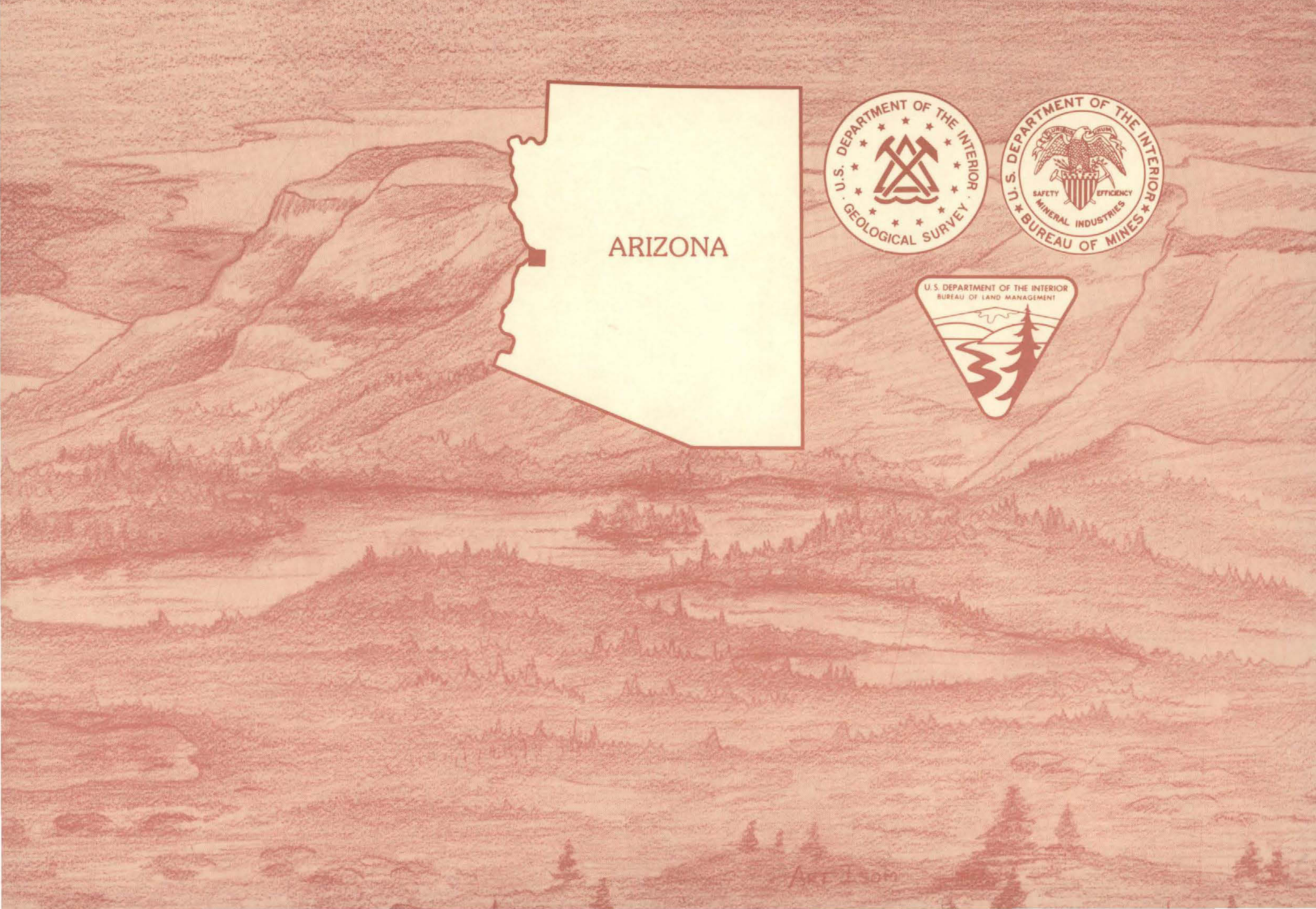
Mineral Resources of the Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1704-D



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Chapter D

Mineral Resources of the Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

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U.S. GEOLOGICAL SURVEY BULLETIN 1704

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
HAVASU REGION, ARIZONA

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

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

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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 Cactus Plain (AZ–050–014–A/B) and East Cactus Plain (AZ–050–017) Wilderness Study Areas, La Paz County, Arizona.

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Mineral Resources of the Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

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SUMMARY

Abstract

The Cactus Plain (AZ–050–014–A/B) and East Cactus Plain (AZ–050–017) Wilderness Study Areas are in west-central Arizona, about 4 mi southeast of Parker, Arizona. At the request of the U.S. Bureau of Land Management, a mineral survey of approximately 79,065 acres was conducted by the U.S. Geological Survey and U.S. Bureau of Mines to appraise their identified mineral resources (known) and to assess their mineral resource potential (undiscovered). In this report, "study area" refers collectively to both wilderness study areas for which a mineral survey was requested by the U.S. Bureau of Land Management.

The southeastern corner of the Cactus Plain Wilderness Study Area is within the northern part of the Plomosa mining district (Northern Plomosa and Bouse mineral districts). The northeastern corner of the East Cactus Plain Wilderness Study Area is in the Midway mining district. The Cienega and Santa Maria mining districts are within 8 mi and lie north of the study area. Gold, silver, copper, and minor amounts of lead, zinc, manganese, barite, and fluorite have been produced from these districts, though no production is reported from mines located within the study area. There are no identified metallic resources in the study area.

The Cactus Plain and East Cactus Plain Wilderness Study Areas have high resource potential for gold, silver, copper, lead, and zinc. An area in the southeastern part of the Cactus Plain Wilderness Study Area has high resource potential for barite and fluorite. Another in the northwestern part of Cactus Plain Wilderness Study Area has moderate resource potential for barite. These same two areas of Cactus Plain Wilderness Study Area also have moderate resource potential for manganese as well as low resource potential for uranium and beryllium. The entire study area has low resource potential for bentonitic clay. The southern three-quarters of the East Cactus Plain Wilderness Study Area and the northern half of the Cactus Plain Wilderness Study Area have high resource potential for sand suitable for foundry, fracturing, and abrasive uses. The study area has no resource potential for oil and gas.

Manuscript approved for publication, August 27, 1990.

Character and Setting

The Cactus Plain (AZ–050–014–A/B) and East Cactus Plain (AZ–050–017) Wilderness Study Areas are approximately 4 mi southeast of Parker, Ariz., and include approximately 79,065 acres of a gentle plain partly covered by sand dunes (fig. 1). Isolated bedrock knobs protrude above the plains and dunes. Elevations within the study area rise from about 700 ft above sea level on the west to about 1,500 ft on the east. The plain is surrounded by mountain ranges, including the Buckskin Mountains on the north and northeast, the Bouse Hills on the southeast, and the Plomosa Mountains on the south. The Colorado River lies about 4 mi to the northwest. Ephemeral washes drain from the study area into Osborne Wash on the north and Bouse Wash on the south. The Central Arizona Project Canal separates Cactus Plain Wilderness Study Area from East Cactus Plain Wilderness Study Area.

The study area lies in the highly extended terrane of west-central Arizona, immediately west and south of middle Tertiary metamorphic core complexes (Rehrig and Reynolds, 1980). Most ranges in this region are fringed by low-angle normal faults of regional extent, known as detachment faults, that accommodated large-scale extensional deformation in the late Oligocene and Miocene (Davis and others, 1980; Spencer and Reynolds, 1986, 1989a, 1989b; Davis, 1988) (see "Appendixes" for geologic time chart). Detachment faults near the study area include the Buckskin-Rawhide detachment fault that is exposed discontinuously near the north and east borders of the study area (fig. 2) and the Plomosa detachment fault that crops out in the northern Plomosa Mountains along the south border of the Cactus Plain Wilderness Study Area. Still farther west, the Moon Mountains detachment fault is exposed on the north flank of the Moon Mountains (fig. 1) and dips northeastward beneath the western part of the Cactus Plain Wilderness Study Area.

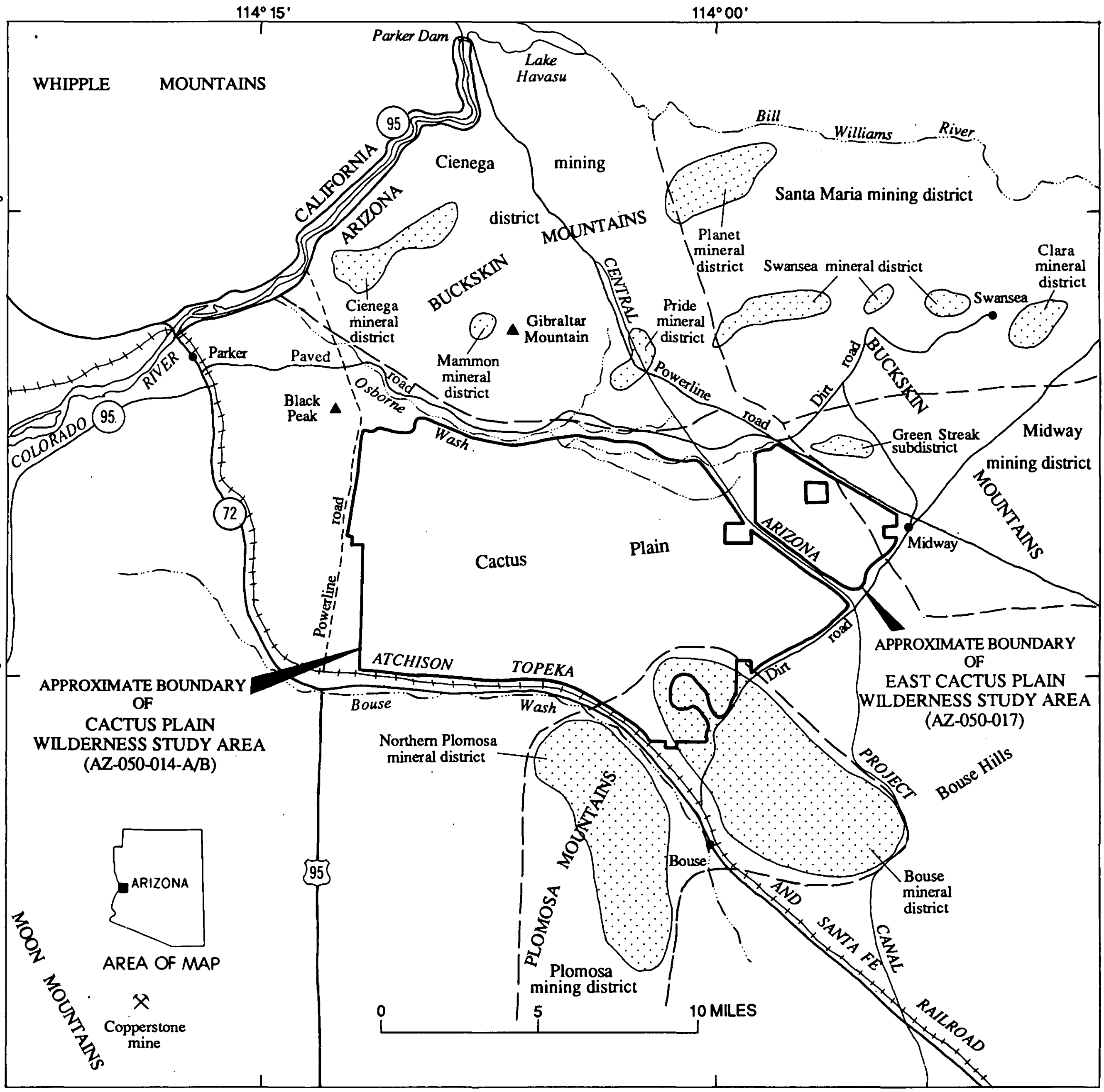


Figure 1. Index map showing location of Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona. Also shown are approximate boundaries of mining districts (dashed lines) as defined by Keith (1978) and their subdivision into mineral districts and subdistricts (patterned areas) by Keith and others (1983a, b) and Spencer and Welty (1989).

Detachment faults divide the bedrock geology of the adjoining mountain ranges into two parts; these are an extended upper plate of Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic, igneous, and sedimentary rocks and a lower plate of Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic and igneous rocks. Sedimentation and volcanism accompanied extension, and these syntectonic rocks now crop out in the highly faulted upper plate (Davis and others, 1980; Spencer and Reynolds, 1989b). Extensional deformation was followed by basaltic volcanism and locally silicic volcanism in the Miocene (Davis and others, 1980; Suneson and Lucchitta, 1983; Grubensky, 1989). Conglomerate and sandstone are interbedded with and overlie the basaltic rocks. In the late Miocene and continuing into the Pliocene and perhaps the Pleistocene, the low areas were flooded by marine waters in which the sedimentary strata of the Bouse Formation were deposited (Metzger, 1968; Buising, 1987). The Bouse Formation, the dominant rock unit at the surface in the study area, overlies unconformably the rocks that underwent extensional deformation in the middle Tertiary.

Detachment faults, associated syntectonic basins, and younger high angle faults are important controls on the distribution of mineral resources in the region (Welty and others, 1985; Spencer and Welty, 1986, 1989). Mineral exploration in western Arizona and southeastern California has demonstrated the association of these rocks and geologic structures to various types of deposits (Sherbourne and others, 1979; Wilkins and Heidrick, 1982; Wilkins and others, 1986; Spencer and others, 1988; Wilkinson and others, 1988; Lehman and Spencer, 1989). In the Cactus Plain and East Cactus Plain Wilderness Study Areas, the Miocene basalt, the Bouse Formation, and the Quaternary eolian and alluvial deposits unconformably overlie the highly extended terrane and effectively conceal any metallic deposits that may be present.

Mineral Resource Potential and Identified Resources

Most of the mineral deposits in the region of the Cactus Plain and East Cactus Plain Wilderness Study Areas are located within the intensely faulted rocks that lie in the upper plates of detachment faults (Spencer and Welty, 1989). Less common metallic deposits are found in the mylonitic rock of the lower plate close to the detachment fault (Spencer and Welty, 1989). Upper and lower plate rocks are buried beneath the unconformably overlying late Tertiary sedimentary and volcanic rocks in the study area. This extensive cover hinders the assessment of mineral resource potential of the study area. Despite this limitation, the projection of structures and rock types into the study area, the knowledge of the location of deposits in the region, past mining activity, and the geochemical and geophysical data gathered during this study allow for a mineral resource assessment of the study area. This assessment does not indicate that deposits are actually present or that they are sufficiently near the surface to be accessible. Only with additional work can actual deposits be located.

