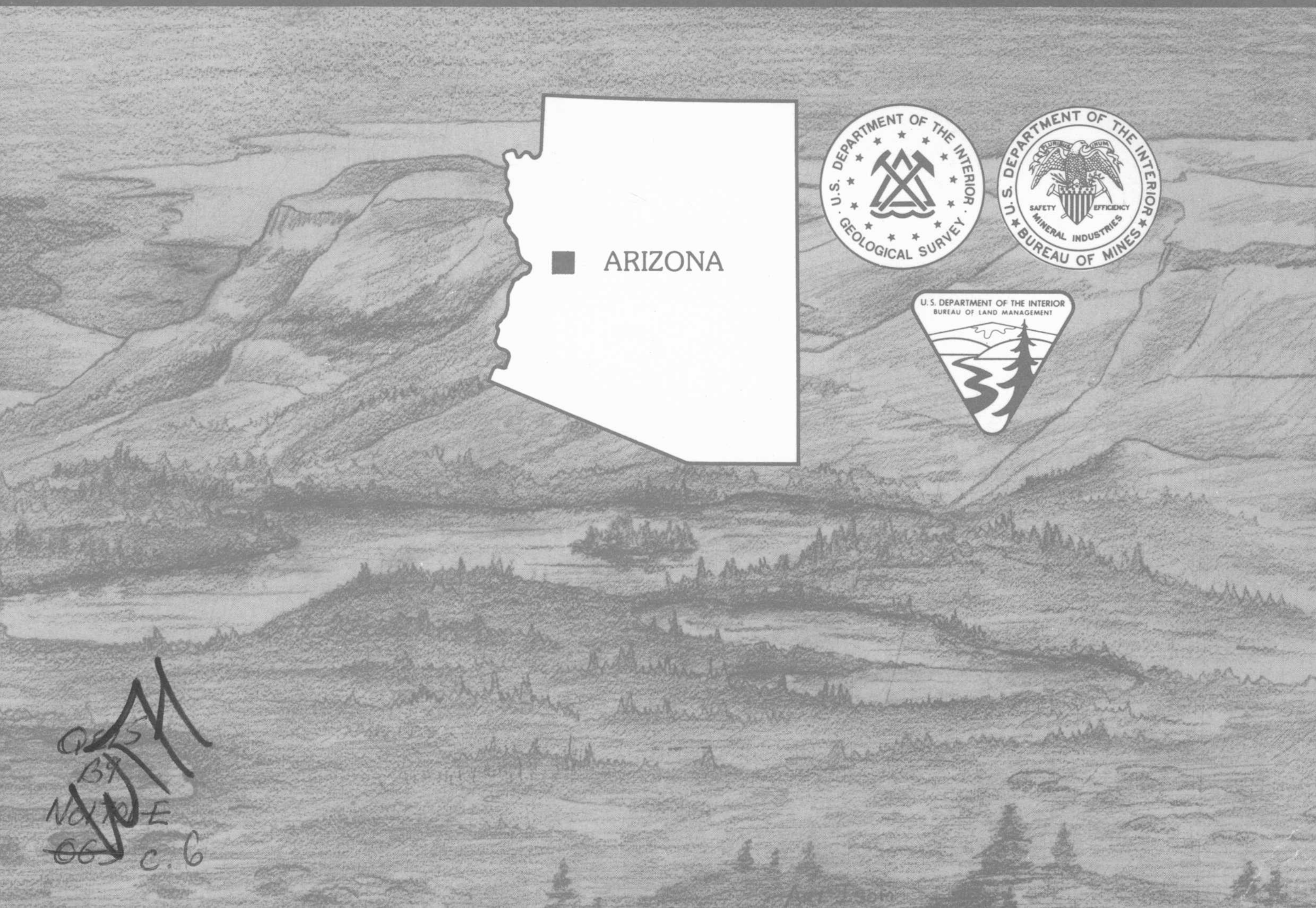
Mineral Resources of the Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1701–E



Chapter E

Mineral Resources of the Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona

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U.S. GEOLOGICAL SURVEY BULLETIN 1701

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

DEPARTMENT OF THE INTERIOR
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 Area

The Federal Land policy and Management Act (Public Land 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys of certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of mineral surveys of the Arrastra Mountain/ Peoples Canyon Wilderness Study Area (AZ–020–059/068), La Paz, Mohave, and Yavapai Counties, Arizona.

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Mineral Resources of the Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona

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SUMMARY

Abstract

At the request of the U.S. Bureau of Land Management, approximately 109,523 acres of the Arrastra Mountain/Peoples Canyon Wilderness Study Area (AZ–020–059/068) were evaluated for mineral resources (known) and mineral resource potential (undiscovered). In this report, the area studied is referred to as the "wilderness study area" or simply "the study area"; any reference to the Arrastra Mountain/Peoples Canyon Wilderness Study Area refers only to that part of the wilderness study area for which a mineral survey was requested by the U.S. Bureau of Land Management. Geologic, geochemical, geophysical, and mineral surveys were conducted by the U.S. Geological Survey and the U.S. Bureau of Mines in 1984–1987 to appraise the identified mineral resources and to assess the mineral resource potential of the study area. These studies indicate that small- to moderate-sized identified resources of manganese, uranium, and gold exist inside the study area, adjacent to several important mining districts. Common sand and gravel in the study area are not likely to be developed. In addition, areas of high mineral resource potential for undiscovered resources exist for sediment-hosted manganese and uranium and for gold and minor silver in shear zones in granite. There is moderate resource potential for gold and minor silver in shear zones in granite; for epithermal veins of silver, gold, lead, and zinc minerals; and for tungsten, rare-earth elements, quartz, and feldspar in pegmatites. The mineral resource potential for copper, lead, and zinc in volcanogenic rhyolite-hosted massive sulfide deposits is low, as it also is for disseminated rare-earth elements and uranium and thorium in the Proterozoic granites. The mineral resource potential for zeolite minerals, clay, and gypsum is considered low in the northwestern part of the study area. The south-central part of the study area has low potential for lacustrine uranium, for coal, and for oil and gas resources. Several low-lying parts of the study area have moderate potential for low-temperature geothermal energy resources.

Manuscript approved for publication, June 30, 1989.

Character and Setting

The Arrastra Mountain/Peoples Canyon Wilderness Study Area (fig. 1) is in west-central Arizona approximately 40 mi northwest of Wickenburg and 30 mi east of the Colorado River. Access to this isolated area is mainly by jeep trails from U.S. Highway 93. The terrain is steep and rugged; elevations range from 1,100 ft near the confluence of the Big Sandy and Santa Maria Rivers in the southwestern part of the study area to 4,807 ft in the Poachie Range in the northeastern part. Artillery Peak (3,213 ft) is a prominent feature in the western part of the study area.

The area is underlain by Early Proterozoic (see "Appendixes" for geologic time chart) metasedimentary and metavolcanic rocks, which were intruded by Early to Middle Proterozoic quartz monzonite to granite plutons. These crystalline rocks were cut by Proterozoic tourmaline-bearing pegmatites and mafic dikes. These rocks were intruded by granite plutons of Cretaceous or Tertiary age. Tertiary sedimentary and volcanic rocks unconformably

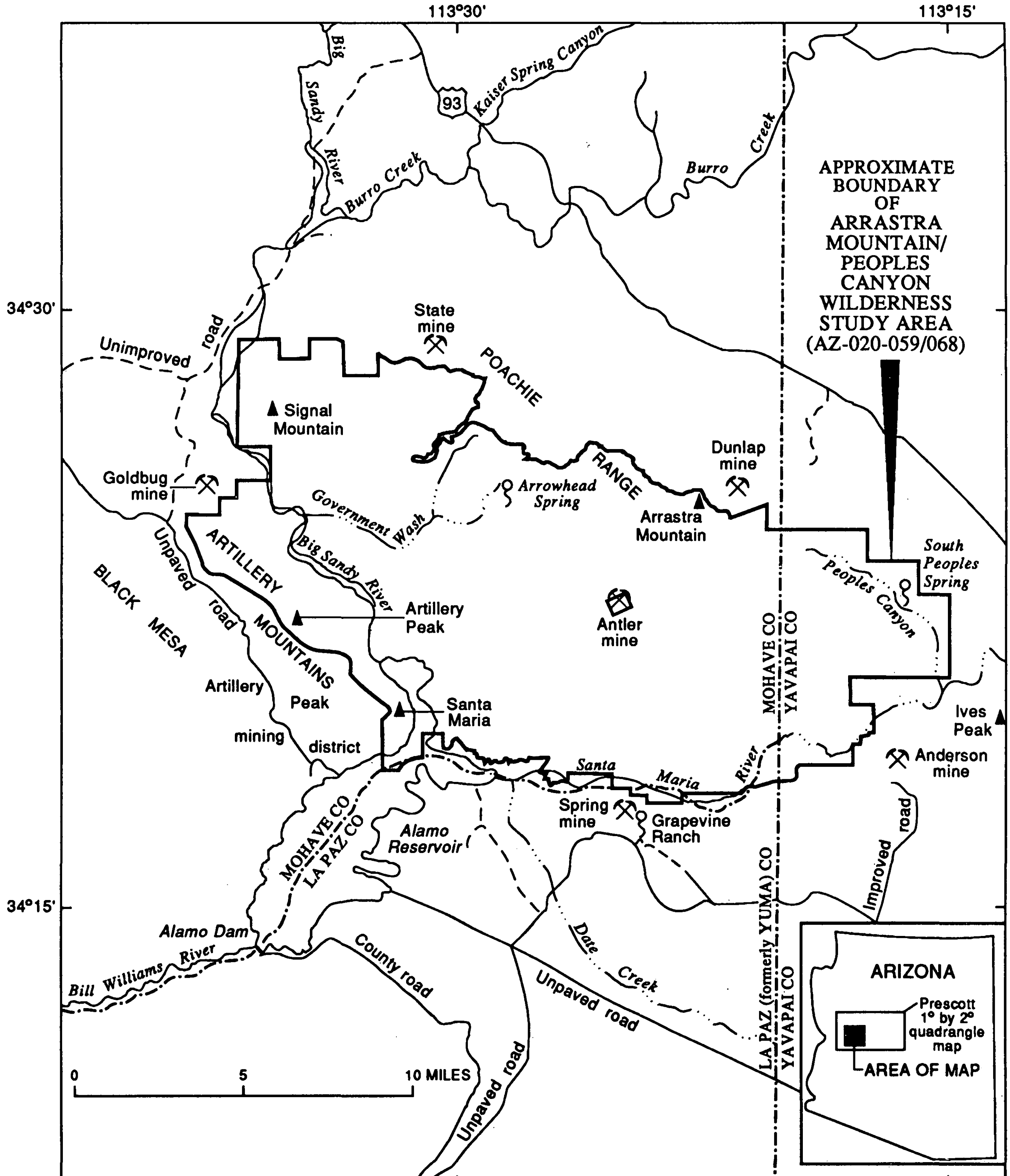


Figure 1. Index map showing location of Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona.

overlie these older rocks. Alluvium occurs in stream beds, on pediment surfaces, and along intermontane valleys.

