Mineral Resources of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1701–A

Chapter A

Mineral Resources of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona

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U.S. GEOLOGICAL SURVEY BULLETIN 1701

MINERAL RESOURCES OF WILDERNESS STUDY AREAS: WEST-CENTRAL ARIZONA
AND PART OF SAN BERNARDINO COUNTY, CALIFORNIA

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

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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 on 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 a part of the Big Horn Mountains Wilderness Study Area (AZ-020-099), Maricopa County, Arizona.

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Mineral Resources of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona

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SUMMARY

Abstract

At the request of the U.S. Bureau of Land Management, the U.S. Geological Survey and the U.S. Bureau of Mines conducted a mineral survey of approximately 21,500 acres of the Big Horn Mountains Wilderness Study Area (AZ-020-099) in the southwest part of the Big Horn Mountains in southwestern Arizona. In this report, the area studied is referred to as the"wilderness study area", or simply "the study area".

Big Horn Peak, the only geographic feature in the region with a formal name, lies in the central part of the study area. Field work for this report was carried out in 1984 and 1985. Additional mapping in the region surrounding the study area and encompassing the Big Horn and adjacent Belmont Mountains was conducted as part of a Cooperative Geologic Mapping Program (COGEOMAP) project, carried out jointly by the U.S. Geological Survey and the Arizona Bureau of Geology and Mineral Technology. The eastern boundary of the study area includes part of an area of weakly mineralized rocks having moderate and low mineral resource potential for undiscovered gold, silver, lead, and zinc in hydrothermally altered areas that are found along Tertiary (about 1.7 to 66 million years before present, (or Ma); see Geologic time chart, last page of report) age high-angle normal faults and fractures and (or) Proterozoic-age (about 240 to 570 Ma) east-trending quartz veins. Similar areas of fault-controlled, hydrothermally mineralized rock in the northeastern and northwestern parts of the study area have low resource potential for undiscovered gold, silver, and copper. The mineral resource potential for undiscovered iron and titanium is considered low in the northern part of the study area because only negligible amounts of iron-titanium-oxide-bearing sands are present in Quaternary (about 0 to 2 Ma) drainages. On the basis of temperatures obtained from nearby wells and the absence of local magmatism less than 5 million years old, geothermal resource potential is low for the entire study area. On the basis of extrapolation of surficial bedrock exposures, oil and gas potential in the study area is low and the presence of geothermal resources is considered extremely unlikely. The resource potential for undiscovered agate resources is also considered low.

Character and Setting

The Big Horn Mountains Wilderness Study Area (AZ-020-099) encompasses approximately 21,500 acres in the southwest part of the Big Horn Mountains, located approximately 55 mi west of Phoenix, in west-central Arizona (fig. 1). Situated in the Basin and Range physiographic province, the study area consists of rugged northwest-trending mountains and gently sloping alluvial valleys along the mountains flanks. Elevation in the study area ranges from about 3,480 ft

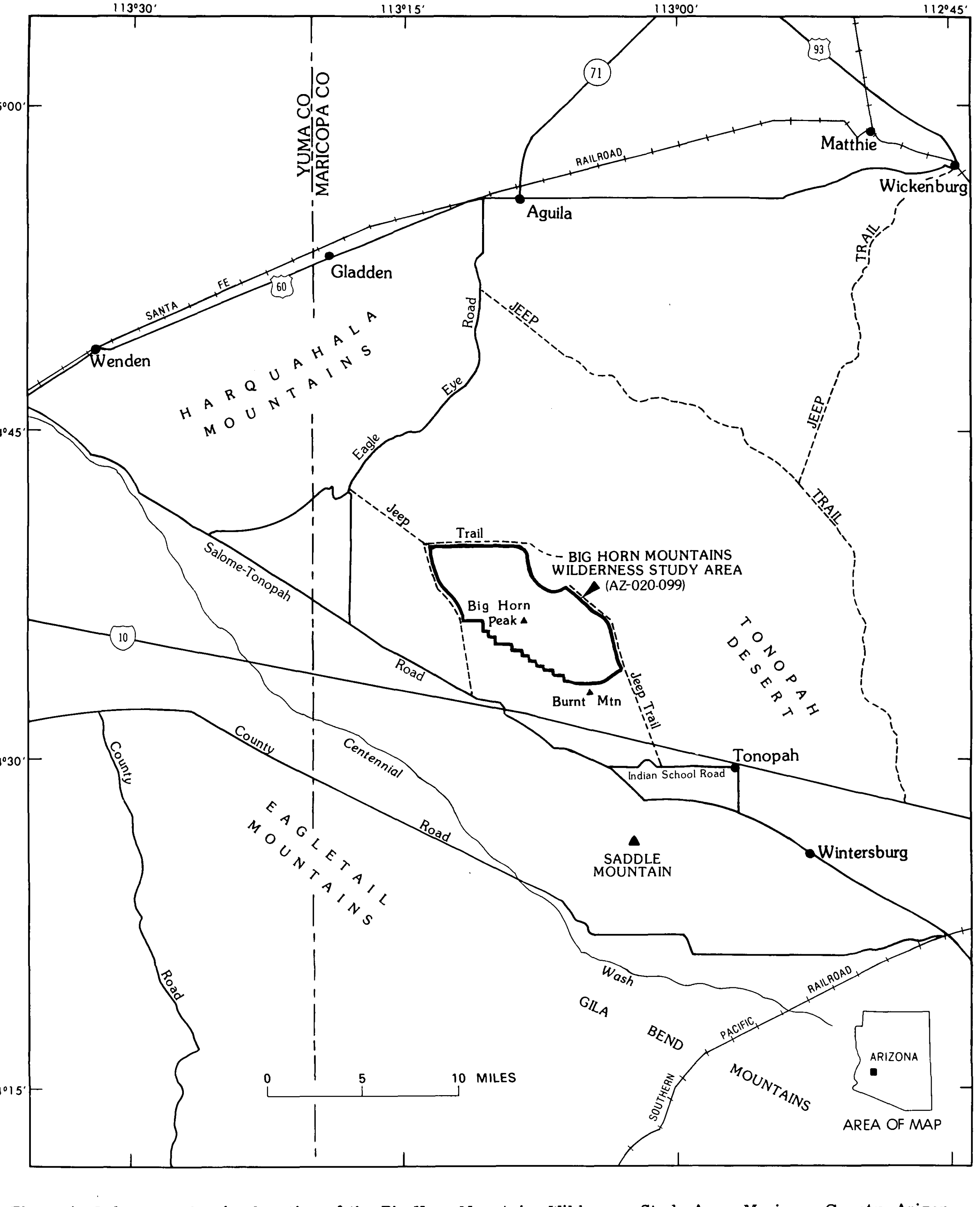

Figure 1. Index map showing location of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona.

above sea level at Big Horn Peak in the center of the study area, to about 1,400 ft on the alluvial surface of the southwest front of the range. Access to the study area is by unimproved roads (jeep trails) branching off of U.S. Interstate Highway 10 and the Eagle Eye Road (fig. 1).

