

Figure 2. Mineral resource potential and generalized geology of the Orocopia Mountains Wilderness Study Area, Riverside County, California. Geology from Crowell (1975). Contour interval, 200 ft; supplementary interval, 100 ft.

EXPLANATION

Area having high mineral resource potential (H) for gold

Area having moderate mineral resource potential (M) for commodities as indicated

Area having moderate mineral resource potential (M) for gypsum and borate

Area having moderate mineral resource potential (M) for fluorite

Area having moderate mineral resource potential (M) for gold

Area having low mineral resource potential (L) for commodities as indicated

Level of certainty of assessment

- B — Data only suggest level of potential
- C — Data give good indication of level of potential
- D — Data clearly define level of potential

Commodities

Au	Gold	Mn	Manganese
Pb	Lead	G, B	Gypsum and borate
Zn	Zinc	Fl	Fluorite
Cu	Copper	T	Talc
Mo	Molybdenum	Geo	Geothermal

[ ] Type of deposit or occurrence

1. Crystalline-rock-hosted disseminated gold
2. Low-sulfide gold-bearing quartz veins
3. Volcanogenic massive-sulfide base metals and gold
4. Porphyry copper and molybdenum
5. Gold associated with propylitically altered dikes
6. Placer gold

Mines, prospects, and claims

1. Big Bullett claims
2. Unnamed prospect
3. Goat claims
4. Orocopia mine
5. Orocopia Fluorspar mine

Geologic map units

- QTg — Fanglomerate and alluvium (Quaternary to Pliocene?)
- Td — Diligencia Formation (Early Miocene and Oligocene?)
- Tm — Maniobra Formation (Eocene)
- Orocopia Schist (late Mesozoic)—Metamorphic age is Late Cretaceous; protolith age is Jurassic. Divided into:
  - Mzo — Late metagraywacke
  - Mzob — Metagraywacke with metabasalt, metachert, siliceous marble, and minor ultramafic rock
- Mzg — Granitoid rocks (Mesozoic)
- MzYg — Granitoid rocks (Mesozoic to Middle Proterozoic)
- Ya — Anorthosite, syenite, and related rocks (Middle Proterozoic)
- YXg — Banded augen gneiss and migmatite (Middle and Early Proterozoic)

Contact—Dashed where approximate

Fault—Dashed where approximate; dotted where concealed

Orocopia thrust—Dashed where extent uncertain. Sawteeth on upper plate

Anticline—Dashed where approximate

Syncline—Dashed where approximate

Mine

Prospect or claim area—Red indicates identified resource

Geophysical Studies

Geophysical evaluation of the mineral resources of the Orocopia Mountains Wilderness Study Area was based on interpretations of the three kinds of geophysical surveys: aeromagnetic, gravity, and aerial gramma-ray spectrometer.

An aeromagnetic survey (U.S. Geological Survey, 1983) was flown in 1981 by a private contractor. The aeromagnetic data were collected along parallel east-west flightlines spaced 0.5 mi apart at a nominal altitude of 1,000 ft. The contractor subtracted the Earth's main magnetic field from the data, gridded the data set using a grid spacing of 650 ft, and machine contoured the gridded data at scales of 1:250,000 and 1:62,500 to produce the residual aeromagnetic map. Additional aeromagnetic data are available in the atlas on the Salton Sea quadrangle published for the Department of Energy (LKB Resources, Inc., 1980). These data consist of north-south profiles spaced at an interval of 3 mi and flown by helicopter at an average height of 400 ft above the ground surface; 5 profiles cross the Orocopia Mountains Wilderness Study Area.

Variations in the Earth's magnetic field on a residual map are, in general, caused by variations in the amounts of magnetic minerals in different rock units, magnetite being the common magnetic mineral in this area. Magnetic minerals, where locally either concentrated or absent, may cause a high or low magnetic anomaly that can be a guide to mineral occurrences or deposits. Boundaries between magnetic and relatively less magnetic rock units are located approximately at the steepest gradient on the flanks of the magnetic anomaly because at these magnetic latitudes the inclination of the Earth's main magnetic field is relatively steep (59° below the horizontal).