Numerous minor faults cut the rocks of the study area. Faults of possible early Miocene age generally trend northwest; a younger set of north- to northeast-trending faults occurs in the Poachie Range. The study area lies on the northern edge of the detachment-fault terrane of southeastern California and western Arizona.

The Arrastra Mountain/Peoples Canyon Wilderness Study Area is immediately east of the Artillery Peak mining district, which has produced 95,108 lb of manganese. A uranium-bearing area in the southern part of the study area is near the Anderson mine, which is part of the Date Creek basin uranium district centered southeast of the area and the site of extensive uranium exploration. Gold occurs with quartz and calcite along shear and fault zones at the Button claims group, the Dunlap mine, the Antler mine, and at workings in the western part of the study area.

Identified Resources

Identified manganese resources consist of approximately 520 tons of rock averaging 6.05 percent manganese in a vein in an unnamed adit in the southwestern part of the study area and an estimated 300 tons of ore averaging 16.2 percent manganese in another adit in the same part of the study area.

Identified uranium resources occur near Artillery Peak. Analytical data, with the aid of cross sections drawn through drill holes located along the west boundary of the study area, show that uranium resources in that area consist of 90,000 tons of rock averaging between 0.01 and 0.05 percent uranium oxide (U_3O_8), 20,000 tons averaging between 0.05 and 0.1 percent U_3O_8, and 30,000 tons having more than 0.1 percent U_3O_8.

The Anderson uranium mine, approximately 1.5 mi southeast of the wilderness study area, has extensive surface excavations. Between 1955 and 1959, about 33,230 pounds of U_3O_8 was produced from 10,758 tons of ore with an average grade of 0.15 percent. Recent studies have shown that ore-bearing horizons are more extensive than previously recognized.

Several occurrences of gold and silver were examined within the study area; an inferred subeconomic resource of about 340 tons containing 0.372 oz gold per ton was identified.

The wilderness study area contains sand and gravel in dry washes and river beds that are not close to existing markets, and similar material can be found in abundance closer to local markets. Therefore, development of this material is unlikely. No geothermal resources were identified in the study area. Alluvial areas and adjacent ground within the study area are under lease for oil and gas, but no occurrences of oil and gas resources are known to exist in the study area.

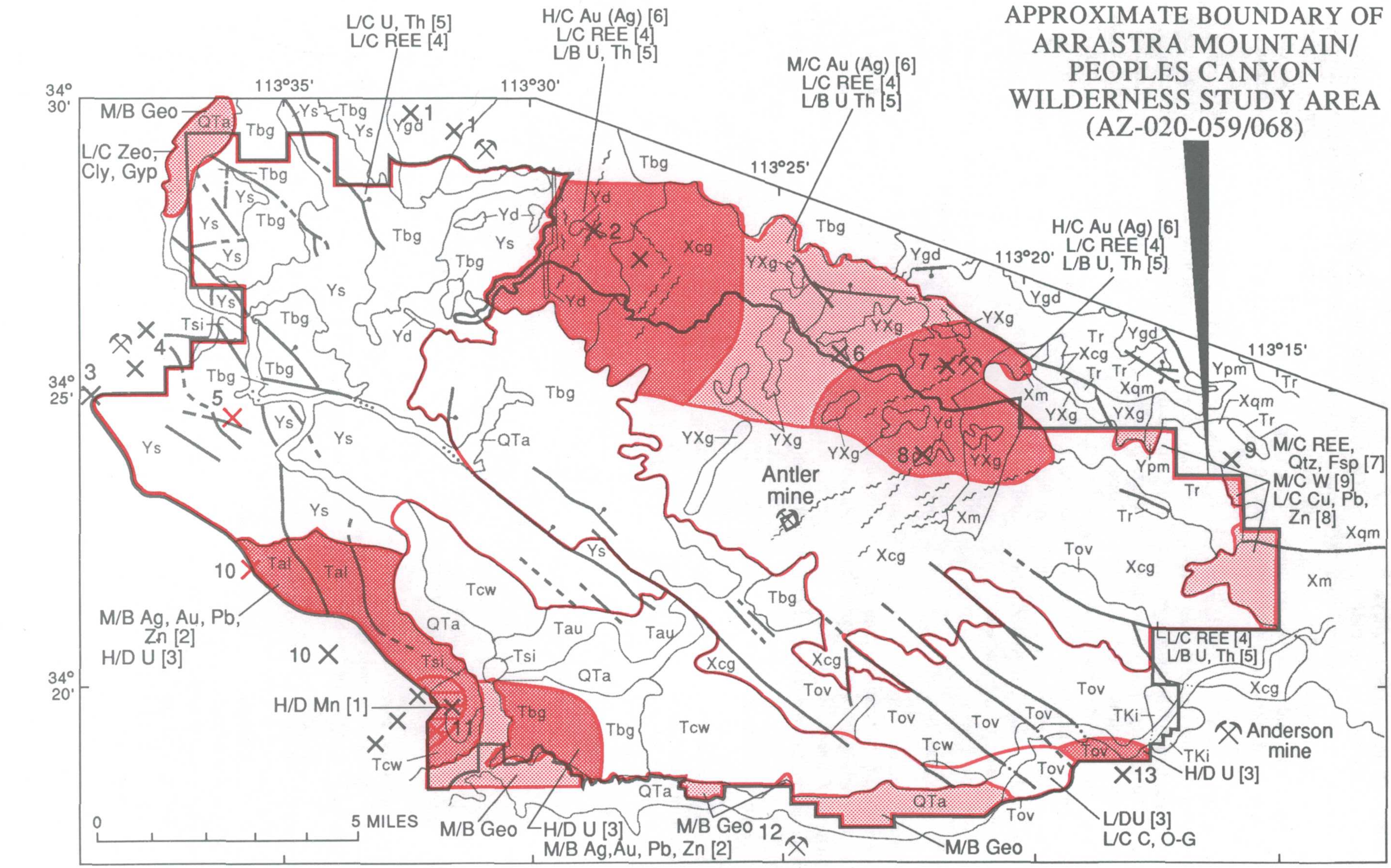
Mineral Resource Potential

Geologic, geophysical, and geochemical data indicate a variety of settings for mineral commodities in the Arrastra Mountain/Peoples Canyon Wilderness Study Area. Figure 2, plate 1, and table 3 show the deposit types expected, host lithologies, commodities, and mineral resource potential.

Sedimentary strata in the western and southern parts of the study area have high resource potential for manganese and uranium deposits and moderate resource potential for silver, gold, lead, and zinc deposits. The potential for disseminated and fault- or shear-controlled gold and minor silver resources in Proterozoic granitic rocks in the north-central part of the study area is high in two areas and moderate in one. Proterozoic granitic rocks in the north and central parts of the study area also have low resource potential for disseminated rare-earth elements (REE) and disseminated uranium and thorium. Moderate potential exists in the eastern part of the study area for tungsten, rare-earth elements, quartz, and feldspar in pegmatites. The mineral resource potential is low for additional sediment-hosted uranium in the southern part of the study area and for volcanogenic massive sulfides containing copper, lead, and zinc in the eastern part. A low resource potential exists for zeolite minerals, clay, and gypsum in the northwest corner and for coal, oil, and gas near the south border. Several alluvium-filled valleys in the study area have moderate potential for low-temperature geothermal energy resources.

INTRODUCTION

This mineral resource study is a joint effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to 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 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 mineral-deposit models. Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. See "Appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.



EXPLANATION

Area having high mineral resource potential (H) for manganese

Area having high mineral resource potential (H) for commodities as shown

Area having *moderate* mineral resource potential (M)

Area having low mineral resource potential (L)

Prospect having *identified resources*—Number refers to table 1

Levels of certainty of assessment

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

Commodities

Ag	Silver	Mn	Manganese
(Ag)	Minor silver	O-G	Oil and gas
Au	Gold	Pb	Lead
C	Coal	Qtz	Quartz
Cly	Clay	REE	Rare-earth elements
Cu	Copper	Th	Thorium
Geo	Geothermal energy	U	Uranium
		W	Tungsten
Gyp	Gypsum	Zeo	Zeolite minerals
Fsp	Feldspar	Zn	Zinc

Deposit types

[1]	Epithermal manganese
[2]	Polymetallic epithermal veins
[3]	Lacustrine uranium
[4]	Disseminated rare-earth elments
[5]	Disseminated uranium and thorium
[6]	Shear- or fault-controlled, disseminated gold
[7]	Pegmatite
[8]	Volcanogenic massive sulfides
[9]	Vein tungsten

Description of map units

QTa	Alluvium, talus, and gravel (Quaternary and (or) Tertiary)
Tbg	Basalt, conglomerate, and older gravel (Tertiary)
Tr	Rhyodacite flows, breccias, pyroclastic rocks, and intrusive plugs (Tertiary)
Tsi	Silicic intrusive rocks (Tertiary)
Tcw	Chapin Wash Formation (Tertiary)
	Artillery Formation (Tertiary)
Tau	Upper part
Tal	Lower part
Tov	Older volcanic and sedimentary rocks (Tertiary)
TKi	Intrusive rocks (Tertiary or Cretaceous)
Yd	Diabase sills and dikes (Middle Proterozoic)
Ys	Signal Granite (Middle Proterozoic)
Ygd	Mafic granodiorite (Middle Proterozoic)
Ypm	Porphyritic quartz monzonite (Middle Proterozoic)
YXg	Leucocratic granite and porphyritic granite (Middle and (or) Early Proterozoic)
Xqm	Porphyritic quartz monzonite (Early Proterozoic)
Xcg	Coarse-grained granite and minor schist and gneiss (Early Proterozoic)
Xm	Metamorphic schist and gneiss (Early Proterozoic)

Contact

Fault—Dashed where approximate, dotted where concealed; bar and ball on downthrown side

Shear zone

Mines, claims, and prospects—May include several workings. Number refers to table 1. Asterisk indicates all or part of site is outside study area

12 Mine

9 Prospect or claim

1	*State mine and Greenwood Spring area	8	Button claims group
2	*Unnamed prospects	9	*Unnamed prospect
3	*Unnamed prospects	10	*Masterson claims group
4	*Goldbug mine	11	*Santa Maria area
5	Unnamed prospects	12	*Spring mine
6	Unnamed prospects	13	*Unnamed prospect
7	Dunlap mine		

Figure 2. Mineral resource potential and generalized geology of Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona.

