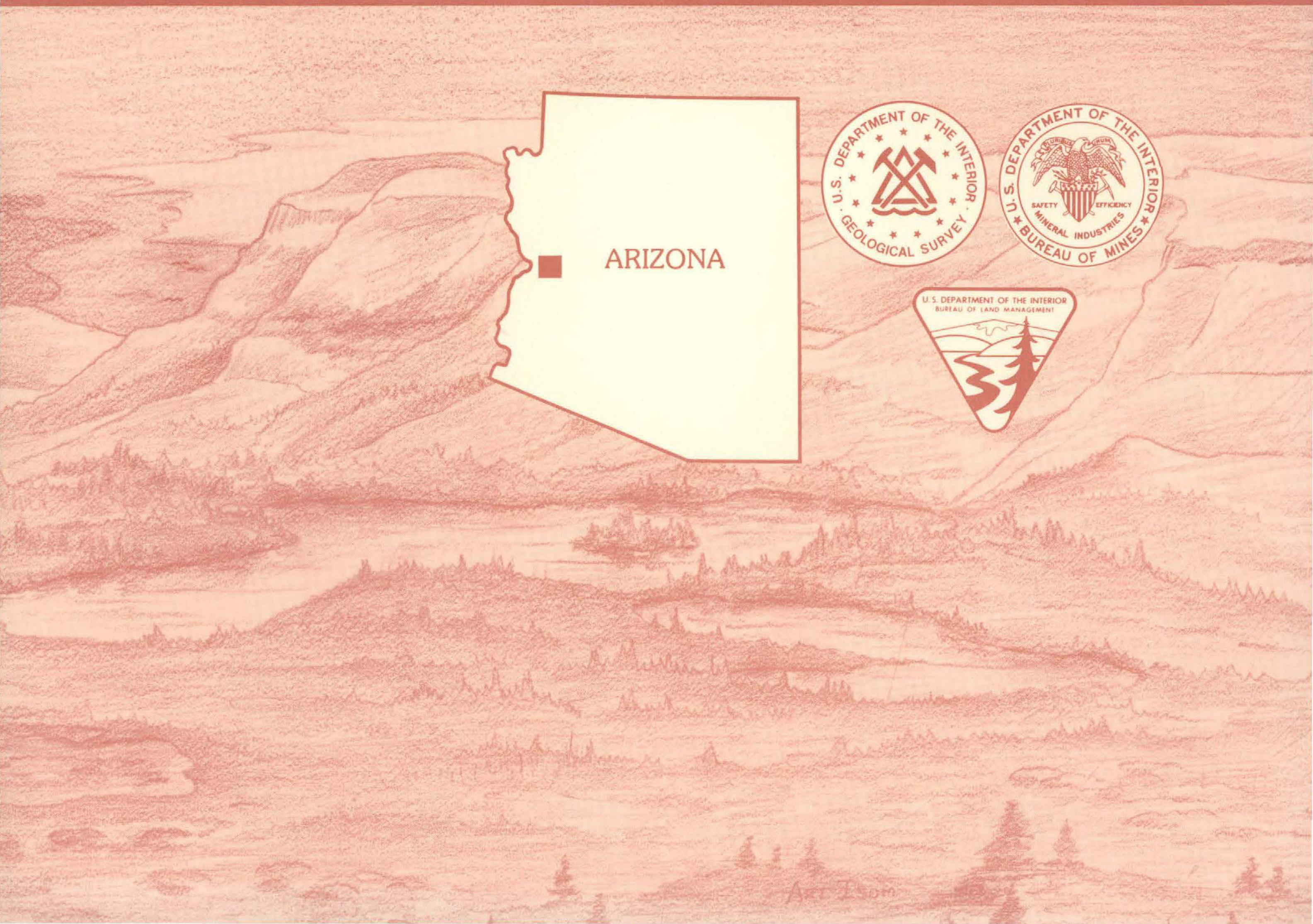
Mineral Resources of the Aubrey Peak Wilderness Study Area, Mohave County, Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1701–D



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Chapter D

Mineral Resources of the Aubrey Peak Wilderness Study Area, Mohave County, Arizona

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U.S. Geological Survey

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U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1701
MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
WEST-CENTRAL ARIZONA

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1989

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Mineral resources of the Aubrey Peak Wilderness Study Area, Mohave County, Arizona / James G. Evans . . . [et al.]
p. cm. — (Mineral resources of wilderness study areas—west-central Arizona and part of San Bernardino County, California ; ch. D)(U.S. Geological Survey bulletin ; 1701-D)
Bibliography: p.
Supt. of Docs. no. : I 19.3:1701-D
1. Mines and mineral resources—Arizona—Aubrey Peak Wilderness.
2. Aubrey Peak Wilderness (Ariz.) I. Evans, James George, 1938- .
II. Series: U.S. Geological Survey bulletin ; 1701-D.

QE75.B9 no. 1701-D	557.3s—dc20	89-600143
[TN24.A6]	[553'.09791'59]	CIP

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 the Aubrey Peak Wilderness Study Area (AZ–020–054), Mohave County, Arizona.

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Mineral Resources of the Aubrey Peak Wilderness Study Area, Mohave County, Arizona

By James G. Evans, Randall H. Hill, William F. Hanna, *and* Daniel H. Knepper
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Michael E. Lane
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SUMMARY

Abstract

At the request of the Bureau of Land Management, the Aubrey Peak Wilderness Study Area, comprising approximately 16,550 acres, was evaluated for mineral resources and mineral resource potential. Throughout this report, "wilderness study area" and "study area" refer to the 16,550 acres for which a mineral survey was requested. The U.S. Geological Survey and the U.S. Bureau of Mines conducted geologic, geochemical, and geophysical surveys to assess the identified mineral resources (known) and mineral resource potential (undiscovered) of the study area. Fieldwork for this report was carried out in 1987 and 1988. Prospecting has occurred in and near the study area, and several adits and a mine shaft are present; there was no mining activity at the time of this investigation. Inferred subeconomic silver resources of 14,000 short tons (st), averaging 6.38 oz (troy)/st, and inferred subeconomic gold resources of 400 st, averaging 0.075 oz/st, exist in the study area. A low-grade perlite demonstrated subeconomic resource of 15 million st is present in the study area. Three areas in the northwestern, northeastern, and southeastern parts of the study area have low resource potential for silver and barium; a small part of the southeastern area with low potential for silver and barium also has low potential for undiscovered gold resources. Areas in the southwestern, southestern, and north-central parts of the study area and an area along the eastern boundary have low mineral resource potential for undiscovered barium. The study area contains sand and gravel deposits that are not economic, largely because of distance from markets. The entire study area has low resource potential for oil and gas. The study area has no potential for geothermal resources.