Comparison of the contoured aeromagnetic map with the geologic map indicates that the Orocopia Mountains Wilderness Study Area contains certain rock types that each have characteristic magnetic patterns or anomalies. The Orocopia Schist forms a regional magnetic low and is essentially nonmagnetic except for a small high (20 gammas in amplitude and about 1 mi across) that appears to be associated with the area of talc prospects at the Goat claims. Evidently, the associated chlorite-actinolite schist and serpentinite are moderately magnetic, a common observation in similar talc deposits elsewhere in the United States. The absence of other similar magnetic highs within the Orocopia Schist suggests that other similar talc occurrences are not present.

Between the Orocopia thrust and the Clemens Well fault is a belt of Proterozoic rocks intruded locally by younger granitic rocks. The Proterozoic rocks include gneisses and substantial amounts of an anorthosite-syenite complex that also contains gabbro and diorite. One might expect such rocks to be relatively magnetic, yet only two magnetic anomalies are associated with this belt: one in the extreme southeast corner of the study area and one about 2 mi north of Orocopia Peak. These two highs are caused by rock masses about 2.5 and 1.5 mi across, respectively. This unexpected scarcity of strong magnetic anomalies in this belt may have significance in relation to the favorable geologic indications for crystalline-rock-hosted disseminated gold deposits that are described in the Mineral Resource Assessment section of this report. The indications include fracturing, brecciation, silica flooding, and oxidized zones containing iron-oxide staining. Such hydrothermal alteration can destroy the primary magnetite of fresh rocks and thus any favorable areas might not be expected to display magnetic variations.

Other magnetic highs within the Orocopia Mountains Wilderness Study Area include small magnetic highs associated with the mafic volcanic rocks of the Diligencia Formation and a major, northwest-trending magnetic high associated with granitic rocks in the extreme northeast corner of the study area. These highs are normal and probably provide no information concerning possible mineral resources.

Gravity data for the study area are available as complete Bouguer gravity maps (Elders and others, 1972; Biehler and Rotstein, 1982; Oliver and others, 1980) and as residual isostatic gravity maps (Roberts and others, 1981; Mariano and others, 1986). The area of Orocopia Schist is characterized by a local gravity high of at least 20 milliGal (mGal). The cause of the gravity high is not evident because the density of the schist probably is about the same or less than that of the surrounding Proterozoic rocks. The source of this anomaly may be fairly deep because the Clemens Well fault (assuming that it is steep) does not appear to influence the gradient on the north side of the high. The unknown basement rocks beneath the schist are probably former oceanic crust on the basis of the associated metabasalt and ultramafic rocks exposed in the Orocopia Schist (Haxel and Dillon, 1978). The gravity high may indicate uplifted former oceanic crust beneath the exposures of the schist (Griscom, 1980), but if so, these presumably magnetic rocks must be too deep to affect the aeromagnetic map pattern. The gravity field slopes down to the granitic rocks in the extreme northeastern part of the study area. Large masses of granitic rocks commonly produce gravity lows.

Radioactivity data were collected and compiled by LKB Resources, Inc. (1980) for the National Uranium Resource Evaluation program of the Department of Energy. Aerial gamma-ray spectrometer measurements are available along 3-mi-spaced east-west flightlines. The recorded flight altitudes generally ranged from 200 to 400 ft. Recordings were made of gamma-ray flux from radioactive isotopes of uranium, thorium, and potassium or their decay products. Abrupt shifts in flux level were recorded over geologic contacts. The results indicate that statistically significant anomalies for uranium, potassium, and thorium were not found within the study area. One feature of possible economic significance is the presence of small potassium anomalies associated with the belt of rocks between the Orocopia thrust and the Clemens Well fault. Such anomalies might be caused by potassium metasomatism associated with hydrothermal alteration.