Geochemical and geophysical data from the study areas indicate that three areas have high resource potential with a high degree of certainty for gold, silver, copper, lead, and zinc, whereas the remainder of the study area has high resource potential with a lower degree of certainty for these elements. The three specific areas lie along the northeast border of the East Cactus Plain Wilderness Study Area and in the northwestern part and southeastern part of the Cactus Plain Wilderness Study Area. An area in the southeastern part of Cactus Plain Wilderness Study Area has high resource potential for barite and fluorite, and another area in the northwestern part of Cactus Plain Wilderness Study Area has moderate resource potential for barite; these two areas also have moderate resource potential for manganese and low resource potential for uranium and beryllium. The entire study area has low resource potential for bentonitic clay. The southern three-quarters of the East Cactus Plain Wilderness Study Area and the northern half of the Cactus Plain Wilderness Study Area have high resource potential for sand suitable for foundry, fracturing, and abrasive uses. The entire study area has no resource potential for oil and gas. No identified resources are present 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). 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. Definition of levels of mineral resource potential and certainty of assessment and the resource/reserve classification are included in the "Appendixes."

Location and Physiography

The Cactus Plain (AZ–050–014–A/B) and East Cactus Plain (AZ–050–017) Wilderness Study Areas are approximately 4 mi southeast of Parker, Ariz., and include approximately 79,065 acres on a gentle plain. Isolated bedrock knobs protrude above the plain. Elevations within the study areas rise from about 700 ft above sea level on the west to about 1,500 ft on the east. The plain is surrounded by mountain ranges, including the Buckskin Mountains on the north and northeast, Bouse Hills on the southeast, and Plomosa Mountains on the south. The Colorado River lies some 4 mi to the northwest (fig. 1). Ephemeral washes drain from the study area into Osborne Wash on the north border and Bouse Wash on the south border. The Central Arizona Project Canal separates Cactus Plain Wilderness Study Area on the west from East Cactus Plain Wilderness Study Area on the east.

Access to the Cactus Plain Wilderness Study Area is from Arizona Highway 72 on the south, a poorly maintained sand road that parallels a powerline along the west border, a paved road along Osborne Wash on the north, the service road for the Central Arizona Project Canal along the northeast, and from maintained dirt roads between Bouse and Swansea along the southeast border of the study area (fig. 1). The Atchison, Topeka, and Santa Fe Railroad borders the Cactus Plain Wilderness Study Area on the south. Access to the East Cactus Plain Wilderness Study Area is also from the service road for the Central Arizona Project Canal along the southwest, from maintained dirt roads between Bouse and Swansea on the southeast and between the Osborne Wash road and Swansea on the north, and by a service road to a powerline along the northeast border (fig. 1).

Previous Work

Early descriptions of the rock types and various mineral deposits in the region are found in Lee (1908), Bancroft (1911), and Jones and Ransome (1920). Jemmet (1966) mapped the northern Plomosa Mountains. Fernandez (1965) and Zambrano (1965) studied mines in the Buckskin Mountains immediately north of the study area. Geologists from the Arizona Geological Survey have studied the geology and setting of the mineral occurrences in the region (Keith, 1978; Scarborough and Wilt, 1979; Keith and others, 1983a, b; Welty and others, 1985; Spencer and Welty, 1986, 1989; Spencer and Reynolds, 1989a; Grubensky, 1989) and their work has been invaluable for this study. Field studies of extensional deformation in the Whipple Mountains and parts of the Buckskin Mountains are also important sources of information (Davis and others, 1980; Frost, 1981, 1983; Marshak and Vander Meulen, 1989). The Bouse Formation was first studied by Metzger (1968) as part of a hydrologic study of the Colorado River area (Metzger and others, 1973). Buising (1987) defined the stratigraphy and paleoenvironment of the Bouse Formation in more detail.

Keith (1978), Keith and others (1983a, b), and Spencer and Welty (1989) defined the mining and mineral districts throughout the region and their nomenclature is used herein. Areas outside the study area have been explored for precious metal and uranium-vanadium deposits (Sherbourne and others, 1979; Wilkins and Heidrick, 1982; Wilkins and others, 1986; Spencer and others, 1988; Lehman and Spencer, 1989) and the results of this work are applicable to the mineral resource potential of the study area.

Methods

The U.S. Geological Survey conducted detailed field investigations of the Cactus Plain and East Cactus Plain Wilderness Study Areas in 1986 and 1988. This work included geologic mapping at scales of 1:24,000, geochemical sampling, and the examination of outcrops for evidence of mineralization. The geochemical survey, conducted between September 21 and 27, 1988, included collection of rocks and stream sediments from areas of bedrock older than the Bouse Formation and Quaternary eolian deposits, the sedimentary rocks and deposits that cover much of the study area. Biogeochemical sampling in areas of the younger sedimentary rock and deposits was necessary for assessing the possibility of buried metallic deposits beneath these units. Available regional gravity, aeromagnetic, and aerial gamma-ray spectrometry surveys were also used in the assessment.

U.S. Bureau of Mines personnel obtained minerals information from published and unpublished literature, U.S. Bureau of Mines files, and mining claim and oil and gas lease records at the U.S. Bureau of Land Management State Office in Phoenix. Fieldwork consisted of a search for mines and prospects and the examining and sampling rock outcrops and unpatented mining claims in and near the study area.

Acknowledgments

This work was supported by the National Mineral Resource Assessment Program of the U.S. Geological Survey. Discussions with the J.E. Spencer and S.J. Reynolds of the Arizona Geological Survey improved our understanding of the geology of the area. J.E. Spencer kindly provided his geologic mapping of the Buckskin Mountains for use in this report. Special thanks are extended to Tom Peacock for preparation of plant samples for geochemical analysis and to Diana Mangan for preparation of the figures.

APPRAISAL OF IDENTIFIED RESOURCES

By Terry J. Kreidler
U.S. Bureau of Mines

U.S. Bureau of Mines personnel reviewed sources of minerals information, including published and unpublished literature, U.S. Bureau of Mines files, and mining claim and oil and gas lease records at the U.S. Bureau of Land Management State Office in Phoenix. Discussions on the mineral resources of the study areas were held with U.S. Bureau of Land Management personnel at the District Office in Yuma and the resource area office in Lake Havasu City, Ariz.

Fieldwork, completed in 16 employee-days, consisted of examining and sampling rock outcrops and unpatented mining claims in and near the study area. Thirteen samples were taken: eight rocks, two stream sediment, one panned concentrate, and two dune sand. Six samples were analyzed for gold and silver by fire assay and six by inductively coupled plasma–atomic emission spectroscopy for copper, lead, zinc, barium, and arsenic. The dune-sand samples were analyzed for silica and other elements that affect the suitability for glass manufacture and other industrial uses. Kreidler (1986, 1987) presents more detail on most aspects of this study. 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 Activity

The Cactus Plain and East Cactus Plain Wilderness Study Areas are surrounded by four mining districts (table 1, fig. 1). The northeastern corner of the East Cactus Plain Wilderness Study Area is in the Midway mining district. This district contains gold, silver, and copper in spotty deposits along faults and fractures in mylonitic gneiss, schist, marble, and calc-silicate rocks of Proterozoic and Mesozoic protolith age. The Cienega mining district (7.5 mi north of Cactus Plain Wilderness Study Area) produced gold, silver, copper, and minor amounts of lead from ore occurring as replacement deposits in weakly metamorphosed Paleozoic and Mesozoic limestone, shale, and quartzites, which structurally underlie Proterozoic gneiss in places. The Santa

Table 1. Summary of production data for mineral districts within the mining districts in the region surrounding Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

[Data from Keith (1978), Keith and others (1983b), and Spencer and Welty (1989). Gold and silver given in troy ounces, copper, lead, and zinc given in short tons of ore. Mn, manganese; –, not applicable]

Mineral district	When active	Production data					
		Gold	Silver	Copper	Lead	Zinc	Other
Cienega mining district							
Cienega.....	1880-1969	12,011	1,596	857	—	—	—
Mammon...	1880-1969	60	142	42.5	—	—	—
Pride..........	1911-1912	100	4,000	0.01	—	—	—
Midway mining district							
Midway.....	Early 1900's to present.	45	35	4.7	—	—	—
Plomosa mining district							
Plomosa....	Intermittently since 1860's.	25,000	129,200	526	344	65	—
Bouse........	1928-1930	100	—	6.5	—	—	9,000 tons Mn; 2,700 tons barite.
Santa Maria mining district							
Clara..........	Intermittently early 1900-1955.	35	1,738	2,335	—	—	—
Planet........	Intermittently since 1860's.	317	268	9,752	—	—	—
Swansea....	Intermittently since 1860's.	507	33,112	13,200	—	—	400 tons Mn ore.

Maria mining district (5 mi north of East Cactus Plain Wilderness Study Area) produced gold, silver, and copper from ore in massive to lensing iron-oxide replacement bodies in Paleozoic and Mesozoic metasedimentary rocks. The Plomosa mining district includes the Black Mountain mine, which lies adjacent to the southern part of Cactus Plain Wilderness Study Area, and base- and precious-metal mines in the northern Plomosa Mountains, a few miles south. The district produced gold, silver, copper, lead, zinc, manganese, and barite from veins and irregular bodies in Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic and sedimentary rocks. As of June 1990, mines within 4 to 5 mi of the study area were inactive. However, the Copperstone mine, some 10 mi southwest of Cactus Plain Wilderness Study Area, is active and is one of the largest producing gold mines in Arizona (Spencer and others, 1988).

A mining district is delineated on the basis of mineral occurrence locations and most production records and early literature use these districts as a means of categorizing information. Keith and others (1983b) arranged the mineral occurrences of Arizona into mineral districts on the basis of geologic criteria of metallogenic systems of similar age and style of mineralization. A single mining district may contain more than one mineral district. The Cienega mining district, for example, includes the Cienega, Mammon, and Pride mineral districts; the Santa Maria mining district includes the Clara, Planet, and Swansea mineral districts; the Plomosa mining district includes the Northern Plomosa and Bouse mineral districts; the Midway mining district includes the Green Streak subdistrict of the Midway mineral district. See figure 1 for location of mining and mineral districts.

Mining claims have been located near the study area in the Cienega, Midway, and Plomosa mining districts, and at least eight claims have been staked on Black Peak, 1 mi northwest of Cactus Plain Wilderness Study Area. U.S. Bureau of Land Management claim records list 15 unpatented claims that are in the Cactus Plain Wilderness Study Area. As of September 1987, no claims were located in the East Cactus Plain Wilderness Study Area. No visible evidence of any recent mining activity was found on any of the claims.

Energy Resources

About 50,000 acres of the study area are covered by oil and gas leases. Ryder (1983, p. C19), however, rates the oil and gas resource potential of the study areas as low because the organic richness, reservoir quality, and thermal history of the rocks are not conducive to the formation of significant volumes of hydrocarbons. The leasing is probably a result of speculation that the hydrocarbon-rich overthrust belt, which produces large quantities of oil and gas in Wyoming, extends southward into Arizona (Keith, 1979, p. 10). To date, all exploratory drilling in Arizona testing this theory has had negative results (Reif and Robinson, 1981). As of September 1986, the leases in the study area had not been drilled or tested, but in 1985, Petty-Ray Geophysical Co. ran a seismic line a few miles north and east of the area; the results of the survey are proprietary.

Resource Appraisal

No metallic mineral resources were identified in the study area. The middle Tertiary and older rocks that crop out in the study area are only sparsely mineralized. Samples taken in and near the study area contain insignificant amounts of gold, silver, copper, lead, and zinc, except for one sample, which is from Tertiary sandstone and conglomerate on the flank of Black Peak outside the northwest corner of the Cactus Plain Wilderness Study Area. This sample (table 2, sample 1) contains concentrations of lead and zinc several times the background level.

At the Green Streak mine, about 1 mi northeast of the East Cactus Plain Wilderness Study Area (fig. 2), oxidized copper minerals occur locally in a quartz vein, trending N. 35° W. and dipping 55° NE., in gneiss and schist in the lower plate of the Buckskin-Rawhide detachment fault. Workings consist of two shafts, about 35 ft and 100 ft deep, an adit, and several prospect pits and trenches; the mine accounts for nearly all the recorded production from the Midway district. Samples from the mine area contain 0.74 to greater than 2 weight percent (or 7,443 to greater than 20,000 parts per million, ppm) copper and 0.4 to 1.87 ppm gold, and anomalous concentrations of silver (table 2). Because of the spotty, discontinuous nature of the mineralized rock, no base- or precious-metal resource was identified. Barium concentrations in the three mine samples are 0.15 to greater than 3 weight percent or 1,500 to greater than 30,000 ppm (table 2) higher than the average of 425 ppm (0.043 weight percent) for metamorphic rocks (Levinson, 1980, p. 865). No barite, a barium mineral, was identified.

In the Cactus Plain Wilderness Study Area, barium and arsenic values in the three basalt and two sandstone samples are higher than average for their respective rock types. Sample values (table 2) ranged from 1,200 to 8,000 ppm barium and 30 to 50 ppm arsenic (the 130 ppm value for sample 7 is suspect). Average contents for similar rock types are: barium, 250 ppm for basalt and 10 to 100 ppm for sandstone; arsenic, 2 ppm for basalt and 1 ppm for sandstone (Levinson, 1980, p. 864–865).

