MINERAL RESOURCES OF THE SWANSEA WILDERNESS STUDY AREA, LA PAZ AND MOHAVE COUNTIES, ARIZONA

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

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 Swansea Wilderness Study Area (AZ–050–015A), La Paz and Mohave Counties, Arizona.

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SUMMARY

Abstract

The Swansea Wilderness Study area (AZ–050–015A) lies in the Rawhide and Buckskin Mountains, west-central Arizona, about 20 mi east of Parker, Ariz. At the request of the U.S. Bureau of Land Management, mineral surveys of approximately 15,755 acres were done by the U.S. Geological Survey and U.S. Bureau of Mines to assess its mineral resources (known) and mineral resource potential (undiscovered). In this report, the study area refers to only that part of the wilderness study area for which a mineral survey was requested by the U.S. Bureau of Land Management.

Mining and prospecting activity has occurred in or adjacent to the Swansea Wilderness Study Area in the Swansea, Mesa, and Owens mineral districts. Copper, silver, and lesser quantities of gold, lead, zinc, and manganese have been produced from mines in these districts. Metals have been recovered from deposits along the Buckskin-Rawhide detachment fault and subsidiary high- and low-angle normal faults (Swansea and Mesa mineral districts) and along northwest-striking high-angle faults that cut mylonitic gneiss and schist (Owens mineral district). There are no identified resources in the study area.

Moderate and high potential for base and precious metals (copper, lead, zinc, gold, silver) in the study area exists in areas along northwest-striking high-angle faults in the northern part of the study area, along high- and low-angle faults in the lower-plate terrane south of the Bill Williams River, and along the Buckskin-Rawhide detachment fault and its upper-plate faults on the south, northeast, and northwest margins of the area; low potential exists in the south-central area. Part of Black Mesa in the northern part of the study area has high potential for manganese, whereas an area in the southeast corner of the study area has low potential for manganese. Areas of low potential for uranium and vanadium are found in the Tertiary sedimentary and volcanic rocks in the northern and southeastern parts of the study area. The entire Swansea Wilderness Study Area has no resource potential for oil and gas and sand and gravel.

Character and Setting

The Swansea Wilderness Study area (AZ–050–015A) covers approximately 15,755 acres in La Paz[1] and Mohave Counties, west-central Arizona, about 20 mi east of Parker, Ariz. (fig. 1). The study area straddles the Bill Williams River, which divides the Rawhide Mountains on the north from the Buckskin Mountains on the south. Elevations in the study area range from about 600 ft along the Bill Williams River to 1,600 to 1,700 ft at the highest point on Black Mesa, north of the river, and at the crest of the Buckskin Mountains south of the river.

The study area lies in the northwest-trending belt of metamorphic core complexes in west-central Arizona (Rehrig and Reynolds, 1980). In these complexes, mid-crustal and deeper rocks were tectonically transported to the surface along shallow-dipping normal faults or detachment faults during a period of extensional tectonism in the late Oligocene and Miocene (Davis and others, 1980; Spencer and Reynolds, 1986; Davis, 1988) (see appendixes for geologic time chart). The detachment fault in the study area is the Buckskin-Rawhide detachment of Spencer and Reynolds (1986, 1989), which crosses the northern part of the study area and crops out discontinuously along the south border of the study area (fig. 2). The detachment fault divides the

[1] La Paz County was created by the Arizona Legislature effective January 1, 1983, from what was the northern half of Yuma County.

bedrock geology of the area into two parts, an extended and highly faulted upper plate of Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic, igneous, and sedimentary rocks, and a lower plate of Tertiary mylonite and mylonitic gneiss that was derived from Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic, igneous, and sedimentary protoliths. Mylonitic deformation in the lower plate is considered to be a deeper level expression of, and slightly older than, brittle extensional faulting along the detachment fault and its upper plate (Davis, 1983; Spencer and Reynolds, 1986; Howard and John, 1987; Davis and Lister, 1988). Sedimentary and volcanic rock deposition accompanied extension, and these rocks now crop out in the highly faulted upper plate terrane (Davis and others, 1980; Spencer and Reynolds, 1989). During the last stages of, or after the end of, the extensional deformation, high-angle faults cut the detachment terrane. Extensional deformation was followed by basaltic and locally silicic volcanism in the middle and late Miocene (Suneson and Lucchitta, 1983). These volcanic rocks are interbedded with locally derived sedimentary rocks that filled depressions within the extended terrane.

The extensional fault system, associated syntectonic basins, and younger high-angle faults are important controls on the distribution of mineral resources in the study area (Spencer and Welty, 1985, 1989). Mineral exploration in western Arizona and southeastern California has focused on these geologic terranes, and some deposits and prospects are known (Sherborne and others, 1979; Wilkins and Heidrick, 1982; Wilkinson and others, 1988; Spencer and others, 1988; Lehman and Spencer, 1989).

Identified Resources

Mining and prospecting activity has taken place in the Owens and Mesa mineral districts of Spencer and Welty (1989) located in the northeastern and northern parts of the Swansea Wilderness Study Area (fig. 2). Minor production of silver, gold, copper, lead, zinc, and manganese is recorded from these districts. The Swansea mineral district is immediately south and southwest of the study area and the Planet mineral district is west of the study area. Significant amounts of copper, silver, and minor gold have been produced from these districts (Spencer and Welty, 1989, p.