Location and Physiography

The U.S. Bureau of Land Management requested that 109,523 acres of the Arrastra Mountain/Peoples Canyon Wilderness Study Area (AZ–020–059/68) be evaluated for its mineral resource potential. The study area includes the junction of Mohave, La Paz, and Yavapai Counties, Ariz. (fig. 1), and is about 40 mi northwest of Wickenburg and 30 mi east of the Colorado River. Access to the area, which is isolated and undeveloped, is mainly by jeep trails from U.S. Highway 93. It lies in the southwest quarter of the Prescott 1° by 2° quadrangle and includes parts of the Artillery Peak 15-minute quadrangle and the Arrastra Mtn., Arrastra Mtn. NE, Arrastra Mtn. SE, and Palmerita Ranch 7-1/2-minute quadrangles.

The study area lies in the Sonoran Desert region of the Basin and Range province in west-central Arizona, near the transition zone adjacent to the Colorado Plateau. The area is characterized by north-northwest-trending intermontane basins and steep, rugged mountain ranges. The Artillery Mountains lie along the southwest boundary of the area, and the Poachie Range, which includes Arrastra Mountain, lies along the north boundary. Peoples Canyon is at the east end of the study area. The Santa Maria River flows along the south boundary of the area, and the Big Sandy River is near the west border; both rivers are partly inside the study area; their junction, at 1,100 ft, is the lowest elevation in the area. In the northern part of area, the Poachie Range rises to 4,807 ft, 2,000 ft above the pediment surfaces. The east end of the range is dominated by the rugged peaks of the Arrastra Mountain area. The southern slopes of the Poachie Range drop gently and are cut by numerous washes, many with narrow winding canyons. This slow descent is interrupted by several hills and mesas in the south-central and west half of the area. The Artillery Mountains rise steeply west of the Big Sandy River and are dominated by the distinctive Artillery Peak.

The climate and sparse vegetation in the area are typical of dryer parts of the desert southwest. Maximum temperatures are about 100 to 110 °F during summers, and minimum temperatures are often below freezing at night during the winter. Common plants include mesquite, palo verde, ocotillo, creosotebush, brittlebush, and cat-claw acacia; desert willow, saguaro, cholla, and other cactuses are common at lower elevations. Sycamore and cottonwood trees grow along the water courses. Juniper and piñon pine are present at higher elevations. The riparian community at South Peoples Spring is significant because of the presence of a woodland fern (*Telypteris puberula vet-sonorensis*) that is restricted to wet shaded canyons below 3,000 ft elevation (U.S. Bureau of Land Management, 1987). The Natural Areas Advisory Council is considering the designation of Peoples Canyon as a Natural Area. The Grapevine Ranch area, in the southern part of the study area along the Santa Maria River, has also been proposed for classification as a Natural Area.

Methods and Sources of Data

The U.S. Geological Survey conducted field investigations of the Arrastra Mountain/Peoples Canyon Wilderness Study Area in 1984–1987. This work included geologic mapping at scales of 1:62,500 and 1:24,000, geochemical sampling, and examining outcrops for evidence of mineralization. The geochemical survey utilized stream-sediment (including a fine fraction and a heavy-mineral concentrate) and rock samples that were analyzed for 33 elements by semiquantitative emission spectrography. Gold, arsenic, antimony, cadmium, mercury, zinc, and bismuth were analyzed by atomic-absorption methods, and uranium and thorium by delayed-neutron count. Earlier geophysical data from a regional gamma-ray survey and regional gravity and magnetic surveys were compiled and analyzed for this study. X-band side-looking airborne radar data and stereoscopic Landsat thematic mapper (TM) images were interpreted by using photographic techniques for structural fabric, major tectonic elements, and areas that may have been hydrothermally altered. Further details on analytical procedures undertaken for this resource assessment are given in the appropriate sections that follow.

The geologic map of the Arrastra Mountain/Peoples Canyon Wilderness Study Area (plate 1) was compiled at a scale of 1:62,500 and is based largely on previous mapping (Bryant, 1988; J.K. Otton, unpublished mapping). Altered and mineralized areas were examined in detail to identify the effects of hydrothermal activity in the area.

The U.S. Bureau of Mines studied prospects and mineralized areas within the study area and investigated the history of mining and production within and adjacent to the study area. These studies included a literature search, field examination of prospects and mines, and assaying of samples. Mining claim information was obtained from the U.S. Bureau of Land Management State Office in Phoenix, Ariz.

Previous Work

The manganese deposits and Tertiary rocks of the Artillery Peak mining district west of the study area have been described by Wilson and Butler (1930), Lasky and Webber (1938, 1944, 1949), Sanford and Stewart (1948), Farnham and Stewart (1958), and Mouat (1962). Reyner and others (1956) described the Tertiary rocks and uranium deposits exposed at the Anderson mine on the northeastern side of the Artillery Peak-Date Creek basin (including the southeastern part of the wilderness study area). The geology and genesis of ores at the Anderson mine were studied by Sherborne and others (1979), Otton (1981a), and Mueller and Halbach (1983). Donnelly and Hahn (1981) described the depositional environment of nearby Proterozoic massive sulfide deposits. Additional studies of uraniferous rocks and the structural setting of the Artillery Peak-Date Creek basin area were done by Otton (1977; 1978a, b; 1981b; 1982a, b), Granger and Raup (1962), Otton and Wynn (1978), and Calzia and Luken (1981). A preliminary assessment of mineral resources of the Prescott 1° by 2° quadrangle includes a discussion of the study area (C.M. Conway, written commun., 1987). Detailed geologic mapping by Bryant (1988) and J.K. Otton (unpub. data) includes a large part of the study area.

Areas outside the study area have been actively explored for precious-metal and uranium-vanadium deposits (Wilkins and Heidrick, 1982; Keith and others, 1983; Spencer and Welty, 1985, 1986; Welty and others, 1985; Wilkins and others, 1986; Spencer and Reynolds, 1988; Spencer and others, 1988), and the results of these studies are applicable to the mineral resource potential of the study area.

Acknowledgments

The assistance of personnel at the U.S. Bureau of Land Management Resource Area Office in Kingman, Ariz., is gratefully acknowledged for providing facilities and equipment. Particular thanks is given to Robert Harrison for supplying information from Bureau of Land Management activity files and for helpful discussions on the geology of the Arrastra Mountain/Peoples Canyon Wilderness Study Area. Bruce Bryant, U.S. Geological Survey, provided information on the Proterozoic geology in the Poachie Range. James K. Otton, U.S. Geological Survey, provided information on the status of uranium exploration and the types of uranium mineralization in the area and added much to our understanding of Tertiary rocks and deformation in the region. Dan Mosier, U.S. Geological Survey, provided helpful discussions and geologic and assessment information from the Prescott pre-assessment study that was pertinent to the Arrastra Mountain/Peoples Canyon Wilderness Study Area. Sincere appreciation is expressed to C.T. Wrucke for his critical review of the manuscript. Field work was assisted by John Brice.

APPRAISAL OF IDENTIFIED RESOURCES

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

Introduction

In 1984 and 1987, the U.S. Bureau of Mines (USBM), in conjunction with the U.S. Geological Survey (USGS) conducted a mineral investigation of the Arrastra Mountain/Peoples Canyon Wilderness Study Area, land that is administered by the U.S. Bureau of Land Management

(BLM). USBM personnel investigated the wilderness study area and adjacent areas within 1 mi of the boundary and collected information from published and unpublished reports. Mining claim locations and land status plats were reviewed at the BLM State Office in Phoenix, Ariz. Mineralized areas, mines, and prospects were sampled and mapped by compass-and-tape methods, and resource calculations were made.

A total of 184 chip, select, and grab samples was collected; 34 were from within the study area. In the area of Peoples Canyon, no workings or mineralized areas were found, and no samples were taken. Most samples were analyzed for 26 elements by neutron activation. Some samples were analyzed by fire assay for gold and silver; 61 samples were analyzed spectrographically for 40 elements at the USBM Reno Research Center, Reno, Nev. (Lane, 1985, 1988). Selected samples were analyzed by atomic absorption methods for manganese, by fluorometric methods for uranium, and by X-ray fluorescence for thorium. Sample data were discussed by Lane (1985, 1988). Some analyses were made by Bondar-Clegg and Company, Lakewood, Colo. A summary of the results is given in table 1, and complete data for all samples and the details of grade and tonnage estimates are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Previous Investigations

Manganiferous sedimentary rocks in the Artillery Mountains and surrounding area have been investigated since the 1920's. This area was drilled intermittently by the M.A. Hanna Co. from 1937 to 1940 and by the USBM from 1941 to 1949 (Farnham and Stewart, 1958). Drilling by the USBM was part of a joint investigation with the USGS on the strategic mineral resources of the area (Lasky and Webber, 1949). Wilson and Butler (1930) described the geology of the various manganese properties. Lasky and Webber (1949) prepared a detailed geologic report of an area bordered by the Bill Williams and Big Sandy Rivers.

Uranium occurrences near the southern part of the wilderness study area were studied extensively by Otton (1977), Sherborne and others (1979), and Mueller and Halbach (1983). The areas around the Anderson Mine and near Artillery Peak were drilled by Jacquays Mining Corp. in the 1950's(?) to determine the extent of uranium mineralization.

Mining Activity

The western part of the Arrastra Mountain/Peoples Canyon Wilderness Study Area is on the edge of the Artillery Peak mining district, which contains some of the largest reserves of low-grade manganese in the United States (Farnham and Stewart, 1958). Most of the manganese production was at least 0.5 mi west and southwest of the study area.

Manganese production from the Artillery Peak district began about 1914 and continued intermittently until 1955 (Farnham and Stewart, 1958). About 95,108,000 lb of manganese ore was mined from the district between 1946 and 1959 (Keith and others, 1983, p. 17). One pit and two short adits were found in the wilderness study area, but no production has been reported from these workings.

The Anderson mine, about 1 mi southeast of the study area, consists of extensive surface excavations. Sherborne and others (1979, p. 625) stated that 10,758 tons of ore containing 33,230 lb of U_3O_8 (uranium oxide) was mined between 1955 and and 1959.

Gold has been mined from quartz veins about 2 mi east of the study area in the Crosby (Eureka) mining district. USBM records indicate that 322 oz gold, 133 oz silver, 825 lb lead, and 140 lb copper were produced between 1935 and 1942 from the Homestake, Big Stick, and Weepah mines in this district.

The Antler mine, surrounded by the study area and the only patented mining claim within it, was developed primarily for gold. Samples were taken at the Antler mine, but data are confidential by request of the owner.

Several mining claims and oil and gas leases are located inside and near the wilderness study area (Lane 1985, 1988), but no evidence of exploration was noted by 1988.

Mineralized Areas

Manganese

Manganese is found in the southwestern part of the Arrastra Mountain/Peoples Canyon Wilderness Study Area (fig. 2, pl. 1, No. 11) in the Artillery Formation of Oligocene and (or) Miocene age and in the younger Chapin Wash Formation. However, all workings and sample localities are in the Artillery Formation. No significant manganese was found elsewhere in the study area.