Barium is highly mobile in mineralizing systems and is commonly associated with lead-zinc-silver deposits; its distribution often extends several miles from a deposit (Levinson, 1980, p. 865). In the northern part of the Plomosa mining district, barite is a common by-product in the silver-copper-lead-zinc ores and is found with fluorite in volcanic agglomerate at the Black Mountain mine adjacent to the southeastern part of the Cactus Plain Wilderness Study

Table 2. Geochemical data for samples from Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

[Gold and silver determined by fire assay, all other elements by inductively coupled plasma-atomic emission spectroscopy. —, not detected; na, not analyzed; <, less than given value; ppm, parts per million; ppb, parts per billion. Complete analytical tables and location of samples are available in Kreidler (1986, 1987)]

Sample no.	Au (ppb)	Ag (ppb)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ba (ppm)	As (ppm)	Description
Stream-sediment and rock samples								
1	na	na	30	400	500	3,700	50	Iron-stained sandstone and conglomerate; collected on flank of Black Peak.
3	na	na	7.9	32	180	8,000	30	Iron-stained sandstone and conglomerate.
4	—	3,500	na	na	na	na	na	Material from wash draining east side of Black Peak.
6	na	na	41	<10	120	3,700	32	Scoriaceous basalt, capped by limestone.
7	na	na	21	27	31	6,200	130	Do.
8	na	na	6.9	<10	170	1,200	30	Do.
Green Streak mine								
1	608	1,500	7,443	7	72	1,500	—	select
2	400	6,400	>20,000	9	78	>30,000	3	chip
3	1,870	600	15,392	56	107	25,500	4	select

Area (fig. 2). Thus, the barium enrichment described previously could be an alteration halo related to the mineralization that took place in the Plomosa mining district. No evidence of a barite deposit was found in the study area.

Arsenic is also associated with deposits of gold, silver, copper, and zinc (Levinson, 1980, p. 864–865), all of which have been produced from the nearby mining districts, particularly the Plomosa mining district. As with barium, arsenic enrichment is probably an alteration halo surrounding the deposits in the northern Plomosa Mountains and possibly those in the other districts as well.

The barium and arsenic alteration patterns could also indicate that base- and precious-metal deposits are concealed beneath the Bouse Formation in the study area. Extensive and costly subsurface exploration would be necessary to test this conjecture.

Analyses of two dune-sand samples from the study area showed it to be unsuitable for use in glass production because of low silica (SiO_2) and high iron (Fe_2O_3), chromium (Cr), and aluminum (Al_2O_3) content (table 3). The sand is, however, suitable for use as foundry, fracturing, and abrasive sand according to criteria described by Bates (1960, p. 99–103). Sand is a high-volume, low-unit-value commodity and transportation costs are a major factor in its economic development. Without a local market, the sand is not likely to be developed.

Table 3. Analytical results for the dune-sand samples from Cactus Plain (CP) and East Cactus Plain (ECP) Wilderness Study Areas, La Paz County, Arizona

[See figure 3 for definition of element symbols and text for definition of chemical compounds. All determinations by inductively coupled plasma–atomic emission spectroscopy. See Kreidler (1986, 1987) for analytical descriptions and location of samples]

Sample type	SiO_2 (percent)	Al_2O_3 (percent)	Fe_2O_3 (percent)	Cr (parts per million)	Co (parts per million)	Ti (parts per million)
CP	90.2	4.5	1.6	180	9.1	1,200
ECP	88.7	4.6	1.3	<50	<10	1,700
Average glass sand[1]	98.5	0.1	.02	6	<2	150

[1]From Coope and Harben, 1977, p. 16.

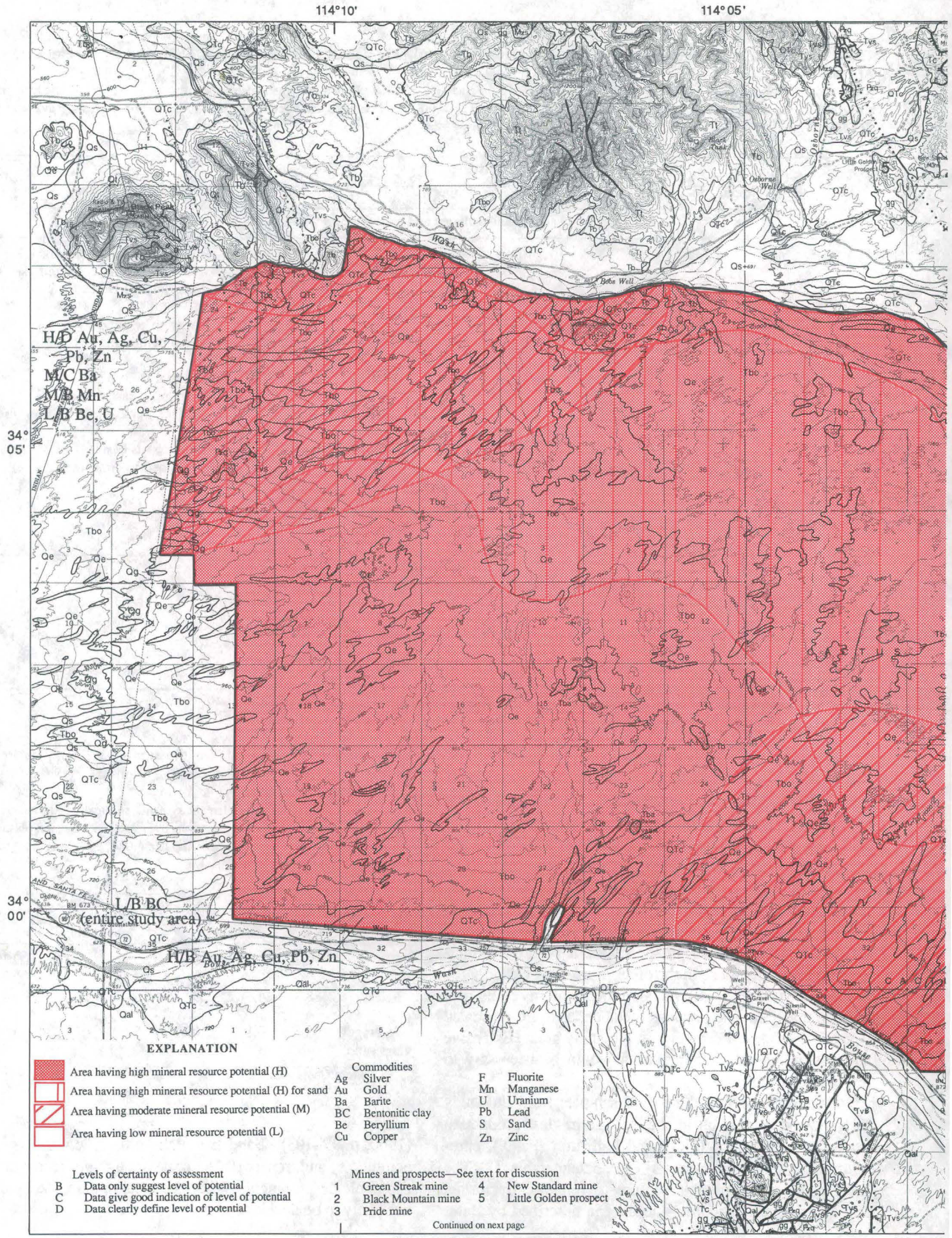
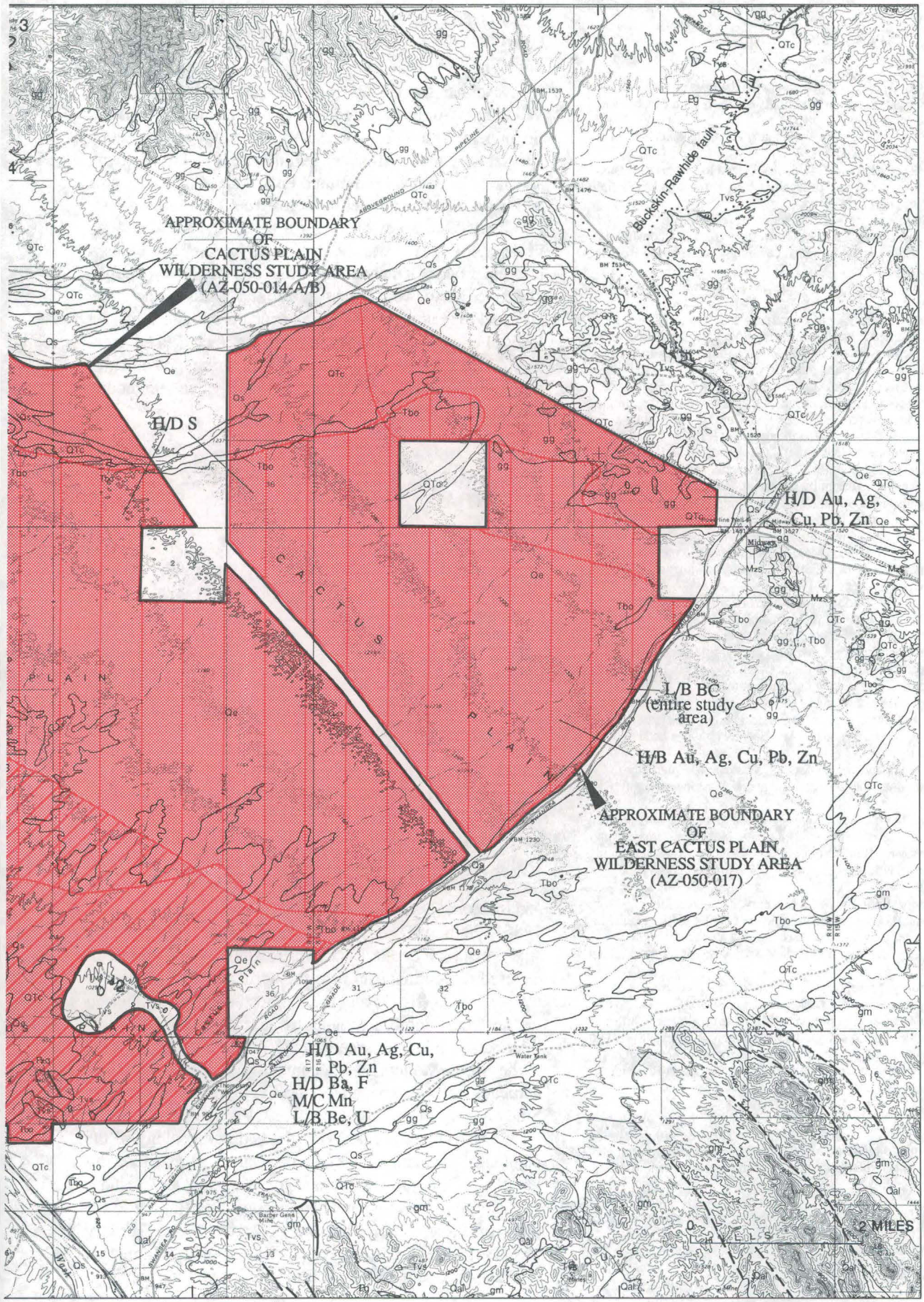


Figure 2. Mineral resource potential and generalized geology (mapped by R.M. Tosdal, 1986) of Cactus Plain and East Cactus (1989), and Marshak and others (1987). Geology of Plomosa Mountains modified from Jemmet (1966). Base from U.S. Geological



Plain Wilderness Study Areas. Geology of Buckskin Mountains modified from J.E. Spencer (unpub. data, 1987), Grubensky Survey, 1:62,500, Black Peak, 1959; Bouse, Utting, 1962; Swansea, 1966. Contour intervals, 20, 40, and 80 ft.

EXPLANATION—Continued

Geologic map units

Qal Alluvium (Quaternary)—Unconsolidated deposits of sand, silt, and gravel in washes and on piedmonts to the west and east of the Plomosa Mountains

Qs Sand and gravel (Quaternary)—Unconsolidated deposits of sand, gravel, and silt in washes

Qt Talus deposits (Quaternary)—Unconsolidated to semiconsolidated talus deposits composed of locally derived gravel and sand; found primarily around Black Peak

Qg Lag gravel (Quaternary)—Unconsolidated pebble to cobble gravel lag deposits on wash terraces in western parts of Cactus Plain. Clasts consist largely of mylonite and gneiss from the Buckskin Mountains

Qe Eolian sand (Quaternary)—Fine-grained sand forming partly stabilized dunes

QTc Conglomerate and sandstone (Quaternary and Tertiary?)—Semiconsolidated conglomerate, fanglomerate, sandstone, and siltstone veneers on piedmonts, talus, and fan deposits at edges of bedrock exposures and older deposits

Tbo Bouse Formation (Pliocene and Miocene)—Sandstone, siltstone, limestone, conglomerate, tuffaceous sandstone, and rare deposits of tufa. On west part of Cactus Plain, unit is covered by a thin veneer of eolian sand (Qe) and lag gravel (Qg)

Tba Basalt and agglomerate (Miocene)—Olivine basalt and plagioclase megaporphyritic basalt flows, agglomerate, and cinders. Unconformably overlain by the Bouse Formation (Tbo). Present only in the middle of Cactus Plain; its relationship to other volcanic units in adjoining ranges is unknown. Forms morphologically distinct cinder cones

Tt Trachyte and rhyolite tuffs (Miocene)—Interbedded trachytic lava flows, lithic-lapilli rhyolitic tuff, hypabyssal intrusions, and basalt flows (Grubensky, 1989)

Tb Basalt (Miocene)—Dark-gray and black basalt flows and minor dikes. Rocks are gently tilted to subhorizontal and unconformably overlie steeply tilted strata

Tc Carbonate rocks (Tertiary)—Massive medium- to dark-brown ferroan carbonate rocks in replacement deposits in Proterozoic and Paleozoic rocks along detachment faults

Tvs Sedimentary and volcanic rocks (Miocene and (or) Oligocene)—Interbedded sandstone, conglomerate, breccia, mudstone, limestone, and tuffaceous rocks. Locally contains beds of dark andesitic lava flows

MzS Metasedimentary and volcanic rocks (Mesozoic)—Quartzite, calcareous quartzite, phyllite, and quartz blastophenocrystic schist

Pzq Quartzite and marble (Paleozoic)—Tan and greenish quartzite and minor amounts of micaceous quartzite, bluish-gray marble, and orange-brown dolomitic marble

Pg Granite (Proterozoic)—Medium- to coarse-grained porphyritic granite

gm Granite and metamorphic rocks (Tertiary, Mesozoic, and Proterozoic)—Leucocratic hornblende-bearing biotite granite and granodiorite, medium- to coarse-grained leucogranite gneiss, amphibolite, and locally abundant northwest-trending mafic and silicic dikes

gg Gneiss (Tertiary, Mesozoic, and Proterozoic)—Predominantly layered mafic and quartzofeldspathic gneiss and pegmatite. Most of the gneiss has plutonic protoliths of several ages. Unit may also include some unmapped metasedimentary rocks (MzS, Pzq). Gneissosity locally overprinted by subhorizontal mylonitic fabrics. Present in the lower plate of the Buckskin-Rawhide detachment fault

Contact

Fault—Steeply to moderately dipping; dashed where approximately located; dotted where concealed; bar and ball on downthrown side

Detachment fault—Low-angle normal fault; dotted where concealed. Ticks on upper plate

Figure 2. Explanation continued.