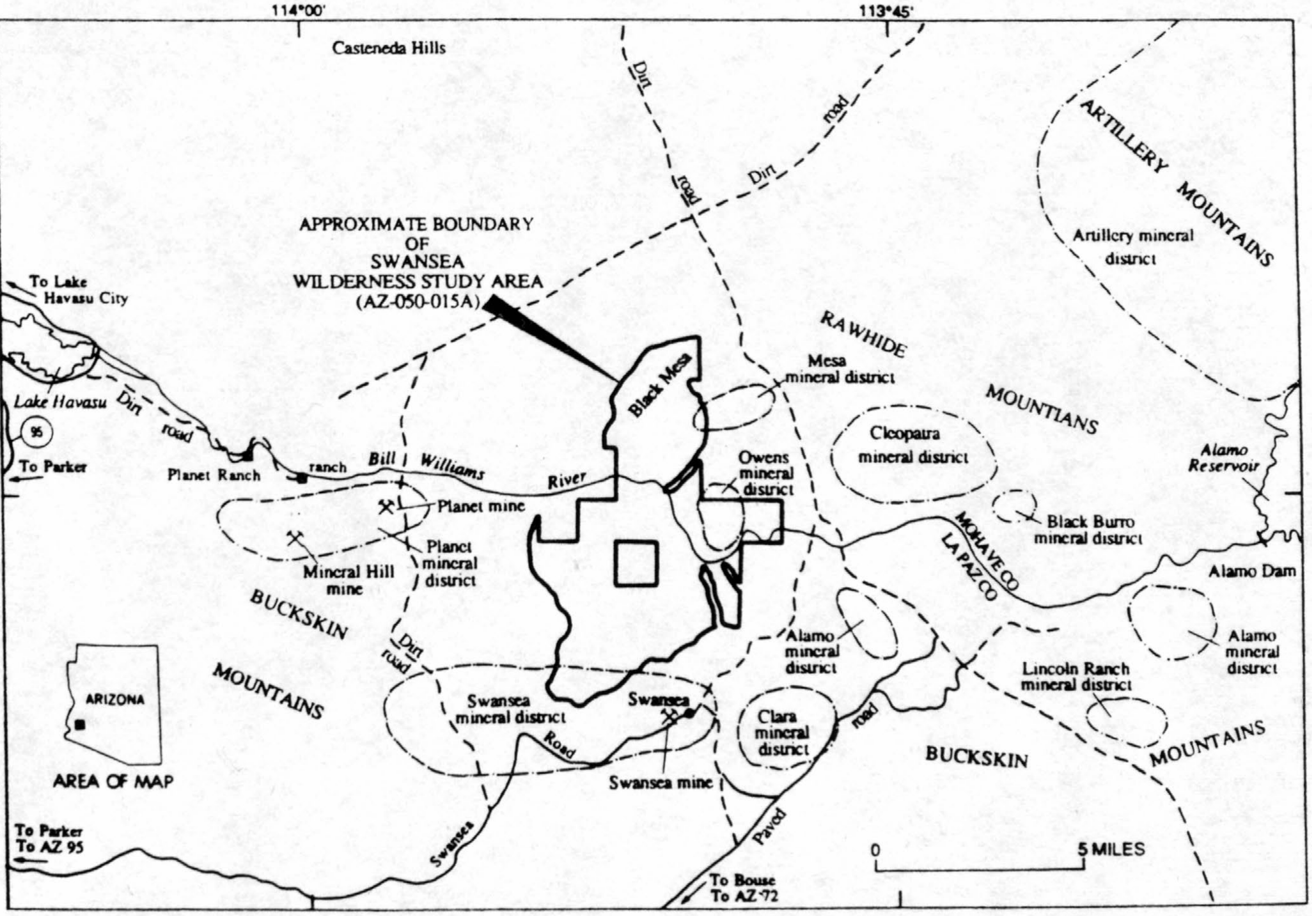

Figure 1. Index map showing location of the Swansea Wilderness Study Area, La Paz and Mohave Counties, Arizona. Dash-dot lines, approximate boundaries of mineral districts near the study area from Keith and others (1983a, b) and Spencer and Welty (1985, 1989).

224–225) (figs. 1 and 2). No identified resources are present in the study area.

Mineral Resource Potential

Moderate, high, and low potential for base and precious metals (copper, lead, zinc, gold, and silver) exists in the Swansea Wilderness Study Area (fig. 2). These areas are located along high-angle faults in the northeastern part of the study area and along the Buckskin-Rawhide detachment fault and related upper plate faults in the northern and southern parts of the study area. Areas of high potential for these elements are defined by favorable geologic and geochemical data in the study area and by past production from mines. Areas of high potential for manganese and low potential for uranium and vanadium are found in the Tertiary sedimentary and volcanic rocks in the northern parts of the study area. Low resource potential for manganese, uranium, and vanadium exists in the southeastern part of the study area. No resource potential for oil and gas resources exists in the study area.

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). Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. 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 modified from 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. See appendixes for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Location and Physiography

The Swansea Wilderness Study area (AZ–050–015A) covers approximately 15,755 acres in west-central Arizona, about 20 mi east of Parker, Arizona (fig. 1). The study area straddles the Bill Williams River, which separates the Rawhide Mountains on the north from the Buckskin Mountains on the south. Alamo Dam, 13 mi east of the study area, controls the flow of the Bill Williams River, and the water level is normally kept low, providing numerous fording points. The part of the study area north of the river is in Mohave County, and that part south of the river is in La Paz County.

The main access to the study area is by Swansea Road east from Arizona Highway 95 south of Parker to the ghost town of Swansea, which is 1 mi south of the study area. Another access road extends east from Arizona Highway 95 along the south side of the Bill Williams River as far as Planet Ranch, where a branch road turns south to intersect the Swansea Road. An unimproved pipeline road continues northeast from Swansea, skirting the southeast boundary of the study area to a ford across the Bill Williams River and then continues north near the eastern side of the study area. The study area also can be accessed by unimproved roads from the north, northeast, and southeast. A private inholding, a Railroad Grant issued in 1922, consists of sec. 7, T. 10 N., R. 15 W. and has no access.

The vegetation of the study area is classified as Sonoran Desert scrub, and the main subdivision found in the study areas is the Arizona Upland subdivision (Brown, 1982). The Arizona Upland subdivision is a shrubland or low woodland of leguminous trees with open areas of shrubs and cacti. Cacti are important in this subdivision, and 20 species of cacti are largely confined to or best represented in the Arizona Upland subdivision. Major areas of the Lower Colorado River subdivision of the Sonoran Desert also are found in the study area, especially in the Buckskin Mountains. Locally common riparian areas and wetland meadows are found around seeps, streams and washes. The dominant shrubs and cacti include cholla (*Opuntia* spp.), saguaro (*Carnegiea gigantea*), creosote bush (*Larrea tridentata*), and littleleaf paloverde (*Cercidium microphylum*).

Previous Work

Early descriptions of the rock types and various mineral deposits in the Rawhide and Buckskin Mountains are found in Lee (1908), Bancroft (1911), and Jones and Ransome (1920). That part of the Rawhide Mountains east of the study area was mapped by Shackelford (1976, 1989). The region north of the Bill Williams River, including the northern part of the study area, was mapped by Suneson and Lucchitta (1979, 1983) and Suneson (1980). Osborne (1981), Woodward (1981), Wilkins and Heidrick (1982), and Spencer and Reynolds (1987) mapped the Tertiary rocks and structures in the area of Swansea mine and Copper Penny prospect. Geologists from the Arizona Bureau of Geology and Mineral Technology have studied the geologic setting of the mineral occurrences within the region (Keith, 1978; Keith and others, 1983a, b; Welty and others, 1985; Spencer and Reynolds, 1986; Spencer and Welty, 1986, 1989; Reynolds and Spencer, 1989; Spencer and others, 1988, 1989) and their work has been invaluable during the course of this mineral resource investigation. Spencer and Welty (1989) defined mineral districts throughout the region, including the study area, and their district names are used in this report.

Studies in the Planet and Swansea mineral districts by Wilkins and Heidrick (1982), Lehman and others (1987), and Lehman and Spencer (1989) demonstrated the ties between the varied structures in the extensional terrane and the base- and precious-metal deposits in the region. Based on this work, other areas outside the study area have been actively explored for precious- and base-metal deposits (Wilkins and others, 1986; Spencer and others, 1988; Wilkinson and others, 1988). A similar link between manganese deposits in the Artillery Mountains and uranium-vanadium deposits in the Date Creek Basin, some 30 mi east of the Swansea Wilderness Study Area, has also been proposed (Lasky and Webber, 1949; Sherborne and others, 1979; Otton, 1981; Spencer and Welty, 1989; Spencer and others, 1989). Results of this work are applicable to the mineral resource potential of the Swansea Wilderness Study Area.

Methods of Study

The U.S. Geological Survey conducted detailed field investigation of the Swansea Wilderness Study Area in the winter of 1987 and 1988. This work included geologic mapping at a scale of 1:62,500, geochemical sampling, and the examination of outcrops for evidence of mineralization. Rocks and stream sediments were collected and analyzed for 35 to 37 elements by semiquantitative emission spectrography and for arsenic, antimony, bismuth, cadmium, gold, and zinc by atomic absorption methods. Regional gravity and aeromagnetic surveys were used in the assessment. Landsat thematic mapper images were interpreted for evidence of hydrothermal alteration in the study area. Further details on each analytical procedure used for this resource assessment are given later.

Acknowledgments

This study was supported by the National Mineral Resources Assessment Program of the U.S. Geological Survey. Discussions with J.E. Spencer and S.J. Reynolds of the Arizona Geological Survey and Bruce Bryant of the U.S. Geological Survey improved our understanding of the geology of the area. A special thanks is extended to Diana Mangan for preparation of the figures and to Carol Ostergren and Nobie Amamoto for patiently overseeing the final publication of the bulletin.

APPRAISAL OF IDENTIFIED RESOURCES AND KNOWN MINERALIZED AREAS

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Methods of Investigation

A review of literature, maps, and unpublished material related to mineral occurrences and mining activities in or near the Swansea Wilderness Study Area was completed before any field work was undertaken. Master title plats and Bureau of Land Management records were checked to locate oil and gas leases and mineral claims in the study area.