Field investigations by the USBM show that manganese in the study area occurs in veins, as matrix in conglomerates, in fault zones, and as disseminations in red sandstone and boulder conglomerate. Farnham and Stewart (1958, p. 30) state that stratified manganese deposits also occur. The manganese-bearing veins and faults in the study area are less than 5 ft wide and have a traceable strike length of less than 150 ft.

Eleven samples taken within the wilderness study area contain more than 1 percent manganese; the average manganese content is 3.88 percent. The highest manganese content in these samples is 26.9 percent; the lowest is 0.01 percent (Lane, 1985, 1988).

Table 1. Description of U.S. Bureau of Mines sample localities in and near the Arrastra Mountain/Peoples Canyon Wilderness Study Area, La Paz, Mohave, and Yavapai Counties, Arizona

[*, samples outside or partly within the study area; A after sample number indicates samples collected in 1987; other samples collected in 1984. Ag, silver; Au, gold, Ba, barium; Th, thorium; MnO_2, manganese oxide; U_3O_8, uranium oxide; Zn, zinc; oz/t, ounce per ton; ppb, parts per billion; ppm, parts per million; %, percent; mi, mile. All information on Antler mine is proprietary. Summarized from Lane (1985, 1988)]

Map No. (pl. 1; fig. 2)	Sample Nos.	Name	Location	Commodity	Description of setting	Workings	Sample data
1	64A-114A	*State mine and Greenwood Spring area.	Secs. 4, 5, and 9, T. 13 N., R. 12 W.	Th------	Samples from several quartz veins and faults that strike NW to NE in diorite, granite, diabase, gneiss, and schist. Samples taken at the State mine (108–114), which is patented, contained anomalously high Th.	7 pits, 7 adits, 1 shaft.	Highest Th concentration, 0.336%, from leached material coating the mine walls.
2	44-57	*Unnamed prospects.	Secs. 14 and 24, T. 13 N., T. 12 W.	None detected.	Fault and shear zones in granite and gneiss locally containing quartz veins and abundant gouge material; limonite and hematite.	3 adits, 4 prospect pits; inactive.	U_3O_8 content between 1.4 ppm and 9.2 ppm; 4 samples contain more than 0.1 oz/t gold (0.25, 0.17, 0.11, 0.17).
3	1A-21A	*Unnamed prospects.	Sec. 1, T. 12 N., R. 14 W.; sec. 6, T. 12 N., R. 13 W.; sec. 31, T. 13 N., R. 13 W.	Au-------	Northwest-striking quartz veins not traceable beyond workings, but some samples may be on same vein. Veins are 4 in. to 35 in. wide and locally contain minor pyrite, hematite, and limonite. Country rock is granite that is altered locally.	14 pits, 1 trench, 2 shafts, 1 adit.	Highest Au content is 1.03 oz/t, and lowest is 14 ppb. 14 samples contain significant Au; 13 contain Au in excess of 0.1 oz/t.
4	22A-50A	*Goldbug mine.	Secs. 29 and 32, T. 13 N., R. 13 W.	Au------	Faults and quartz veins strike NE and NW in granite. Several prospects are in a breccia zone having no measurable attitude.	11 pits, 2 adits - -	Three samples contain Au in excess of 0.1 oz/t; highest is 0.314 oz/t.
5	51A-63A	Unnamed prospects.	Sec. 3, T. 12 N., R. 13 W.	Au------	Faults and quartz veins in gneiss. Subeconomic resources of 340 tons ore averaging 0.372 oz gold/t.	3 shafts, 3 adits, 3 pits.	Au, 70 ppb to 0.776 oz/t.
6	58-60	Unnamed prospects.	Sec. 34, T. 13 N., R. 11 W.	None detected.	Quartz stringers in fractured and jointed granite; hematite.	Inactive------	All samples contain 1.8 ppm U_3O_8.
7	66-68	Dunlap mine.	Sec. 36, T. 13 N., R. 11 W.	Au, Ag, U_3O_8.	Limonite and hematite along fault in fractured and altered granite gouge and quartz.	Inactive shaft - -	Au content between trace and 1.6 oz/t; highest Ag content 0.4 oz/t.
8	61-65	Button claims group.	Sec. 11, T. 12 N., R. 11 W.	Au, Ag, U_3O_8, MnO_2.	Quartz veins in fractured and altered granite and gneiss; abundant hematite.	Shaft and 3 prospect pits; inactive.	Au content between trace and 0.41 oz/t; Ag content between 0.1 and 0.3 oz/t.
9	115A-116A	*Unnamed prospect.	Sec. 11, T. 12 N., R. 10 W.	Au, Th, Ba.	Pegmatite dike in gneiss, minor copper in gneiss outcrop.	2 trenches-----	Samples contain 0.3 oz/t and 150 ppb Au, 31 ppm Th, and 1,300 ppm Ba.
10	36-43	*Masterson claims group.	Secs. 22, 26, 35, and 36, T. 12 N., R. 13 W.	U_3O_8----	Strata bound disseminated U_3O_8 in sandstone and siltstone; sparse carnotite(?).	8 prospect pits - -	U_3O_8 content between 7.2 and 123.9 ppm.
11	6-35	*Santa Maria area.	Secs. 5-7, T. 11 N., R. 12 W.	MnO_2, U_3O_8.	MnO_2 veins in boulder conglomerate and volcanic breccia along fault. Abundant manganite(?), psilomelane(?), and calcite.	2 mines, 5 adits, 2 prospect pits; inactive.	U_3O_8 content between 0.63 and 10.38 ppm; MnO_2 content between 0.04 and 26.9%.
12	4-5	*Spring mine	Sec. 21, T. 11 N., R. 11 W.	MnO_2, U_3O_8.	Strata bound, vein in red to brown conglomeratic sandstone; calcite.	Inactive mine - -	Disseminated MnO_2; 10.2 and 16.2% MnO_2.
13	1-3	*Unnamed prospect.	Sec. 9, T. 11 N., R. 10 W.	U_3O_8----	Strata bound, pink to red fractured siltstone and sandstone; sparse carnotite.	Inactive mine - -	1,298 to 2,419 ppm U_3O_8.

Identified reserves of 520 tons of rock averaging 6.05 percent manganese are estimated in a vein in an unnamed adit (Lane, 1985, fig. 3); another adit in the area is estimated to contain about 300 tons of identified reserves averaging 16.2 percent manganese. An accurate average grade could not be determined because of insufficient access for sampling but is probably less than 10 percent manganese.

Uranium

Detectable uranium exists in all samples taken during the field investigation. The highest uranium content of samples from within the study area is 13 parts per million (ppm); the average is 3.4 ppm. The highest uranium content in all the samples is 2,419 ppm in a sample from near the Anderson mine (Lane, 1985, 1988).

Geologic cross sections from sparse holes drilled along the west boundary near Artillery Peak by Jacquays Mining Corp., in the 1950's(?), were obtained from the Arizona Department of Mineral Resources in Phoenix. Using these data and analytical results, three tonnage and grade estimates of identified uranium resources containing uranium oxide (U_3O_8) were calculated: 90,000 tons of material averaging between 0.01 and 0.05 percent; 20,000 tons between 0.05 and 0.1 percent; and 30,000 tons greater than 0.1 percent (Lane, 1985). The accuracy of these estimates is not known because the data are incomplete. Uranium resources were identified only in the Artillery Peak area (fig. 2, pl. 1, No. 10). The uranium-bearing Anderson Mine Member of the Chapin Wash Formation occurs in the southern part of the study area, but subsurface sampling would be needed to define accurately any resources that may exist there.

According to Mueller and Halbach (1983), the Anderson mine is in the Chapin Wash Formation; however, Sherborne and others (1979) describe the mine as being in the Anderson Mine unit, which intertongues with other parts of the Chapin Wash Formation. Uranium contents at the Anderson mine range from 0.03 to 0.1 percent U_3O_8 and average about 0.07 percent.

Gold and Silver

Gold, in excess of trace amounts, was detected in 18 samples taken within the study area (Lane, 1985, 1988). The gold content of the samples is between 0.002 and 0.766 oz per ton. The average gold content of all the samples is 0.16 oz per ton.

Gold was detected (0.002 to 0.776 oz per ton) in all samples taken at workings in sec. 3, T. 12 N., R. 13 W. (fig. 2, pl. 1, No. 5). The workings expose quartz veins and associated faults in gneiss. An indicated subeconomic resource of 340 tons averaging 0.372 oz gold per ton occurs in the western part of the study area. Additional resources may exist, but their determination would require subsurface sampling.

Silver was detected in 15 samples taken within the wilderness study area (Lane, 1985, 1988). The highest silver content in samples from the study area is 0.4 oz per ton; the average value is 0.2 oz per ton.

Gold- and silver-bearing faults and veins at the Button claims group (fig. 2, pl. 1, No. 8) are in Proterozoic granite; resources could not be calculated because the structures are not visible on the surface and could not be traced beyond the workings.

Sand and Gravel

The wilderness study area contains abundant sand and gravel in dry washes and river beds. The two largest and most accessible deposits are along the Big Sandy and Santa Maria Rivers. Such deposits are typical of desert environments and can be found outside the wilderness study area in abundance and closer to markets. This material is not likely to be developed.

Oil and Gas

The wilderness study area is covered with oil and gas leases and lease applications; however, no evidence was found to indicate the presence of oil and gas. At the time of this investigation, no oil and gas exploration had taken place in or near the study area. Ryder (1983) rated hydrocarbon potential as low to zero because the area is underlain by gneiss, granite, and schist.

Conclusions

Manganese, uranium, and gold are present in samples taken from parts of the Arrastra Mountain/Peoples Canyon Wilderness Study Area near regions known to have produced these commodities. Manganese was found in veins, faults, conglomerate, and sandstone in the southwestern part of the study area near the confluence of the Santa Maria and Big Sandy Rivers. The wilderness study area is estimated to have about 820 tons of identified resources of low-grade manganese-bearing rock.

Uranium was detected in all samples taken; however, the grade is considered too low for mining at current prices. A minimum identified resource of 140,000 tons containing from at least 0.01 to more than 0.1 percent U_3O_8 was estimated. Additional uranium resources may exist in the southeastern part of the study area near the Anderson mine, where uranium-bearing host rocks are known to exist. Subsurface sampling would be needed to determine any additional uranium resources.

An indicated subeconomic resource of about 340 tons averaging 0.372 oz gold per ton occurs in the western part of the study area, and additional resources may exist. Gold occurs at the Button claims group in the northeastern part of the study area, but resources could not be calculated because of poor exposures.

Sand and gravel deposits in the wilderness study area are typical of the desert southwest and can be found in abundance outside the study area.