Conclusions

Neither the Cactus Plain nor the East Cactus Plain Wilderness Study Area contains known or identified metallic mineral resources. Rocks in the study area contain anomalous concentrations of barium and, to a lesser extent, arsenic. Barite has been mined just south of the study area and is an accessory mineral in ores from the Plomosa mining district, but no evidence for a barite deposit was found in the study area. Arsenic, as well as barium, can be used as a pathfinder element for deposits of gold, silver, copper, and zinc, all of which occur north and south of the study area and may underlie the eolian deposits and the subjacent Bouse Formation, but the requisite subsurface data are lacking. The sand is usable in foundry, fracturing, and abrasive purposes, but this high-volume, low-unit-value commodity can not be shipped any distance profitably.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geologic Setting

The Cactus Plain and East Cactus Plain Wilderness Study Areas lie in the highly extended terrane of west-central Arizona immediately west and south of middle Tertiary metamorphic core complexes (Rehrig and Reynolds, 1980). Most ranges in this region are fringed along the range-basin interface by low-angle normal faults of regional extent, known as detachment faults, that accommodated large-scale extensional deformation in the late Oligocene and Miocene (Davis and others, 1980; Spencer and Reynolds, 1986, 1989b, c; Davis, 1988). Detachment faults near the study area include the Buckskin-Rawhide detachment fault exposed discontinuously near the north and east borders of the study area (fig. 2) and the Plomosa detachment fault in the northern Plomosa Mountains near the south border of the Cactus Plain Wilderness Study Area. Still farther west is the Moon Mountains detachment fault that projects underneath the western part of the Cactus Plain Wilderness Study Area.

Detachment faults divide the bedrock geology of the adjoining mountain ranges into two parts: an extended upper plate of Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic, igneous, and sedimentary rocks and a lower plate of Proterozoic, Paleozoic, Mesozoic, and Tertiary metamorphic and igneous rocks. Extensional deformation resulted in a penetrative subhorizontal mylonitic fabric in the lower plate rocks in the Buckskin Mountains. Sedimentation and volcanism accompanied extension, and these syntectonic rocks unconformably overlie Mesozoic and older rocks in the highly faulted upper plate (Spencer and Reynolds, 1989c). The middle Tertiary volcanic and sedimentary rocks usually consist of fanglomerate, sandstone, local lacustrine limestone, andesitic volcanic flows and agglomerates, and silicic ash flows. Monomictic and polymictic breccias and conglomerates are locally interbedded with volcanic and sedimentary rocks and these are likely fault-scarp deposits along normal faults above the detachment fault.

This extended terrane is present above the alluviated basins as a series of northeast-trending antiformal and synformal culminations that plunge beneath the alluvial cover in the study area (Spencer and Reynolds, 1989b). Lower plate mylonitic rocks form the antiforms and faulted upper plate rocks occupy the synforms. Most of the metallic mineral deposits in the Buckskin Mountains are found in the synforms (Spencer and Welty, 1989).

Outcrops of bedrock affected by extensional deformation are sparse within the study area. In the northwestern part of the Cactus Plain Wilderness Study Area, several knobs above the surrounding younger sedimentary rocks consist of Paleozoic marble and micaceous quartzite that are faulted against Tertiary megabreccia. This fault contains specularite and carbonate cement. The knobs along the south border of the Cactus Plain Wilderness Study Area are Miocene limestone, sandstone, andesite, and megabreccia and Paleozoic marble that represent the highly faulted upper plate of the Plomosa detachment fault. Mylonitic gneiss of the lower plate crops out along the northeast border of East Cactus Plain Wilderness Study Area.

Extensional deformation in the region was followed by basaltic volcanism and local silicic volcanism in the Miocene (Suneson and Lucchitta, 1979, 1983, Grubensky, 1989). Conglomerate and sandstone deposited in alluvial fan environments are interbedded with the volcanic rocks. These rocks are referred to as the Osborne Wash Formation of Davis and others (1980) and as mesa-forming basalts by Suneson and Lucchitta (1983). In the western Buckskin Mountains north of the Cactus Plain Wilderness Study Area, the postdetachment volcanic and sedimentary rocks are more than 600 ft thick, dip slightly southwest, and are cut by northwest-trending high-angle faults (Davis and others, 1980; Grubensky, 1989; Spencer, 1989).

Basalt crops out locally in the central part of the Cactus Plain Wilderness Study Area where it is present in two forms: fine-grained flows that form linear ridges, and megaporphyritic lavas, cinders, and agglomerates that make up morphologically distinct cinder cones above the surrounding and onlapping sedimentary rocks of the Bouse Formation. The fine-grained basalts probably are correlative with the gently tilted Miocene basalts on the prominent mesas north of the Cactus Plain Wilderness Study Area, where they have been included in the Osborne Wash Formation of Davis and others (1980) by Grubensky (1989). The megaporphyritic basalts may be broadly correlative with late Miocene megacrystic basalts found elsewhere in the region (Suneson and Lucchitta, 1979, 1983).

In the late Miocene(?) and continuing into the Pliocene and perhaps the Pleistocene, low areas were flooded by marine waters in which the sedimentary strata of the Bouse Formation were deposited (Metzger, 1968; Buising, 1987). Fine-grained sandstone, limestone, and siltstones make up the Bouse Formation. Conglomerate and coarse sandstone facies of the formation are adjacent to bedrock and represent talus and fan deposits (Buising, 1987). Calcareous tufa deposits, a distinctive rock type of the Bouse Formation (Metzger, 1968), cap most of the bedrock knobs in the Cactus Plain Wilderness Study Area. The Bouse Formation is the dominant unit at the surface in the study area. About 500 ft of the Bouse Formation overlies upper Miocene conglomerate in the lower part of a 1,000-ft-deep drill hole immediately west of the study area (Metzger, 1968); post-Bouse Formation sedimentary rock, including deposits of the Colorado River, are in the top few hundred feet of the drill hole. The Bouse Formation thins to the east across the study area toward the southwestern Buckskin Mountains.

During the Pleistocene and the Holocene, the Colorado River drainage formed. Tributary washes were established across the region and eolian deposits developed on the broad interfluvial plains. Eolian deposits dominate the northern part of the Cactus Plain Wilderness Study Area and most of the East Cactus Plain Wilderness Study Area. The eolian deposits are probably no more that a few tens of feet thick.

Geochemical Studies

A reconnaissance geochemical survey of the Cactus Plain and East Cactus Plain Wilderness Study Areas was conducted in 1988 to locate altered, mineralized, or geochemically anomalous areas but was not designed to find individual mineral deposits. Because of the sparse outcrops (less than one percent exposure) and extensive alluvial and eolian cover in the study area, this geochemical survey consisted of two parts. One part followed the conventional geochemical approach that uses stream sediments, heavy-mineral concentrates, and rock samples. Forty-eight rocks, 18 stream sediments, and 20 heavy-mineral concentrates were collected in outcrops of pre-Bouse Formation rock inside the study area. The second part consisted of a biogeochemical reconnaissance survey, which augmented the scant data base from the conventional approach by providing information on soluble metals that are available at depths of less than 70 ft or that are present in the direction from which the ground water flows. Biogeochemical exploration surveys broadly similar to this one have proven successful in exploration for disseminated gold prospects beneath basin fill in Nevada and in China in areas wholly covered with eolian sands (Lovering and McCarthy, 1978; Li and others, 1989).

For the biogeochemical study, samples of creosotebush (*Larrea tridentata* [DC.] Coville) and two species of paloverde, blue paloverde (*Cercidium floridum* Benth.) and little-leaf, or foothill, paloverde (*C. microphyllum* [Torr.] Rose and Johnston) were collected and analyzed, where possible, from 80 sites within and around the study area. Creosotebush, a shallow-rooted desert plant, was most useful because of its widespread distribution and its effectiveness for detecting gold anomalies in areas with as much as 70 ft of colluvial cover in desert regions (Busche, 1989). The more deeply rooted plants such as paloverde, particularly blue paloverde, also absorb metals from ground water and accumulate them in various above-ground parts (Chaffee, 1976, 1977). These plants can indicate local mineralized ground in areas where no evidence appears in the overburden (Cohen and others, 1987). In this study, however, metal anomalies in creosotebush probably indicate the more local mineralized sources than do anomalies in paloverde, because the shallow-rooted creosotebush does not reflect regional ground-water geochemistry to the extent that the deep-rooted paloverdes do.

Soil samples also were collected at the 80 vegetation sample sites to determine the spore content of the bacterium *Bacillus cereus*. The discovery of *B. cereus* spore population anomalies and the original study of its ecology in mineralized soil are discussed by Watterson and others (1986). These initial findings were the basis for further investigation on the potential use of *B. cereus* in mineral exploration, particularly near gold deposits (Parduhn and others, 1986; Parduhn, 1987).

Methods

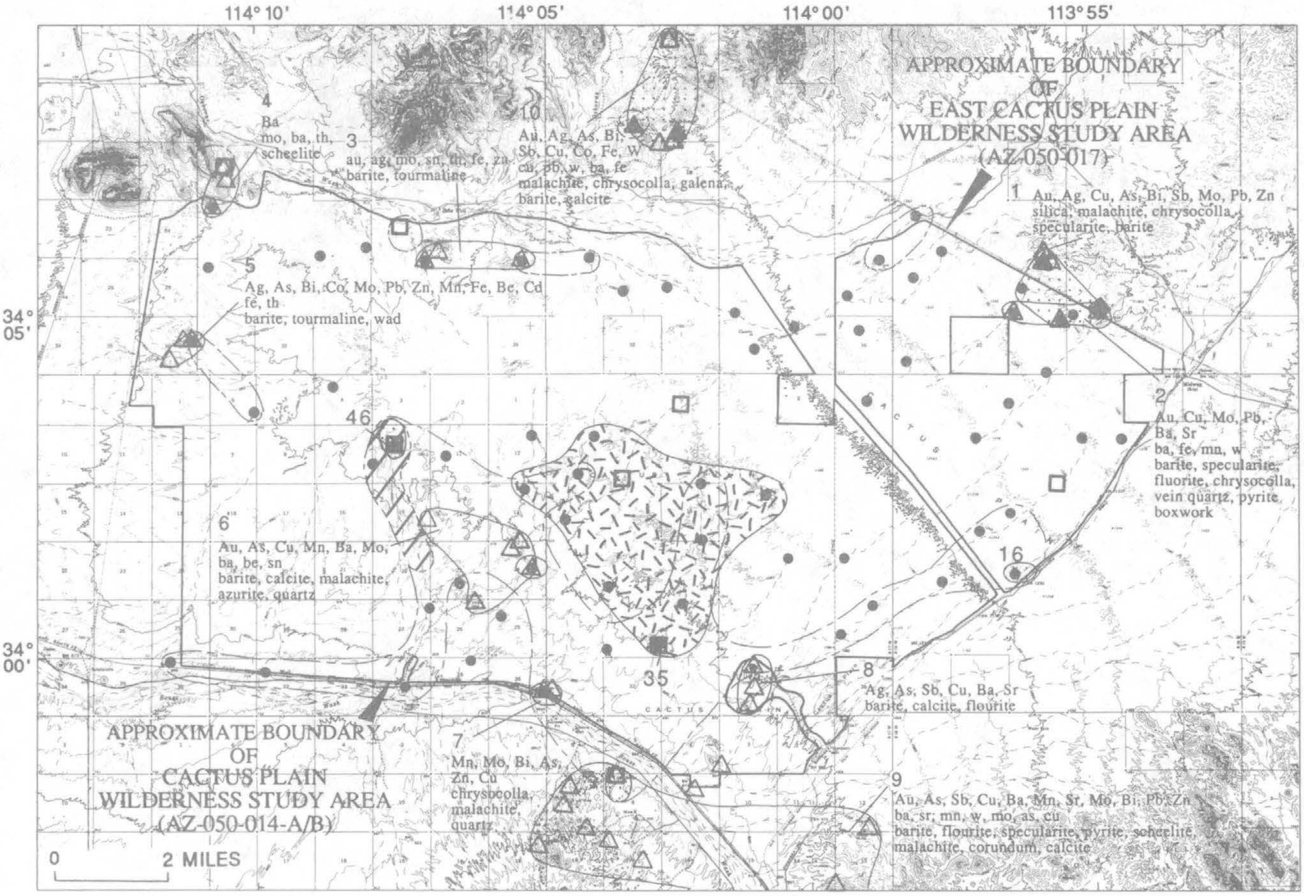
Stream-sediment samples, representing a composite of rock and soil exposed in the drainage basin, were collected from small active alluvial channels draining bedrock and were sieved and pulverized for chemical analysis (Eppinger, 1990a, b). From each site, additional heavy-mineral-concentrate samples were collected and separated in the laboratory into three fractions using an electromagnet: a magnetic, slightly magnetic, and nonmagnetic fraction. Nonmagnetic fractions commonly contain the primary and secondary ore minerals, and this fraction was examined for mineralogical content by microscopic and X-ray diffraction methods. Nonmagnetic and slightly magnetic fractions were pulverized for chemical analysis, and the magnetic fraction was archived. Rocks were collected from prospects, altered zones, and outcrops within the study areas; examined microscopically; and then pulverized for chemical analysis (Eppinger, 1990a, b).

Vegetation samples generally were collected from shallow arroyos or washes (Eppinger, 1990a, b). For creosotebush, branch-tip samples stripped by hand from three adjacent shrubs were composited into a single sample at each site. These samples were predominantly leaf tissue with some admixture of fine twigs. Of the two paloverde tree species, neither is as widespread as creosotebush. However, at least one of the two paloverde species was sampled at most sites. Single paloverde trees were sampled at each site, and the samples consisted of branch ends about 8-in. long. For the more riparian blue paloverde, leaves and stems were combined, but for the more drought tolerant little-leaf paloverde, samples consisted almost entirely of stem material because the leaves appear only after significant rainfall. Blue paloverde was found at 42 sites and little-leaf paloverde was found at 36 sites. Five extra samples of creosotebush were collected along mineralized faults and shear zones, and multiple samples were collected at several of the mines and prospects outside the study area. For both plant and soil samples for *B. cereus* assays, duplicate samples were collected at 10 sites to assess the site variability; one of the duplicate samples from these sites was later split after the sample was milled to estimate analytical precision.