Mineral Resource Assessment

This assessment of the mineral resource potential of the Orocopia Mountains Wilderness Study Area is based upon geologic, geochemical, and geophysical data from previous literature; geologic and geochemical field studies by the authors and their colleagues; oral and written communication with geologists in the mining industry; and application of ore-deposit models (Cox and Singer, 1986; Eckstrand, 1984). These data and methods were used to delineate favorable tracts within the study area; an estimate was then made of the level of resource potential and degree of certainty for each tract for certain ore-deposit types. Selection of ore-deposit models was based on the geology of the Orocopia Mountains Wilderness Study Area and on mineral resource assessments of nearby or geologically similar areas (Powell and others, 1984a, b; Morton, 1977; Bagby and others, 1987; Smith and others, 1987; Peterson and others, 1987; Morton and others, 1988). The mineral resource potential refers to undiscovered mineral resources. In addition to the descriptive ore-deposit models in the compilation cited above, we have used models based on mineral occurrences in the Orocopia Mountains Wilderness Study Area and vicinity and, more importantly, models based on newly discovered gold deposits and occurrences recently recognized in southeasternmost California.

The assessment is organized by deposit type. Characteristics of known deposits are briefly summarized and each tract is evaluated according to several assessment criteria. Definitions of levels of mineral resource potential and certainty of assessment are presented in the appendixes.

Crystalline-Rock-Hosted Disseminated Gold

Recent mineral exploration and development in southeastern California has resulted in recognition of a new type of gold deposit. The original or discovery example of this deposit type is the Mesquite deposit, at the southern tip of the Chocolate Mountains, about 60 mi southeast of the Orocopia Mountains (Manske and others, 1987; Willis and others, 1987; Smith and others, 1987; Tosdal and Smith, 1987a, b). The Picacho deposit (Drobeck and others, 1986; Van Nort and Harris, 1984), also in southeasternmost California, may be another example of, or have affinities to, this deposit type. In crystalline-rock-hosted disseminated gold deposits, gold is generally hosted by gneiss or granitoid rocks and is localized or concentrated in intensely brecciated and oxidized zones. Gold and in some cases arsenic are the best geochemical indicators for this deposit type. Favorable geologic indications for this type of deposit include strong fracturing or shattering, silica flooding, and iron-oxide staining. Scattered anomalous concentrations of arsenic, antimony, mercury, tungsten, tellurium, and possibly thorium may also be present. The present understanding of this deposit type is insufficient to unequivocally characterize the environment of deposition; several models have been proposed (see references cited above). In southeasternmost California, the age of final, economic mineralization is probably middle or late Tertiary, but "precursor mineralization," that is, initial introduction of gold into the upper crust, may have occurred in Jurassic and (or) Cretaceous time (Tosdal and others, 1985; Keith, 1986).

The northwest-trending strip of crystalline rocks between the Orocopia thrust and the Clemens Well fault is judged to have high resource potential, certainty level D, for gold in crystalline-rock-hosted disseminated gold deposits (fig. 2). This strip of mineralized ground is approximately 12 mi long and 0.3 to 1 mi wide. It is the surface expression of an irregular, downward-tapering wedge bounded on the northeast by the subvertical Clemens Well fault and on the southwest by the northeast-dipping Orocopia thrust.

The following summary of the results of exploration geochemistry within the strip between the Orocopia thrust and Clemens Well fault is based on conversations in October 1987 with, and data shown to us by, Leigh Freeman of Orvana Resources Corp. in Golden, Colo. Surface rock sampling shows numerous samples containing anomalous arsenic concentrations from 20 to greater than 150 ppm. (The average upper crustal abundance of arsenic is approximately 1.5 ppm; Taylor and McLennan, 1985.) Anomalous gold concentrations range from 10 ppb to greater than 800 ppb; a few samples contain as much as about 6 ppm gold. (The average upper crustal abundance of gold is about 2 ppb (1 ppm ≈ 0.03 troy oz/ton.) Anomalous concentrations of arsenic and gold are strongly correlated. Based on this geochemical sampling, eight rotary drill holes were drilled in the area about 6 mi southwest of Chiriaco Summit. Results of this drilling program were not available at the time this report was prepared.

The geochemically anomalous whole-rock arsenic and gold concentrations, and the tract considered favorable for gold in crystalline-rock-hosted disseminated gold deposits, does not extend into the Orocopia Schist southwest of the Orocopia thrust nor into the Diligencia Formation and crystalline rocks northeast of the Clemens Well fault. Throughout southeastern California, the Orocopia Schist consistently appears to be an unfavorable host for disseminated gold mineralization. Stream-sediment analyses from the Orocopia Schist in the Orocopia Mountains Wilderness Study Area do not contradict this generalization.