Character and Setting

The Aubrey Peak Wilderness Study Area is located near Lake Havasu and is 27 mi east of Lake Havasu City, Arizona (fig. 1). The study area has a total relief of 1,500 ft and consists mostly of hills and washes; it contains a few steep ridges and canyons that are cut to depths of as much as 500 ft. The study area is underlain by a Precambrian granite and gneiss rock unit that is partly covered by volcanic, volcaniclastic, and sedimentary rocks of Miocene and early Pliocene age and by Holocene sand and gravel deposits (fig. 2) (see "appendixes" for geologic time chart). Numerous minor faults cut the rocks of the study area. The entire study area is in the upper plate of the regional Rawhide detachment fault of Miocene age.

Manuscript approved for publication, May 10, 1989.

Identified Resources

Approximately 14,000 st of inferred subeconomic silver resources was identified in the study area. Of this amount, 4,000 st averages 10.03 oz/st, 7,000 st averages 4.44 oz/st, and 3,000 st averages 6.02 oz/st. An inferred subeconomic gold resource of about 400 st averages 0.075 oz/st. A low-grade demonstrated subeconomic perlite resource of about 15 million st was identified. About one-third of the study area is covered by oil and gas leases, but no drilling has been done.

Mineral Resource Potential

Three areas in the northwestern, northeastern, and southeastern parts of the Aubrey Peak Wilderness Study Area have low resource potential for silver and barium; these commodities are associated with weak hydrothermal alteration of Precambrian granite and Miocene arkose, conglomerate, and sedimentary breccia. A smaller area within the southeastern part of the study area with low potential for silver and barium also has low potential for gold in Precambrian rocks. There are four areas of low resource potential for barium in the study area; three of them are adjacent to areas of low silver and barium resource potential. Barium may also be present in unaltered Miocene clastic rocks that may contain authigenic barite, although no such barite was observed during this study. The entire study area has low energy resource potential for oil and gas. There is no resource potential for geothermal energy.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is the result of a cooperative 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 a system that is a modification of that described by McKelvey (1972) and U.S. Bureau of Mines and U.S. Geological Survey (1980). U.S. Geological Survey studies are designed to provide a 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. Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. See "appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Area Description

The Aubrey Peak Wilderness Study Area (AZ–020–054) covers approximately 16,550 acres in the desert highlands east of Lake Havasu City, Arizona (fig. 1). The terrain of the study area is rugged, rising from about 1,600 ft at the south end to 3,132 ft at an unnamed peak in the west-central part. The hills and sharp ridges

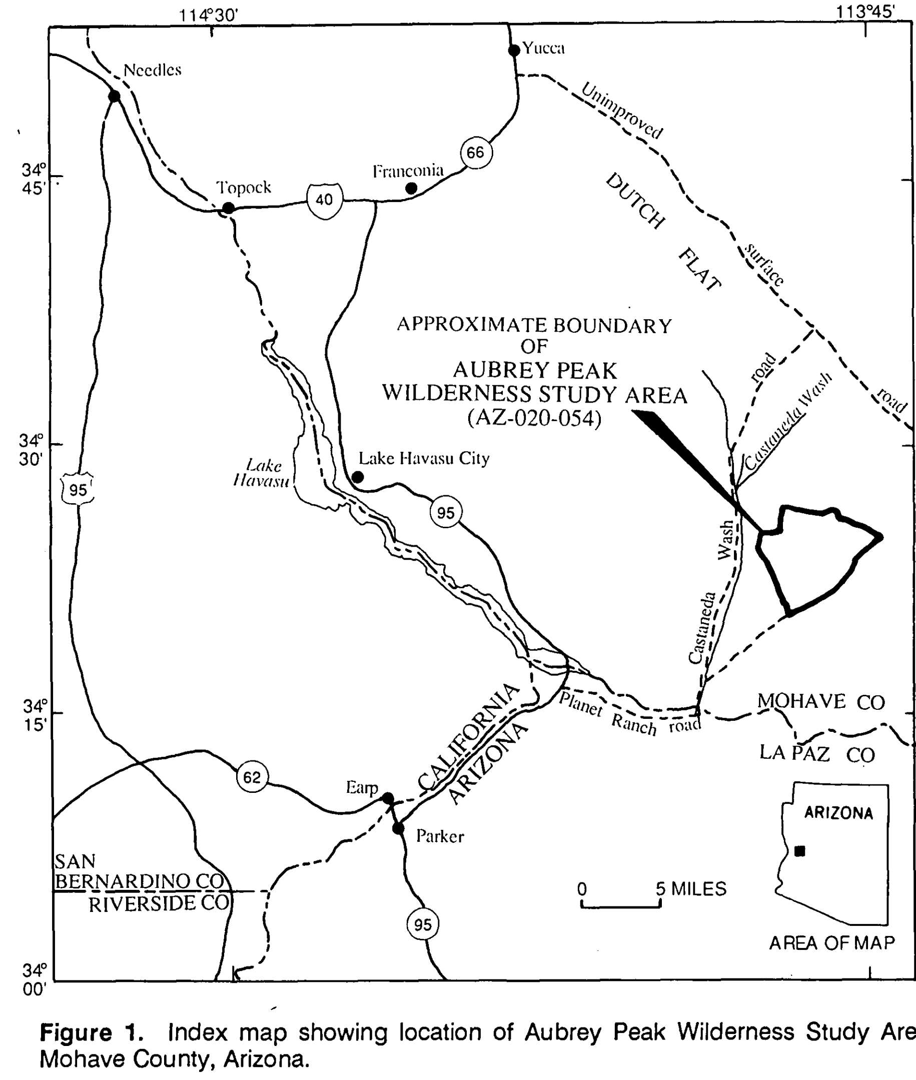

Figure 1. Index map showing location of Aubrey Peak Wilderness Study Area, Mohave County, Arizona.

are cut by broad sandy washes and steep rocky canyons as much as 500 ft deep. Although arid, the study area supports a variety of desert plants including native grasses, creosotebush, ocotillo, cactuses (several varieties ranging in size from small barrel cactus to saguaro as tall as 20 ft), and desert trees (ironwood, smoketree, cat-claw acacia, mesquite, and paloverde). Numerous species of birds, small mammals, and reptiles including several species of lizards, desert tortoises, and four species of rattlesnakes inhabit the study area.

The study area is accessible from a gravel road along Castaneda Wash (fig. 1). This road connects with Arizona Highway 95 by way of Planet Ranch road (gravel) on the south, and it connects with Interstate 40 by way of a gravel road across Dutch Flat on the north. Dirt roads and jeep trails follow the boundary of the study area.