Two geologists conducted a 12-day field examination in the study area and vicinity. Thirty-seven samples were taken from adits, mines, prospects, and outcrops. All samples were analyzed for 32 elements by inductively coupled plasma-atomic emission spectrometry and for gold and silver by fire assay. Eighteen samples were assayed for barium and copper by the atomic absorption method, and five samples were analyzed for manganese using neutron activation methods. All analyses were done by the Chemex Lab, Inc., Sparks, Nevada. A summary of the geochemical data is available in Ryan (1989). The complete analytical data are available for inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Mining History

Early mining near the study area consisted of Indian diggings in thick hematite layers found at the Mineral Hill and Planet mine areas, 6 to 8 mi west of the study area. Also, the "coyote holes" along copper carbonate horizons at Mineral Hill are ascribed to the Indians or possibly the Spanish (Paul Konow, oral commun., Mineral Hill prospector, 1988). Larger scale copper mining began at the Planet and Swansea districts in the 1860's and steady production was sustained during the 1880's. Later, the declining price of copper resulted in intermittent closing of the mines for several years at a time.

The southern part of the study area lies in the Swansea mineral district (fig. 1). The Mesa mineral district encompasses Black Mesa north of the Bill Williams River, and the Owens mineral district is in the northeastern part of the study area north of the Bill Williams River. Other mineral districts within 12 mi of the study area include the Planet and Clara. Recorded production from all districts includes some 930 troy ounces (oz) of gold, 43,700 troy oz of silver, 24,000 tons of copper, 32 tons of lead, less than 1 ton of zinc, and 300 tons of manganese ore at an unspecified grade (Keith, 1978, p. 67; Kreidler, 1986, p. 5; Spencer and Welty, 1989, p. 224). The total production includes manganese ore produced during World War II from the Mesa Manganese Prospect on the northeast boundary of the study area (Ryan, 1989). Although most mining had ceased by 1942, one unidentified mine produced copper until the 1970's (Keith, 1978, p. 71).

Placer gold has been produced from the Clara mining district, 4 mi southeast of the study area, and placer claims have been located northeast, east, and northwest of the study area. At the time of this investigation, no mining activity was being conducted in any of the areas.

Though some exploration drilling has been conducted near the Swansea mine (fig. 2, No. 1) Copper Penny prospect, (fig. 2, No. 2), and in the Planet mineral district (fig. 1) in the last 10 years (Wilkins and Heidrick, 1982; Lehman and others, 1987), no mineral development or production has resulted. As of July 1988, no mining claims had been staked in the study area and no exploration activities were observed.

Oil and Gas

Petroleum resources are considered to be nonexistent in the study area because of the middle Tertiary metamorphic and tectonic history. Ryder (1983, p. C–19) rates the oil and gas potential of the region of the study area as low because the organic content, reservoir quality, and thermal history of the rocks are not conducive to the generation or preservation of significant volumes of hydrocarbons. As of August, 1988, no active oil or gas leases were extant in the study area.

Appraisal of Sites Examined

In the study area, mineral production has taken place in the Owens mineral district north of the Bill Williams River. Elsewhere, prospect pits, bulldozer cuts, near surface stopes, adits, or shafts are found in the northern, west-central, and southwestern parts of the area (Ryan, 1989). Evidence of manganese and copper oxides and carbonate minerals in association with hematite or specularite are present locally.

The Mesa Manganese prospect (fig. 2, No. 3) consists of two small adjoining stopes near the surface on the east side of Black Mesa in the northern part of the study area (Ryan, 1989). The manganese is in lenses in a megabreccia of Paleozoic limestone and quartzite that lies in the upper plate of the Buckskin-Rawhide detachment fault. It is estimated that about 150 tons of low-grade ore was removed during World War II. One sample of residual material at the entry to one of the stopes assayed 10.9 percent manganese oxide (MnO), whereas another sample, from a trench northwest of the stopes, assayed 20.3 percent MnO. This last sample is probably more representative of the material that was mined (Ryan, 1989). Most samples from the prospect area contain minor silver and elevated concentrations of barium.

A 265-ft-long exploration adit lies in a side drainage leading into the wash that drains from the area of the Swansea mine across the southeast corner of the study area and terminates at the Bill Williams River (fig. 2, No. 4). The adit is at the base of a rugged cliff in which no structure or minerals were observed. The adit crosses several moderately to steeply dipping faults that strike northwest and north (Ryan, 1989). Five chip samples were taken in the adit from crosscutting faults. Two samples from a 2-ft-wide, hematite-stained, northwest-striking fault zone contain 0.015 troy ounces of gold per short ton (oz/st), 1,510 and 4,500 part per million (ppm) of barium, 1,755 and 2,050 ppm lead, and 2,400 and 3,930 ppm zinc (Ryan, 1989). These concentrations are considered typical of those found along the northwest-striking high-angle faults that cut the lower plate mylonitic gneisses.

Caved adits, shafts, and prospect pits north of the Bill Williams River are in the Owens mineral district, located in the northeastern part of the study area. Many of the caved adits are probably less than 30-ft long, based upon the amount of subsidence and the dump size. At least one shaft in sec. 4, T. 10 N., R. 15 W. may account for some of the limited production of metals in the district. The shaft is caved and inaccessible, but a sample taken from the site of a loading bin contains 3.6 weight-percent copper and less than 15 weight-percent iron. Other samples collected in the area of the shaft were from pits, caved adits, and outcrops containing copper carbonates and oxides and ubiquitous specularite. These samples contain elevated concentrations of copper and iron and some also contain about 1,420 ppm manganese (Ryan, 1989). One sample also contains 415 ppm strontium and another sample from a caved adit contains 0.01 troy ounces per ton silver.

Elevated concentrations of arsenic, barium, magnesium, lead, strontium, and zinc found in various samples throughout the study area are consistent with the suite of minerals noted at the older producing properties in the region (Harrer, 1964, p. 143; Ryan, 1989). Hematite or specularite is found at most of the workings examined. Chloritic alteration, noted as being typical of detachment-related lower-plate mineralization (Reynolds, 1980, p. 7), also was found at all of the workings examined in the study area except the Mesa Manganese prospect. The presence of oxide, carbonate, silicate, and sulfate minerals suggest that conditions during deposition were oxidizing and that the minerals probably formed at a shallow depth. More reduced, sulfide-rich assemblages may be present at depth (Wodzicki and others, 1982, p. 94).

Quantities of sand and gravel are readily available along the Bill Williams River and its tributaries. However, the material in the study area has no unique characteristics that would make it more desirable than similar deposits outside the study area. The desert environment of southern Arizona provides numerous sources of similar material closer to population centers.

Conclusions

The Swansea Wilderness Study Area contains no identified metallic mineral resources. Mineral assemblages in the various samples taken in the study area are similar to those noted in epithermal deposits found in various structural settings in the Tertiary extensional terrane of Arizona, as described by Spencer and Welty (1989). These minerals suggest the possibility of unidentified subsurface occurrences.

The metamorphic rocks that underlie much of the study area and the lack of significant sedimentary basins preclude oil and gas resources.

Sand and gravel in the study area has no unique characteristics that would make it more desirable than similar deposits outside the study area and closer to population centers.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

The Swansea Wilderness Study area lies in the northwest-trending belt of metamorphic core complexes in west-central Arizona (Rehrig and Reynolds, 1980). In these complexes, mid-crustal and deeper rocks in the lower plate were tectonically transported to the surface along shallow-dipping normal faults or detachment faults during a period of extensional tectonism in the late Oligocene and Miocene (Spencer and Reynolds, 1989). Hydrothermal fluid circulation and mineralization accompanied extensional deformation (Spencer and Welty, 1989). Several deposits in the region that were formed during the extensional deformation have been mined and explored for their base and precious metals and for manganese, uranium, and vanadium. The detachment fault in the map area is known as the Buckskin-Rawhide detachment fault of Spencer and Reynolds (1986, 1989). It crosses the northern half of the study area and crops out discontinuously along the southern border of the study area (fig. 2).

The geology of the study area can be divided into three parts (fig. 2). The upper and lower plates of the Buckskin-Rawhide detachment fault compose two parts. The posttectonic rocks that include rocks deposited in depressions within the extended terrane and modern alluvial deposits along washes and the Bill Williams River form the third.