The study area is underlain by Proterozoic metamorphic-plutonic basement rocks that are unconformably overlain by Miocene (5 to 24 Ma) volcanic and minor volcaniclastic rocks. The Miocene strata, an essentially bimodal sequence of intercalated rhyolite and basalt, cover most of the region. Large-displacement normal faults, active at least through Tertiary time, bound the northeastern side of the study area (fig. 2).

The study area is adjacent to four mineral districts located in the Big Horn and Belmont Mountains (Allen, 1986): (1) the Tiger Wash barite-fluorite district, (2) the Aguila manganese district, (3) the Big Horn Mountains gold-quartz vein district, and (4) the Osborne base- and precious-metal district (copper, lead, zinc, silver, and gold). Only minor prospecting for copper, gold, silver, iron, and agate has occurred within the study area since the late 1800's.

Identified Mineral Resources

No mineral resources were identified in the wilderness study area. Minor occurrences of gold and copper in quartz veins and silver, copper, lead, and zinc in fault zones are sporadic and of limited extent throughout the Proterozoic basement rocks within the study area. Low-grade placer magnetite deposits and agate in rhyolite flows are also present in the study area.

The wilderness study area lies in a region of possible geothermal activity (the Basin and Range geomorphic province), but no evidence of geothermal resources was found.

Parts of the study area are under oil and gas leases, but no hydrocarbon resources are known to exist in the study area.

Mineral Resource Potential

Geological, geophysical, and geochemical data, as well as an inventory of mines and prospects indicate that the study area contains regions with moderate and low resource potential for undiscovered gold, silver, lead, and zinc (fig. 2). These metals occur in small epithermal veins that fill fractures in Early Proterozoic gneiss, schist, and metamorphosed granite and Miocene basalt. Quartz veins filling fractures in Early or Middle Proterozoic quartz monzonite have a low potential for undiscovered gold, silver, and copper resources. The potential for geothermal energy and oil and gas is low for the entire study area.

The study area lies on the outskirts of four metallic-mineral districts: the Big Horn gold-quartz vein district, the Tiger Wash barite-fluorite district, the Aguila manganese district, and the Osborne base- and precious-metal district (Allen, 1986). Of these four, the Big Horn gold-quartz vein district and the Osborne base- and precious-metal district have the closest affinity to the types of occurrences in the Big Horn Mountains Wilderness Study Area.

An area of claims and prospects located along and adjacent to the eastern boundary of the study area is characterized by two proximal mineralizing systems: (1) hydrothermal activity along extensively brecciated northwest-trending Tertiary-age normal faults and fractures, and (2) east-trending Proterozoic-age quartz veins. The Tertiary-age structures are distinguished by dominantly calcite gangue hosted by Proterozoic basement rocks and younger mafic volcanic rocks of the basal part of the Tertiary section. Alteration is in the form of thin selvages localized along veins, fractures, or faults. This Tertiary-age hydrothermal activity overprinted occurrences of mineralized quartz veins in Early Proterozoic schist and metamorphosed granite. Rock and stream-sediment samples yield anomalous concentrations of arsenic, barite, copper, gold, lead, molybdenum, silver, and zinc associated with the altered areas. For this reason, the study area is judged to have a moderate and low potential for undiscovered gold, silver, lead, and zinc resources (fig. 2).

Altered granitic rocks underlie areas north and just northwest of Big Horn Peak that contain weakly mineralized vein- and fault/fracture-type occurrences accompanied by quartz with or without calcite. Within these areas, anomalous concentrations of gold, silver, and copper, and less significant concentrations of lead, zinc, and arsenic were found in stream-sediment and pan-concentrate samples. Intrusive rocks of intermediate composition are associated with fault/fracture systems and metallic-mineral occurrences. These two areas have a low mineral resource potential for undiscovered gold, silver, and copper.

Occurrences of gem-quality agate have been reported in a few scattered pockets within rhyolite flows, but the potential for undiscovered agate resources is considered to be low.

The potential for undiscovered geothermal energy within the study area is low because well-temperature data from the surrounding area are average for this region of the Basin and Range province (Bliss, 1983).

Geologic data indicate a low probability for the occurrence of undiscovered oil and natural gas in the Cenozoic rocks of the wilderness study area. Evidence for hydrocarbon potential is negligible; the volcanic rocks and minor sedimentary strata immediately underlying the study area might include suitable reservoir rocks, but lack hydrocarbon source beds.

INTRODUCTION

Location and Physiography

The Big Horn Mountains Wilderness Study Area (AZ-020-099) covers approximately 21,500 acres in the western Big Horn Mountains, about 55 mi west of Phoenix, Ariz. (fig. 1). The southern tip of the area is approximately 0.5 mi north of Burnt Mountain (fig. 1). Low-lying areas adjacent to the study area are