Previous and Present Investigations

Bancroft (1911), in his report on ore deposits in northern Yuma County (now called La Paz County), included the McCracken mine about 1 mi north of the study area in southern Mohave County. The study area is included in the geologic map of Mohave County by Wilson and Moore (1959) and in the geologic map of the Castaneda Hills 15-minute quadrangle by N.H. Suneson and Ivo Lucchitta (unpub. data, 1980). Suneson and Lucchitta also studied the volcanism and tectonism of the region (Lucchitta and Suneson, 1977a, b; 1979; Suneson, 1980; Suneson and Lucchitta, 1978, 1979, 1983).

The U.S. Geological Survey conducted field investigations in the study area during 1987. This work included geological reconnaissance and geochemical sampling. Samples of the Precambrian rocks were collected for petrographic analysis. Geochemical data were obtained from 40 stream-sediment samples, 40 heavy-mineral-concentrate samples, and 59 rock samples (R.H. Hill, unpub. data, 1988).

The U.S. Bureau of Mines spent 10 days in 1987 examining surface and accessible underground workings (Lane, 1988). Seventy-seven rock samples were collected; 62 of these samples were from within the study area and 15 samples were from sites less than 0.5 mi outside the study area.

APPRAISAL OF IDENTIFIED RESOURCES

By Michael E. Lane
U.S. Bureau of Mines

Methods

Prior to the field investigation, U.S. Bureau of Mines' geologists reviewed literature on mining and geology of the region. In addition, Bureau of Land Management records were reviewed for mining-claim information and oil and gas leases and lease applications. Surface and accessible underground workings were surveyed by compass and tape, mapped, and sampled. A total of 77 samples was taken; 62 were from within the study area. Chip samples were taken at workings and perlite outcrops, and grab samples were taken of dump material. All but the perlite samples were analyzed by neutron activation for 34 elements including gold and silver. In addition, 6 samples were analyzed for gold by fire assay, 6 samples were analyzed for zinc by atomic absorption, 1 sample was analyzed for manganese by atomic absorption, 35 samples were analyzed for barium by X-ray diffraction and gravimetric methods, and 7 samples were analyzed for fluorine by distillation. These analyses were done by Bondar-Clegg and Company, Ltd., Denver, Colo. Perlite samples were analyzed by the Perlite Corp., Chester, Penn. Complete analytical data for all samples are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Mining History

No production records for the study area were found. There are no patented claims in the study area; however, three blocks of unpatented claims are located in the study area near and along the southeast boundary. Approximately one-third of the wilderness study area is covered by oil and gas leases, but no drilling for oil or gas has taken place in the study area.

The McCracken mine, about 1 mi north of the study area, is a lead-silver mine that was discovered in 1874 (Arizona Bureau of Geology and Mineral Technology, unpub. data, 1987). The ore at the mine occurs in four prominent north-striking veins 6 to 30 ft wide and at least 750 ft deep. One vein was reported by Bancroft (1911, p. 125) to extend 2 mi south of McCracken Mountain, but no structure could be traced beyond the mine area during the present study because the rocks are covered by alluvium. No veins or mineralized fault zones were seen at the surface during an aerial reconnaissance.

Production in the McCracken district was intermittent from 1875 until 1985 when the mine was shut down due to low silver prices. Between 1911 and 1981, 10,000 pounds (lbs) of copper, 3,031,000 lbs of lead, 43,000 lbs of zinc, 100 lbs of molybdenum, 100 troy ounces (oz) of gold, and 699,000 oz of silver were produced at the McCracken mine (Keith and others, 1983, p. 36–37). In 1980 alone, about 60,000 st of ore averaging 3.5 oz/st of silver was produced at the McCracken mine. In 1984, about 30,000 st of ore averaging 12 oz/st of silver was produced (Corwin Coe, Arizona Silver Corp., oral commun., 1987).

The mining districts near the study area are described by Farnham and Stewart (1958, p. 52, 53). Production data are from Keith and others (1983, p. 36–40). The Castaneda mining district is adjacent to the west boundary of the study area and was established by claims located in 1953; no workings of that district were found to extend into or near the study area. Only a small quantity of manganese that was hand-picked from float was produced in this district. The Owens and Mesa mining districts are about 6 mi south of the wilderness study area. Production in the Owens district between 1921 and 1956 was 63,000 lbs of lead, 100 oz of gold, 10,000 oz of silver, and 3,000 lbs of copper from veins in schistose diorite and pegmatite. Production in the Mesa