Gold-Bearing Quartz Veins

This deposit type is characterized by the occurrence of gold in massive quartz veins, typically in regionally metamorphosed oceanic sedimentary or volcanic rocks (Berger, 1986). The veins are typically metamorphogenic and postmetamorphic in their fabric relations to their host metamorphic rocks. Native gold may be accompanied by minor sulfide and (or) carbonate minerals. In general, geochemical indicators include arsenic, gold, silver, lead, copper, zinc, and tungsten.

Small veins and pods of white quartz are common throughout the Orocopia Schist; most are postmetamorphic, a few are synmetamorphic. The largest pods are typically no more than a few yards in largest exposed dimension. Typical quartz veins are few inches to about 3 ft wide and a few tens of feet long. Few of these quartz veins have been prospected. Geologic observations, absence of appreciable prospecting of these highly visible veins, and conversations with geologists actively engaged in mineral exploration in the southeastern California desert suggest that the metamorphogenic quartz veins in the Orocopia Schist have low potential, with a certainty level of B, for gold resources. A single nonmagnetic heavy-mineral concentrate from an area draining the Orocopia Schist contains anomalous gold and silver concentration, but the values are not necessarily derived from nor associated with the quartz veins.

Gold Associated with Propylitically Altered Mafic Dikes

In both the Chuckwalla and Eagle Mountains Wilderness Study Areas (east and northeast, respectively, of the Orocopia Mountains Wilderness Study Area), propylitically altered mafic dikes cut by quartz veins and small faults crop out in areas characterized by anomalously high abundances of a suite of elements including tungsten, molybdenum, silver, bismuth, and tin in the nonmagnetic fraction of stream-sediment samples (Powell and others, 1984a, b). Scheelite and fluorite are abundant in these samples. This geochemical and mineralogic signature is consistently associated with the altered mafic dikes, even though these dikes intrude a number of diverse Proterozoic gneiss units and Mesozoic plutonic units. In the Chuckwalla Mountains, almost all of the gold mines and prospects are in quartz veins and faults crosscutting the altered mafic dikes. This empirical geologic and geochemical association of gold occurrences with altered mafic dikes does not fit conveniently into any currently recognized ore-deposit model. However, the association did provide a framework for assessing mineral resource potential in the Chuckwalla and Eagle Mountains Wilderness Study Areas (Powell and others, 1984a, b).

In the study area, propylitically altered mafic dikes in the gneissic rocks of the Canyon Spring block, east of the Clemens Well fault and west of fault and unconformable contacts with the Diligencia Formation, are petrographically similar to the altered mafic dikes in the Chuckwalla and Eagle Mountains. Furthermore, the geochemical and mineralogic character of stream-sediment samples derived from the Canyon Spring crystalline block is similar to that of samples from the areas of altered mafic dikes in the Chuckwalla and Eagle Mountains. The propylitically altered mafic dikes in the Canyon Spring crystalline block are heavily prospected, and it is in that geologic setting the Orocopia (Dos Palmas) mine is located. The "chlorite schist" referred to in older descriptions of this mine is foliated, propylitically altered mafic dike rock.

On the basis of these data and comparisons, the block of gneissic rocks between the Clemens Well fault and the Diligencia Formation is considered to have moderate potential, with certainty level C, for gold in quartz veins associated with and, possibly, in fault zones crosscutting the propylitically altered mafic dikes. Lacking an established ore-deposit model, grade-tonnage relations for such deposits are uncertain; but grade-tonnage relations for low-sulfide gold-bearing quartz veins (Berger, 1986) may be useful as a rough guide. The estimated tonnage (850 tons) and average grade (4 ppm) of the remaining ore at the Orocopia mine plot near the lower tenth-percentile end of the grade-tonnage models of Bliss (1986). This comparison, if valid, suggests that gold deposits in quartz veins associated with the altered mafic dikes are likely to be quite small.

Volcanogenic Massive-Sulfide Base Metals and Gold

This type of deposit consists of copper, lead, and (or) zinc sulfides, possibly accompanied by native gold, in submarine mafic or silicic metavolcanic or volcanic rocks. The geochemical signature commonly includes gold, arsenic, boron, and antimony.