Oil and gas leases cover the wilderness study area, but the study area has been rated low to zero for hydrocarbon potential because the area is underlain by gneiss, granite, and schist.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Floyd Gray, Robert J. Miller, James A. Pitkin, William C. Bagby, Jerry R. Hassemer, J. Howard McCarthy, William F. Hanna, *and* Mary Lou Conant Callas
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Geology

Rock Units

The Arrastra Mountain/Peoples Canyon Wilderness Study Area is underlain by Early Proterozoic plutonic and metamorphic rocks intruded by Early and Middle Proterozoic and Cretaceous or Tertiary plutonic rocks (pl. 1, fig. 2). These older rocks are overlain unconformably by lower to middle Tertiary volcanic and sedimentary rocks that were deposited in structural basins.

The oldest rocks in the study area are Early Proterozoic schists and gneisses. As described by Bryant (1988), the oldest of these rocks are dark-greenish-gray to black, fine-grained biotite-hornblende-plagioclase schist and gneiss and plagioclase porphyroblastic gneiss. They contain numerous intrusions and have gradational contacts with adjacent units. A migmatitic gneiss and schist unit in the north-central part of the study area includes biotite-plagioclase schist and gneiss, biotite-quartz-plagioclase schist, amphibolite schist, and, less commonly, muscovite-garnet-biotite schist and gneiss. The plagioclase-quartz schist and gneiss in the eastern part of the area contain variable proportions of biotite, muscovite, and garnet and locally include sillimanite ranging from individual fibers to aggregates as much as 8 cm long. The map unit has a complex contact with later Early Proterozoic intrusions and has a sharp contact along the east side of the Middle Proterozoic coarse-grained Signal Granite batholith.

The most aerially extensive Early Proterozoic rock unit in the study area is a pluton consisting of hornblende-biotite and biotite quartz monzonite, granodiorite, monzonite, and granite. The rock is equigranular to porphyritic, having potassium feldspar phenocrysts commonly 1 to 2 cm across but locally as much as 4 cm across. Foliation is well developed to absent. The pluton contains scattered inclusions of metamorphic rock, migmatite, and mafic phases. Inclusions are numerous near contacts with metamorphic rocks. Granodiorite is the dominant rock type in the pluton, except in the southern part of the map unit where quartz monzonite and granite dominate. Zircon from a gneissic granodioritic part of the pluton give a uranium-lead (U-Pb) age of 1,706±2.8 Ma (J.L. Wooden, written commun., 1987). Rocks of this unit are locally intruded by fine- to medium-grained biotite granite and quartz monzonite and muscovite-biotite quartz monzonite and granodiorite. The granodiorite has an age of 1,688±14 Ma determined from U-Pb data on zircon (J.L. Wooden, written commun., 1987).

Fine- to medium-grained leucocratic granite, biotite granite, quartz monzonite, and minor granodiorite of Early and (or) Middle Proterozoic age cut Early Proterozoic rocks; some of them contain inclusions of metamorphic rocks. These rocks crop out as a variety of small, irregular intrusive bodies.

The older Middle Proterozoic rocks crop out principally in the eastern part of the area (pl. 1) and consist of porphyritic quartz monzonite and of coarse-grained biotite quartz monzonite, granite, and granodiorite containing potassium feldspar crystals as much as 6 cm long. Textures range from equigranular to porphyritic. Samples of these units give a minimum U-Pb age of 1,416.2±2.4 Ma (J.L. Wooden, written commun., 1987).

The Middle Proterozoic Signal Granite, emplaced coevally with a porphyritic hornblende-biotite and augite-hornblende granodiorite and diorite, is the most extensive unit in the western part of the study area. It consists of coarse-grained quartz monzonite and granodiorite containing potassium feldspar crystals as much as 6 cm across, plagioclase and quartz as much as 1 cm across, and biotite and hornblende as much as 0.5 cm long and in aggregates as long as 1 cm. Only part of the granodiorite is porphyritic. Flow foliation is shown by aligned potassium feldspar crystals. Scattered inclusions in the Signal Granite consist of mafic granodiorite, hornblende-biotite gneiss, and gabbro. The Signal Granite has yielded U-Pb ages of 1,409.6±2.5 and 1,410±3 Ma (J.L. Wooden, written commun., 1988). Granite similar to the Signal Granite but having smaller feldspar phenocrysts intrudes Early Proterozoic metamorphic rocks in north-central part of the study area.

Middle Proterozoic diabase intrusive rocks thought to have an age of about 1,200 Ma are ubiquitous in the region and consist of hornblende, plagioclase, and subordinate pyroxene. The diabase forms dikes and sills ranging from 1 cm to a few tens of meters thick.

Unmapped Middle(?) Proterozoic pegmatite bodies intrude all the crystalline rocks except the diabase. They may be the same age as the diabase. Large sill-like bodies of pegmatite are exposed in the eastern part of the study area.

In the southeastern part of the study area is a group of rocks originally mapped as fine- to medium-grained porphyritic granite and minor diorite (Wilson and others, 1969). Recent studies by J.K. Otton (oral commun., 1989) indicate the rocks are rhyodacitic flow domes of Tertiary age (23 to 19 Ma).

Tertiary rocks that unconformably overlie the Proterozoic basement complex were deposited principally in the northwest-striking Artillery Peak-Date Creek basin, most of which is southwest and south of the study area (fig. 3). The oldest Tertiary rocks in the study area are in an undifferentiated unit consisting of arkosic sandstone at the base and conglomerate, silicic tuffs, volcanic breccia, ash-flow tuff, rhyolite, and andesitic to dacitic agglomerates and flows exposed in fault blocks on the south flank of the Poachie Range (Otton, 1982b and unpub. mapping). Feldspar detritus and lithic fragments of granitic composition within the basal beds were derived from the underlying porphyritic quartz monzonites. The unit is locally hydrothermally altered.

The overlying lower part of the Artillery Formation consists of a basal arkosic sandstone that locally contains conglomerate. The unit includes andesitic to rhyolitic agglomerate and flows with interbedded alkaline basalts and basaltic andesites. The upper part of the Artillery Formation consists of a lower limestone and siltstone, a sandstone and conglomerate, an upper limestone and shale (with silicic flows), and a boulder conglomerate; minor basaltic andesite flows are also interbedded with clastic rocks (Lasky and Webber, 1949; J.K. Otton, unpub. mapping). In the western and southern parts of the study area, thick fanglomerate and fluvial and lacustrine sedimentary deposits are interlayered with silicic flows, tuffs, and pyroclastic debris of the overlying Chapin Wash Formation (Shackleford, 1977).

The Chapin Wash Formation consists of a basal volcanic section with overlying calcareous boulder conglomerate, sandy conglomerate, and conglomeratic sandstone. Finer grained sedimentary rock within this unit was deposited in an alluvial-fan and lake setting (fig. 3); finer grained facies are normally more tuffaceous.

Biotite-hornblende phyric silicic intrusive rocks intrude older rocks in the western part of the study area on and near Artillery Peak. Silicic, biotite-bearing flows, breccias, and plugs of rhyodacite occur in the northeastern part of the study area.

Gently southwest-dipping sandstones and sandy conglomerates and overlying olivine basalts are generally found in topographically high positions in the northern part of the study area.

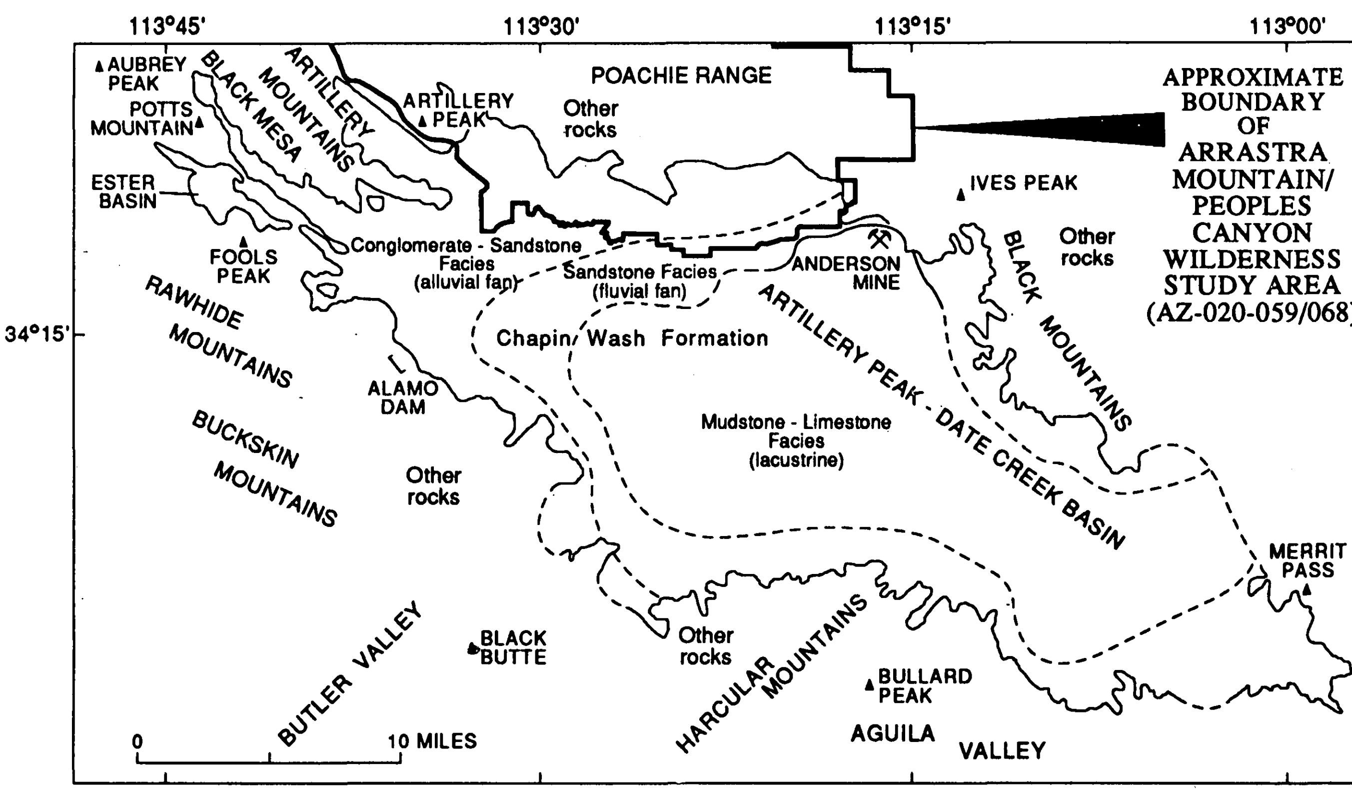


Figure 3. Generalized lithofacies map of the uranium-bearing Chapin Wash and Artillery Formations, undivided except as noted, in Artillery Peak–Date Creek basin, a region including southern part of Arrastra Mountain/Peoples Canyon Wilderness Study Area, Arizona. Contacts dashed where inferred. Modified from May and others (1982, fig. 7).

Gravel and sand of Tertiary and (or) Quaternary age that formed during an earlier stage of the modern drainage are found along some stream courses above Quaternary sand and gravel in the modern stream beds.