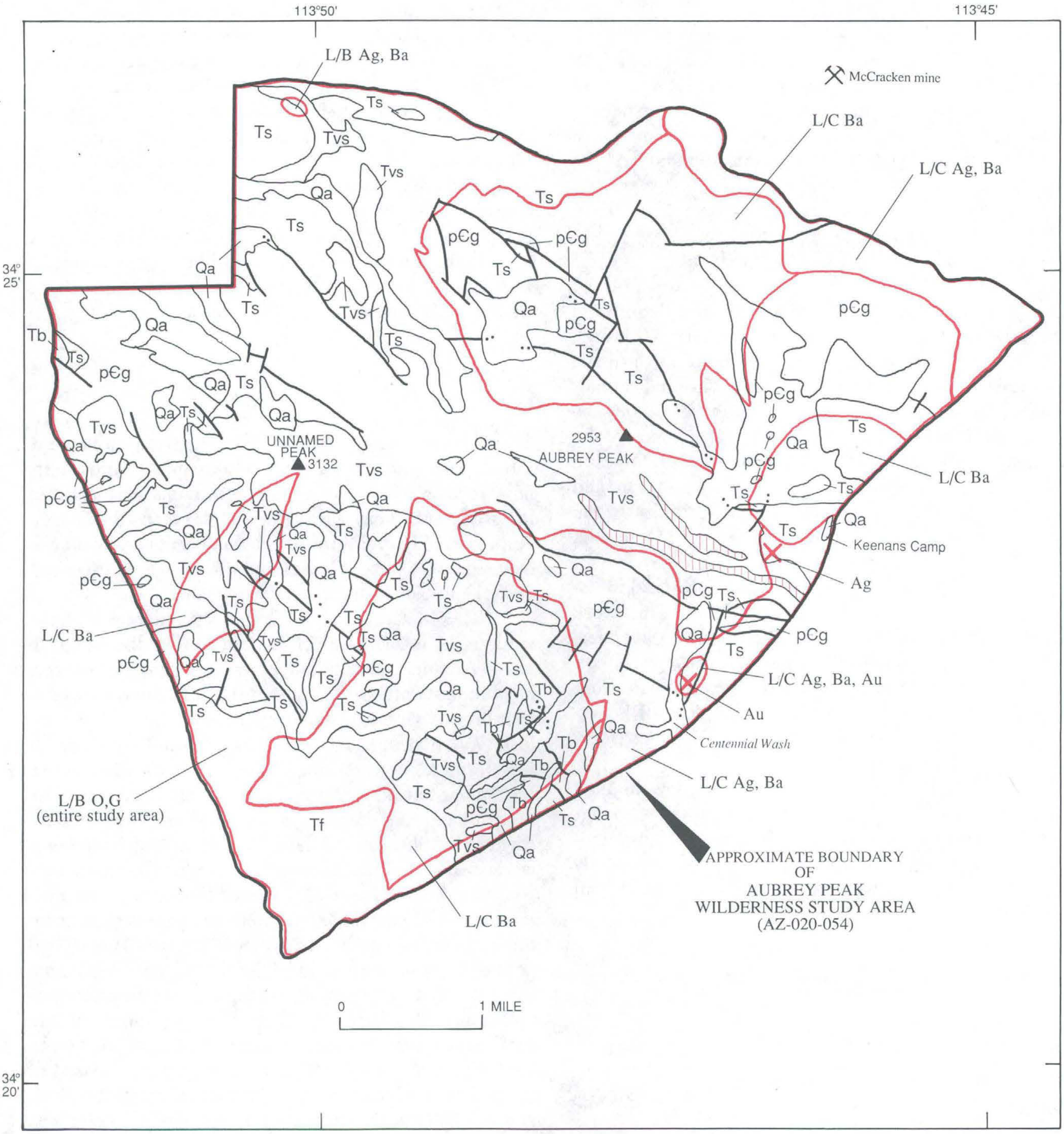

Figure 2. Mineral resource potential, identified resources, and generalized geology of Aubrey Peak Wilderness Study Area, Mohave County, Arizona. Geology modified from N.H. Suneson and Ivo Lucchitta (unpub. data, 1980).

district in 1954 was between 40,000 and 80,000 st of manganese ore from fractures in Paleozoic limestone and bedded manganese deposits in Tertiary sandstone.

Appraisal of Sites Examined

Thirty-three pits, 4 short adits, and 1 shallow shaft inside the study area were sampled (Lane, 1988). Most of the workings are concentrated near Keenans Camp and along Centennial Wash near the southeast boundary of the area; three are near the northeast boundary. No information was found to indicate when the pits, adits, and shaft were worked.

The veins sampled in the study area are similar in composition to those at the McCracken mine; they contain quartz, barite, calcite, and minor amounts of fluorite. These veins are not traceable beyond the vicinity of the workings, and it is not known if the veins in the study area are related to the veins at the McCracken mine.

EXPLANATION

Area of low mineral resource potential (L)

Levels of certainty of assessment
- B — Data only suggest level of potential
- C — Data give good indication of level of potential

Commodities
- Ag — Silver
- Au — Gold
- Ba — Barium
- O,G — Oil and gas

Identified resources
- X — Workings having inferred subeconomic gold or silver resources—See text for amount and grade
- Outcrops of perlite—See text for amount and grade

Geologic map units
- Qa — Alluvium (Quaternary)
- Tf — Fanglomerate (Pliocene or upper Miocene)
- Tb — Basalt (upper Miocene)
- Tvs — Volcanic, volcaniclastic, and sedimentary rocks (middle Miocene)
- Ts — Sedimentary rocks (middle to lower Miocene)—Arkose, conglomerate, and sedimentary breccia
- p-Ꞓg — Granite and gneiss (Precambrian)

Contact

Fault—Dotted where concealed

Figure 2. Continued.

Gold concentrations in excess of 0.01 oz/st were found in 13 of the 20 samples taken at a cluster of workings along Centennial Wash within the study area (fig. 2). The samples are from fracture zones and veins in volcanic breccia, conglomerate, schist, diorite, and altered granite; their gold content ranges from 16 parts per billion (ppb) to 12 parts per million (ppm).

An inferred subeconomic gold resource of about 400 st of material averaging 0.075 oz/st was estimated for rock in two short adits (Lane, 1988). The estimate was based on an assumed length of 47 ft, width of 25 ft, average sample width of 3.74 ft, and a tonnage factor of 12 cubic feet per short ton (ft^3/st). Trace amounts of gold (3.13 ppm or 0.1 oz/st) were found in two samples in the study area southwest of Centennial Wash, but no resources could be estimated at this site because of the limited exposure of mineralized rock. Subsurface sampling is necessary to determine if gold continues at depth (Lane, 1988, p. 7).

Silver is contained in 23 of the 25 samples taken at workings near Keenans Camp (fig. 2). The samples are from veins of calcite and barite containing minor amounts of quartz and hematite in arkose. The silver content of the samples ranges from 0.8 to 636 ppm (0.026 to 18.6 oz/st). Fifteen samples contain silver in excess of 2 oz/st. Inferred subeconomic silver resources were estimated using a tonnage factor of 12 ft^3/st and a width of 50 ft. Different lengths and average sample widths were used for each of three areas. One area contains 4,000 st averaging 10.03 oz/st (length of 265 ft, average sample width of 3.65 ft). Another area contains about 7,000 st averaging 4.44 oz/st (length of 347 ft, average sample width of 4.67 ft). Another area contains about 3,000 st averaging 6.02 oz/st (length of 247 ft, average sample width of 3.30 ft). Silver occurs in two other samples (5.3 and 18.6 oz/st), but no resources could be estimated because a continuous ore-bearing structure was not found.

Five perlite samples were taken in the wilderness study area at two perlite outcrops (fig. 2). The larger outcrop is traceable for about 8,500 ft and is estimated to be about 700 ft wide. The smaller outcrop is estimated to be 4,700 ft long and about 200 ft wide. Both perlite beds are about 30 ft thick. A tonnage factor of 13.0 ft^3/st was used in estimating the amount of resources in the two outcrops. The perlite has expansion densities of 5.25 to 16.00 pounds per cubic foot (lbs/ft^3), which covers the most widely used bulk-density range (7 to 15 lbs/ft^3), and could be used for filter aids, horticultural applications, lightweight concrete aggregate, loose-fill applications, abrasive in soaps and cleansers, a curing agent in caulking compounds, and in castings in foundries. However, the perlite generally expands poorly, has a gray color, contains much unexpandable material, and is, therefore, not of desirable commercial quality. Therefore, the perlite in the study area would not compete favorably with other perlite being commercially exploited at this time. A low-grade demonstrated subeconomic perlite resource of approximately 15 million st was estimated for the two large outcrops within the study area (Lane, 1988, p. 8–10).