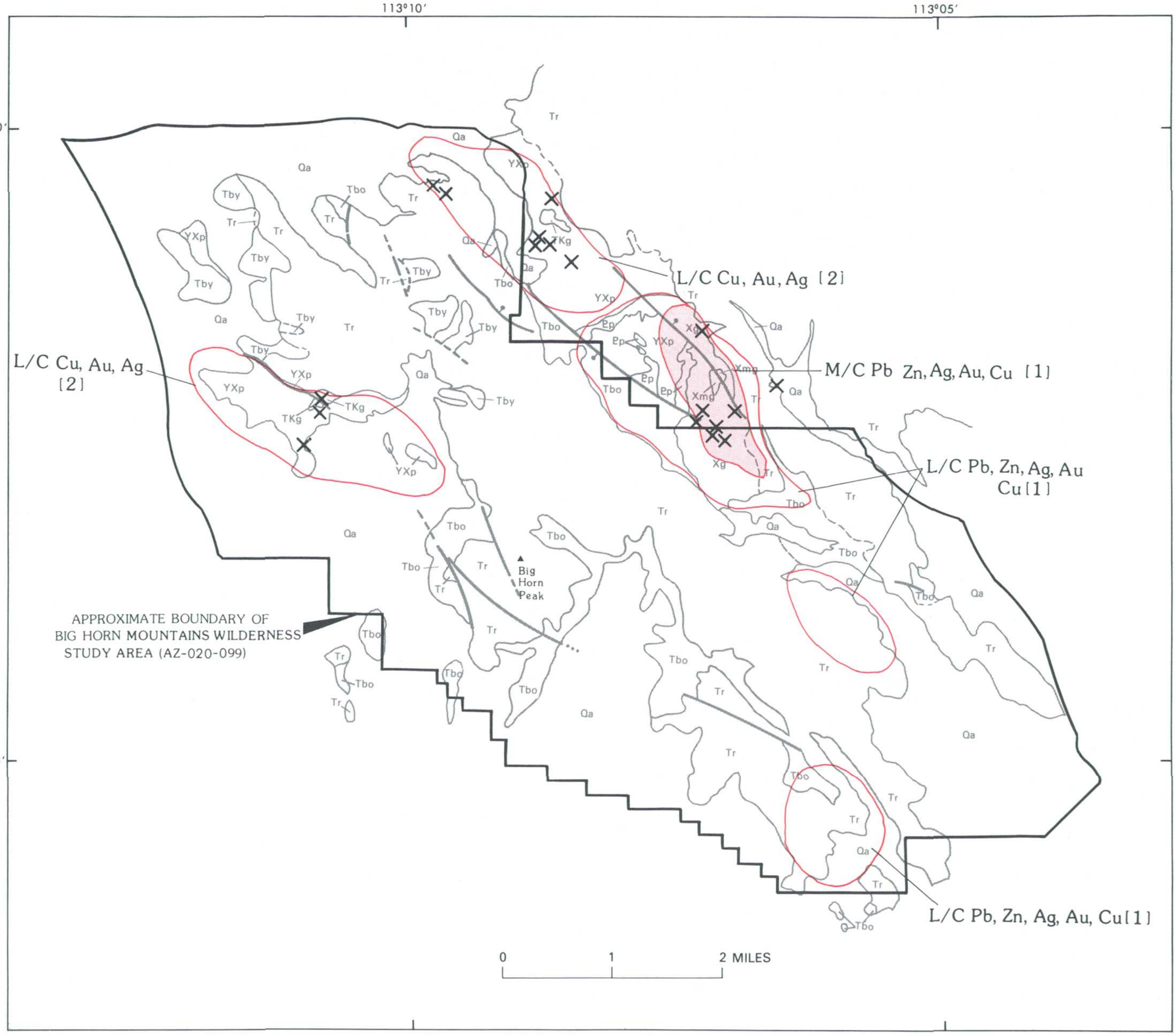

Figure 2. Generalized geologic map showing mineral resource potential of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona.

EXPLANATION

(shaded red box)	Area of moderate potential for metallic resources in hydrothermal veins
(open red box)	Area of low potential for metallic resources in hydrothermal veins

See appendix 1 for definition of resource potential and certainty of assessment

Commodities

Au	Gold
Ag	Silver
Cu	Copper
Pb	Lead
Zn	Zinc

[ ] Types of deposits and occurrences

1	Epithermal base- and precious-metal deposits in Early Proterozoic metamorphosed granite and gneiss, and Miocene basalt; quartz veins in Early Proterozoic metamorphosed granite and gneiss
2	Epithermal base- and precious-metal deposits in Early or Middle Proterozoic quartz monzonite porphyry

Geologic map units

Qa	Alluvium (Quaternary)
Tby	Younger basalt (Miocene)
Tr	Rhyolite (Miocene)
Tbo	Older basalt (Miocene)
TKg	Granodiorite (early Tertiary and Late Cretaceous)
Ep	Pegmatite (Proterozoic)
YXp	Quartz monzonite porphyry (Middle or Early Proterozoic)
Xg	Gneiss (Early Proterozoic)
Xmg	Metamorphosed granite and associated granitic rocks (Early Proterozoic)

———— – – –	Contact--Dashed where approximately located
——•—— – – ...	Normal fault--Dashed where approximately located; dotted where concealed; ball and bar on downthrown side
×	Location of prospect

Figure 2. Continued.

accessible by dirt roads. A few jeep trails lead to abandoned claims and prospects within the eastern boundary of the wilderness study area. The terrain is steep and rugged in most places, with elevations ranging from approximately 3,480 ft above sea level at Big Horn Peak in the center of the study area, to approximately 1,400 ft on the alluvial surface along the southwest front of the range. From the west, the Big Horn Mountains are striking, with their flanks rising steeply from the desert floor and their dramatic alternating light and dark banding. The climate is arid to semiarid and vegetation is sparse. Creosote bush brittle bush, paloverde, ironwood, mesquite, ocotillo, cholla, and saguaro are the dominant plant species; many varieties of desert wildflowers are present seasonally.

Procedures and Sources of Data

In 1984 and 1985, U.S. Geological Survey personnel mapped the wilderness study area and collected rocks, stream-sediment, and heavy-mineral-concentrate samples for geochemical analysis (Miller and others, 1986). The result of that field work (Floyd Gray, Robert Miller, and J.R. Brice III, unpub. data) was a 1:48,000-scale geologic map of the study area, a generalized version of which appears as figure 2 in this report.

The U.S. Bureau of Mines conducted a literature search and examined mining claim information, land status maps, and oil- and gas-lease maps acquired from the U.S. Bureau of Land Management to determine the extent of mining and prospecting activity within the study area. In 1984, U.S. Bureau of Mines personnel did site-specific sampling in and around the study area and carried out laboratory analyses of these samples by several spectrographic techniques (Schreiner, 1985).

Generalized regional studies that include the wilderness study area appear in Wilson and others (1957, 1969); more recent investigations of the regional geochronology, structure, and stratigraphy of that part of southwest Arizona are reported in Eberly and Stanley (1978) and Rehrig and others (1980). The geology of the Big Horn and Belmont Mountains east of the study area was published by Capps and others (1985). A detailed study of the mineral deposits in metallic-mineral districts adjacent to the study area was published by Allen (1986).

The present work by the U.S. Geological Survey and the U.S. Bureau of Mines is reported upon jointly according to guidelines provided by Goudarzi (1984).

APPRAISAL OF IDENTIFIED RESOURCES

By Russell A. Schreiner, U.S. Bureau of Mines

Method of Investigation

Published and unpublished literature relating to the Big Horn Mountains Wilderness Study Area was reviewed to obtain information concerning mineral occurrences and mining activity. Mining-claim information, land-status maps, and oil- and gas-lease maps were acquired from the U.S. Bureau of Land Management State Office, Phoenix, Ariz.

A field investigation was conducted within the study area and about 1 mi outside its boundaries. Claims and prospects were surveyed by the compass and tape method, mapped, and sampled. Fifty-four rock samples were collected, of which 26 were within the study area. All samples were analyzed by fire assay for gold and silver. Inductively coupled argon plasma-atomic emission spectroscopy or atomic-absorption spectrophotometric methods were used to analyze for copper, lead, zinc, iron, and titanium in selected samples. At least one sample from each prospect was analyzed for 40 elements by semiquantitative optical-emission spectroscopy to determine if any unexpected elements were present. Assay results and sample descriptions appear in Schreiner (1985, table 1).

Mining History

The Big Horn Mountains Wilderness Study Area includes the Big Horn Mountains mining district. In the part of the district that was studied, only minor gold, silver, copper, iron, and agate prospecting has occurred since the late 1800's. Prospects located in and near the study area, as of March 1984, are shown in figure 2 and plate 1. As of March 1984, most of the study area was leased for oil and gas exploration. No production has occurred in the area.