Part of the upper plate terrane consists of Proterozoic, Paleozoic, and Mesozoic igneous and metamorphic rocks that had complex geologic histories prior to extensional deformation in the Tertiary (Reynolds and Spencer, 1989). Currently these rocks are fault-bounded and commonly intensely brecciated and fractured as a result of the extensional deformation. Within the fault-bounded blocks, thrust faults and folds of probable Cretaceous age complicate the stratigraphy of these rocks (Reynolds and Spencer, 1989). Tertiary volcanic and sedimentary rocks unconformably overlie the older rocks and make up the remainder of the upper plate terrane (Davis and others, 1980; Suneson, 1980; Suneson and Lucchitta, 1983; Spencer and Reynolds, 1986, 1989). The Tertiary rocks were deposited during regional extension.

The lower plate terrane consists of Tertiary mylonitic rocks derived from Proterozoic layered mafic, granitic, and pegmatitic gneiss and the Tertiary Swansea Plutonic Suite (Bryant and Wooden, 1989). These rocks are characterized by a subhorizontal mylonitic foliation and an accompanying northwest-trending elongation lineation. Mylonitic deformation in the lower plate is considered to be a deeper level expression of, and slightly older than, brittle extensional faulting along the detachment fault and the upper plate (Spencer and Reynolds, 1986; Howard and John, 1987; Davis and Lister, 1988).

During the last stages of, or after the end of, the extensional deformation, high-angle faults cut the detachment terrane. Some of these faults have reverse motion in areas east of the study area (Shackleford, 1976; Spencer, 1989). Within the study area and elsewhere in the region, these faults were the sites of epithermal mineralization (Spencer and Welty, 1989).

Posttectonic rocks are common north of the Bill Williams River and sparse south of the river. The rocks are here divided into two broad units. The older unit consists of subhorizontal volcanic and sedimentary rocks of Miocene age that were deposited in depressions within the extensional terrane. To the west of, and within, the study area, basalt is the most common posttectonic volcanic rock and typically erodes to form mesas (Suneson and Lucchitta, 1979, 1983; Suneson, 1980). Black Mesa, north of the Bill Williams River, is one example. Less extensive younger megaporphyritic basalt of presumed late Miocene age is present in the northern part of the study area and in adjoining areas where it fills paleovalleys (Suneson, 1980). Rhyolite occurs locally and forms most of the Casteneda Hills immediately north of the study area (fig. 1; Suneson, 1980; Suneson and Lucchitta, 1983). Conglomerate and sandstone, composed of locally derived detritus, also are common and characterize the older post-detachment rocks south of the study area in the Buckskin Mountains near Swansea.

The younger posttectonic units consist of unconsolidated to poorly consolidated sandstone and conglomerate and alluvium of late Tertiary and Quaternary age that unconformably overlie older rock units. These rocks were deposited in alluvial fan and in fluvial environments. Mylonitic rocks of the lower plate are a major source of detritus for these rocks. The sandstone and conglomerate now crop out in moderately dissected fans and as terrace gravels above the modern washes. The alluvium is along the modern washes and in the larger valleys.

Geochemistry

Introduction

A reconnaissance geochemical survey of the Swansea Wilderness Study Area was conducted in May 1988 to aid in the mineral resource evaluation. The principal geochemical sampling media were stream sediments and heavy-mineral concentrates, collected at 55 sites within the study area. A stream-sediment sample represents a composite of the rocks and soils exposed in the drainage basin. The nonmagnetic fraction of a heavy-mineral-concentrate sample is useful in detecting mineralized areas because primary and secondary ore minerals are commonly found in this fraction. The concentration of ore and ore-related minerals in the heavy-mineral-concentrate sample facilitates determination of elements that are not easily detected in bulk stream sediments. Rock samples provide information on background metal concentrations in unaltered bedrock and information on anomalous metal suites in mineralized areas.

This geochemical survey was designed to locate altered, mineralized, or geochemically anomalous areas, but not to find individual mineral deposits. Detailed follow-up geochemical studies in areas of anomalous metal concentrations found in this reconnaissance study were not undertaken.

Methods

Stream-sediment and heavy-mineral-concentrate samples were collected from active alluvial channels generally along first-order streams. Each heavy-mineral-concentrate sample was separated into magnetic, slightly magnetic, and nonmagnetic fractions using an electromagnet in the laboratory. Nonmagnetic fractions were examined for mineralogical content; these fractions and the slightly magnetic heavy-mineral-concentrate fractions were pulverized for chemical analysis, and the magnetic fraction was archived. Rock samples were examined microscopically and then pulverized for chemical analysis.

Stream sediment and rock samples were analyzed for 35 elements, and the heavy-mineral concentrate samples were analyzed for the same elements and platinum and paladium, all by semiquantitative emission spectrography. In addition, stream sediments and rocks were analyzed by more sensitive atomic-absorption methods for arsenic, bismuth, cadmium, antimony, and zinc. Stream-sediment and rock samples were analyzed for low-level gold concentrations (detection limit: 50 parts per billion (ppb) for stream sediments, 2 ppb for rocks) by atomic absorption methods.

Histograms showing the general distribution and range of the data were constructed for selected elements. Boundaries between background and anomalous element concentrations were chosen using histograms, percentiles, and average crustal abundances for elements given by Levinson (1980). Analytical results and full descriptions of sampling and analytical techniques are found in Eppinger and others (1990a, b).

Results

Geochemical anomalies likely related to lithologic differences and to mineralization were found in samples from the study area. Anomalies possibly related to mineralization are found in 6 areas in the study area and are shown in figure 3. Gold was detected in only 1 nonmagnetic heavy-mineral-concentrate sample and in only 2 rock samples, in areas 1 and 6, discussed below. Anomalous concentrations of silver, copper, lead, zinc, arsenic, barium, bismuth, cobalt, iron, molybdenum, manganese, antimony, tin, thorium, vanadium, and tungsten were found in samples from the study area. Anomalous concentrations of metals in stream-sediment and heavy-mineral-concentrate samples, their ranges, and the threshold values used in this study are listed in table 1.

Two distinct geochemical suites that likely represent two different rock types are apparent in the samples. One is a barium-nickel suite in stream-sediment and heavy-mineral-concentrate samples draining Miocene basalt on Black Mesa. The other is a lanthanum-yttrium-niobium suite in stream-sediment and heavy-mineral-concentrate samples derived from three large areas in the southern and central parts of the study area. The latter association, common to granitic terrains, likely represents granitic phases within the lower plate crystalline rocks underlying the majority of the study area. Sphene contains these elements (Deer and others, 1962) and is the dominant mineral phase in heavy-mineral-concentrate samples rich in these elements.

Samples from area 1 contain the highest concentrations found in this study for several metals, including arsenic, copper, molybdenum, lead, antimony, tin, vanadium, tungsten, and zinc. Other metals present in anomalous concentrations include silver, barium, bismuth, and elements in slightly anomalous concentrations include cobalt, iron, and thorium. Ore-related minerals identified in nonmagnetic heavy-mineral-concentrate samples include abundant fluorite and barite, lesser vanadinite, descloizite, and malleable lead, and trace amounts of pyrite, scheelite, and thorite. Both rock samples containing detectable gold are from this area (quartz vein, 2 ppb gold; siliceous mylonite, 20 ppb gold). The area is dominated by lower plate mylonitic rocks, though the Buckskin-Rawhide detachment fault and associated syndetachment breccias, carbonate minerals, and retrograde chlorite-rich gneisses are found locally (fig. 2; Spencer, 1989). Several small chrysocolla- and specularite-bearing prospects and an adit in the south end of area 1 are near the detachment fault.

Area 2 contains samples with anomalous concentrations of silver, arsenic, barium, cobalt, copper, lead, vanadium, tungsten, and zinc and slightly anomalous concentrations of molybdenum and thorium. Ore-related minerals identified in nonmagnetic heavy-mineral-concentrate samples include barite and fluorite, small amounts of vanadinite and chrysocolla, and trace amounts of wulfenite, pyrite, and scheelite. Bedrock in the area is predominantly mylonitic gneiss. Cobbles of carbonate-rich, chloritic, and metasedimentary rocks common to the upper plate terrane and the areas adjoining detachment faults were observed in sampled drainages. These rocks crop out upstream from the major wash that crosses this area.