Sand and gravel deposits occur in the study area, but their properties are not unique and other deposits closer to markets are abundant in the region. For these reasons, the sand and gravel are unlikely to have economic value in the foreseeable future.

About one-third of the study area is covered by oil and gas leases, but no drilling for oil and gas has been done in the study area. There are no geothermal leases in or near the study area. There are no thermal springs, wells, or known geothermal resource areas in or near the study area (Muffler, 1979; Witcher and others, 1982).

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By James G. Evans, Randall H. Hill, William F. Hanna, *and* Daniel H. Knepper
U.S. Geological Survey

Geology

The Aubrey Peak Wilderness Study Area is underlain by Precambrian gneiss and granite and by Miocene to Quaternary sedimentary, volcanic, and volcaniclastic rocks and alluvium. Geology shown in figure 2 is simplified from mapping by N.H. Suneson and Ivo Lucchitta (unpub. data, 1980).

The oldest rock unit (p€g) in the study area contains medium- to coarse-grained, commonly porphyritic granitic rocks containing potassium feldspar phenocrysts as much as 2 in. long, weakly foliated gneiss, augen gneiss containing potassium feldspar augen as much as 1 in. long, and minor amounts of recrystallized cataclasite and schist. The unit is cut by vertical dikes of very coarse grained granite pegmatite as much as 3 ft wide and by veins of quartz and calcite as much as 0.5 ft wide. Compositions range from quartz monzonite to granite in the granitic rocks and from quartz diorite to granite in the gneiss, which is probably foliated plutonic rock. Most of the unit consists of plagioclase, potassium feldspar (perthite, antiperthite, and microcline), and quartz. The chief mafic minerals are biotite (1 to 7 percent) and hornblende (0 to 4 percent). Some gneiss contains aggregates of epidote, biotite, ilmenite, and sphene. Magnetite, garnet, pyrite, zircon, and quartz-feldspar symplectite are also present.

The granite and gneiss have undergone several kinds of alteration. The potassium feldspar phenocrysts and augen appear to have replaced plagioclase and quartz. This relation suggests that the present granitic composition of some of the rocks is a result of metasomatism of a less potassic protolith, possibly granodiorite or quartz diorite. Plagioclase is commonly slightly altered to sericite and is locally saussuritized. Mafic minerals are slightly altered to chlorite. Magnetite is partly altered to hematite, and this alteration is locally abundant. Ilmenite is altered to sphene and leucoxene. Microscopic quartz veins cut potassium feldspar phenocrysts. As much as 15 percent of some sheared rocks are replaced by calcite.

Much of the unit east of approximately 113°50′ W. long. in the study area is composed of the Signal Granite (Lucchitta and Suneson, 1982), a granitic batholith at least 20 mi in diameter and well exposed near the ghost town of Signal, 13 mi northeast of the study area. The age of the Signal Granite is Middle Proterozoic on the basis of a U-Pb (uranium-lead) age of 1410±3 million years before present (Ma) (Gray and others, 1989). Rocks west of 113°50′ W. long. are also likely Precambrian, but they may be older than the Signal Granite.

Tertiary arkose, conglomerate, and coarse sedimentary breccia overlie the Precambrian rocks (fig. 2). The description of these rocks is taken from N.H. Suneson and Ivo Lucchitta (unpub. data, 1980). The base of the section is pale red arkosic sandstone and granule to pebble conglomerate that are generally poorly consolidated and sorted and are moderately stratified; clasts are coarse-grained, locally derived granite. These basal beds are overlain by poorly to well-consolidated, well-stratified arkose, limestone, and tuffaceous sedimentary rock; clasts include several kinds of plutonic and metamorphic rock. These beds are overlain by the breccia of Ester Basin, which has a breccia facies and an alluvial facies. The breccia facies is a widespread, chaotic, primarily monolithologic sedimentary unit that consists mostly of angular meta-andesite clasts as much as several feet across. The breccia facies is unstratified, unsorted, and moderately to poorly indurated; this facies also includes minor amounts of poorly foliated metasedimentary rocks, white quartzite, and gray limestone. The alluvial facies comprises a well-stratified, well-consolidated arkosic sandstone and a granule-to-cobble conglomerate containing abundant subrounded clasts of meta-andesite. In places, a poorly consolidated sedimentary breccia of angular blocks of foliated, sheared coarse-grained granite overlies the breccia of Ester Basin. A heterogeneous sedimentary unit consisting of limestone, chert, gypsiferous beds, siltstone, sandstone, and tuff overlies the breccia units.

The age of these sedimentary rocks (Ts) is not clearly understood. Seven miles west of the study area, they underlie a basalt unit that has been dated at early to middle Miocene (K-Ar (potassium-argon) ages, 18.7±0.3 Ma and 16.5±0.2 Ma, Suneson, 1980, p. 185).

Included in these sedimentary rocks is the arkose of Keenans Camp, a widespread arkosic conglomerate that overlies the sedimentary rocks described above and is partly contemporaneous with the basalt mentioned above and the overlying volcanic rocks described below. The lower part of this arkosic conglomerate is a reddish-brown, well-consolidated, well-stratified, locally tuffaceous coarse sandstone and pebble and cobble conglomerate that grades upward to sandstone and siltstone. The upper part is a poorly stratified, poorly consolidated sandstone and boulder conglomerate; clasts consist of granitic rock, gneiss, basalt, metavolcanic rock, quartzite, and diabase. The arkose of Keenans Camp is early to middle Miocene, based on its relations with dated volcanic rocks.

Overlying the sedimentary rocks is a unit of volcanic, volcaniclastic, and sedimentary rocks that consists mostly of rhyolite flows, small rhyolite intrusions that fed the flows, and volcaniclastic rocks of rhyolitic composition. A few dikes of quartz-bearing basalt are included in this unit. The rhyolite flows and intrusions are aphyric or porphyritic, glassy to devitrified, locally brecciated, and flow banded. Phenocrysts include sanidine, quartz, plagioclase, biotite, and minor amounts of hornblende. The groundmass is granophyric, cryptocrystalline, or glassy. Contemporaneous volcaniclastic rocks include ash-flow and air-fall tuff and tuffaceous sandstone and conglomerate. The tuff is well-stratified and locally lapilli rich. The sandstone is distinctly bedded and contains some crossbedding and siltstone beds. The quartz-bearing basalt included in the unit is light to dark gray and contains from 4 to 12 percent phenocrysts of quartz, very corroded plagioclase, and minor amounts of olivine and clinopyroxene. The quartz phenocrysts are embayed and have pyroxene reaction rims.