Appraisal of Sites Examined

Claims, prospects, and occurrences of gold, silver, and copper in small fissure veins and pegmatites, iron (magnetite) in placers, and agate in cavity fillings are present in and near the study area. Prospects in and adjacent to the Big Horn Mountains Wilderness Study Area are discussed by commodity and host rock (that is, metamorphic rock, igneous rock, and alluvium).

Gold, Silver, and Copper Prospects

Gold, silver, and copper are present in veins in metamorphic and plutonic igneous rocks. Small sporadic occurrences of secondary copper minerals are present in quartz veins in the metamorphic rocks, in silicified pockets along faults, and in pegmatites in the plutonic rocks.

Gold, silver, and copper in quartz veins in metamorphic rocks occur predominantly on and near a group of patented claims (Copper Belt Nos. 1 and 2, Golden State Limited Nos. 1 and 2, and Lead Dome) about 0.25 mi outside the study area (Schreiner, 1985, pl. 1). On these claims, four shafts and several pits and trenches are located along a black, siliceous, north-striking vein containing fine-grained specular hematite, chrysocolla, and malachite. The vein could not be traced outside of the claim block because of alluvial cover. The owners of the patented claim could not be located to obtain permission to map and collect samples from the property.

Nearby quartz veins have been prospected by means of pits, trenches, and two shafts. Three of the prospects are located within the study area. The veins average 2.5 ft in thickness and consist of quartz and sheared wall rock with sporadic hematite staining. Chrysocolla and minor malachite occur as scattered blebs at some sites. Most of the veins are exposed in small pits and trenches, but in two areas, the veins have been explored by trenching as much as 200 ft along strike.

Twenty-four samples were collected from quartz veins in the metamorphic rocks (7 from prospects inside the study area). Eighteen of the 24 samples do not contain detectable gold; six samples (2 from the study area) contain gold concentrations above detection limits, with values as high as 0.32 oz/ton (Schreiner, 1985, table 1). Eleven samples (one from the study area) contain silver concentrations at or above detection limits, with values as high as 1.6 oz/ton. Copper concentrations significantly above detection limits are present in 11 of 24 samples (one from the study area); nine chip-sample values ranged from 79 parts per million (ppm) to 10,000 ppm, and two selected grab samples contained 2,000 and 46,000 ppm copper. Minor lead and zinc concentrations (46 to 280 ppm) are present in some samples. One select grab sample contains 3,200 ppm lead and 2,500 ppm zinc. Because of the sporadic, low concentrations of metals and the limited extent of the occurrences, no resources could be identified within the study area.

Occurrences of gold, silver, and copper in the granitic rocks have been prospected by means of two shafts (17 and 20 ft deep), pits, trenches, and bulldozer cuts in fault zones and pegmatite pods. Seven of these prospects, including the 17-foot shaft, are located within the study area. The Copper Gem, Silverhorn, Scorpion, Sidewinder, Blue, and Red Rock claim blocks cover these areas (Schreiner, 1985, pl. 1). A few blebs of chrysocolla and minor malachite and hematite staining are present in small isolated siliceous pockets along the faults (generally narrow shears) and in small pegmatite pods.

Twenty samples of the granitic rocks were collected (13 from prospects inside the wilderness study area). Eighteen of the 20 samples do not contain detectable gold, but two samples, both outside the study area, contain 0.01 oz/ton gold. Six samples (1 from the study area) have concentrations of silver above detection limits, with values as high as 0.7 oz/ton. Eighteen samples (11 from the study area) have copper concentrations above detection limits; 13 chip-sample values range from 51 ppm to 5,800 ppm, and six select-grab-sample values range from 13,000 ppm to 48,000 ppm.

Two areas within 0.5 mi of the study area contain prospects in alluvium (Saguaro claims) where a 150-ft-long trench and an 8-ft-deep partially caved shaft are present (Schreiner, 1985, pl. 1). These prospects are probably for placer gold, but no gold was detected in the samples collected by the Bureau of Mines during this study. In addition to these areas, a block of claims (Omega, Toni, Nita Wash, Luv, and Alpha claims) were located in alluvium in the eastern part of the study area (Schreiner, 1985, pl. 1). No evidence of any other prospecting was found.

Iron Prospect

The northern and northwestern parts of wilderness study area are covered by 2,600 acres of a 6,000-acre block of placer claims, the Magma and Iron Mac claims, staked for titaniferous magnetite (Schreiner, 1985, pl. 1). Deposits of titaniferous magnetite sand within alluvial stream beds, ranging in thickness from a few feet to more than 100 ft, is reported by Harrer (1964, p. 71). The only workings found are outside the study area and include several pits and trenches (1 to 3 ft deep) in the alluvium. No concentrations of magnetite sand were observed at the prospects. Concentrations of magnetite sand are present as irregular streaks in shallow sand washes in and near the study area. On the surface, the zones of magnetite-sand concentrations are as much as 50 ft long and 15 ft wide. Magnetite-sand occurrences are distributed widely over the alluvial plain, suggesting that the magnetite is derived from weathering of surrounding igneous and metamorphic rocks. The subsurface alluvial section was not exposed in or near the study area, and the distribution and amount of magnetite below the surface is not known.

Six samples of magnetite-bearing alluvium were collected along the northern boundary of the study area. The samples, which consisted of two 12-in. gold pans level full of sand, contained from 3.9 to 10.1 percent total soluble iron, and from 0.12 to 0.25 percent titanium; two samples contained 0.1 and 0.4 oz/ton silver (Schreiner, 1985, table 1). The average iron content of the surface samples is 6.6 percent, present predominantly as magnetite. This is equivalent to approximately 9 percent magnetite. These are high-grade samples and the average magnetite content of the sand probably is lower.

Although there are some concentrations of magnetite exposed at the surface, extensive mapping and sampling would be required to determine if a resource is present. As of March 1985, cement-plant and blast-furnace operators were buying magnetite concentrates (55- to 60-percent iron) for about $20/ton. The cost to mine, recover, and transport magnetite concentrates to buyers from this location would exceed $20/ton, so it is unlikely that this occurrence will be developed in the near future.

Fire Agate Prospects

Fire agate, the silicate chalcedony that contains layers of minute inclusions of geothite or limonite and produces an iridescent, fire-like play of colors when polished, is reported from three prospects (Rainbow and Big Horn claims) in the study area. Two of the prospects are in the northern part of the study area and one is located just outside the study area boundary on the southwest. White to brown chalcedony occurs as cavity fillings in the volcanic rocks; the fire-agate variety does not appear to be adundant. Claim holders reported that they had extracted high-quality fire agate from the two northern prospects. The workings at these three localities consist of small, shallow pits and trenches.

Oil and Gas

Although the Big Horn Mountains consist of metamorphic and igneous rocks, most of the acreage within the wilderness study area is leased for oil and gas (fig. 2). However, no drilling had occurred as of March 1984 (Richard Park, U.S. Bureau of Land Management, Phoenix District office, Phoenix, Ariz., oral commun., 1984). Tertiary sedimentary rocks and Quaternary sediments in the valleys adjoining the Big Horn Mountains would be the only host rocks where oil and gas could accumulate; however, no oil and gas resources have been identified in the study area.