Anomalous concentrations of metals in area 3 include barium, copper, iron, and vanadium and slightly anomalous concentrations of arsenic, cobalt, and molybdenum. Abundant fluorite, moderate amounts of barite, and trace amounts of pyrite, chrysocolla, cuprite, native copper, and malleable lead were identified in nonmagnetic heavy-mineral-concentrate samples. Lower plate mylonitic gneiss crops out throughout area 3. Northwest-trending, and locally mineralized, high-angle faults cut the gneiss. No detachment fault or upper plate rocks are known in the area (fig. 2). Cobbles of retrograde gneiss were observed locally, and chrysocolla-malachite-epidote-specularite cobbles were observed in three drainages. Shafts and adits along high-angle faults are upwash from the geochemical sample sites in two of these drainages. Ryan (1989) reports anomalous copper, iron, manganese, and silver from the area of these shafts.

Silver, arsenic, and lead are found in slightly anomalous concentrations in stream-sediment and nonmagnetic heavy-mineral-concentrate samples from area 4, along with trace amounts of pyrite and malleable lead in nonmagnetic heavy-mineral-concentrate samples. Sparse chrysocolla and specularite are in the alluvium at one site. Lower plate mylonitic crystalline rocks throughout the area are cut by high-angle fractures and small faults. Many cobbles of lower plate gneiss in the washes are strongly chloritized and epidotized.

Anomalous concentrations of metals in samples from area 5 include barium, iron, manganese, nickel, lead, vanadium, zinc, and slightly anomalous silver, arsenic, lead, antimony, and thorium. Abundant barite, small amounts of fluorite, and trace amounts of pyrite were observed in heavy-mineral-concentrate samples. Arroyos in area 5 drain the east side of Black Mesa, a west-dipping mesa capped by postdetachment Miocene basalt. Upper plate volcanic and sedimentary rocks crop out along the east flank of the mesa (fig. 2). Cobbles of sandstone, conglomerate, vein quartz, biotite gneiss, muscovite schist, and granitic rocks were observed in drainages. A manganese prospect is present in the area (Ryan, 1989).

Samples from area 6 contain anomalous concentrations of gold, silver, barium, lead, tin, and thorium. Gold (700 ppm) and silver (70 ppm) were found in a single heavy-mineral-concentrate sample along the south edge of area 6. Abundant barite, and trace amounts of fluorite, pyrite, hematite pseudomorphs after pyrite, and paraschachnerite, a silver-mercury alloy, were observed in several samples in area 6. Bedrock in the area is almost exclusively Tertiary postdetachment basalt, although cobbles of lower plate mylonitic gneiss were observed in one drainage.

Interpretation

The strong anomalous concentrations of silver, arsenic, barium, copper, molybdenum, lead, antimony, tin, vanadium, tungsten, and zinc and slightly anomalous concentrations of bismuth, cobalt, iron, thorium, and gold and abundant ore-related minerals in heavy-mineral-concentrate samples from area 1 are likely related to mineralization associated with the Buckskin-Rawhide detachment surface, which crops out locally. The large extent of the geochemical anomaly relative to the mapped exposures of the detachment surface suggests that lower plate rocks are more mineralized here than elsewhere in the study area. A possible reason for more metal-rich lower plate rocks in area 1 is that these rocks may be erosional remnants of a relatively metal-rich zone that enveloped a detachment fault. In this model, the detachment fault would have been present prior to erosion a short distance above the bedrock outcrops in the area. Mineralization in lower plate rocks within this envelope may result from replacement, dissemination, or fracture filling in the lower plate gneisses immediately beneath the detachment fault, as described by Spencer and Welty (1989).

The anomalous concentrations of silver, arsenic, barium, cobalt, copper, lead, vanadium, tungsten, and zinc, slightly anomalous concentrations of molybdenum and thorium, and the ore-related minerals observed in heavy-mineral-concentrate samples in area 2 are similar to those found in area 1. The Buckskin-Rawhide detachment surface does not crop out in this area but crops out just outside the study area (fig. 2; Spencer, 1989). The carbonate-rich and chloritic gneiss observed in alluvium from area 2 indicates the proximity of a detachment surface. The sources of these geochemical anomalies and ore-related minerals in area 2 are likely similar to those postulated for area 1.

The anomalous concentrations of barium, copper, iron, and vanadium, slightly anomalous concentrations of arsenic, cobalt, and molybdenum, and ore-related minerals in area 3 are probably related to mineralized ground similar to that explored by shafts and adits in 2 of the 10 drainages included in the area. The anomalous concentrations of metals and ore-related minerals found within this relatively large area likely are due to a more widespread presence of mineralized rocks than the area presently indicated by known shafts and adits. The geochemical suite and ore-related minerals observed in area 3 are not so complete as those in areas 1 and 2, but nevertheless are likely the result of similar mineralizing processes during extensional faulting and subsequent high-angle faulting.

Weakly anomalous concentrations of silver, arsenic, and lead in area 4 are probably due to mineralizing processes like those in areas 1, 2, and 3. However, the relatively low-level concentrations of these metals, coupled with the paucity of ore-related minerals found in samples from area 4, suggest that mineralized rocks are not extensive at present levels of exposure.

The anomalous concentrations of barium, iron, manganese, nickel, lead, vanadium, and zinc and the slightly anomalous concentrations of silver, arsenic, lead, antimony, and thorium in area 5 may have at least three origins. One, much of the bedrock in the area is of basaltic composition, which tends to be enriched in many of the above metals. Two, the anomalous concentrations of metals may result from the adsorption of the metals onto manganese and iron oxides, as both manganese and iron are found in anomalous concentrations in the samples. These absorbed metals may reflect mineralization related to the Buckskin-Rawhide detachment fault, as manganese has been mined in upper plate rocks in the region. Three, unrecognized epithermal deposits may be present in and along the detachment fault. Pyrite and fluorite are found in heavy-mineral concentrate samples from this area, as they are in areas 1 and 2, where the detachment fault is proximal.

Barite in area 6 is likely derived from extensive outcrops of basalt in the area. However, the elevated concentrations of gold and silver in one heavy-mineral-concentrate sample, anomalous concentrations of lead in another heavy-mineral concentrate, and the presence of tin, thorium, and trace amounts of fluorite, paraschachnerite, and pyrite in several heavy-mineral-concentrate samples from the area are problematic. These metals and minerals are not generally associated with basalt. Further studies are necessary to determine the origin of the anomalous elements, pyrite, and fluorite in samples from basalt in area 6.

Malleable lead and paraschachnerite were observed in several heavy-mineral-concentrate samples, the former in samples from areas 1, 3, and 4, and the latter in samples from area 6. These occurrences are interpreted to be of anthropogenic origin and probably introduced during past mining activity from precious-metal recovery processes using mercury amalgamation and as solder from food cans or from lead shot.

Geophysical Studies

Aeromagnetics and Gravity

Aeromagnetic and gravity data for a region encompassing the Buckskin and Rawhide Mountains and including the Swansea Wilderness Study Area were compiled from available data sources. Two sources of aeromagnetic data were utilized: a survey of the Prescott, Arizona 1° by 2° quadrangle flown in support of the National Uranium Resource Evaluation (NURE) program and a survey of the Needles 1° by 2° quadrangle, California and Arizona, flown for the USGS (Western Geophysical Company, 1979; U.S. Geological Survey, 1981). The NURE traverses were made on east-west headings at spacings of 1 mi and a nominal height of 400 ft above ground. The USGS traverses were similarly on east-west headings but at 0.5-mi spacings and a nominal drape height of 1,000 ft. Gravity data were obtained from files of the Defense Mapping Agency (DMA) through the National Center for Solar-Terrestrial and Geophysical Data (Boulder, CO 80303). No new geophysical field work was performed for the present investigation.