The volcanic, volcaniclastic, and sedimentary rocks unit is assigned a middle Miocene age; K-Ar ages of rhyolites in and near the study area range from 15.1±0.1 to 10.3±0.1 Ma, and most are between 12 and 13 Ma (Suneson, 1980, p. 185). Two samples from the Aubrey Peak Wilderness Study Area were dated at 12.4±0.1 Ma and 12.4±0.2 Ma (Suneson and Lucchitta, 1979) or middle Miocene. Potassium-argon ages of quartz-bearing basalts are similar (13.7±0.3 and 12.4±0.1 Ma, Suneson, 1980, p. 186); the older age is for a sample from the study area.

Several small exposures of megacryst-bearing basalt crop out in the study area. These basalt flows contain abundant phenocrysts of plagioclase and clinopyroxene but include minor amounts of olivine, spinel, and magnetite that are as much as 3 in. long and typically 0.13 to 0.5 in. long. Potassium-argon ages on samples of this basalt near the Aubrey Peak Wilderness Study Area range from 6.8±0.2 to 8.6±0.3 Ma (Suneson, 1980, p. 187–188), which indicates a late Miocene age.

The Precambrian and Tertiary rocks described above are overlain in the southern end of the study area by a sequence of heterogeneous, coarse clastic strata. The lower part of this sequence is well-stratified, consolidated, coarse sandstone and pebble-to-boulder conglomerate containing thin local tuff beds. The upper part of this sequence is poorly consolidated, stratified, and sorted fanglomerate with abundant angular clasts. The age of these deposits is late Miocene or Pliocene.

Quaternary alluvium includes unconsolidated channel fill (silt, sand, gravel, and boulders), undissected pediment gravel, desert pavement with desert varnish, and locally derived slope wash, talus, and landslides.

The entire study area is in the upper plate of the Rawhide low-angle detachment fault that is exposed in the Rawhide Mountains 5 mi south of the study area. Movement of the upper plate was northeastward (Shackelford, 1980). The study area is in the 60-mi-wide Colorado River extensional corridor, across which slip on all faults is estimated to total about 30 mi (Howard and John, 1987). Age of inception of the extensional movement is not known. Suneson and Lucchitta (1983), however, suggest that most movement on the Rawhide detachment fault and related listric faults occurred after eruption of the oldest basalts in the region (18.7 and 16.5 Ma) and ceased by 14 million years ago. The period of detachment faulting was succeeded by development of steep normal faults, most of which strike northwesterly. The normal faults may have been active until about 7 million years ago, as suggested by the mostly unfaulted porphyritic basalts of that age 7 mi west of the study area. Several steep northeast-striking faults offset the northwest-striking normal faults.

Geochemical Studies

A reconnaissance geochemical survey was conducted in the Aubrey Peak Wilderness Study Area. Minus-60-mesh stream-sediment samples, nonmagnetic heavy-mineral concentrates derived from stream sediment, and rocks were selected as the sample media in this study. Stream sediments and heavy-mineral concentrates were collected at 40 sites. Twenty-eight fresh and unaltered rock samples were collected near these sample sites. In addition, 1 rock sample was taken from a mine dump, and 30 rock samples, mostly of altered Precambrian rock, were taken elsewhere in the study area.

Stream-sediment samples were collected from active alluvium in stream channels. Stream sediments represent a composite of rock and soil exposed upstream from the sample site. Heavy-mineral concentrates represent a concentration of ore-forming and ore-related minerals and permit determination of some elements that are not easily detected in bulk stream sediments.

Heavy-mineral concentrates derived from stream sediments are a useful sample medium in arid and semiarid environments or in areas of rugged topography where mechanical erosion is greater than chemical erosion (Bugrov and Shalabey, 1975; Overstreet and Marsh, 1981).

Rocks were taken from mineralized and unmineralized outcrops and one mine dump. Samples that appeared fresh and unaltered were collected to determine geochemical background values. Altered or mineralized samples were collected to determine the suite of elements associated with the observed altered or mineralized rock.

Samples of the stream sediments, nonmagnetic heavy-mineral concentrates, and rocks were analyzed for 31 elements using a semiquantitative direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). In addition, rock and stream-sediment samples were analyzed for certain elements by more sensitive methods. These elements and methods are as follows: arsenic, antimony, bismuth, cadmium, and zinc by inductively coupled plasma-atomic emission spectrometry (Crock and others, 1987); gold, tellurium, and thallium by electrothermal atomic-absorption spectroscopy (Hubert and Chao, 1985); and uranium by a fluorometric method (O'Leary and Meier, 1984). These analyses were used to identify drainages with anomalous concentrations of minor elements. Anomalous concentrations in the stream-sediment, heavy-mineral-concentrate, and rock samples were determined for each element by inspecting histograms for each of the sample media.

Samples from the study area contain anomalous concentrations of several elements, of which barium, gold, lead, molybdenum, silver, tin, tungsten, and zinc are possibly related to mineralization. Areas in the eastern, northeastern, southeastern, and southwestern parts of the study area have anomalous values of barium in nonmagnetic heavy-mineral concentrates. Drainages in the northeastern part of the study area are downstream from the McCracken mine. They are characterized by anomalous concentrations of barium (greater than 10,000 ppm), lead (300 to 1,000 ppm), silver (20 to 200 ppm), tungsten (100 ppm), and zinc (700 to 1,500 ppm) in the heavy-mineral-concentrate samples and by weakly anomalous concentrations of lead and zinc in the minus-60-mesh stream-sediment samples. These values are partly a result of contamination from mine dumps in the McCracken mine area. Some rock samples from the northeastern part of the study area contain anomalous concentrations of barium, copper, molybdenum, silver, and zinc, and they indicate that some mineralized ground also occurs in the study area. Anomalous concentrations of barium in heavy-mineral concentrates collected in drainages along the east side of the study area that lie partly outside the study area may also be attributable to contamination from mine dumps. One of these drainages also carries anomalous concentrations of silver (10 ppm), lead (2,000 ppm), and zinc (1,500 ppm) that may be partly derived from the mine workings outside the study area near Keenans Camp. Mine workings within the study area along this drainage also contain high concentrations of lead, silver, and zinc.

In the northwestern corner of the study area is a small drainage that contains high concentrations of barium (greater than 10,000 ppm), lead (15,000 ppm), silver (150 ppm), and zinc (15,000 ppm) in the heavy-mineral concentrates and high values of lead (1,000 ppm), silver (7 ppm), and zinc (2,000 ppm) in minus-60-mesh stream-sediment samples. The source of the small isolated anomaly is not known. It may be due to mineralization in the study area or to contamination from alluvium brought in from the McCracken mine area during a previous episode of alluvial fan formation.