Conclusions

Occurrences of gold, silver, and copper in small fissure veins and pegmatites, iron in placers, and agate as cavity fillings are present in and near the wilderness study area. The occurrences are small and too low grade to qualify as identified mineral resources.

Gold, silver, and copper occurrences in fissure-vein and pegmatite deposits occur in metamorphic and plutonic basement rocks in the northern half of the study area. Because these occurrences are sporadic, of limited extent, and contain only small concentrations of metals, no resources have been identified.

Iron magnetite is present in alluvium in the northern and northwestern part of the study area. These occurrences are small and of low grade. Production and transportation costs for this low-grade alluvial deposit would be high and development is unlikely.

Small amounts of fire agate occur sporadically as cavity fillings in the volcanic rocks. It may be of interest to individual collectors, but any large development of this material is unlikely.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Floyd Gray, R.J. Miller , J.R. Hassemer, William F. Hanna, and John C. Brice III
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Geology

Lithology

The Big Horn Mountains Wilderness Study Area, located in west-central Arizona (fig. 1), lies in the Sonoran Desert region of the Basin and Range physiographic province within a zone of north- to northwest-trending normal faults (Rehrig and others, 1980). Along this zone, large crustal blocks were downdropped to the west and tilted northeast during a period of active basin-and-range extensional deformation. The rocks of the study area consist of a Proterozoic metamorphic-plutonic basement complex intruded by Mesozoic (Laramide) plutons and unconformably overlain by a Miocene, essentially bimodal, basalt-rhyolite volcanic sequence that includes minor sedimentary rocks.

Basement outcrops in the wilderness study area are restricted to an upturned section in the northwestern part of the area and to low-lying hills and canyons along the eastern part of the area. The basement includes a complexly faulted sequence of gneiss, schist, and phyllite associated with foliated leucocratic granite. These rocks are intruded by coarse-grained quartz-monzonite porphyry and associated pegmatites that are locally tourmaline bearing. The quartz-monzonite porphyry is the most common basement unit and is intruded by Laramide monzonite and granodiorite that have affinity with the Wickenburg batholith (Rehrig and others, 1980). Potassium-argon ages (63 ± 1.9 and 68 ± 2 Ma) determined on biotite indicate a Cretaceous age for the granodiorite (R. J. Miller, unpub. data).

Basalt deposited unconformably on the basement complex forms the basal Miocene unit. Bedded cinder deposits, vent breccias, and reworked volcaniclastic sediments are locally present within the basal basalt; it is overlain by a unit of aphyric rhyolite flows, domes, and plugs. Aphyric rhyolite present in the southern half of the wilderness study area is commonly altered and hematite-stained near rhyolitic intrusive plugs and domes. The upper part of the rhyolite unit is dominated by porphyritic rhyolite flows containing biotite, hornblende, and feldspar phenocrysts. Overlying basalt flows are locally intercalated with the rhyolite and constitute the youngest volcanic unit within the study area. Just outside the study area, at Burnt Mountain, the basalt unit is dominated by laharic breccias, debris flows, and ash deposits intercalated with local thin basalt flow units.

Structure

Several large-displacement, high-angle normal faults exist along the eastern boundary of the study area. These faults are thought to be basin-and-range structures (Rehrig and others, 1980) and upper Tertiary megabreccia units are associated with them. The faults trend principally N. 30° W. and drop blocks down to the east. These faults penetrate to great depths and were perhaps conduits for circulating hydrothermal fluids.

Brecciation and Alteration

Brecciation and minor alteration are present in areas coincident with Tertiary fault/fracture systems and older quartz veins that are restricted to Proterozoic rocks. The Tertiary fault/fracture system may have served as a conduit for circulating hydrothermal fluids driven by proximal rhyolitic magmatism. The most intensely brecciated rock is found in zones approximately 60 ft wide consisting of a melange of oxidized basalt, rhyolite, and silicified Proterozoic greenstone and granitic fragments in a matrix of crushed rock and coarse black calcite. Secondary veinlets of white calcite also occur throughout the breccia. Fragmentation of the rocks decreases outward from the central brecciated zone; the entire zone is typically as much as 250 ft wide.

Small-scale displacement faults and fractures in Proterozoic metamorphosed granite, gneiss, and other metamorphic rocks are locally impregnated by hydrothermal-vein material. These veins are engulfed in 6-15-ft-wide zones stained irregularly by iron and manganese oxide.

In quartz monzonite of Early or Middle Proterozoic age, alteration includes widespread propylitically altered rock with irregular patches of argillic alteration.

In addition to vein-related alteration, limonite-stained and argillically altered rocks occur locally in and around rhyolite intrusions.

Geochemical Studies

Methods

In 1984 and 1985, the U.S. Geological Survey collected stream-sediment samples from 77 sites within the study area. Panned nonmagnetic heavy-mineral concentrates were prepared from a portion of the sediment sample collected at each of the sites.

Stream-sediment samples represent eroded material from within drainage basins. Chemical analyses of the minus-80-mesh and the panned-concentrate fractions of stream sediments were used to identify areas of mineral resource potential. The panned concentrate represents selectively concentrated minerals that may be related to metallization processes.

Samples were analyzed for 31 elements using a six-step semiquantitative emission-spectrographic method (Grimes and Marranzino, 1968); samples were analyzed for gold by an atomic-absorption method, and for uranium and thorium by the delayed neutron-counting method of Millard (1976). The sample sites and complete analytical results are included in Miller and others (1986). In this report, the geochemical interpretation is based on analytical data from heavy-mineral-concentrate, stream-sediment, and whole-rock samples. Seventeen of the 31 elements for which the samples were analyzed are indicative of possible hydrothermal alteration and (or) mineralization.

Anomalous geochemical values were determined by inspection of histograms, percentiles, and enrichment of elements relative to crustal abundance. Most often these anomalies reflect known mining activity, but in some instances they indicate the location of undisclosed or previously unrecognized metal concentrations. In general, the higher the analytical values from a sampling site, the more significant is that site (or drainage basin) in terms of mineral potential. In addition, sites characterized by suites of anomalous elements are considered to be more significant than sites characterized by a single-element anomaly.

Results and Interpretation

In this particular study, arsenic, barium, copper, gold, lead, molybdenum, silver, and zinc are typically associated with mineralized areas and altered zones in the Big Horn Mountains.

Metallic and nonmetallic elements present in anomalous amounts, and minerals identified from stream-sediment samples, indicate that base- and precious-metal (copper, lead, zinc, gold, and silver) epithermal mineralization has occurred in the wilderness study area. Changes in the character of the geochemical anomalies reflect variation in host-rock assemblages.