The metagraywacke of the Orocopia Schist contains sparse to locally abundant layers of metabasalt, metachert, and siliceous marble. Metachert and siliceous marble layers are typically 1 to 30 ft thick. This oceanic lithologic assemblage (Haxel and others, 1987) constitutes a permissive geologic setting for volcanogenic massive-sulfide deposits, possibly containing gold. However, six independent lines of evidence indicate that the potential for gold and (or) base metals (copper, lead, zinc) in massive-sulfide deposits within the Orocopia Schist is low, at certainty level C. (1) Extensive mapping of the Orocopia Schist and similar, related schist units in southern California by many geologists (see summaries by Haxel and Dillon, 1978; Ehlig, 1981; Jacobson and others, 1988) revealed no occurrences of metalliferous sediments or massive-sulfide deposits. (2) Although metachert and siliceous marble in the Orocopia Schist are commonly ferromanganiferous, as indicated by metamorphic magnetite and spessartite and (or) piemontite, the rocks typically contain no more than 2 percent manganese oxide. (3) For nine samples of metachert and siliceous marble from the Orocopia Schist, typical abundances of copper, lead, and zinc are 170, 12, and 100 ppm, respectively. These copper and zinc concentrations are several times greater than average upper-crustal abundances, but are far below any conceivable ore grade for these base metals. (4) All nine samples contain less than 50 ppm boron, less than 1 ppm tungsten, less than 10 ppm arsenic, less than 100 ppb gold, less than 0.5 ppm antimony, and less than 1 ppm thallium. (5) Interpretation of trace-element systematics indicates that the metacherts and siliceous marbles in the Orocopia Schist are derived from fundamentally biogenic deposits (probably radiolarian cherts), in which the hydrothermal metalliferous component is minor (Haxel and others, 1987). Furthermore, this minor metalliferous component was not necessarily produced by *in situ* hydrothermal activity (compare with Dymond, 1981; Ruhlin and Owen, 1986). (6) Fuchsite (chromian muscovite) is an alteration mineral associated with some massive-sulfide deposits. Although the Orocopia Schist contains fuchsite, it is scattered through the metagraywacke rather than associated with the metabasalt, metachert, or siliceous marble.

Manganese metachert layers in the Orocopia Schist commonly contain 0.2 to 2 percent manganese oxide (Haxel and others, 1987). The small amount of pyrolusite ore reportedly mined from the Big Bullett claims was apparently produced by remobilization of this manganese, possibly during Tertiary faulting. Available geologic and geochemical data suggest that the potential for manganese associated with metachert in the Orocopia Schist is low, certainty level C.

Talc

Pods and irregular masses of ultramafic rocks, ranging from several inches to 30 ft in largest exposed dimension, are sparsely scattered through the Orocopia Schist. In some areas, these masses are aligned along shear or fault zones. Some of the ultramafic masses are composed of antigorite serpentinite, but most are composed of variable proportions of actinolite (or tremolite) and talc, with or without minor chlorite, fuchsite, carbonate, serpentine, and (or) iron oxide. Ultramafic masses composed largely or entirely of talc are much rarer than those consisting of subequal amounts of talc and actinolite. The Goat claims are located in one such talc-rich mass. The Orocopia Schist of the study area has moderate potential, with certainty level C, for additional talc. Any such deposits would probably be small compared to those currently of commercial interest.

Fluorite

Based on the presence of a small vein-fluorite (fluorspar) deposit (the Orocopia Fluorspar mine, in Mesozoic granite north of the Orocopia Mountains Wilderness Study Area), the north-central part of the study area is judged to have moderate potential, with certainty level B, for fluorite. Any such deposits would probably be small compared to those currently of commercial interest.

Evaporite Deposits

The middle part of the Diligencia Formation contains some thin-bedded lacustrine evaporite beds (Spittler and Arthur, 1982). These evaporite beds are restricted to the southwestern part of the outcrop area of the Diligencia Formation. They are generally composed of laminated gypsum; borate-bearing beds are present locally. The principal trace elements in stream-sediment samples from the southeastern part of the Diligencia Formation are boron, barium, and strontium. No other information on the composition of the evaporite beds is available. The southeastern and stratigraphically medial part of the Diligencia Formation has moderate potential, at certainty level B, for gypsum and borate in evaporite deposits