Low concentrations of gold (16 ppb to 12 ppm) were found by the U.S. Bureau of Mines in volcanic breccia, conglomerate, schist, diorite, and altered granite near the eastern edge of the study area. These concentrations of gold are greater than crustal abundance (3 to 4 ppb, Simons and Prinz, 1973) and are considered anomalous. Gold was not detected in rock samples collected by the U.S. Geological Survey in that area or in stream sediments and heavy-mineral concentrates collected in nearby drainages.

Much of the mineralized area characterized by anomalous concentrations of barium, gold, lead, molybdenum, silver, tin, tungsten, and zinc is underlain by the Signal Granite (mapped as part of unit p€g, fig. 2). The age of mineralization is not known, but it may be Miocene or younger because there is evidence of silver, lead, and zinc mineralization in the Miocene arkose of Keenans Camp. The mineralization may have been related to the Miocene volcanism, as suggested by a sample of rhyolite containing 5 ppm silver. The possibility exists, however, that the Miocene mineralization may have involved a partial redistribution of elements from older, possibly Precambrian, mineralized rocks. Anomalous concentrations of barium in stream sediments and heavy-mineral concentrates may be due in part to authigenic barite in sedimentary rocks (unit Ts, fig. 2) of the study area, although such barite was not observed during this study.

Geophysical Studies

A digitally processed Landsat Thematic Mapper color-ratio composite image was used to interpret the location and distribution of spectral-reflectance characteristics in the Aubrey Peak Wilderness Study Area that suggest the presence of selected minerals commonly associated with hydrothermally altered rocks. No field studies were made to confirm the inferences of the reflectance studies. The anomalous areas of most interest are associated with outcrops of Tertiary volcanic and volcaniclastic rocks in a zone trending northwestward across the study area. Other clusters of anomalies are associated with Tertiary volcanic and volcaniclastic rocks in the southwestern part of the study area and with Precambrian crystalline rocks and Tertiary sedimentary rocks in the northern and southeastern parts of the study area.

Areas of possible ferric oxide minerals (particularly hematite, goethite, and jarosite) coincide with areas having barium, barium and silver, and barium, gold, and silver anomalies in the northern and eastern parts of the study area. In the southern part of the study area, areas possibly containing ferric oxide minerals and hydroxyl-bearing, hydrated sulfate and carbonate minerals (clay minerals, micas, gypsum, alunite, jarosite, calcite, and dolomite) overlap areas of anomalous barium. The prominent northwest-trending zone that shows reflectance values characteristic of hydrothermal alteration is coincident with Tertiary volcanic rocks across the central part of the study area and is not associated with any geochemical anomalies; it does include most of the perlite resources and coincides with a zone of aeromagnetic lows. The suggestion of widespread hydrothermal alteration in the study area is consistent with the geological observations, although the actual areas of hydrothermal alteration observed in the field and inferred by the geochemical data do not closely coincide with the areas of possible hydrothermal alteration inferred from the reflectance studies.

The Aubrey Peak Wilderness Study Area is covered by regional gravity (Aiken and others, 1981; Defense Mapping Agency Aerospace Center, 1974, 1975) and aeromagnetic surveys (Western Geophysical Company of America, Aero Service Division, 1979); aeromagnetic surveys have sufficient resolution to define anomalies of about 2 mi^2 or larger. Contours of complete (terrain-corrected) Bouguer gravity anomalies are defined by 25 gravity stations surrounding the study area. Contours of total-field magnetic anomalies are defined by measurements made along nine east-west flightlines spaced 1 mi apart and one north-south tieline at a nominal height of 400 ft above the terrain.

The study area is transected by a smooth gravity gradient defined by values increasing southwestward from a low northeast of the study area to a high southwest of the study area. The lows and the highs do not closely correspond to the pattern of late Tertiary sedimentary rock and exposures of crystalline basement rock; therefore, they probably reflect subsurface rock density contrasts.

Of several large-amplitude aeromagnetic anomalies in this region, five are within the study area, labeled A through E in figure 3. These five anomalies have amplitudes and wavelengths characteristic of highly mafic igneous rocks, such as gabbro and diorite, that occur in core complexes of Arizona but are not exposed in the Aubrey Peak Wilderness Study Area.

Highs A and D overlap small mapped areas of basalt, which suggests that the mafic intrusive rocks causing these highs may be part of a feeder system for the basalt. Highs B and E, not associated with mapped basalt, are also inferred to be caused by mafic intrusive rocks having strong total magnetization of normal polarity. Low C, nested between highs A and B, is probably a polarization feature coupled to high A. Hypothetically, low C could be caused partly by a mafic pipe having a total magnetization of reversed polarity, but there is no other evidence for such a feature. Most of the high-amplitude anomalies border the northwest-trending zone of small-amplitude lows in figure 3, which coincides with a fairly nonmagnetic northwest-trending zone of rhyolitic volcanic rocks.

Several high-amplitude aeromagnetic anomalies overlap areas having geochemical anomalies. For example, high A overlaps the small barium, gold, and silver anomaly and a barium and silver anomaly; high B overlaps two barium anomalies; and high E flanks a small barium and silver anomaly, although this geochemical anomaly may be associated with fossil placers from outside the study area. Because many barite vein deposits in the western United States are associated with igneous rocks of Tertiary age (Brobst, 1973), the spatial association of aeromagnetic anomalies to barium anomalies in the study area suggests that the barium may have been derived from hydrothermal activity near the margins of the inferred subsurface mafic intrusions.

Mineral and Energy Resource Potential

Geologic and geochemical data indicate that zones within the Aubrey Peak Wilderness Study Area have low resource potential for silver, barium, and gold, for silver and barium, and for barium alone with a C certainty level and for silver and barium with a B certainty level. The resource potential for petroleum and natural gas for the entire study area is low with a B certainty level.

Geologic, geochemical, and geophysical data suggest that there is low resource potential for silver and barium in the northwestern, northeastern, and southeastern parts of the study area (fig. 2). This potential is indicated by anomalous concentrations of barium and silver in heavy-mineral-concentrate samples, which also contain anomalous concentrations of lead, molybdenum, tin, tungsten, and zinc that may indicate hydrothermal alteration. The potential is low because the rocks that look most altered and mineralized have fairly low concentrations of barium and silver, and no large deposits enriched in either element were found. A certainty level C is assigned to the areas in the northeastern and southeastern parts of the study area because the rocks there are generally well exposed, and the geochemical data do not suggest the possibility of large, undiscovered near-surface silver and barium resources. The higher concentrations of silver in some heavy-mineral concentrates are partly due to contamination from mine workings outside the study area. The small area of low potential for silver and barium in the northwestern part of the study area is assigned a certainty level B because the source of the barium and silver is unknown and may not be in the study area.