Linear north-northwest-trending mineralized zones characterized by multiple-element geochemical anomalies lie along the east-central boundary of the study area. The trace-element suite from stream-sediment samples (panned concentrates) that defines this zone consists of barium (5,000-10,000 ppm), lead (5,000- 50,000 ppm), molybdenum (50-500 ppm), silver (15-70 ppm), and zinc (1,000-1,500 ppm). These concentrates contain identified detrital galena, pyrite, barite, and sphalerite. The Scorpion Copper Belt, Golden State, Limited, and Lead Dome claims are located within this region (Schreiner, 1985, pl. 1); similar values were obtained from drainages downstream from prospects and from those drainages that did not include prospects. Grab samples collected from these zones contain anomalous concentrations of arsenic (6-25), barium (500-2,000 ppm), copper (500-700 ppm, with one sample greater than 20,000 ppm), silver (1.5-7 ppm), and zinc (200-400 ppm). Two areas located near the east and northwest boundary of the study area contain a slightly different geochemical-anomaly assemblage of barium, copper, molybdenum, and silver found in rock and panned-concentrate samples. This area is underlain by coarse-grained quartz monzonite. The Sidewinder, Blue and Red Rock, and Silverhorn claims are characteristic of this deposit type. Virtually all of the strongest clusters of anomalies are coincident with the high-angle normal faults or fault systems and the proximal older quartz veins.

Scattered geochemical anomalies whose patterns are similar to both of the basement-hosted anomalies described above occur locally in the southern part of the study area where there are Miocene rhyolitic volcanic rocks. Anomalous elements from these localities include arsenic, barium, lead, molybdenum, and zinc. In general, barium found as a single anomalous element is conspicuous throughout the eastern and southern parts of the study area.

Anomalous concentrations of thorium (700 to more than 5,000 ppm) in the coarse-grained quartz monzonite unit of the northern part of the study area are found in several samples. The anomalies cover the entire exposed area of this unit and may represent elevated background values for this Early and Middle Proterozoic granitic unit.

Geophysical Studies

The Big Horn Mountains Wilderness Study Area is covered by regional gravity (Lysonski and others, 1980a, b; Aiken and others, 1981) and magnetic (Sauck and Sumner, 1970; LKB Resources, Inc., 1980) surveys having sufficient resolution to define anomalies of several square kilometers in area. Contours of complete (terrain-corrected) Bouguer gravity anomalies are defined by about 60 observation points, most of them inside of or within a few kilometers of the study-area boundary. Contours of total-intensity magnetic anomalies are defined by 3 traverses flown 9,000 ft above sea level and 3 traverses flown 400 ft above terrain.

Lithologies exposed in the study area can be expected to have contrasting magnetic properties, both in remanent magnetization (commonly measured in paleomagnetic studies) (Calderone and Butler, 1984) and induced magnetization (or magnetic susceptibility) (Klein and Wynn, 1984), based on rock magnetic crust. Most regional (broad and high amplitude) magnetic anomalies appear to have total magnetizations (sum of remanent and induced magnetizations) that are normal, that is, of the same polarity and approximate direction as the ambient geomagnetic field, considering that polarization lows commonly occur northward of the magnetic highs.

Several high-gradient gravity features are present within or at the margin of the wilderness study area. A salient 20-milligal (mGal) gravity-high gradient, nosing northwestward parallel to the southwestern boundary of the study area, is associated with mapped Early or Middle Proterozoic quartz monzonite and Miocene rhyolite and basalt; it is inferred to be caused primarily by quartz monzonite underlying the less dense volcanic pile. A strong gradient, expressed by northwest-trending contour lines, traverses the central part of the study area along its longitudinal axis; this gradient is caused by a major lateral density contrast between quartz monzonite and low-density basin fill northeast of the study area. This gradient terminates at gravity minima in the basin, suggesting a thickness of at least 5,000 ft, based on the two-dimensional gravity modeling of Oppenheimer (1980). Similar modeling studies indicate that sediments filling the intermontane basin southwest of the study area are even thicker, perhaps about 7,000 ft thick. The gravity low over the basin northeast of the study area is broken by a conspicuous local 5-mGal high principally associated with high-density Early Proterozoic gneiss, metamorphosed granite, and schist.

The magnetic-anomaly map is dominated by a broad high that covers the western half of the study area. This high may be caused by buried Proterozoic intermediate plutonic rocks extending continuously beneath rhyolitic and basaltic cover between and beyond exposed tracts of quartz monzonite in the northwest part of the study area. Two other magnetic highs trending northward near the eastern margin of the study area (LKB Resources, Inc., 1980) are presumably caused by similar intermediate plutonic rocks underlying alluvium and rhyolitic cover.

Because a large number of local occurrences of Tertiary intrusive rocks in the Basin and Range province in Arizona are associated with the flanks of regional magnetic highs, we cannot dismiss the possibility that the broad magnetic high in the study area is caused primarily by Tertiary, rather than Proterozoic, intermediate plutonic rocks. If Tertiary plutonism is manifested by the anomaly, then this magnetic feature could directly or indirectly point to mineralization associated with metamorphic core complexes (Crittenden and others, 1980; Coney and Reynolds, 1980) and Tertiary detachment faults (Spencer and Welty, 1986). However, apart from the possibility of hidden Tertiary intrusive rocks, the available regional geophysical data do not delineate terranes of high mineral resource potential.

Summary of Mineralization and Resource Features

Field and geochemical data indicate that weak epithermal vein-type mineralization occurred in the Big Horn Mountains Wilderness Study Area. This mineralization was strictly controlled by at least two major high-angle faults located on the eastern side of the study area and one on the outlying northwestern part of the study area.

Base- and precious-metal (copper, lead, zinc, gold, and silver) mineralization that occurred in zones controlled by faults and (or) fractures offers the greatest mineral resource potential in the study area. Vein-mineral assemblages and several types of alteration appear to have been generated by mineralizing fluids at various degrees of equilibration with host rocks. Faults cutting Miocene basaltic rocks are marked by irregular zones of breccia stained by iron and manganese oxides and cemented by black calcite. The zones are irregular, approximately 10 to 20 ft wide, and can be traced as far as a 100 ft along strike. Lithic fragments within these local mineralization zones are deeply oxidized and are coated with manganese and hematite.

Faults cutting Early Proterozoic metamorphosed granite and gneiss form narrow fractures typically filled with assemblages consisting of quartz, iron oxide, chrysocolla, azurite, malachite, fluorite, and calcite (Allen, 1986). Comparison between gangue minerals and metal suites within the Osborne District, several miles northeast of the study area, suggests that, at that locality, quartz gangue with or without fluorite correlates with gold-silver-copper-lead-zinc mineralization, and that black-calcite gangue with or without quartz correlates with silver-lead mineralization (Allen, 1986). Faults and veins associated with the Early or Middle Proterozoic quartz monzonite typically display irregular patches of bleaching with quartz veins containing copper oxide in argillic-alteration zones as much as 100 ft wide. Although Late Cretaceous and early Tertiary(?) biotite hornblende granodiorite appears to intrude country rock near the high-angle faulting, the main stage of mineralization is considered to be Middle Tertiary. Mobilization of the anomalous elements occurred on a regional scale at relatively low temperatures (between 190-240°C), based on fluid-inclusion homogenization temperatures from nearby deposits (see Allen, 1986). The mineralization model calls for a hydrothermal system driven by local emplacement of high-level rhyolitic intrusions. Pre-existing faults and shear zones in the host rocks probably acted as conduits for the hydrothermal solutions and, subsequently, as sites of mineral deposition. Fluids with high concentrations of CO_2 were mobilized, equilibrated with country rocks, and, during the thermal cooling of the system, deposited base and precious metals in fractures and faults in response to cooling and dilation (Allen, 1986; see also Berger and Cox, 1983).