Porphyry Copper-Molybdenum

Porphyry copper deposits are associated with epizonal or shallow mesozonal granitoid plutons, typically including rocks with porphyroaphanitic textures (Titley, 1982; Cox, 1986). Ore occurs in both the plutons and their altered country rocks. Such deposits and plutons are associated with convergent (subduction) plate margins. Disseminated and stockwork chalcopyrite and pyrite, with or without molybdenite, are typical. Porphyry copper mineralization is associated with characteristic types and patterns of alteration (Titley and Beane, 1981). Supergene alteration produces secondary copper carbonates, silicates, and sulfides. The geochemical signature of porphyry copper deposits includes, but is not limited to, copper, molybdenum, gold, silver, boron, strontium, tungsten, manganese, lead, zinc, sulfur, arsenic, antimony, selenium, technetium, and tellurium.

The numerous porphyry copper deposits in southern and northwestern Arizona, northern Sonora, Mexico, and southwestern New Mexico are almost entirely associated with granitoid rocks of Late Cretaceous to early Tertiary age. Only one deposit is associated with a Jurassic pluton. Furthermore, all but one of the Arizona-Sonora-New Mexico porphyry copper deposits lie along or northeast of a line from La Caridad, Mexico, to Kingman, Arizona. The single exception is Ajo, in southwestern Arizona. A small area of porphyry copper-type alteration is associated with a Jurassic granodiorite in the northern Kofa Mountains, Arizona (Bagby and others, 1987). Although southeastern California has been extensively explored for porphyry copper deposits, no such deposits have been found.

Although the ages of the granitic rocks in the Orocopia Mountains Wilderness Study Area are not well known, both Late Cretaceous plutons and Jurassic plutons are probably present. The regional data summarized above indicate that the likelihood of a porphyry copper deposit in the Orocopia Mountains Wilderness Study Area is small. However, no geologic or geochemical evidence of porphyry copper-type mineralization or alteration is known in the study area. Therefore, those areas of the Orocopia Mountains Wilderness Study Area underlain by granitic rocks are assigned low potential, with certainty level B, for copper and molybdenum in porphyry copper deposits.

Placer Gold

Apparently, there has been no extensive, longstanding placer gold mining in the Orocopia Mountains. Nonetheless, the recognition of high potential for lode gold mineralization in the strip of crystalline rocks between the Orocopia thrust and the Clemens Well fault raises the possibility of placer gold in drainages downstream from this strip. No gold was detected in the stream-sediment concentrates. The areas that drain from the above-mentioned strip are considered to have moderate potential, with certainty level B, for placer gold occurrences.

Geothermal Energy

Available information pertaining to the possibility of geothermal energy in the Orocopia Mountains Wilderness Study Area is summarized in the Geothermal Resources section. The southwestern two-thirds of the Orocopia Mountains Wilderness Study Area is considered to have moderate potential, at certainty level B, for geothermal energy.

Oil and Gas

The high-grade metamorphic rocks in the study area prohibit oil and gas accumulation. The Orocopia Mountains Wilderness Study Area has no oil and gas potential, certainty level D.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

H **HIGH** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

M **MODERATE** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L **LOW** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.

N **NO** mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

U **UNKNOWN** mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.
B Available information only suggests the level of mineral resource potential.
C Available information gives a good indication of the level of mineral resource potential.
D Available information clearly defines the level of mineral resource potential.

LEVEL OF RESOURCE POTENTIAL ↑

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
</table>

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.

Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40-42.

Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84-0787, p. 7, 8.

RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, V.E., 1972, Mineral resource estimates and public policy: American Scientist, v. 60, p. 32-40; and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	[1]~570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				
		(3800?)			
pre-Archean[2]					4550

[1]Rocks older than 570 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.

Mineral Resources of Wilderness Study Areas: South-Central California Desert Conservation Area, California

This volume was published as separate chapters A–E

U.S. GEOLOGICAL SURVEY BULLETIN 1710

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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[Letters designate the separately published chapters]

GPO 685-041/9776

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Preliminary Determination of Epicenters (issued monthly).

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Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

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U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Haxel and others—MINERAL RESOURCES, OROCOPIA MTS. WILDERNESS STUDY AREA, RIVERSIDE COUNTY, CALIF.—U.S. Geological Survey Bulletin 1710-E