For *B. cereus* spore counts, surface soil was sampled from a single pit at each site. The top 1.25-in. layer of soil was sieved through a 30-mesh screen. The minus-30-mesh fraction was later further sieved through a 60-mesh screen and the *B. cereus* count was estimated using the fine fraction. The *B. cereus* spore determinations were made in U.S. Geological Survey laboratories following the method outlined by Watterson (1985).

Stream-sediment, heavy-mineral-concentrate, and rock samples were analyzed for 35 elements by semiquantitative emission spectrography (Grimes and Marranzino, 1968). In addition, stream sediments and rocks were analyzed for arsenic, bismuth, cadmium, antimony, and zinc by the more sensitive atomic-absorption and inductively coupled plasma–atomic emission spectroscopy (ICP-AES) methods (Crock and others, 1987; Motooka, 1988). Stream-sediment and rock samples were analyzed for low-level gold (detection limit: 50 parts per billion (ppb) for stream sediments, 2 ppb for rocks) by graphite-furnace atomic absorption (GFAA) methods (Thompson and others, 1968; Meier, 1980).

Plant samples were washed, milled, ashed, acid-digested, and the solutions analyzed by three techniques: ICP-AES, GFAA, and ICP-AES with an organic extraction by diisobutyl ketone (ICP-AES/DIBK). A 100-mg (milligram) aliquot of each sample was analyzed by ICP-AES (Crock and others, 1987) for 40 elements. A 300-mg aliquot was analyzed for silver, arsenic, gold, bismuth cadmium, copper, molybdenum, lead, antimony, and zinc by ICP-AES/DIBK (Motooka, 1988), a more sensitive method for most



EXPLANATION

△ Rock, stream-sediment, or heavy-mineral-concentrate sample collection site

●35 Vegetation and soil sample collection site—Specific elements detected in these samples are listed in text

2 Area containing anomalous concentrations of elements shown [1]

Au, Ag — Upper and lowercase letters denote elements detected in rock samples

au, ag — Lowercase letters denote elements detected in heavy-mineral-concentrate samples

malachite — Listed minerals detected in either heavy-mineral-concentrate or rock samples

Area containing anomalous levels of copper in creosotebush or paloverde samples

Area containing anomalous levels of barium in creosotebush or paloverde samples

Area containing anomalous levels of molybdenum in creosotebush or paloverde samples

□ Sample site with anomalous levels of gold in both creosotebush and paloverde samples

◆ Sample site with anomalous levels of gold in creosotebush samples only

Area containing anomalous amounts of *Bacillus cereus* spores in soil samples

1 Ag, silver; As, arsenic; Au, gold; Ba, Barium; Be, beryllium; Bi, bismuth; Cd, cadmium; Co, cobalt; Cu, copper; Fe, iron; Mn, manganese; Mo, molybdenum; Pb, lead; Sb, antimony; Sn, tin; Sr, strontium; Th, thorium; W, tungsten; Zn, zinc—Same definitions apply to elements shown in lowercase letters

Figure 3. Geochemically anomalous areas in and near Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona, delineated using data from rock, heavy-mineral-concentrate, and vegetation samples and by *Bacillus cereus* spores detected in soils. Base from U.S. Geological Survey, 1:62,500, Black Peak, 1959; Bouse, Utting, 1962; Swansea, 1966. Contour intervals 20, 40, and 80 ft.

Table 4. Summary statistics for anomalous concentrations of elements from rock, stream-sediment, heavy-mineral-concentrate, creosotebush, and paloverde samples; and for *Bacillus cereus* spore counts from samples collected in and around Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona

[See figure 3 for definition of element symbols. See Eppinger and others (1990a, b) for complete analytical data. Lower limits of determination shown in parentheses. n, number of samples analyzed, N, not detected; L, detected but lower than determination limit; G, greater than upper determination limit. Analyses by emission spectrography, except for elements with "-a" or "-i" suffixes, which are by atomic absorption or inductively coupled plasma-atomic emission spectroscopy methods, respectively. Values in parts per million unless noted otherwise; pct, percent; ppb, parts per billion]

Element	Minimum	Maximum	50th Percentile	Average crustal abundance[2]	Threshold	Number of samples above threshold
Rocks[1] (n = 33)						
Ag (0.5)	N	5	N	0.07	1	6
As-i (1)	N	170	7	1.8	20	11
Au-a (2 ppb)	N	400 ppb	N	4 ppb	20 ppb	4
Ba (20)	100	3,000	500	425	2,000	6
Be (1)	N	7	L	2.8	5	3
Bi-i (1)	N	49	N	0.17	10	4
Cd-i (0.05)	N	12	.25	0.2	10	2
Co (10)	N	500	15	25	300	1
Cu (5)	L	10,000	20	55	300	6
Fe (.05 pct)	0.07 pct	G	1.5 pct	—	20 pct	2
Mn (10)	10	3,000	300	950	2,000	6
Mo (5)	N	30	N	1.5	5	9
Pb (10)	N	200	15	13	50	3
Sb-i (1)	N	32	L	0.2	5	3
Sr (100)	N	5,000	200	375	2,000	3
Zn-i (0.05)	3.6	1,200	55	70	200	6
Nonmagnetic heavy-mineral concentrates[1] (n=8)						
Ag (1)	N	1	—		L	1
Au (20)	N	L	—		L	1
Ba (50)	4,000	G(10,000)	6,000		G(10,000)	3
Be (2)	N	3	2		3	1
Sn (20)	L	70	25		70	2
Th (200)	N	500	L		L	5
Weakly magnetic heavy-mineral concentrates[1] (n = 8)						
Fe (0.1 pct)	10 pct	30 pct	20 pct		30 pct	3
Mo (10)	N	10	N		L	4
Th (200)	N	L	N		L	2
W (50)	N	70	N		L	1
Zn (500)	N	500	N		L	1
Creosotebush (n = 98)						
Au-a (1 ppb)	N	6 ppb	0.1 ppb		<1 ppb	11
Cu-a (0.1)	32	490	67		92	25
Ba-a (2)	170	1,300	590		760	23
Mo-a (0.3)	2.7	21	7.2		8.4	25
Bi-a (2)	N	3.3	<2		<2	4
Blue paloverde (n = 55)						
Au-a (1 ppb)	N	13 ppb	0.1 ppb		<1 ppb	13
Cu-a (0.1)	38	170	81		98	14
Ba-a (2)	190	2,000	760		800	26
Mo-a (0.3)	.74	6.1	2.9		2.5	28

Table 4. Summary statistics for anomalous elements from rock, stream-sediment, heavy-mineral concentrate, creosotebush, and paloverde samples; and for *Bacillus cereus* spore counts from samples collected in and around the Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County Arizona—Continued

Element	Minimum	Maximum	50th Percentile	Average crustal abundance[2]	Threshold	Number of samples above threshold
Little-leaf paloverde (n = 43)						
Au-a (1 ppb)	N	4 ppb	0.1 ppb		<1 ppb	10
Cu-a (0.1)	34	120	73		65	27
Ba-a (2)	190	1,600	810		1,000	10
Mo-a (0.3)	.39	7.2	1.1		2.0	10
***Bacillus cereus* spore counts (n = 98)**						
counts/g (10)	L	25,000	380		1,100	22

[1] These data are derived from samples collected in areas 1-8 shown in figure 3. Areas 9 and 10 are excluded.
[2] Data from Levinson (1980).

of these ore-related elements. One-gram aliquots were analyzed by a modified GFAA method of Meier (1980) to determine the ultralow concentrations of gold normally found in plants. Though for plants the GFAA stated lower limit of determination for gold is 1 ppb, further work on a subset of these samples suggests that typical background gold concentrations are about 0.1 ppb in the ash.

Frequency distribution diagrams (histograms) and cumulative frequency plots that show the general distribution and range of the data were constructed for selected elements. Boundaries between background and anomalous element concentrations were chosen based on the crustal abundances for elements given by Levinson (1980). For the plant data, any detectable concentrations of gold, antimony, bismuth, and vanadium are considered anomalous.

Geochemical anomalies in rock, heavy-mineral-concentrate, creosotebush, and paloverde samples and *B. cereus* spore counts in and around the study area are shown in figure 3. Summary statistics and thresholds for anomalous elements identified in samples from the study area are listed in table 4. Rock and heavy-mineral-concentrate data from samples collected in nearby mineralized areas, area 9 in the northern Plomosa Mountains (fig. 3), and from area 10 in the Pride mineral district (fig. 3) aided in identifying suites of anomalous element concentrations and thresholds in metallic deposits in the region but are not included in the data summary presented in table 4. No detailed follow-up geochemical studies of the anomalies identified in the study area have been undertaken.

Rock, Stream-Sediment, and Heavy-Mineral-Concentrate Samples

Rock, stream-sediment, and heavy-mineral-concentrate samples were collected from outcrops in and around the study area (fig. 3) (Eppinger, 1990a, b). Anomalous concentrations of elements were found in rock samples and in the nonmagnetic and slightly magnetic heavy-mineral-concentrate samples. No anomalous concentrations of elements were found in stream-sediment samples.

Samples of quartz veins cutting lower plate mylonitic gneiss collected from dumps near the Green Streak mine in area 1 (fig. 3) contain gold concentrations of 220 and 400 ppb (Eppinger, 1990a, b) and 400 to 1,870 ppb (Kreidler, 1987). These rocks contain anomalous concentrations of silver (1-5 ppm) and copper (1,500-10,000 ppm) and slightly anomalous concentrations of arsenic, bismuth, antimony, molybdenum, lead, and zinc.

Six rock samples were collected from three outcrops of lower plate mylonitic crystalline rocks in area 2, 1 mi south of the Green Streak mine. These rocks contain anomalous concentrations of gold (1 sample, 30 ppb), copper (as much as 7,000 ppm), molybdenum, lead, barium, and strontium (Eppinger, 1990a, b). Thin quartz veins following shear zones cut the gneiss in this area. Oxidized pyrite boxwork and chrysocolla were observed in float of vein quartz. Two heavy-mineral-concentrate samples from arroyos draining these outcrops contain anomalous concentrations of barium, iron, molybdenum, and tungsten. Barite, specularite, and fluorite are present in the nonmagnetic heavy-mineral-concentrate samples.

No anomalous concentrations of metals were found in three rock samples of tufa-capped basalt collected in area 3 (fig. 3). However, gold (less than 20 ppb) was detected by emission spectrography in one heavy-mineral-concentrate sample collected from an arroyo draining the north side of an unnamed hill where the Osborne VABM (vertical-angle benchmark) is located (Eppinger, 1990a, b). The same sample contains anomalous concentrations of silver (1 ppm) and slightly anomalous concentrations of tin and thorium. No gold was observed in a mineralogical scan of the heavy-mineral-concentrate sample. A second heavy-mineral-concentrate sample collected from an arroyo draining the south side of this unnamed hill contains anomalous concentrations of iron, zinc, molybdenum, and thorium.

A rock sample from basalt cropping out in area 4 (fig. 3) contains anomalous concentrations of barium. Of two heavy-mineral-concentrate samples from the same area, one contains anomalous concentrations of molybdenum and the other contains anomalous concentrations of barium and thorium. A small amount of scheelite, a tungsten-bearing mineral, was observed in one nonmagnetic heavy-mineral-concentrate sample.

Five rock samples were collected from small isolated outcrops of Paleozoic metasedimentary rocks in area 5 (fig. 3). These rocks, collected along iron- and manganese-oxide-rich fault zones, contain anomalous concentrations of silver, arsenic, bismuth, cobalt, molybdenum, lead, zinc, iron, and manganese and slightly anomalous concentrations of lead, beryllium, and cadmium (Eppinger, 1990a, b). A single heavy-mineral-concentrate sample collected from this area contains anomalous concentrations of iron and slightly anomalous concentrations of thorium. Minerals identified in the nonmagnetic heavy-mineral-concentrate sample include barite and tourmaline.

Eight rock samples were collected from basalt outcrops in area 6 (fig. 3). Three samples, collected from malachite-stained, quartz-calcite veins cutting faulted basalt, contain detectable gold (6, 10, and 20 ppb) (Eppinger, 1990a, b). Two gold-bearing samples also contain anomalous concentrations of arsenic and copper. Other rock samples in the area contain anomalous concentrations of manganese, barium, and slightly anomalous concentrations of molybdenum. A single barite-rich, heavy-mineral-concentrate sample from the area contains anomalous concentrations of barium as well as slightly anomalous concentrations of beryllium and tin.

Two samples of calcite veins were collected from brecciated andesitic rocks in area 7 (fig. 3). Anomalous concentrations of manganese, molybdenum, bismuth, and arsenic and slightly anomalous concentrations of zinc and copper are present in the veins (Eppinger, 1990a, b). Chrysocolla, malachite and quartz are also present in the calcite veins.

Three samples of andesitic volcanic rocks were collected in area 8, which includes the Black Mountain mine. All three samples contain slightly anomalous concentrations of silver (as much as 1 ppm) and two of the three contain anomalous concentrations of arsenic, antimony, copper, barium, and strontium. Barite, calcite, and fluorite form part of the steeply dipping veins in the area.

Several samples, collected in area 9 (fig. 3), provide additional information for interpreting the data from the study area. Nine mineralized rock samples from prospects in granitic and felsic volcanic rocks contain gold (100 ppb and 1,200 ppb) and silver (1 sample, 1 ppm); anomalous concentrations of arsenic, copper, barium, manganese, and strontium; and slightly anomalous concentrations of molybdenum, bismuth, lead, and zinc (Eppinger, 1990a, b). All six heavy-mineral-concentrate samples collected in area 9 contain anomalous concentrations of barium, strontium, and manganese, and several samples also contain anomalous concentrations of tungsten, molybdenum, arsenic, and copper. Barite is abundant in heavy-mineral-concentrate samples. Other minerals include fluorite, specularite, pyrite, corundum, and scheelite.