When assessing the potential for undiscovered resources within these mineralized areas, it is useful to look at the production and tonnage figures from nearby districts in order to gauge the potential size and extent of undiscovered resources in the study area. The size of deposits expected to be found in the Big Horn Mountains Wilderness Study Area should fall within the size range exhibited by these known local deposits. In fact, surface evidence, including low threshold values of geochemical anomalies, degree and extent of alteration, and relative lack of visible ore minerals suggests that the types of deposits one would expect to find in the study area would be at the smaller end of the size range of these known deposits.

The Osborne district contains approximately twenty precious- and base-metal occurrences and produced 1,369,000 lb of copper, 7,710,000 lb of lead, 500 lb of zinc, 13,000 oz of gold, and 195,000 oz of silver (Keith and others, 1983). The Tonopah-Belmont mine, one of the larger mines in the district, has recorded production of 1 million lb of copper, 150,000 oz of silver, and 8,500 oz of gold. The Scott mine has reported production from 1942 through 1949 to be approximately 12,000 lb of lead, 500 lb of zinc, and 100 oz of silver. Within the Big Horn district, production from gold quartz veins is reported as 2,800 oz of gold, 1,000 oz of silver, 26,300 lb of copper, and 6,000 lb of lead (Keith and others, 1983). Mines with significant past production located in the district consist of the El Tigre (2,300 oz of gold, 150 oz of silver, and 700 lb of copper) and the Pump or Purple Pansey (200 oz gold, 50 oz silver, 150 lb copper). Most of the mines and prospects in these districts, however, consist of only small workings and had virtually no production. Data suggest that the smaller deposits in the districts have mineralization features similar to those inside the Big Horn Mountains Wilderness Study Area.

CONCLUSION

Geologic studies, geochemical sampling, and an examination of mines and prospects indicate that the Big Horn Mountains Wilderness Study Area lies within a province characterized by hydrothermal vein deposits that contain trace amounts of copper, gold, lead, silver, and zinc.

Anomalous values of base and precious metals (copper, lead, zinc, gold, and silver) in pan concentrates and rock samples from alteration zones associated with vein and fracture systems constitute the most significant type of occurrence in the study area. In the eastern part of the study area, silver, trace amounts of gold, and anomalous amounts of the base metals copper, lead, and zinc are found in rock and stream-sediment (pan-concentrate) samples. Clearly defined alteration zones along Tertiary north-northwest-trending high-angle faults and older east-trending quartz veins in the eastern part of the study area have been explored by a number of prospects in Early Proterozoic metamorphosed granite and gneiss and in Miocene basalt. Terrane along the eastern margin of the study area (fig. 2) has moderate to low resource potential, certainty level C (see appendix 1 for definitions of levels of mineral resource potential and levels of certainty) for undiscovered gold, silver, copper, lead, and zinc.

Hydrothermal mineralization (also fault controlled) occurs in Early or Middle Proterozoic coarse-grained quartz monzonite in two areas inside the wilderness study area (due north and northwest of Big Horn Peak). These areas contain gold-, silver-, and copper-bearing quartz veins and fractures. The alteration associated with this deposit type is of a very limited extent, and only slightly anomalous concentrations are displayed in the sample media. The areas have low potential for undiscovered copper, gold, and silver resources, with certainty level C. Geochemical anomalies located in the southern part of the area that are associated with rhyolite plugs are assigned a low potential for undiscovered resources of copper, lead, zinc, gold, and silver with a certainty level of C.

Traces of agate were seen in isolated rhyolite flows. A low potential for undiscovered agate resources, with a certainty level of C, is assigned.

Geothermal potential for the study area is low with a C level of certainty. Information derived from a nearby well (Bliss, 1983) indicates that local water temperatures are normal for this part of the Basin and Range province; the existence of a geothermal resource is therefore considered unlikely.

Geologic data indicate a low probability for the occurrence of oil and gas due to the predominance of granitic bedrock and scarcity of traditional hydrocarbon-bearing lithologies.

REFERENCES CITED

Aiken, C.L.V., Lysonski, J.C., Sumner, J.S., and Hahman, W.R., 1981, A series of 1:250,000 complete residual Bouguer gravity anomaly maps of Arizona: Arizona Geological Society Digest, v. 13, p. 31-37.

Allen, G.B., 1986, Economic geology of the Big Horn Mountains west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-17, 140 p.

Berger, B.R., Cox, D.P., ed., 1983, Epithermal gold, silver: model 5:4 in U.S. Geological Survey-Ingeominas Mineral Resource Assessment of Colombia: Ore Deposit Models: U.S. Geological Survey Open-File Report 83-423, p. 39.

Bliss, J.D., 1983, Arizona: basic data for thermal springs and wells as recorded in Geotherm: U.S. Geological Survey Open-File Report 83-427, 200 p.

Calderone, Gary, and Butler, R.F., 1984, Paleomagnetism of Miocene volcanic rocks from southwestern Arizona: Tectonic implications: Geology, v. 12, no. 10, p. 627-630.

Capps, Richard, Reynolds, C., Kortemeier, S.J., Curtis, P., Stimae, J.A., Scott, E. A., Allen, G. B., 1985, Preliminary geologic map of the eastern Big Horn and Belmont Mountains, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-14, 25 p.

Coney, P.J., and Reynolds, S.J., 1980, Cordilleran metamorphic core complexes and their uranium favorability: Final report: Laboratory of Geotectonics, Department of Geosciences, University of Arizona, Tucson, v. 2, 627 p.

Crittenden, M.D., Coney, P.J., and Davis, G.H., eds., 1980, Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, 490 p.

Dobrin, M.B., 1976, Introduction to geophysical prospecting: New York McGraw Hill, Inc., 630 p.

Eberly, L.D., and Stantley, T.B., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v. 89, p. 921-940.

Goudarzi, G.H., Compiler, 1984, Guide to preparation of Mineral Survey Reports on Public Lands: U.S. Geological Survey Open-File Report 84-787, 42 p.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analyses of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Harrer, C.M., 1964, Reconnaissance of iron resources in Arizona: U.S. Bureau of Mines Information Circular 8236, 204 p.

Keith, S.B., Gest, D.E., Dewitt, E., Woode-Toll, N., and Everson, B.A., 1983, Metallic mineral districts and production in Arizona: Arizona Bureau of Geology and Mineral Technology Bulletin 194, 58 p.