Structural Geology

The structure of the region is complex due to faulting that possibly is as old as Early Proterozoic. Major Proterozoic faults in western Arizona, which may represent sutures between possible terranes that were accreted to the North American craton in Early Proterozoic time (Conway and Karlstrom, 1986), were not identified in the Arrastra Mountains/Peoples Canyon Wilderness Study Area.

Otton (1981a, 1982b) has shown that tilting along north-northwest-trending listric normal faults occurred at least twice in Tertiary rocks in the western and southern parts of the study area. The earlier deformation generated fault blocks of variable sizes in which basal units dip as much as 70°. Higher parts of the sections have shallower dips. Many of the listric faults probably resulted from major crustal extension. Later listric faulting tilted the sedimentary rocks more gently. Younger volcanic rocks are not tilted and follow modern drainages.

Northeast-trending high-angle faults and shear zones, presumed to be of late Tertiary age, cut the Proterozoic granitic rocks in the north-central part of the area. Some of these faults drop Tertiary rocks down against Proterozoic rocks. Faults having similar orientation occur in the rocks of the McLendon volcano area located several miles southeast of the study area (Brooks, 1984, 1985).

Brecciation and Alteration

Brecciated and intensely altered Proterozoic rocks occur along the Tertiary faults and shear zones in the Poachie Range in the north-central part of the study area. These zones served as conduits for circulating hydrothermal fluids. The most intensely altered rock is found in fault and shear zones that contain 3 to 15 ft of gouge. This rock is surrounded by intensely argillically altered, variably limonite-stained breccia. The outer part of this altered zone is characterized by irregular propylitically and argillically altered rock. A network of late-stage limonite-jarosite veins is present locally, as are less common quartz and calcite veins.

Geophysics

Gravity and Aeromagnetic Data

The Arrastra Mountain/Peoples Canyon Wilderness Study Area is included in regional gravity surveys (Wynn and Otton, 1978; Wynn and others, 1978; Lysonski and others, 1980a, b; Aiken and others, 1981) and regional magnetic surveys (Sauck and Sumner, 1970 [1971]); Aero Service Division, Western Geophysical Company of America, 1979) that have sufficient detail to define anomalies of a few square kilometers or larger. Contours of complete (terrain-corrected) Bouguer gravity anomalies are defined by about 20 observation points, some inside but most immediately outside the study area boundary. Contours of total magnetic intensity anomalies are defined by six traverses flown 2.75 km (9,000 ft) above sea level and 16 traverses flown 122 m (400 ft) above the terrain. The magnetic data are shown as a reduced-to-pole anomaly map, which represents the original anomaly data corrected for Earth's field inclination in such a way that anomalies associated with rocks having normally polarized total magnetization are superposed directly over their source rocks, somewhat the same way a gravity anomaly is superposed directly over its source.

On the basis of rock magnetic investigations elsewhere in central and southern Arizona, lithologies exposed in the study area can be expected to have a variety of contrasting magnetic properties, both in a remanent magnetization commonly measured in paleomagnetic studies (Calderone and Butler, 1984) and in induced magnetization or magnetic susceptibility studies (Klein and Wynn, 1984). On the basis of studies of magnetic anomalies and comparisons with seismic P-wave velocities, the base of the magnetic crust, interpreted as the position of the Curie point isotherm corresponding to titanomagnetite-bearing igneous rocks, has been estimated by Byerly and Stolt (1977) to be about 10 km below sea level in the vicinity of the wilderness study area. Most regional magnetic anomalies (areally broad and high in amplitude) appear to have total magnetizations (sum of remanent and induced magnetizations) that are normal; that is, they have the same polarity and approximate direction of the ambient geomagnetic field, considering that polarization lows commonly occur northward of the magnetic highs.

The gravity anomaly map (fig. 4*A*) shows that two lobed highs transect the study area, one having a northeasterly strike in the center of the area and the other having a northerly strike at the western extremity of the area. These lobes are inferred to be caused by subsurface occurrences of metamorphic and associated intrusive rocks that have higher density than laterally adjacent terrane, some of which contains alluvium. Contrary to expectations, the gneissic terrane mapped in the eastern part of the study area does not appear to have an average density greater than that of the Signal Granite mapped in the western part of the area.

The magnetic anomaly map (fig. 4*B*) shows four significant groupings of highs: one each near the northwest, north-central, and southeast margins of the study area, and one in the south-central part of the area. These anomalies obliquely cross many mapped rocks presumed to be magnetic, and therefore they partly represent hidden sources that may be related to the mapped rocks. The fact that more than half of the mapped basalt produces no high-amplitude anomalies suggests thicknesses of less than 30 ft if these basalts are not pervasively weathered.

The most significant geophysical features are outlined by regions shown in figure 4*C*. Outlines of regions I, II, III, and IV are gradient crest lines representing the maximums of magnitude of horizontal gradients of pseudogravity anomalies derived by a mathematical transformation of a coarsely gridded set of the original magnetic anomaly data. These crest lines tend to broadly outline the horizontal boundaries of magnetic source rocks if their upper edges are steeply dipping. Region V is outlined on the basis of gravity anomaly contours.

Region I is inferred to be underlain by magnetic basalts and by a magnetic phase of the underlying Middle Proterozoic Signal Granite, perhaps a quartz monzonitic or dioritic phase. On the basis of magnetic modeling, some basalts may have thicknesses exceeding 80 ft in this region. Region II likewise appears to be underlain by small volumes of magnetic basalts and some magnetic parts of the Early Proterozoic granite, in addition to older Tertiary volcanic rocks of unknown magnetization. The granite appears to extend in the subsurface a few miles north of its mapped contact, intruding a small area of gneiss and schist. Region III is enigmatic in that a northeast-striking high transects several mapped lithologies. The most plausible explanation is that the region is underlain by thick sequences of the older Tertiary volcanic rocks, perhaps more than 300 ft thick, or by subsurface mafic feeders connected to these rocks exposed at the surface. Region IV is represented by a diverse assemblage of intrusive rocks; perhaps a magnetic phase of Proterozoic granitic rocks is far more extensive in the subsurface than at the surface. Scattered dikes and sills of rhyodacitic rocks do not appear to be significant anomaly producers. Region V is relatively quiet magnetically and appears to be underlain by a nonmagnetic phase of the Signal Granite and perhaps by other metamorphic rocks of high density. Basalt exposures in this region are notably thin, weathered, or both.

Aerial Gamma-Ray Spectrometry

Aerial gamma-ray spectrometry data for the Arrastra Mountain/Peoples Canyon Wilderness Study Area includes Department of Energy (DOE) National Uranium Resource Evaluation (NURE) surveys of the Prescott 1° by 2° quadrangle (Aero Service Division, Western Geophysical Company of America, 1979; May and others, 1982) and of a smaller area centered at the Anderson mine (High Life Helicopters, Inc./QEB, Inc., 1983), just southeast of the study area. The survey of the Prescott quadrangle acquired aerial gamma-ray data along east-west flightlines spaced 1 mi apart at a nominal altitude of 400 ft above ground level; the smaller survey acquired data along east-west flight lines spaced one-quarter mile apart and 400 ft above ground level. An aerial gamma-ray system at 400 ft above ground level effectively detects terrestrial gamma radiation from a swath 800 ft wide along the flightline. Aerial gamma-ray measurements represent the near surface (<50cm) distribution of the natural radioelements potassium (K), uranium (eU), and thorium (eTh). The "e" prefix, for equivalent, denotes the potential for disequilibrium in the uranium and thorium decay series.

The preliminary eU (fig. 5*A*) and eTh (fig. 5*B*) maps of Arizona were derived from a database made from NURE aerial gamma-ray data for all 23 of the 1° by 2° quadrangles that include Arizona. The maps show clear distinction between the relatively low radioactivity of the sedimentary rocks of the Colorado Plateau province and the variably low to high radioactivity of the igneous and metamorphic rocks that commonly occur in the Basin and Range province. The Prescott quadrangle (outlined on fig. 5) contains areas of relatively higher concentrations or anomalies of eU and especially eTh. A significant number of these anomalous areas occur within the Arrastra Mountain/Peoples Canyon Wilderness Study Area.

These anomalous features are shown in more detail in the eU (fig. 6*A*) and eTh (fig. 6*B*) contour maps of the study area, derived from NURE data for the Prescott quadrangle (Aero Service Division, Western Geophysical Company of America, 1979). The study area is characterized by radioelement concentrations of 1 to 12 ppm eU, 5 to 125 ppm eTh, and 1 to 3.5 percent K (not shown). The highest values for both eU and eTh (as well as K) occur in the northern and western parts of the study area (fig. 6), which are underlain by the Middle Proterozoic Signal Granite and the Artillery Formation of Tertiary age. The eTh concentrations are clearly anomalous for the Proterozoic crystalline rocks, Tertiary sedimentary and volcanic rocks, and Quaternary materials that are present in the study area.

Side-Looking Airborne Radar (SLAR)

X-band (3.1 cm) side-looking airborne radar (SLAR) data were acquired in October 1984 in a north-south flight direction looking east. Approximately 14 SLAR image swaths were manually mosaicked to produce a 1:250,000-scale image mosaic (Conway and others, 1987, pl. 30) that includes the Arrastra Mountain/Peoples Canyon Wilderness Study Area. Near-range data of approximately 27° depression angle were interpreted by using photogeologic techniques for structural fabric and major tectonic elements. In addition, stereoscopic Landsat thematic mapper (TM) images covering part of the Prescott 1° by 2° quadrangle were analyzed for structure to complement the SLAR interpretation.