The residual total-intensity aeromagnetic field for the 800-mi^2 region surrounding the Swansea Wilderness Study Area reveals three features pertinent to the study area (fig. 4). One, a striking contrast in magnetic expression is evident between the postdetachment volcanic rocks, chiefly basalts, that produce intense short-wavelength anomalies and the rocks affected by the extensional deformation that produce much more subdued and longer wavelength anomalies. The boundary between these two magnetic domains traces an arc across the region. The study area lies mostly east of the domain of short-wavelength anomalies. Two, in the terrane affected by the extensional deformation, the aeromagnetic data trace out long-wavelength, northeast-trending anomaly highs and lows that correspond approximately to the corrugations in the detachment terrane. In this terrane, the mylonitic rocks in the lower plate form the antiformal arches and the faulted rocks in the upper plate crop out in the synformal troughs (Spencer and Reynolds, 1989). `Metallic mineral deposits are most prevalent in the synformal troughs (Spencer and Welty, 1989). The magnetic highs crossing the study area overlie the mylonitic rocks in the lower plate, whereas the magnetic lows overlie

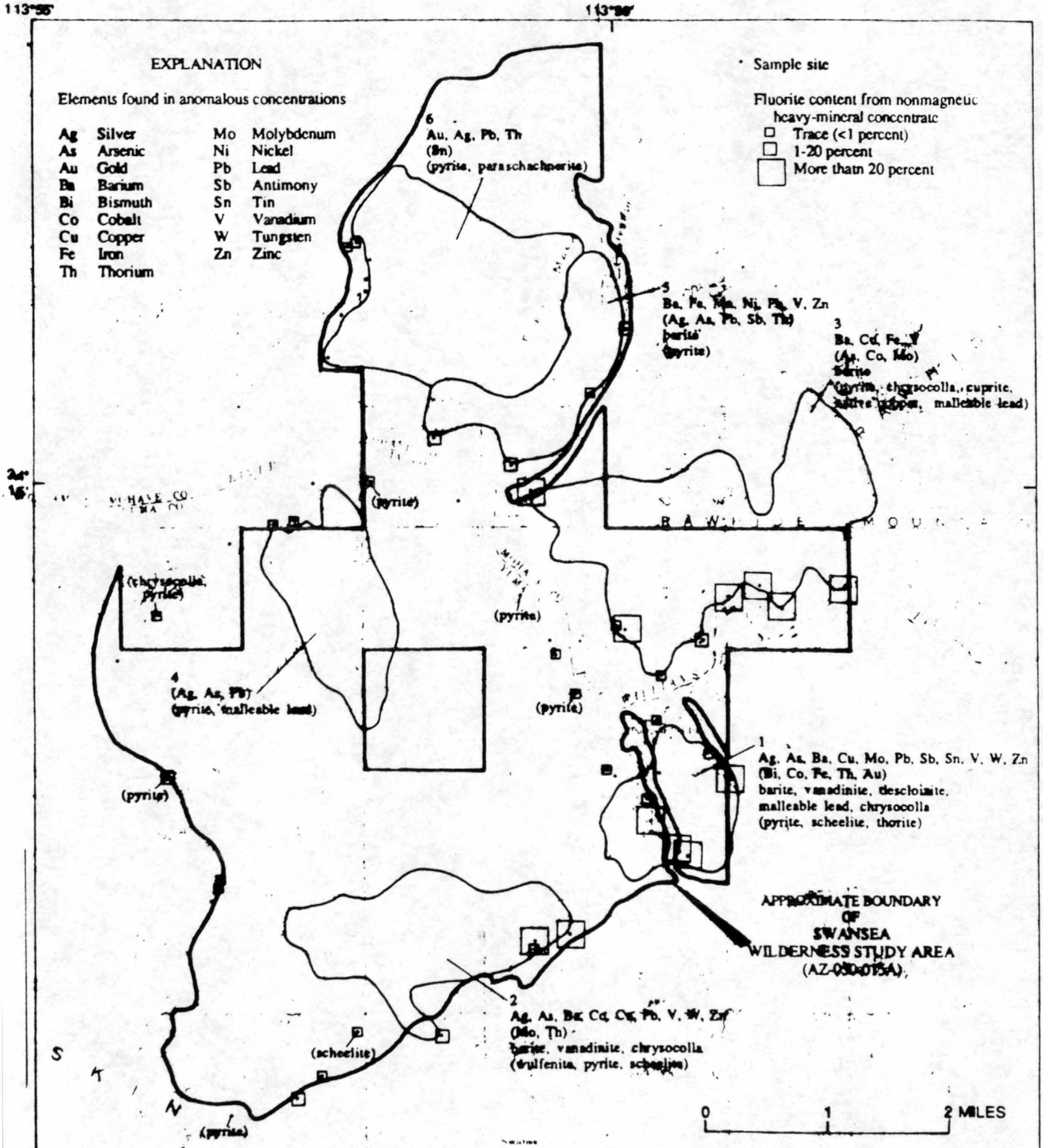

Figure 3. Geochemical anomalies from stream-sediment, heavy-mineral-concentrate, and rock samples from the Swansea Wilderness Study Area, La Paz and Mohave Counties, Arizona. Elements and minerals in parenthesis denote slightly anomalous concentrations. See text for discussion of anomalous areas 1–6. Contours are in feet.

Table 1. Summary data for elements found in anomalous concentrations in stream-sediment and heavy-mineral-concentrate samples in the Swansea Wilderness Study Area, Arizona

[Lower limits of analytical determination are shown in parentheses. N, not detected; L, detected but lower than determination limit; G, greater than upper determination limit; %, percent, *n*, number of determinations. Analyses are by emission spectrography except for elements with an "-a" suffix, which are by atomic absorption methods. Values are in parts per million unless noted otherwise.]

Element	Minimum	Maximum	50th percentile	Threshold	Number of samples above threshold
			Nonmagnetic heavy mineral concentrates (*n* = 55)		
Ag (1)	N	70	N	L	2
As (500)	N	1500	N	L	3
Au (20)	N	700	N	L	1
Ba (50)	5000	G(10,000)	1000	G(10,000)	16
Bi (20)	N	L	N	L	1
Cu (10)	N	7000	L	150	6
Mo (10)	N	100	N	L	4
Pb (20)	N	15,000	50	100	15
Sb (200)	N	500	N	L	2
Sn (20)	N	500	30	100	3
Th (200)	N	700	N	300	7
V (20)	20	10,000	100	700	7
W (50)	N	200	N	L	2
Zn (500)	N	5000	N	L	3
			Weakly magnetic heavy mineral concentrates (*n* = 55)		
Co (20)	30	300	100	200	8
Cu (10)	L	1500	100	500	9
Fe (0.1%)	3%	50%	10%	30%	6
La (100)	N	2000	500	1000	12
Mn (20)	700	5000	1000	5000	3
Mo (10)	N	30	L	15	7
Ni (10)	30	1000	70	200	9
Pb (20)	20	1000	70	150	10
Th (200)	N	300	L	200	4
V (20)	70	700	200	500	3
Zn (500)	N	700	N	L	1
			Stream sediments (*n* = 55)		
Ag (0.5)	N	1	N	L	13
As-a (5)	L	21	9	15	8
Ba (20)	200	2000	500	1500	6
Cu (5)	7	500	30	70	10
La (50)	L	200	70	150	8
Mo (5)	N	5	N	5	3
Nb (20)	N	50	L	30	4
Ni (5)	10	200	20	150	2
Pb (10)	20	300	30	70	7
Sb-a (2)	L	5	L	2	3
V (10)	20	500	50	150	1
Y (10)	15	100	30	70	7
Zn-a (5)	16	190	39	200	1

the extended upper plate rocks. Three, northwest-trending gradients within the aeromagnetic data cut across the northeast-trending highs and lows. Where these gradients overlie bedrock, they correspond to the northwest-trending high-angle faults, one of which crosses the southwestern part of the study area. These faults locally contain base- and precious-metal deposits, as in the Alamo and Owens mineral districts (Spencer and Welty, 1989)

The complete Bouguer gravity anomaly field computed from about 165 stations of the DMA set and terrain-corrected to 167 km (Hayford-Bowie zones A-O) for the region of the Buckskin and Rawhide Mountains is shown in figure 5. Across the area of the map is an unexplained nonuniform decrease in anomaly levels to the north-northeast. The steepest part of this gradient transects the study area. Superimposed on this gradient in the region are broad lows that roughly correspond to areas of Tertiary volcanic rocks in the upper plate of the detachment fault.