Klein, D.P., and Wynn, J.C., 1984, Density porosity and magnetic susceptibility of rocks from the Silver City 1° by 2° quadrangle, Arizona and New Mexico: U.S. Geological Survey Open-File Report 84-017, 11 p.

LKB Resources, Inc., 1980, National Uranium Resource Evaluation aerial gamma-ray and magnetic reconnaissance survey, Colorado/Arizona area, Salton Sea, El Centro, Phoenix, Ajo, and Lukeville quadrangles—Final Report: U.S. Department of Energy Grand Junction Office Report GJBX 12-80, v. 2.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980a, Complete residual Bouguer gravity anomaly map of Arizona: Arizona Bureau of Geology and Mineral Technology, Tucson, scale 1:500,000.

_____1980b, The complete residual Bouguer gravity anomaly map of Arizona (ISGN 71): Laboratory of Geophysics, Department of Geoscience, University of Arizona, Tucson, scales 1:500,000 and 1:1,000,000.

Millard, H.T., Jr., 1976, Determination of uranium and thorium in U.S. Geological Survey standard rocks by the delayed-neutron technique: U.S. Geological Survey Professional Paper 840, p. 61-65.

Miller, R.J., Gray, F., Hassemer, J., Detra, D.E., Briggs, P.H., and Brice, J., III., 1986, Analytical results and sample locality maps of stream-sediment heavy-mineral concentrate and rock samples from the Big Horn Mountains Wilderness Study Area (AZ-020-099), Maricopa County, Arizona: U.S. Geological Survey Open-File Report 86-184, 27 p.

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, unpublished Master's thesis (this is the stated reference for the following publications: (1) Oppenheimer, J.M., and Sumner, J.S., 1980, Depth-to-bedrock map, Basin and Range province, Arizona, Tucson, scale 1:500,000; (2) Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115).

Rehrig, W.A., Shafiquallah, M., and Damon, P.E., 1980, Geochronology, geology and listric normal faulting of the Vulture Mountains, Maricopa County, Arizona: Arizona Geological Society Digest, v. 12, p. 89-110.

Ryder, R.T., 1983, Petroleum potential of wilderness lands in Arizona, in Miller, B.M., ed., Petroleum potential of wilderness lands in the western United States: U.S. Geological Survey Circular 902-C, p. C1-C22.

Sauck, W.A., and Sumner, J.S., 1970, Residual aeromagnetic map of Arizona: Tucson, Arizona, The University of Arizona, Department of Geosciences, scale 1:1,000,000.

Schreiner, R.A., 1985, Mineral Resources of the Big Horn Mountains Wilderness Study Area, Maricopa County, Arizona: U.S. Bureau of Mines Mineral Land Assessment Open-File Report MLA 44-85, 28 p.

Spencer, J.E., and Welty, J.W., 1986, Possible controls of base- and precious-metal mineralization associated with Tertiary detachment faults in the lower Colorado River trough, Arizona and California: Geology, v. 14, no. 3, p. 195-198.

Wilson, E.D., Moore, R.T., and Pierce, H.W., 1957, Geologic Map of Maricopa County, Arizona: Arizona Bureau of Mines, scale 1:375,000.

Wilson, E.D., Moore, R.T., and Cooper, J.R., compilers, 1969, Geologic map of Arizona: Arizona Bureau of Mines and U.S. Geological Survey, scale 1:500,000.

Witcher, J.C., 1981, Thermal springs of Arizona: Fieldnotes, v. 11, no. 2.

APPENDIX 1. Definition of levels of mineral resource potential and certainty of assessment

Mineral resource potential is defined as the likelihood of the presence of mineral resources in a defined area; it is not a measure of the amount of resources or their profitability.

Mineral resources are concentrations of naturally occurring solid, liquid, or gaseous materials in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Low mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment where the existence of resources is unlikely. This level of potential embraces areas of dispersed mineralized rock as well as areas having few or no indications of mineralization. Assignment of low potential requires specific positive knowledge; it is not used as a catchall for areas where adequate data are lacking.

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 a reasonable chance for resource accumulation, and where an application of genetic and (or) occurrence models indicates favorable ground.

High mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resources, where interpretations of data indicate a high likelihood for resource accumulation, where data support occurrence and (or) genetic models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential requires positive knowledge that resource-forming processes have been active in at least part of the area; it does not require that occurrences or deposits be identified.

Unknown mineral resource potential is assigned to areas where the level of knowledge is so inadequate that classification of the area as high, moderate, or low would be misleading. The phrase "no mineral resource potential" applies only to a specific resource type in a well-defined area. This phrase is not used if there is the slightest possibility of resource occurrence; it is not appropriate as the summary rating for any area.

Expression of the certainty of the mineral resource assessment incorporates a consideration of (1) the adequacy of the geologic, geochemical, geophysical, and resource data base available at the time of the assessment, (2) the adequacy of the occurrence or the genetic model used as the basis for a specific evaluation, and (3) an evaluation of the likelihood that the expected mineral endowment of the area is, or could be, economically extractable.

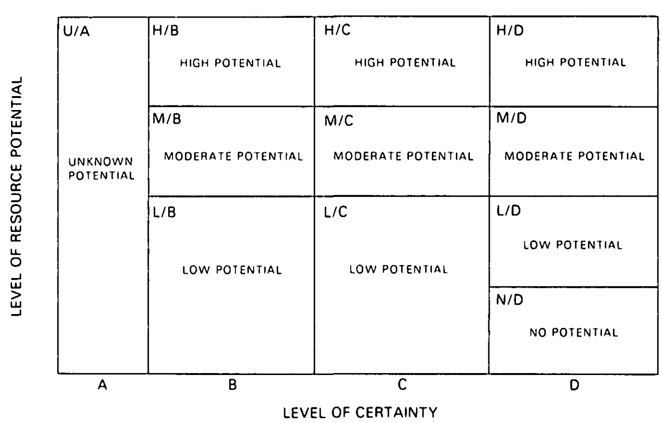
Levels of certainty of assessment are denoted by letters, A-D.

A. The available data are not adequate to determine the level of mineral resource potential. Level A is used with an assignment of unknown mineral resource potential.

B. The available data are adequate to suggest the geologic environment and the level of mineral resource potential, but either evidence is insufficient to establish precisely the likelihood of resource occurrence, or occurrence and (or) genetic models are not known well enough for predictive resource assessment.

C. The available data give a good indication of the geologic environment and the level of mineral resource potential, but additional evidence is needed to establish precisely the likelihood of resource occurrence, the activity of resource-forming processes, or available occurrence and (or) genetic models are minimal for predictive applications.

D. The available data clearly define the geologic environment and the level of mineral resource potential, and indicate the activity of resource-forming processes. Key evidence to interpret the presence or absence of specified types of resources is available, and occurrence and (or) genetic models are adequate for predictive resource assessment.



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 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	~570[1]
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.

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