Samples collected in area 10 (fig. 3) also provide information for interpreting the data from the study area. Nine samples of mineralized lower plate mylonitic gneiss from three areas (Pride and New Standard mines and Little Golden prospect) contain anomalous concentrations of gold (3 samples, 100 ppb, 200 ppb, and 200 ppb), silver (3 samples ranging from 1 to 2.1 ppm), arsenic, bismuth, antimony, copper, cobalt, and iron as well as slightly anomalous concentrations of tungsten (Eppinger, 1990a, b). Heavy-mineral-concentrate samples (3 total) contain anomalous concentrations of copper, lead, tungsten, barium, and iron and lesser amounts of thorium. Minerals in heavy-mineral-concentrate samples include calcite, malachite, chrysocolla, and barite (Eppinger, 1990a, b). Trace amounts of galena were detected in a sample from the Pride mine area.

Creosotebush and Paloverde Samples

Gold was detected in only 10 percent of the creosotebush and paloverde samples (Eppinger, 1990a, b). The maximum concentrations determined were 6 ppb for creosotebush, 13 ppb for blue paloverde, and 4 ppb for little-leaf paloverde. Because background levels appear to be about 0.1 ppb, well below the 1 ppb limit of determination, samples with detected gold are anomalous, and those sites where two or more plant samples contain detectable gold are especially noteworthy (fig. 3). The highest concentrations of gold were detected in the paloverde sample from site 35, where samples of creosotebush and paloverde also contain anomalous concentrations of barium and molybdenum (fig. 3).

Copper anomalies in plants within the study area are generally restricted to areas having known copper occurrences. Two exceptions are sites 16 and 46 (fig. 3), where there are no outcrops. Site 46 is of particular interest because of additional anomalous concentrations of gold and molybdenum in vegetation and because of the high *B. cereus* spore count. Copper is relatively immobile in most arid environments and is therefore reflected in vegetation near its source. For example, Lovering and McCarthy (1978) reported that twigs and leaves from mesquite trees (*Prosopis* sp.) that tap alkaline ground water near the Sierrita, Ariz., copper orebody concentrated molybdenum but did not concentrate copper. Yet similar samples of mesquite trees that grew on caprock in an acidic environment over an oxidizing pyritic copper orebody at Ray, Ariz., yielded strong copper anomalies. Thus, the anomalous concentrations of copper in vegetation samples collected in the study area probably indicate a nearby source.

Analyses of creosotebush and blue paloverde revealed an extensive barium-rich zone in the south-central part of the Cactus Plain Wilderness Study Area. A cluster of four sites with particularly high levels in creosotebush lies immediately north of basalt in area 6 (fig. 3). Dunn and Hoffman (1986) found that plants growing over mineralized veins in the boreal forests of northern Saskatchewan contain unusually high concentrations of barium. Because of the shallow nature of the creosotebush roots, the barium-rich bedrock source may be near the surface.

In sharp contrast to the limited areas marked by anomalous concentrations of copper, anomalous concentrations of molybdenum in the south-central part of the Cactus Plain Wilderness Study Area (fig. 3) show a broad dispersion halo that is associated with locally mineralized outcrops and with anomalous concentrations of copper and barium in plants. This broad molybdenum halo is consistent with the conclusions of Huff (1970), who delineated a widespread area of anomalous concentrations of molybdenum in mesquite samples around known alluvium-covered copper deposits in the Pima mining district of southern Arizona. Probably because of such large dispersion halos for molybdenum, Chaffee (1976) considers copper a more useful metal for defining areas for detailed exploration, though molybdenum is more useful in broad reconnaissance prospecting.

Creosotebush samples from the Pride and New Standard mines and the Little Golden prospect in area 10 (fig. 3) are unique because they contain exceptionally high concentrations of copper and, more importantly, the only detectable amounts of bismuth in vegetation. These anomalous concentrations of bismuth mirror the bismuth-rich rocks of area 10.

Bacillus cereus

Of the five mineralized areas sampled, only soils from the New Standard mine (area 10, fig. 3) yielded high amounts of *B. cereus* in spores (Eppinger, 1990a, b). Single-site *B. cereus* anomalies were common, generally without associated anomalies in vegetation, rock, or heavy-mineral-concentrate samples. These facts, coupled with evidence of high within-site variability, diminish the usefulness of this microbiological method, by itself, to assess the resource potential of the study area. Reasons are unclear for the general lack of *B. cereus* anomalies in mineralized areas or for *B. cereus* anomalies without coincident anomalies in other sample media. Cattle activity throughout the region may have affected bacterial populations enough to overshadow any *B. cereus* anomalies related to metal enrichment. Alternatively, perhaps this bacterium simply does not respond predictably to mineralized areas in this region. Nevertheless, the locality of the highest observed *B. cereus* spore count overlaps an area where the creosotebush and paloverde contain anomalous concentrations of metals (fig. 3).

Interpretation

Three suites of elements are found in anomalous concentrations in rock and (or) heavy-mineral-concentrate samples from five mineralized bedrock areas at various localities around the Cactus Plain and East Cactus Plain Wilderness Study Areas (areas 1, 7, 8, 9, and 10; fig. 3). These are: (1) an anomalous silver-arsenic-bismuth-copper suite in four of the five areas; (2) an anomalous gold-barium-molybdenum-lead-antimony-zinc suite that is found in three of the five areas; and (3) an anomalous tungsten-manganese-strontium suite that is found in two of the five areas.

Metals in anomalous concentrations in creosotebush and paloverde from these five bedrock areas include gold, copper, molybdenum, and, in area 10, bismuth. Mineral deposits in these areas are interpreted as being related to Tertiary detachment faults in the region (Spencer and Welty, 1986, 1989). Though bedrock is sparse, many of the elements of the previously described suites are found in anomalous concentrations in rock and heavy-mineral-concentrate samples collected within the study area. Areas 2, 5, and 6 are noteworthy for being anomalous in at least 6 of the 13 elements.

Elements in anomalous concentrations in rocks and heavy-mineral-concentrate samples from area 2 most likely reflect areally extensive metal enrichment along shears and quartz veins in lower plate rocks related to the nearby mineralizing system in the Green Streak mine area. In area 2, the gold-barium-copper-molybdenum-lead-strontium-tungsten geochemical suite in rocks and heavy-mineral-concentrate samples, the occurrence of specularite, chrysocolla, fluorite, oxidized pyrite boxwork, and vein quartz in samples from isolated outcrops, and the large copper anomaly and local gold anomaly in vegetation suggest that similar deposits to those in the Green Streak mine area may be concealed under alluvium surrounding the isolated bedrock.

The silver-arsenic-barium-beryllium-cadmium-cobalt-molybdenum-lead-thorium-zinc suite in rocks and heavy-mineral-concentrate samples and the anomalous concentrations of molybdenum in vegetation in area 5 were detected in samples collected along iron- and manganese-oxide-rich faults cutting upper plate Paleozoic rocks. Most of these metals are readily scavenged by iron and manganese oxides, a process undoubtedly responsible for much of the metal enrichment. Nevertheless, the assemblage of metals is similar to that for detachment fault-related deposits. The possibility that the scavenged metals have been remobilized and are derived from concealed deposits cannot be ruled out.

A silver-gold-barium-beryllium-copper-molybdenum-manganese-tin suite is found in area 6 in rock and heavy-mineral-concentrate samples derived from postdetachment, locally vented basalts. This assemblage and the occurrence of chrysocolla and azurite in quartz and calcite veins along faults suggest the possibility of leakage halos related to remobilization of metals in underlying detachment fault-related deposits. Analyses of vegetation samples surrounding and east of area 6 yield widespread anomalous concentrations of barium and molybdenum and local anomalous concentrations of copper and gold, including the highest gold concentrations in vegetation found in this study. Thus, the leakage halos may be much more extensive than the limited bedrock exposures in area 6 indicate.

Geochemical anomalies in rock and heavy-mineral-concentrate samples in areas 3 and 4 may be related to a similar remobilization of underlying deposits, though these anomalies are less extensive, and associated veins or shears were not observed. However, molybdenum and gold anomalies in vegetation are positive criteria for possible concealed deposits in these areas.

Geophysical Studies

The Cactus Plain and East Cactus Plain Wilderness Study Areas are covered by regional gravity anomaly data (Lysonski and others, 1980; Aiken and others, 1981; Defense Mapping Agency Aerospace Center, 1974, 1975), re-

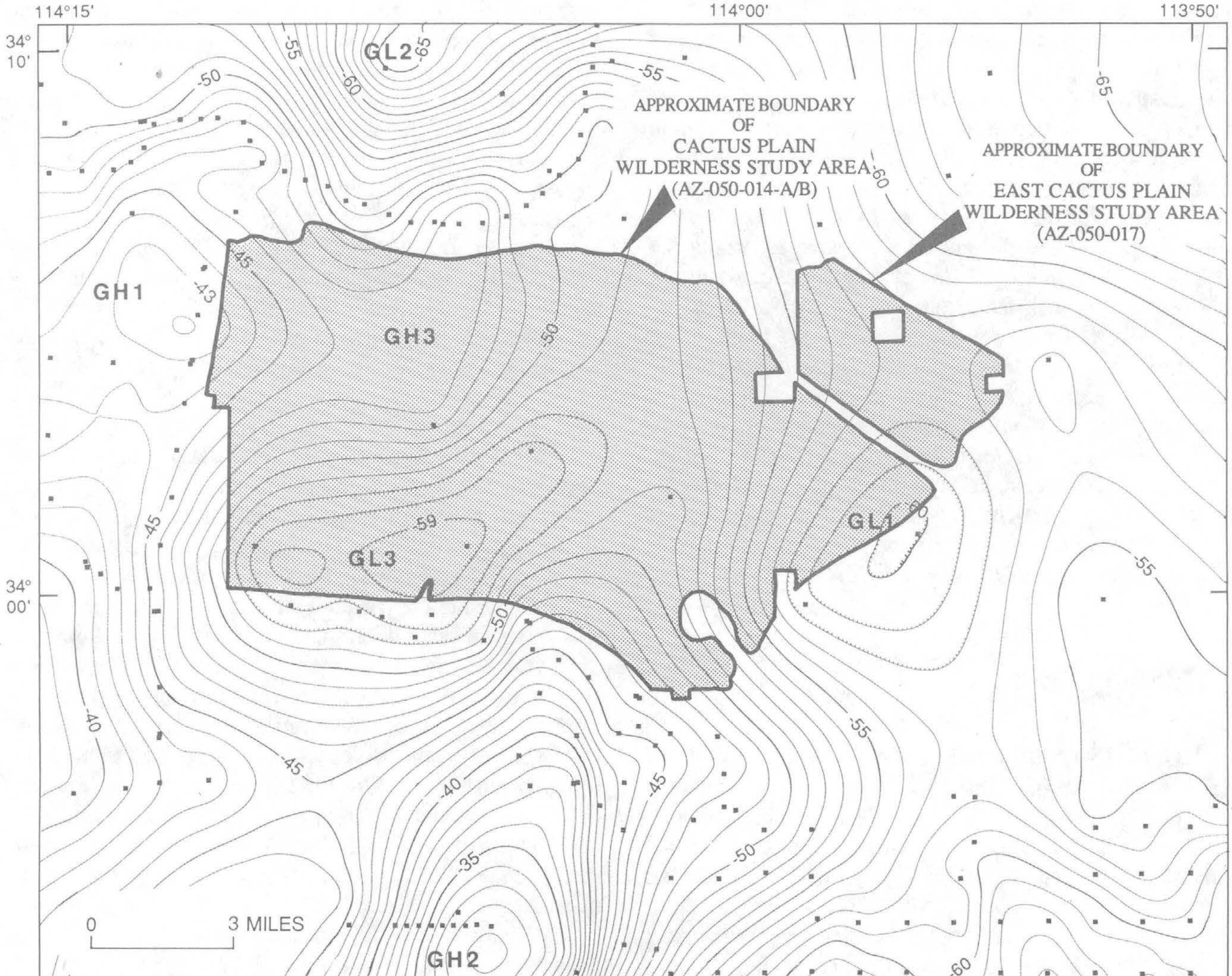


Figure 4. Bouguer gravity anomaly map of Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona, and surrounding region. Contour interval, 1 milligal; grid interval, 1.5 km (5,000 ft); hachures in direction of gravity low. Squares denote observation points; see text for discussion of labeled anomalies.

gional aeromagnetic anomaly data obtained in the National Uranium Resource Evaluation (NURE) program (U.S. Department of Energy, 1979a, b; LKB Resources, Inc., 1980), and detailed aeromagnetic anomaly data (U.S. Geological Survey, 1981) having sufficient resolution to define anomalies of 1 mi² or larger. Contours of complete (terrain-corrected) Bouguer gravity anomalies are defined by about 45 observation points, most of which immediately surround the study area (fig. 4). Contours of total-field magnetic anomalies are defined by five surveys having differing flight specifications. Northwest of lat 34° N., long 114° W., one survey was flown east-west at 0.5-mi spacing and 1,000 ft altitude (U.S. Geological Survey, 1981) and another survey was flown east-west at 3-mi spacing and 400 ft altitude (U.S. Department of Energy, 1979a). Northeast of this coordinate, lines were flown east-west at 1-mi spacing and 400 ft altitude (U.S. Department of Energy, 1979b). Southeast and southwest of this coordinate, lines were flown east-west at 3 mi spacing and 400 ft altitude (LKB Resources, Inc., 1980). These data were merged to produce an aeromagnetic map that covers a large region (fig. 5) and aeromagnetic maps that cover only the study area (figs. 6 and 7).