Remote Sensing

Digital image data acquired by the Thematic Mapper (TM) system on the Landsat-4 satellite (Scene I.D. 40174-17383) were analyzed to detect and map areas that may contain hydrothermally altered rocks. The six bands of image data in the visible and near-infrared range were digitally processed to enhance spectral characteristics of minerals that often accompany alteration or are derived from the weathering of altered rocks. Visual interpretation of a vegetation-masked TM color-ratio composite consists of identifying concentrations of limonite (Group 1), hydroxyl-bearing and (or) hydrated minerals (Group 2), and areas where both groups of minerals occur together (Group 3). Identification of the different groups is based on the spectral responses of the different limonitic minerals in the TM bands (Hunt and Salisbury, 1971, Hunt and Ashley, 1977; Raines, 1977).

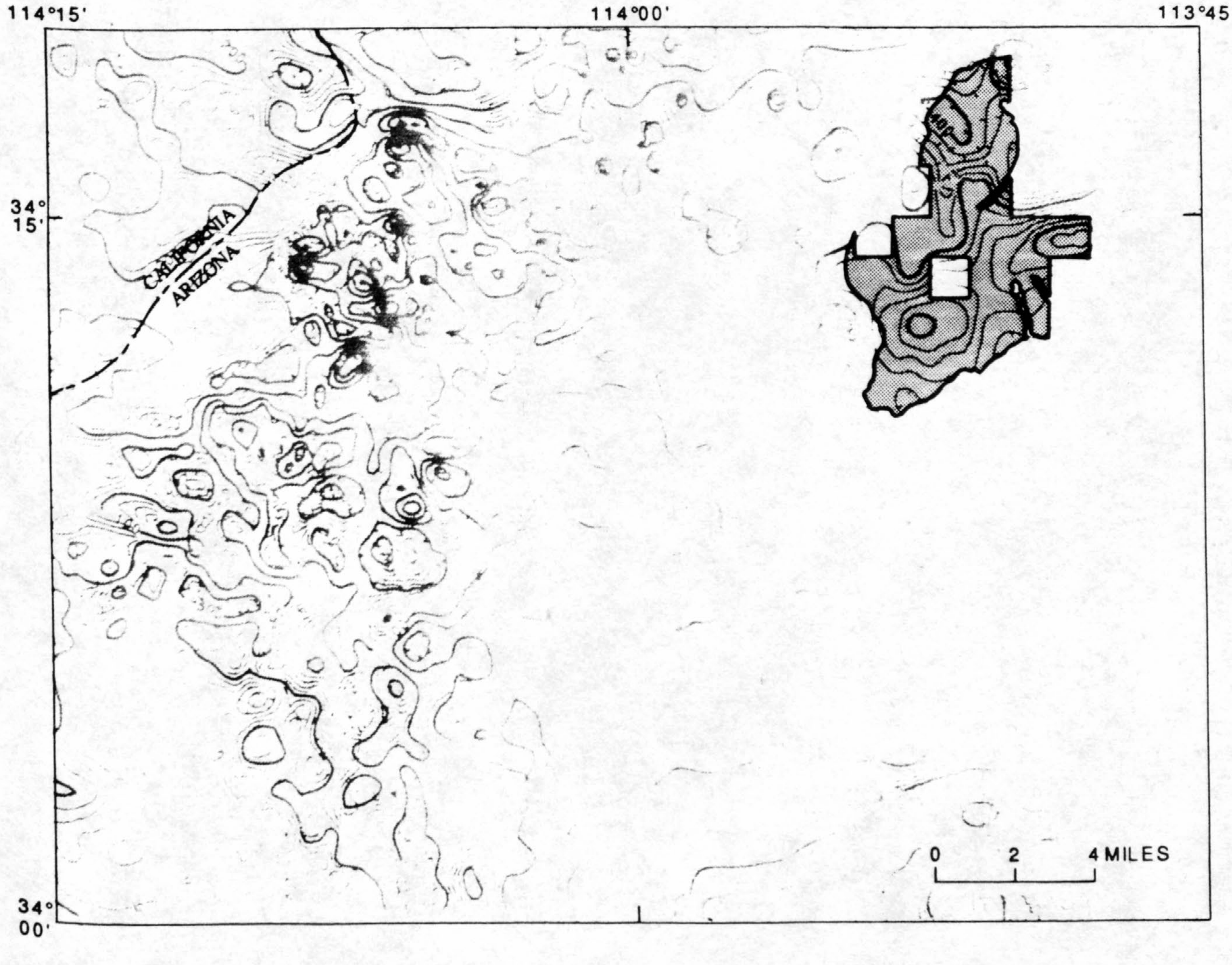

Figure 4. Aeromagnetic anomaly map of the Swansea Wilderness Study Area, La Paz and Mohave Counties, Arizona (shaded). Contour interval, 20 nanoteslas; hachured in direction of magnetic low.

That part of the Swansea Wilderness Study Area south of a line that projects continuously southwestward from Centennial Wash (fig. 2) contains a fairly uniform distribution of limonite or limonite-group minerals (Group 1). This area is also underlain almost entirely by subhorizontally layered mylonitic mafic and less common granitic gneiss in the lower plate of the Buckskin-Rawhide detachment fault. The limonitic minerals are inferred to be related to the distribution and weathering of the mylonitic gneiss and not to reflect hydrothermal alteration.

Radioelement Distribution

Natural radioelement distribution in the Swansea Wilderness Study Area was evaluated by examination of available data from an aerial gamma-ray spectrometric survey of the Prescott 1° by 2° quadrangle (Western Geophysical Company, 1979). The survey acquired aerial gamma-ray spectrometry data along 1-mi-spaced east-west flightlines at 400 ft above ground level. Nine lines cross the study area and provide about 15 percent ground coverage, because an aerial gamma-ray system at 400 ft above ground level effectively measures terrestrial gamma radiation from a swath 800 ft wide along flightline. The 15 percent coverage represents a reconnaissance sampling of the near-surface (0-18 inches depth) distribution of the natural radioelements potassium (K), equivalent uranium (eU), and equivalent thorium (eTh). The prefix e for equivalent denotes the potential for disequilibrium in the uranium and thorium decay series.