SLAR image data produce the highest possible resolution, synoptic map base for physiographic and structural

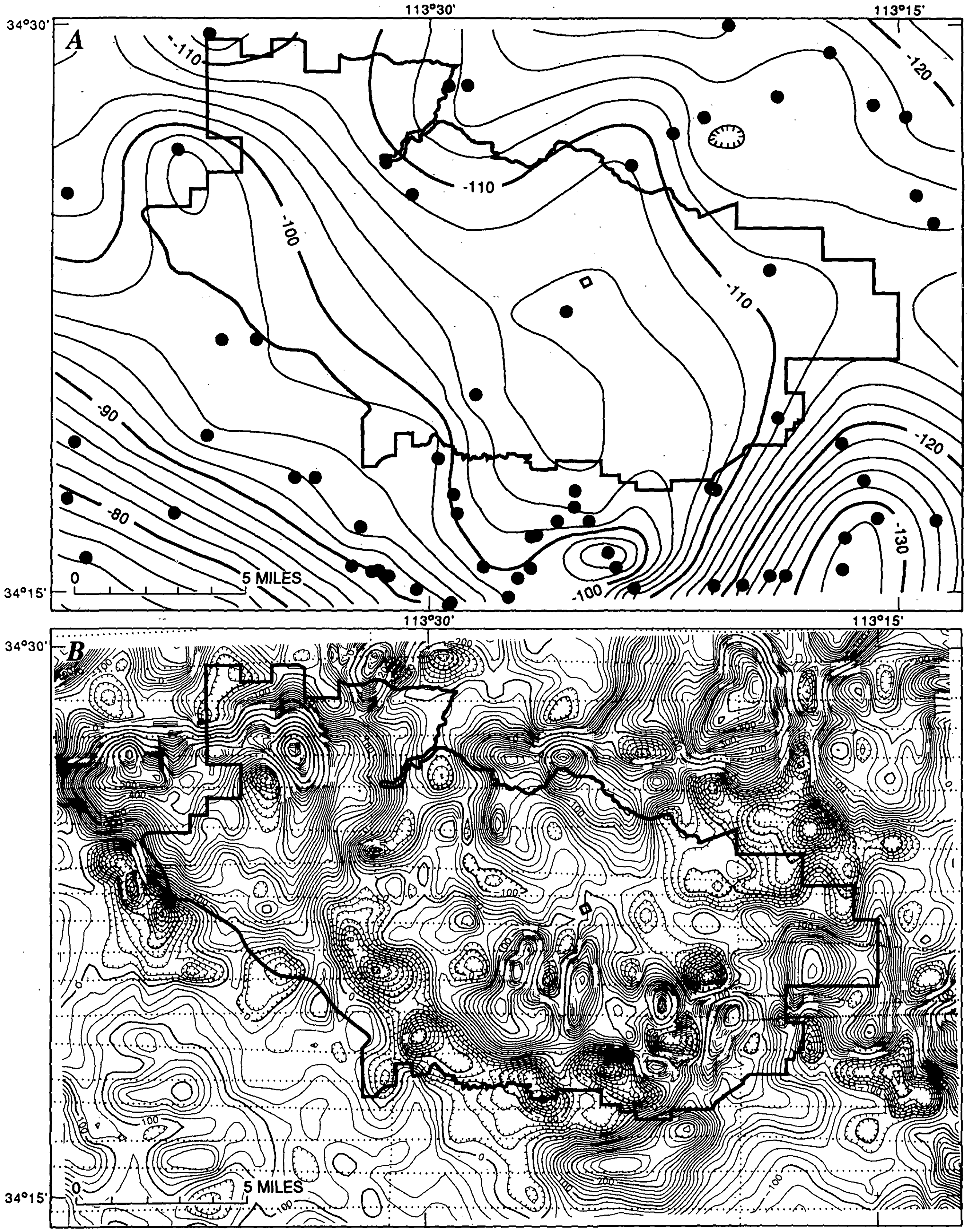


Figure 4. Geophysical anomaly maps of region including Arrastra Mountain/Peoples Canyon Wilderness Study Area (bold outline). Hachures indicate closed areas of lower values. *A*, Bouguer gravity anomaly map; contour interval 2 milligals. Dots represent gravity observation points. *B*, Reduced-to-pole magnetic anomaly map; contour interval 100 nanoteslas. Dotted lines represent flightlines. *C*, Regions of geophysical significance discussed in text.

information within the wilderness study area. The resulting map produced from the SLAR and Landsat TM images (not shown) shows several northwest-trending major lineaments that correspond to known structures. Parallel linear fractures (minor lineaments) typically accompany the major structures. At least one major east-northeast-trending lineament exists in the study area. En echelon and subparallel structures accompany it. In addition, a large circular or half-circular feature transects the study area (Robert Harrison, oral commun., 1988). Intersections of linear structures and the curvilinear feature occur in the western and northern parts of the area and correspond to known mineralized districts and geochemical anomalies.

Geochemistry

From 1984 through 1987, the U.S. Geological Survey collected stream-sediment samples from 230 sites within and near the Arrastra Mountain/Peoples Canyon Wilderness Study Area; 209 panned, nonmagnetic heavy-mineral concentrates and 84 raw panned heavy-mineral concentrates were prepared from portions of those samples.

The stream-sediment samples were collected from active alluvium in the stream channels. Each sample was composited from several localities along a channel length of approximately 50 ft. The stream sediments were sieved through an 80-mesh screen and pulverized to a fine powder before analysis. To prepare a heavy-mineral concentrate, stream sediment was seived through a 10-mesh screen and then panned until most of the quartz, feldspar, clay-sized material, and organic matter were removed. The remaining minerals of low density were removed with a heavy liquid (bromoform, specific gravity 2.8). The sample was then separated into magnetic, slightly magnetic, and nonmagnetic fractions by use of an electromagnet. The nonmagnetic fraction of the concentrates was ground to a fine powder and analyzed.

Samples were analyzed for 31 elements using a six-step semiquantitative emission-spectrographic method (Grimes and Marranzino, 1968); samples were analyzed for gold by an atomic-absorption method (Thompson and others, 1968) and for uranium and thorium by the delayed neutron-counting method of Millard (1976). In this report,

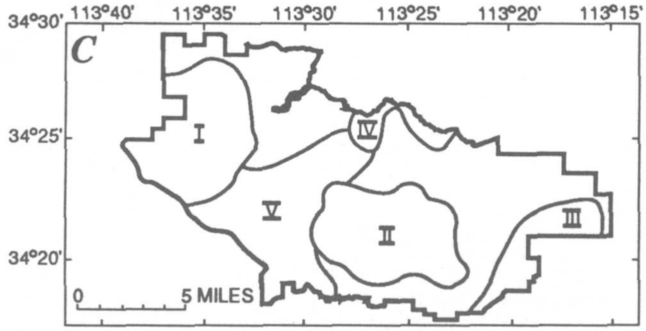


Figure 4. Continued.

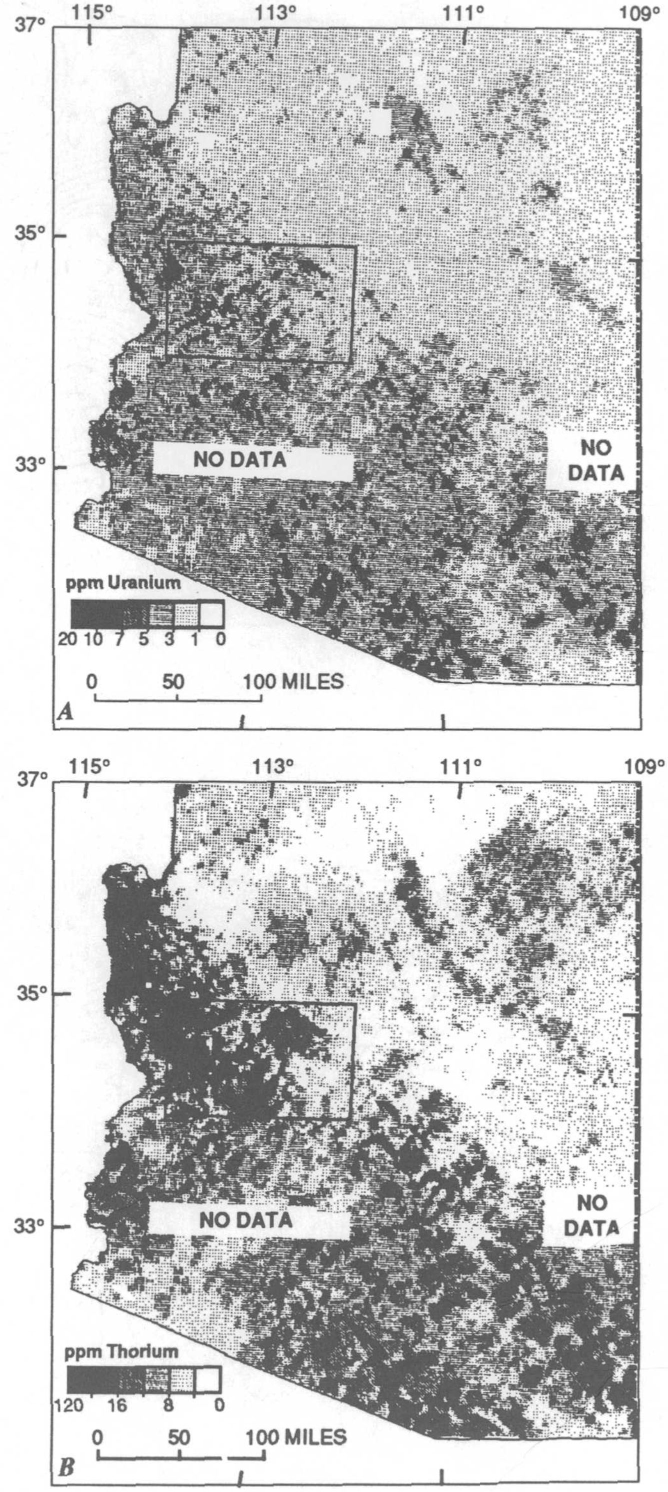


Figure 5. Preliminary gray-scale contour maps of eU (*A*) and eTh (*B*) distribution in Arizona. Derived from gamma-ray spectrometry data. Arrastra Mountain/Peoples Canyon Wilderness Study Area, in southwest part of Prescott 1° X 2° quadrangle (bold rectangle), is outlined on *A*.