The NURE magnetic anomaly data northeast of lat 34° N., long 114° W. were previously reprocessed (DeWitt and others, 1988) and for this investigation were merged mathematically with all other NURE data and reprocessed using algorithms and computer programs of the Branch of Geophysics (1989). The resulting aeromagnetic data (fig. 6) show spatial relationships of broad anomalies defined by sparse data of similar resolution and shows most importantly if these anomalies continue across various aeromagnetic survey boundaries. The detailed U.S. Geological Survey aeromagnetic data northwest of lat 34° N., 114° W. (fig. 7), recompiled from original aircraft data for this investigation, cover about 80 percent of the Cactus Plain Wilderness Study Area and are useful for judging the quality of the sparse NURE data and for assessing in detail some geologic sources of anomalies. For example, the

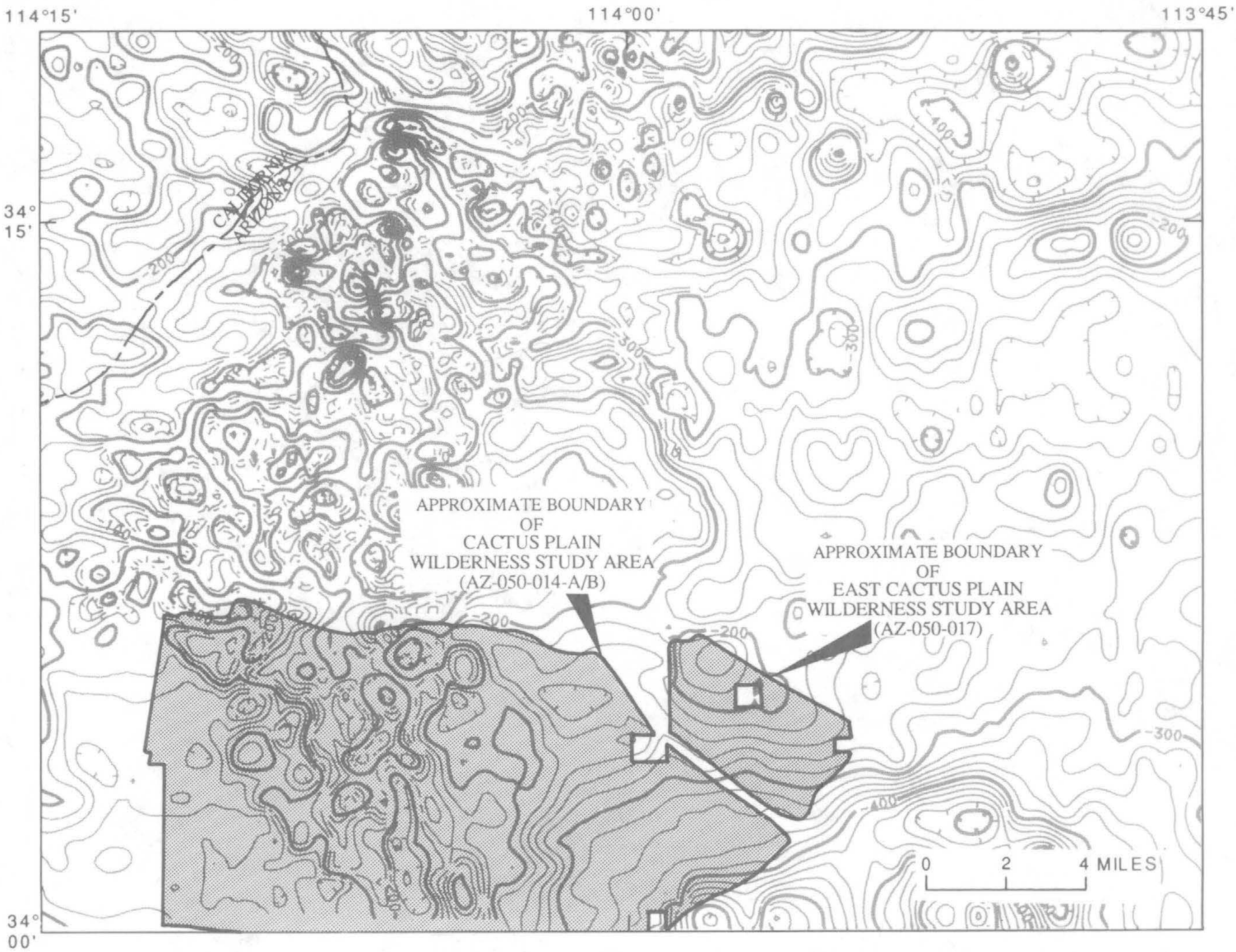


Figure 5. Residual total-intensity aeromagnetic map of the Whipple, Buckskin, and northern Plomosa Mountains, Arizona and California. Contour interval, 20 nanoteslas. Hachured in direction of lower values.

conspicuous highs at about lat 34° 10' N., long 114° 15' W. (A1 on fig. 6) and lat 34° 04' N., long 114° 12' W. (A2 on fig. 6) based on the NURE data are largely artificial but other anomalies are generally consistent with patterns shown on the detailed map (fig. 7).

Gravity Data

The gravity anomaly map (fig. 4) shows that the study area is surrounded by prominent lows to the east (GL1) and north (GL2) and by prominent highs to the west (GH1) and south (GH2). Data east and northeast of the study area are sparse, limiting their usefulness for drawing specific conclusions about subsurface density contrasts. Between the highs, low GL3 traverses the south-central part of the Cactus Plain Wilderness Study Area and is flanked by gravity plateau GH3 at its north margin. Where the gravity anomalies lie over bedrock, highs tend to be associated with high-density granitic and metamorphic rocks in the lower plates of the detachment faults, whereas the lows tend to be associated with low-density sedimentary rocks and sediments in a veneer or basin fill above the bedrock. Basin fill underlying the region of low GL3 is inferred to have a maximum thickness of about 3,000 to 3,500 ft., consistent with estimates of Oppenheimer and Sumner (1980), on the basis of drillhole data and gravity modeling. Fill underlying GL1 may have a maximum thickness of as much as 1,000 ft, although this estimate remains highly uncertain because of the sparseness of data. Where sedimentary rocks are overlain or intruded by high-density basalt, the basalt is too vesicular or too thin (small in volume) to increase signifi-

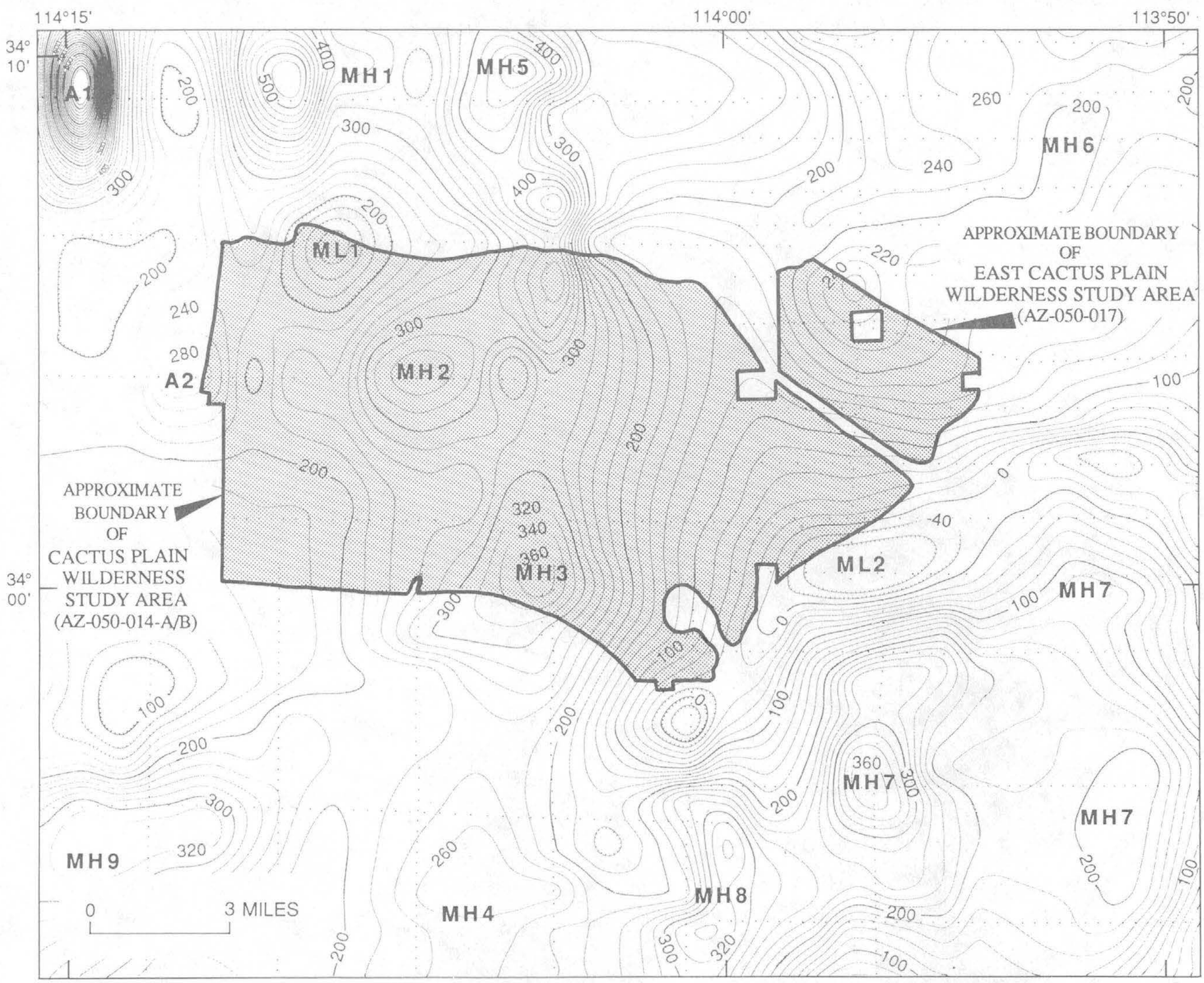


Figure 6. Aeromagnetic anomaly map of Cactus Plain and East Cactus Plain Wilderness Study Areas, La Paz County, Arizona, and surrounding region. Contour interval, 20 nanoteslas; grid interval, 1.5 km (5,000 ft); hachures in direction of lower anomaly values; dotted lines represent flightline traces; labeled anomalies discussed in text. Compiled from National Uranium Resource Evaluation (NURE) program data.

cantly the integrated density and gravity response. Rocks of greatest density in and near the study areas are local occurrences of specularite breccia, massive iron oxide, and sulfide-bearing breccia in the detachment faults and related high-angle faults in the upper plate. Though these rocks have bulk densities that range from about 3.0 to 3.8 g/cm³ (grams per cubic centimeter), their volumes are too small to generate highs observable on the regional gravity anomaly map. These high-density rocks could only be detected and followed in the subsurface by detailed gravity profiles having a spacing no larger than about 25 ft.

Aeromagnetic Data

The residual total-intensity aeromagnetic field for the 800 mi² region surrounding the Cactus Plain and East Cactus Plain Wilderness Study Areas reveals four pertinent features (fig. 5). (1) A striking contrast in magnetic expression is evident between the postextension 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 out an arc of a circle centered on the southeast corner of the map. (2) Within the terrane lacking postextension rocks, the aeromagnetic data traces out long wavelength, northeast-trending anomaly highs and lows that correspond approximately to corrugations associated with the detachment fault, where the mylonitic rocks in the lower plate crop out in antiformal arches and the faulted rocks in the upper plate crop out in synformal troughs (Spencer and Reynolds, 1989a). Metallic mineral deposits are commonly

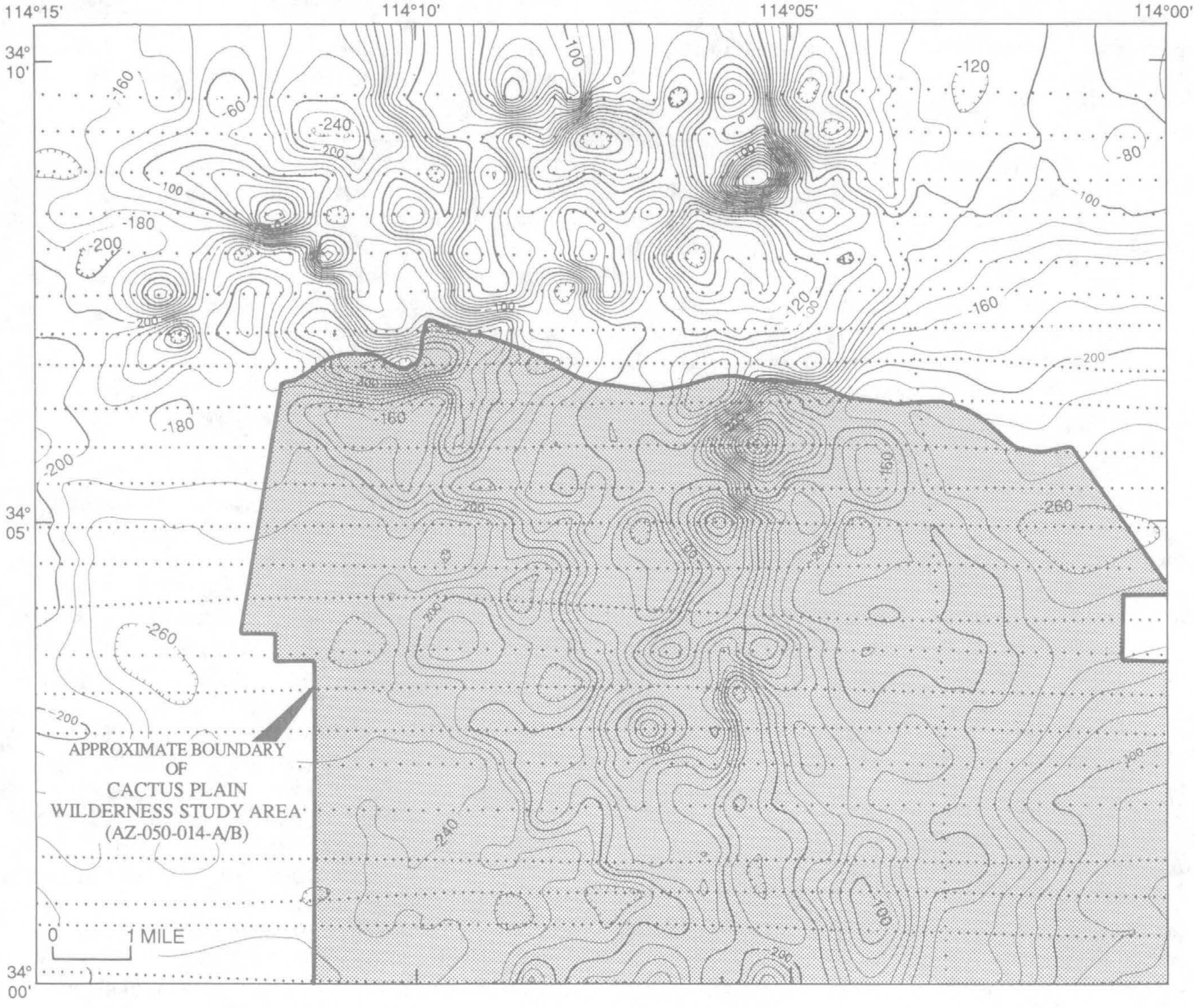


Figure 7. Aeromagnetic anomaly map of a region northwest of lat 34° N., long 114° W. that includes part of the Cactus Plain Wilderness Study Area, La Paz County, Arizona. Contour interval, 20 nanoteslas; grid interval, 0.25 km (800 ft); hachures in direction of lower anomaly values; dotted lines represent flightline traces. Compiled from U.S. Geological Survey data.

preserved in the troughs (Spencer and Welty, 1989). The broad anomaly trends associated with lower plate corrugations cannot be traced through the belt of short-wavelength anomalies produced by the postextension basaltic rocks concealed beneath Cactus Plain. (3) Northwest-trending gradients within the aeromagnetic data cut across the northeast-trending highs and lows. Where these gradients overlie bedrock, they correspond to northwest-trending high-angle faults. Therefore, buried northwest-trending faults can be inferred in areas of alluvial cover. (4) An area of strong field disturbances on the southern margin of the map overlies the Bouse Hills, where Proterozoic, Mesozoic, and Tertiary volcanic, plutonic, and metamorphic rocks crop out.