Examination of preliminary radioelement contour

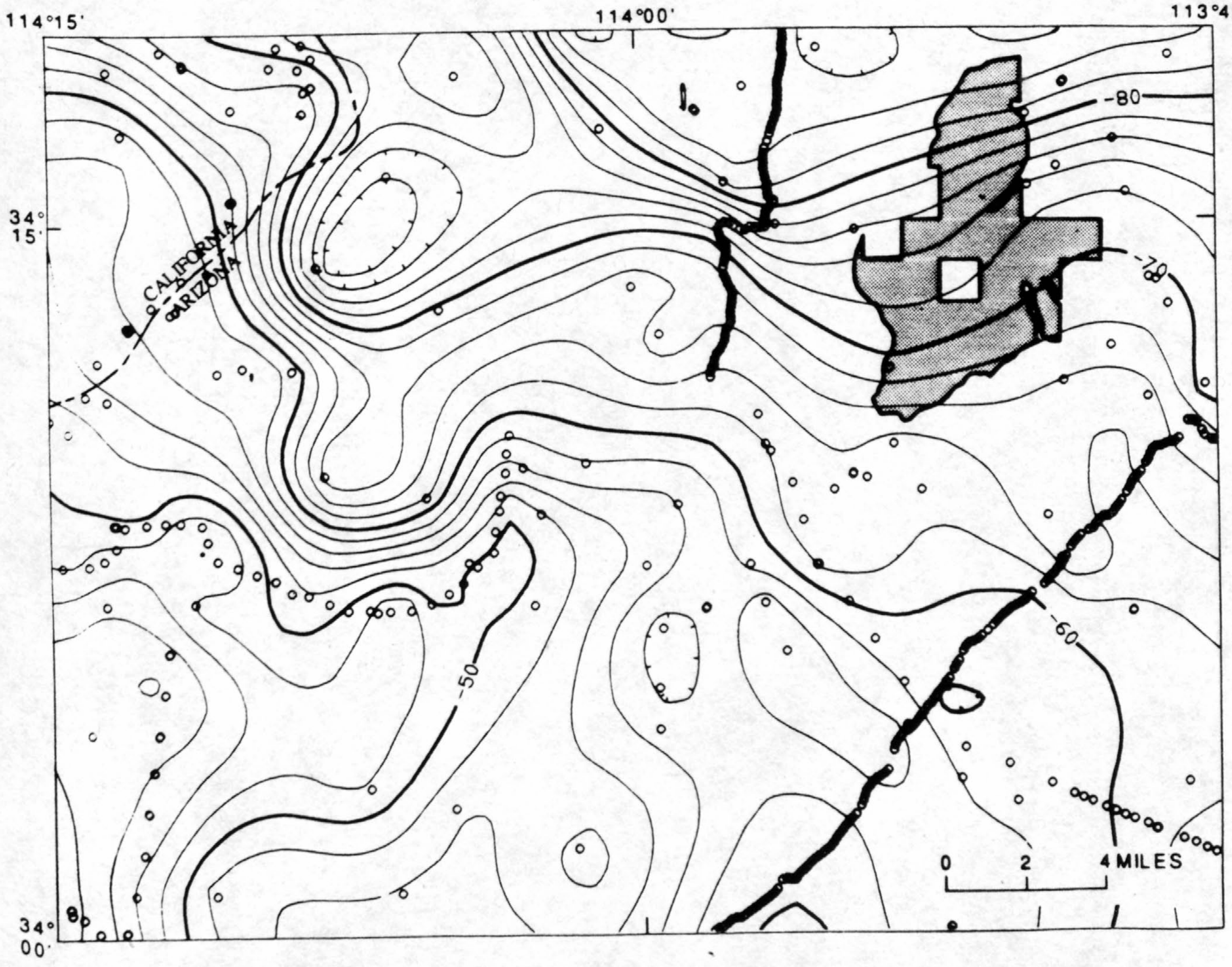

Figure 5. Bouguer gravity anomaly map of the Swansea Wilderness Study Area, La Paz and Mohave Counties, Arizona (shaded). All data reductions and terrane corrections employed a standard Bouguer density of 2.67 g/cm³ and followed conventional U.S. Geological Survey procedures (for example, Cordell and others, 1982). Contour interval, 2 mGals; hachured in direction of closed low; circle, gravity stations.

maps that include the Swansea Wilderness Study Area indicates that differing radioelement concentrations characterize the northern and southern parts of the study area. Generally, in terranes where crystalline rocks predominate, higher radioelement concentrations relate to more silicic, more radioactive rocks and the detritus derived from them. Lower concentrations relate to less silicic, less radioactive rocks and detritus derived from them. The northern part of the study area has relatively lower concentrations of 0.5 to 1.5 percent K, 2 to 4 ppm eU, and 10 to 15 ppm eTh, which reflect the presence of less radioactive Miocene basalt. The southern part has relatively higher concentrations of 1.5 to 2.0 percent K, 4 to 6 ppm eU, and 15 to 20 ppm eTh, which reflect the presence of more silicic, more radioactive mylonitic gneiss. For the study area as a whole, the radioelement concentrations of 0.5 to 2 percent K, 2 to 6 ppm eU, and 10 to 20 ppm eTh are thought to be usual (not anomalous) levels for the rock types present.

Mineral Resource Assessment

The assessment of the mineral resource potential of the Swansea Wilderness Study Area draws upon regional geology, geochemistry, geophysics, mineral occurrence maps, mining claim records, and the available ore deposit models that are applicable to the geologic terrane in the study area. These data were used to delineate favorable tracts within the study area, and an estimate of the level of resource potential and degree of certainty for each tract was made using the criteria outlined in the appendixes. Throughout this discussion, mineral resource potential refers only to undiscovered mineral resources.

Areas of potential for gold, silver, base metals, manganese, uranium, and vanadium resources are present in the study area. These are outlined on figure 2 and are discussed below. Applicable metallic ore deposit models for the study area include detachment fault-related base- and precious-metal deposits (Wilkins and Heidrick, 1982; Wilkins and others, 1986; Spencer and Welty, 1986, 1989), stratabound and fault-controlled manganese deposits (Cox and Singer, 1986; Spencer and Welty, 1985), and stratabound uranium and vanadium deposits (Sherborne and others, 1979; Otton, 1981; Spencer and Welty, 1985).

Base and Precious Metals

Base- and precious-metal mines and prospects in and adjacent to the Swansea Wilderness Study Area have been worked intermittently since the late 1800's. The mineral occurrences are of epithermal origin. The mines are developed in replacement deposits in carbonate rocks and in epithermal veins in low- and high-angle faults in and above the Buckskin-Rawhide detachment fault (Swansea, Planet, and Mesa mineral districts) (Wilkins and Heidrick, 1982; Welty and others, 1985; Spencer and Welty, 1989). Other mines are developed along veins in high-angle faults in lower-plate mylonitic gneiss (Owens mineral district) (Spencer and Welty, 1989).

Based on the known occurrences within the entire region, all areas along the high- and low-angle faults, particularly where reactive (carbonate) rocks are present, are assigned a moderate potential with a certainty level of C for gold, silver, copper, lead, and zinc. These areas are in the northern and southern parts of the study area (fig. 2). Geochemical data support this assignment. Areas of high potential with a certainty level of C for gold, silver, copper, lead, and zinc are assigned to areas adjoining known mineral occurrences. These areas include the Owens mineral district within the study area and the area in the southeast where the Buckskin-Rawhide detachment fault crops out (fig. 2). The central part of the study area is assigned a low potential with a certainty level of B for these elements.

Manganese

Mines in the Mesa mineral district in the northern part of the Swansea Wilderness Study Area and to the east in the Black Burro, Lincoln Ranch, and Artillery mineral districts (fig. 1) have produced manganese (Keith, 1978; Keith and others, 1983a, b). The manganese deposits are in upper plate Tertiary rocks either along high-angle faults or as stratabound deposits (Lasky and Webber, 1949; Spencer and others, 1989). Upper plate Tertiary rocks are present only in small areas in the study area. The area around the Mesa mineral district in the northern part of the study area is assigned a high potential for manganese with a certainty level of D based on the presence of anomalous concentrations of manganese and the evidence of local past production.

Tertiary rocks in the southeastern part of the study area are assigned a low potential for manganese with a certainty level of C based on the presence of permissive rocks and structures (fig. 2). A moderate or high potential for this area is unwarranted because there is no evidence for any manganese in these rocks, either in outcrop or in the geochemical data.

Uranium and Vanadium

The Anderson uranium-vanadium mine in the Date Creek Basin, 30 mi east of the Swansea Wilderness Study Area, is in fine-grained sedimentary and volcanic rocks assigned to the middle Tertiary Chapin Wash Formation (Sherborne and others, 1979; Otton, 1981; Spencer and Welty, 1985). These rocks are broadly correlative with the upper plate Tertiary volcanic and sedimentary rocks near the study area, though correlations between the two rock sections are uncertain (Spencer and Reynolds, 1989). The presence of permissive rock units and anomalous concentrations of vanadium in heavy-mineral-concentrate samples indicate that these areas should be assigned a low resource potential with a certainty level of B (fig. 2).

Oil and gas

No resource potential exists for oil and gas in the Swansea Wilderness Study Area because of the lack of hydrocarbon-bearing rocks, because the generally thin sections of unmetamorphosed rock are structurally bounded at shallow depths and are underlain by mylonitic rocks that were metamorphosed at midcrustal depths, and because much of the exposed terrane is underlain at the surface by metamorphic rocks.

Sand and gravel

Quantities of sand and gravel are available in the Swansea Wilderness Study Area as unconsolidated to poorly consolidated alluvial deposits in washes and along the Bill Williams River. These deposits, however, contain no unique characteristic that make them more attractive than areas closer to population centers (Ryan, 1989).

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

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

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

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

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

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

LEVELS OF CERTAINTY

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

LEVEL OF RESOURCE POTENTIAL →

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

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

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

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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.