There is low resource potential for barium in the northeastern (two areas, one of which lies along the east boundary), southeastern, and southwestern parts of the study area (fig. 2). The potential is suggested by the anomalous concentrations of barium in heavy-mineral concentrates and is low because of the absence of large occurrences in the region; the barite occurs as thin, discontinuous veins. The barium is associated with anomalous concentrations of one or more of the following elements that may indicate hydrothermal alteration: lead, tin, and tungsten. The barium anomalies may be partly due to contamination from outside the eastern part of the study area. Elsewhere, the barium may have been derived from barite veins or possible authigenic barite in Miocene sedimentary rocks. A certainty level C is assigned because no large deposits were found in the generally well exposed rocks.

A small area having low resource potential for silver, barium, and gold occurs in the southeastern part of the study area (fig. 2). This potential is indicated by

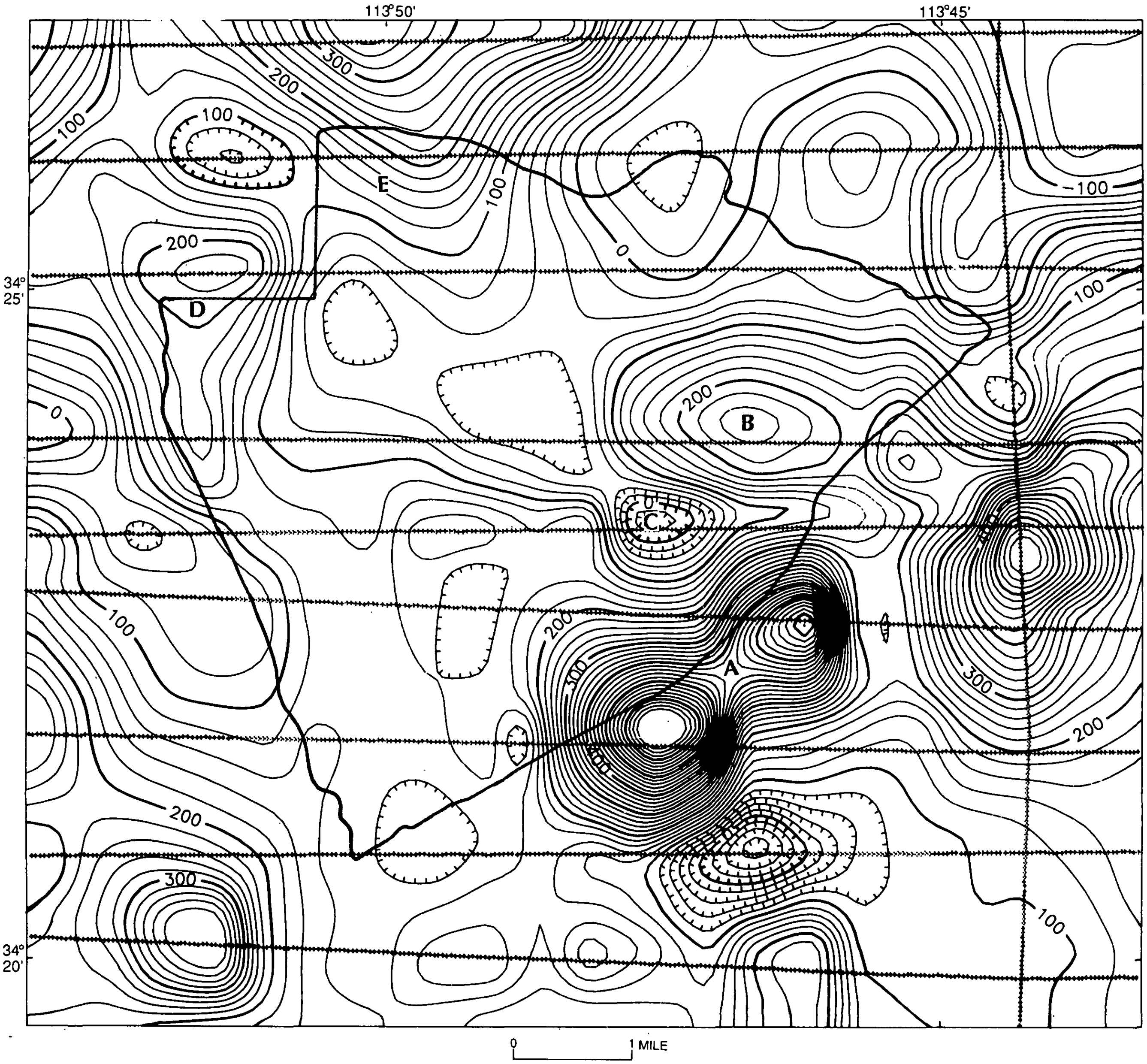

Figure 3. Aeromagnetic anomaly map of Aubrey Peak Wilderness Study Area, Mohave County, Arizona. Contour intervals 20 and 100 nanoteslas. Hachures indicate closed areas of lower values. See text for discussion of anomalies labeled A through E. Crosshatched lines denote flightline traces.

anomalous concentrations of gold in rock samples near pits and tunnels. The potential is considered low because of the low concentrations of gold and the small areal extent over which gold-bearing structures can be traced. A certainty level of C is assigned because the area of the anomaly is well exposed, and the geochemical data do not suggest the possibility of large amounts of undiscovered resources.

Anomalous concentrations of lead, molybdenum, tin, tungsten, and zinc in stream-sediment, panned-concentrate, and rock samples in the study area may indicate hydrothermal alteration and possible mineralization. These elements, however, do not occur in concentrations suggesting that they form deposits in the study area.

Ryder (1983) assessed the oil and gas potential of the study area as zero to low, on the basis of the extensive occurrences of Precambrian granite and gneiss constituting the basement rocks of the wilderness study area and of the overlying Tertiary volcanic rocks. Such rocks are not conducive to the accumulation of hydrocarbons. If present, hydrocarbons would be associated with deposits on the flanks of the Tertiary basins. The resource potential for oil and gas is low, certainty level B, for the entire study area.

No geothermal resources were found in or adjacent to the study area (Witcher and others, 1982; Muffler, 1979). Although the study area contains numerous rhyolite and basalt intrusions and the study area is in a region that probably underwent greater than normal heat flow during the Miocene and early Pliocene, the Miocene intrusions in the study area are small, and the entire region has most likely cooled to near ambient temperatures since the early Pliocene. Therefore, there is no potential for geothermal resources, 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 →	A	B	C	D
	U/A UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
		M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
		L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
				N/D NO POTENTIAL

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.
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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.

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

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.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

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Evans and others—MINERAL RESOURCES, AUBREY PEAK WILDERNESS STUDY AREA, ARIZONA—U.S. Geological Survey Bulletin 1701–D