The NURE aeromagnetic anomaly map (fig. 6) shows that a northwest-trending belt of anomalies, primarily highs (MH1, MH2, MH3, and MH4), traverses the center of the Cactus Plain Wilderness Study Area, extending from a region capped by basalt north of the study area (MH1) to a region of granitic and metamorphic rocks south of the study area (MH4). The map also shows that small-amplitude highs are generally associated with granitic and metamorphic rocks (MH5, MH6, and MH7 and probably MH8 and MH9) and that large-amplitude highs are associated with basalt (MH1 and probably MH2 and MH3). Trachytic and rhyolitic flows and tuffs adjoining the study areas on the north (ML1), volcanic and sedimentary rocks of the Bouse Hills south of the study area, and sedimentary rocks of the Bouse Formation in and east (ML2) of the study area do not generate significant anomalies and are inferred to be only slightly magnetic. The specularite breccia, massive iron oxide (mostly hematite), and sulfide-bearing breccia of previously noted high density have only weak magnetizations and are not aeromagnetic anomaly producers.

The U.S. Geological Survey aeromagnetic anomaly map (fig. 7) shows that the broad NURE anomalies of the northwest-trending belt consist of numerous local highs and lows; these highs and lows reflect in detail structural trends of basaltic flows and intrusions, probable occurrences of reversed or anomalously directed total magnetization (sum of induced remnant magnetization) of basalt, local variations of basalt-covered topography, and subtle changes in basalt thickness. For example, short-wavelength lows are typically larger in amplitude than short-wavelength highs, and many of these lows do not appear north of counterpart highs, as would be expected if the total magnetization were normally directed. Of significance are the short-wavelength anomalies that indicate basalt is pervasive at shallow depth beneath a cover of sand dunes at least as far south as lat 34° N. Furthermore, both maps, when considered together, indicate that the belt of anomalies is caused by a combination of basalt and older granitic and metamorphic rocks and that the granitic and metamorphic rocks may underlie basalt in the northern part of the Cactus Plain Wilderness Study Area (near GH1, fig. 4). The small flightline spacing of this survey permits development of maps showing where boundaries of buried magnetic rocks are likely to be present (Branch of Geophysics, 1989). Such maps showing crest lines and points of maximum horizontal gradients of pseudogravity anomalies were prepared and used, in part, to estimate the subsurface horizontal extent of magnetic rocks.

Postdetachment sediment and sedimentary rock covering the extended upper plate and lower plate rocks is a thin veneer less than 500 ft thick, except where it is inferred to thicken to as much as 3,500 ft on the basis of the gravity low's magnitude. Therefore, any mineral occurrence that might be postulated to occur near the detachment surface would be generally accessible for recovery, except in the region of thickened sedimentary cover, such as in the southwestern to south-central parts of Cactus Plain Wilderness Study Area (area of GL3 on fig. 4). Such accessibility might be somewhat hindered, however, by the presence of basalt at shallow depths in a northwest-trending belt that traverses the central part of the study area (area of GH3, fig. 4).

The specularite breccia, of perhaps greatest interest because similar rocks contain abundant gold at the Copperstone mine 10 mi to the southwest, is sufficiently dense to be detected and followed in the subsurface, provided that very detailed, high-precision gravity surveys are made. This breccia, though weakly magnetic, could probably be detected and followed by high-precision, ground-based magnetic gradiometer surveys.

Natural Radioelement Data

Natural radioelement distributions in the Cactus Plain and East Cactus Plain Wilderness Study Areas were evaluated by examination of available data from aerial gamma-ray spectrometry surveys of the Needles (U.S. Department of Energy, 1979a) and Prescott (U.S. Department of Energy, 1979b) 1° by 2° quadrangles. These surveys acquired aerial gamma-ray spectrometry data along 3-mi (Needles) and 1-mi-spaced (Prescott) east-west flightlines at 400 ft above ground level. Three flightlines cross the part of the study area within the Needles quadrangle and have about 5 percent ground coverage, because an aerial gamma-ray system at 400 ft above ground level effectively measures terrestrial gamma radiation in an 800-ft-wide swath along the flightline. Six flightlines cross the part of the study area within the Prescott quadrangle and provide about 15 percent ground coverage. The respective 5 percent and 15 percent coverages represent a reconnaissance sampling of the near-surface (0- to 18-in. depth) distribution of the natural radioelements potassium (K), uranium (eU), and thorium (eTh). The prefix "e" for equivalent denotes the potential for disequilibrium in the uranium and thorium decay series.

Radioelement contour maps indicate that the study area is characterized by radioelement concentrations of 0.8 to 2 percent K, 1 to 3 ppm eU, and 5 to 10 ppm eTh. Higher concentrations of 2 to 3 ppm eU and 7.5 to 10 ppm eTh are present in the eastern part of the study area and probably reflect a relatively greater abundance of uranium- and thorium-bearing minerals in eolian deposits. For the study area, the concentrations detected are thought to be of reasonable (not anomalous) level for the eolian deposits and other sedimentary rocks of the Bouse Formation that compose most of the surface material. Radioelement concentrations could not be determined for sparse outcrops of older sedimentary, metamorphic, and igneous rocks.

Mineral Resource Potential

To assess the mineral resource potential of the Cactus and East Cactus Plain Wilderness Study Area, regional geology, geochemistry, geophysics, mineral occurrence maps, mining claim records, and available ore deposit models applicable to geologic terrane in the region were studied. Because much of the study area is covered by unmineralized sedimentary rock, biogeochemical and geophysical data are the most useful in assessing the mineral resource potential. An estimate of the level of resource potential and degree of certainty for each tract was made using criteria outlined in the "Appendixes." Throughout this discussion, mineral resource potential refers only to undiscovered mineral resources.

Areas having mineral resource potential for gold, silver, copper, lead, zinc, barite, fluorite, manganese, beryllium, and uranium resources were delineated. Applicable metallic ore deposit models for the study areas include detachment fault-related base- and precious-metal deposits (Wilkins and Heidrick, 1982; Wilkins and others, 1986; Spencer and Welty, 1986, 1989; Spencer and others, 1988), stratabound and fault controlled manganese deposits (Spencer and Welty, 1986), and stratabound uranium and vanadium deposits (Sherbourne and others, 1979; Cox and Singer, 1986; Spencer and Welty, 1986). Some areas have resource potential for sand and bentonitic clay.

Base and Precious Metals

Base- and precious-metal mines and prospects adjacent to the Cactus Plain and East Cactus Plain Wilderness Study Areas have been worked intermittently since the late 1800's (Keith, 1978; Keith and others, 1983a, b). The mineral occurrences are epithermal and contain iron-bearing minerals, usually specularite and less commonly pyrite, chalcopyrite, and magnetite. Most mines have produced copper and lesser amounts of lead and zinc (Spencer and Welty, 1989). Several mines have also produced gold and silver, either as primary commodities or as by-products. The mines are developed in replacement deposits in carbonate rocks, in epithermal veins in faults, in veins, and in replacement deposits localized in high- and low-angle faults in and above the detachment faults (Spencer and Welty, 1989). The Moon Mountains detachment fault in the northern Dome Rock Mountains underlies the Copperstone mine, the largest producer of gold in Arizona (Spencer and others, 1988). Other past productive mines are along the Buckskin-Rawhide detachment fault system in the Buckskin Mountains (Cienega, Mammon, Pride, and Midway mineral districts) and in the Plomosa Mountains (Northern Plomosa mineral district). All the deposits are associated with detachment faults that project beneath the study area.

On the basis of regional occurrences of metallic mineral deposits, Spencer and others (1988) and Spencer and Welty (1989) argued that the Cactus Plain and East Cactus Plain Wilderness Study Areas must be classified as having a high resource potential for gold, silver, copper, lead, and zinc. The geochemical and geophysical data obtained in this study support this appraisal. This appraisal, however, ignores the economic problems for any future development of potential ore deposits resulting from local significant thickness (greater than 300 ft) of postmineralization basalts and sedimentary rocks that underlie parts of the study area.

Following Spencer and others (1988) and Spencer and Welty (1989), the entire study area is assigned high potential for gold, silver, copper, lead, and zinc. Three specific areas have a certainty level of D, whereas the remaining parts of study area have a certainty level of B (fig. 2). The three areas with a certainty level of D are immediately southwest of the Green Streak mine along the northeast border of the East Cactus Plain Wilderness Study Area, in the northwestern part of the Cactus Plain Wilderness Study Area, and in the southeastern part of the Cactus Plain Wilderness Study Area. The certainty of level D is based primarily on geochemical data and the presence of the sparse bedrock outcrops in the area. Two other observations support the certainty level assignment; these are (1) most metallic deposits in the extended terrane are preserved within the synformal troughs where the upper plate rocks have not been removed by erosion and (2) the aeromagnetic data, which suggest that these synformal troughs project into the study area.

Barite and Fluorite

Barite and fluorite have been produced locally from mines in the Northern Plomosa and Bouse mineral districts (Stewart and Pfister, 1960; Keith, 1978). These minerals are in veins and faults in upper plate Tertiary volcanic and sedimentary rocks adjoining the southern edge of the Cactus

Plain Wilderness Study Area. Stream-sediment and biogeochemical data in this area indicate a large halo of barium enrichment around these deposits. Because of these mineral occurrences and the geochemical anomalies, this area is assigned high resource potential with a certainty level of D for barite and fluorite (fig. 2).

Geochemical data from stream-sediment and rock samples indicate the possible presence of unexposed barite in the northwestern part of the Cactus Plain Wilderness Study Area. Because of the lack of exposed mineralized ground, this area is assigned a moderate potential for barite with a certainty level of C (fig. 2). There is no evidence available to assess the mineral resource potential of fluorite in this area.

Manganese

Mines in the Northern Plomosa and Bouse mineral districts have produced small amounts of manganese (Farnham and Stewart, 1958; Keith, 1978). The deposits are in high-angle faults cutting the unmetamorphosed upper plate Tertiary volcanic and sedimentary rocks. Outcrops of upper plate Tertiary volcanic and sedimentary rocks are only in, or adjoining, the southeastern part of and northwest corner of the Cactus Plain Wilderness Study Area. Therefore, the southeastern corner in the Cactus Plain Wilderness Study Areas is assigned moderate resource potential for manganese with a certainty level of C because of the past production of manganese from nearby areas. The northwestern corner of the Cactus Plain Wilderness Study Area also is assigned moderate potential, though with a certainty level of B because no occurrences of manganese are known in this area (fig. 2).

Uranium

Scarborough and Wilt (1979) noted weak evidence for uranium mineralization along a low-angle fault separating middle Tertiary limestone from crystalline rocks north of Osborne Wash. These moderately to steeply dipping rocks were deformed during extensional deformation. Uranium occurs in the middle Tertiary sedimentary rocks elsewhere in the extended terrane of this region (Welty and others, 1985). Most notable is uranium at the Anderson mine in the Date Creek Basin about 40 mi to the northeast (Sherbourne and others, 1979). The association of uranium with Tertiary sedimentary rocks suggests that the two areas in the northwestern and southeastern parts of the Cactus Plain Wilderness Study Area where these rocks crop out have low potential with a certainty level of B for uranium (fig. 2). The presence of thorium in the geochemical data supports this assessment.

Beryllium

Trace amounts of beryllium are present in manganese ore produced from the southwesternmost Bouse Hills (Keith, 1978). The mines are developed in northwest-trending fractures and faults that cut Tertiary volcanic rock. The faults are in the upper plate of the detachment fault. The association of trace beryllium with manganese ore and anomalous concentrations of beryllium are the basis for two areas in the northwestern and southeastern parts of the Cactus Plain Wilderness Study Area being assigned low potential for beryllium, certainty level B.

Bentonitic Clay

A few hundred tons of bentonitic clay were produced for local drilling muds from sedimentary horizons adjacent to the Bouse Hills (Wilson and Roseveare, 1949; Keith, 1978). The deposits are in subhorizontal beds that are reported to be altered tuffaceous sedimentary rocks. Tuffaceous horizons are found in the region within the highly faulted and extended volcanic rocks, in postdetachment trachytic and rhyolitic volcanic centers, and as horizons in the Bouse Formation. On the basis of these occurrences, the entire study area is assigned low resource potential with a certainty level of B for bentonitic clay (fig. 2).

Sand

Extensive eolian sand covers the southern three-quarters of the East Cactus Plain Wilderness Study Area and the northern half of the Cactus Plain Wilderness Study Area. As noted previously, this sand is unsuitable for use in glass production though it is suitable for foundry, fracturing, and abrasive materials. These areas are assigned high resource potential with a certainty level of D for sand (fig. 2).

Oil and Gas

Despite a significant number of oil and gas leases and lease applications, the Cactus Plain and East Cactus Plain Wilderness Study Areas have no resource potential for oil and gas with a certainty level D. This assignment is justified because of the general lack of hydrocarbon-bearing source or reservoir rocks, because of the abundance of metamorphic rocks in the ranges surrounding the study area, and because the unmetamorphosed rock, where present in the region, generally forms thin deposits (fig. 2).

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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.

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 RESOURCE POTENTIAL →

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

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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.

Mineral Resources of Wilderness Study Areas: Havasu Region, Arizona

This volume was published as separate chapters A–D

U.S. GEOLOGICAL SURVEY BULLETIN 1704

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

CONTENTS

[Letters designate the separately published chapters]

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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.

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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.

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