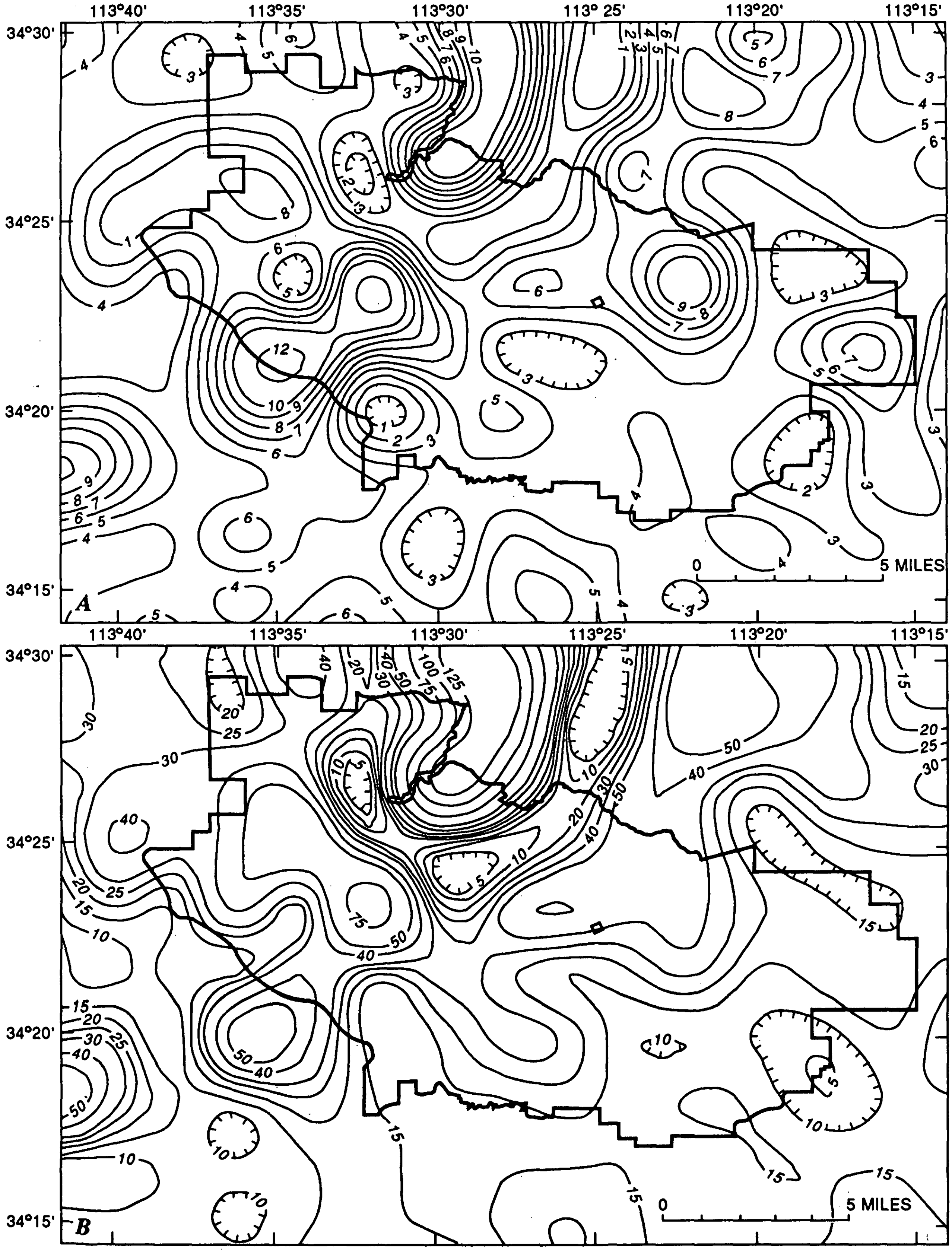


Figure 6. Contour maps of uranium and thorium distribution in Arrastra Mountain/Peoples Canyon Wilderness Study Area, Arizona (bold outline); derived from gamma-ray spectrometry data. Hachures indicate closed areas of lower values. *A*, Uranium contours, intervals 1 and 2 parts per million (ppm) eU. *B*, Thorium contours, intervals 5, 10, and 25 ppm eTh.

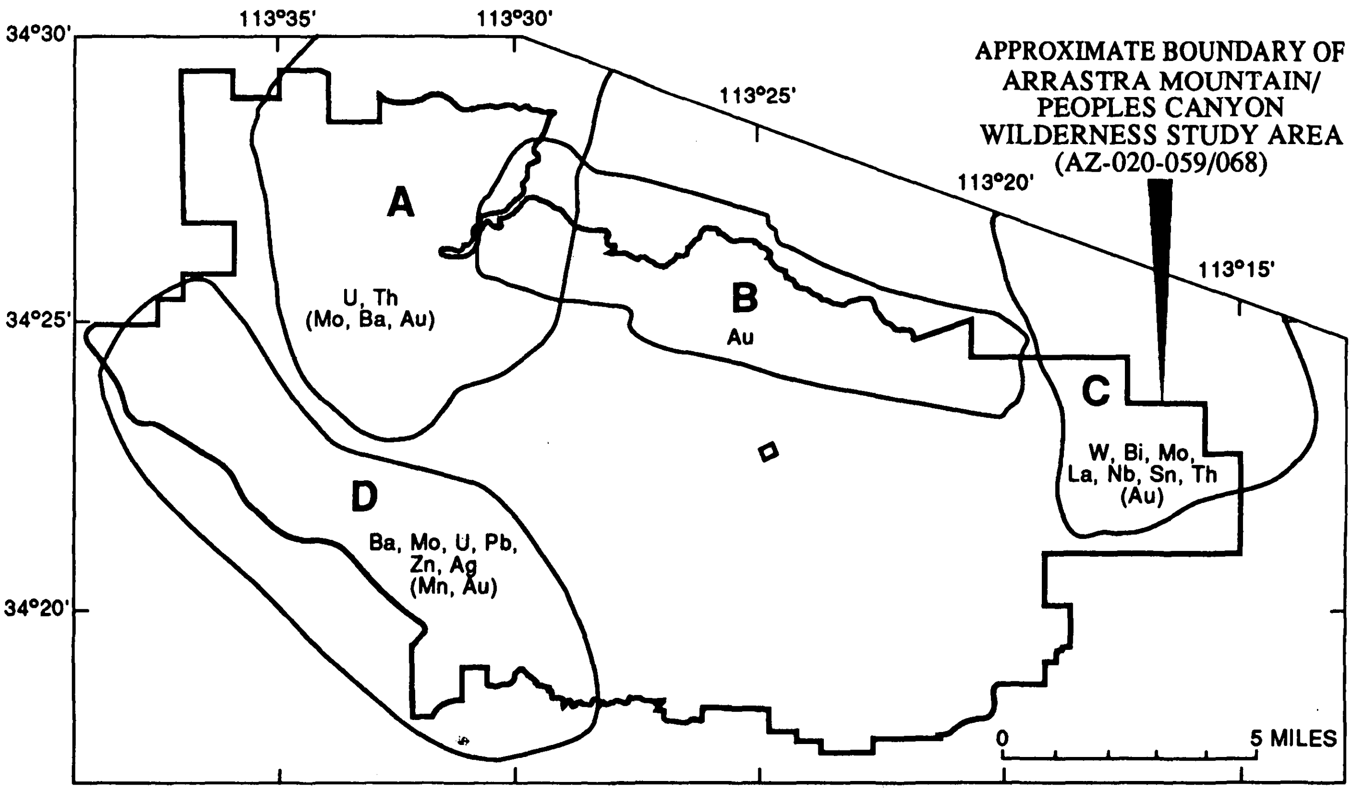
the geochemical interpretation is based on analytical data from heavy-mineral-concentrate, stream-sediment, and whole-rock samples. Of the 31 elements for which the samples were analyzed, 17 are indicative of possible hydrothermal alteration and (or) mineralization.

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

Results of the geochemical survey for the Arrastra Mountain/Peoples Canyon Wilderness Study Area are suggestive of a number of deposit types including (1) disseminated uranium-thorium in metalliferous granite, (2) gold in fault or shear zones and associated brecciated and veined granitic rocks, (3) tin- and rare-earth-element (REE)-bearing veins and associated tungsten-bearing veins and pegmatites, (4) gold-silver quartz veins, (5) sediment-hosted manganese deposits, (6) sediment-hosted uranium deposits, and (7) epithermal base- and precious-metal veins.

Stream-sediment samples from area A (fig. 7; table 2) show a close association of anomalous concentrations of uranium and thorium. Some panned-concentrate samples from the area also contain anomalous concentrations of molybdenum, barium, and gold. Area A encompasses much of the Signal Granite, where stream-sediment samples containing more than 250 ppm Th constitute more than 12 percent of the 157 samples taken in the study area (table 2). Geochemical data from the area fit some of the geochemical criteria for disseminated uranium-thorium deposits.

Raw panned-concentrate samples from area B contain anomalous concentrations of gold. A concentrate sample from a basin just inside the northwestern part of the area contains 200 ppm gold. Most of the samples from this area, however, contain between 0.10 and 7.1 ppm gold. Although possible associated elements arsenic (As), antimony (Sb), mercury (Hg), and cadmium (Cd) are not re-



Elements in anomalous concentrations (Elements in parentheses have anomalous amounts in only a few samples)

Ag	Silver	Bi	Bismuth	Mn	Manganese	Sn	Tin	W	Tungsten
Au	Gold	La	Lanthanum	Nb	Niobium	Th	Thorium	Zn	Zinc
Ba	Barium	Mo	Molybdenum	Pb	Lead	U	Uranium		

Figure 7. Geochemically anomalous areas of Arrastra Mountain/ Peoples Canyon Wilderness Study Area, Arizona. Lettered areas discussed in text.

Table 2. Statistical summary of stream-sediment analyses for thorium and uranium in U.S. Geological Survey samples from the Arrastra Mountain/Peoples Canyon Wilderness Study Area, Arizona

Value groups (ppm)	Samples in value groups			Analytical values (ppm)			
	Frequency number	Cumulative number	Percentage of samples	High	Low	Average	No. of deviant[1] samples
Thorium							
>250	20	20	12.7	754	254	428.7	9/11
100–250	23	43	14.6	240	103	154.7	8/1
50–99	38	81	24.2	90.9	50.4	71.0	21/17
<50	76	157	48.4	48.9	6.4	34.5	29/47
Uranium							
>25	25	25	15.9	62.5	25.3	38.8	9/16
10–25	85	110	54.1	24.8	11.0	16.8	42/43
5–10	39	149	24.8	9.58	5.04	7.4	22/17
<5	8	157	5.1	4.5	2.00	3.6	5/3

[1]Numerator denotes number of samples above the average value; denominator denotes number below the average value.

ported here for the panned concentrate data, localized areas of quartz veins, gouge zones, and stockwork limonite veins indicate that mineralization has taken place. Information gathered from stream-sediment data suggest that concentrations of gold-associated elements are very low and near the detection limit by the atomic absorption method; therefore, these elements do not serve as good path-finder elements for gold in this area. Several composite chip samples also confirm that concentrations of As (4–12 ppm), Sb (4–12 ppm), Hg (0.02–0.08 ppm), and Cd (0.3–0.4) are characteristically low.

Panned-concentrate samples from area C contain anomalous concentrations of tungsten, bismuth, molybdenum, lanthanum, niobium, tin, and thorium. This area is underlain by Proterozoic gneiss, schist, and minor quartz monzonite; pegmatite dikes, aplite dikes, and quartz veins are common. One panned-concentrate sample contains an anomalous concentration of gold (52 ppm). The association of tungsten, bismuth, and molybdenum suggests the possibility of tungsten-bearing veins such as those that occur in the Boriana mining district several miles to the north. The association of lanthanum, niobium, tin, and thorium in the panned concentrates reflects the presence of known pegmatites in the area.

Panned-concentrate samples from area D contain anomalous amounts of barium, molybdenum, uranium, lead, zinc, and silver. Several raw panned-concentrate samples contain anomalous amounts of gold. Area D encompasses numerous claims that consist of epithermal manganese and sediment-hosted uranium in sandstone and lacustrine deposits. Geochemical data from area D also fit the geochemical criteria for undiscovered polymetallic epithermal-vein deposits.

MINERAL AND ENERGY RESOURCES

Investigations by the U.S. Geological Survey and the U.S. Bureau Mines indicate that the Arrastra Mountain/Peoples Canyon Wilderness Study Area has identified or inferred subeconomic resources of three elements and high to low mineral resource potential for 13 types of deposits; certainty levels range from B to D (table 3).

Two workings in the southwestern part of the study area have identified manganese resources in the Artillery Formation: one has approximately 520 tons of rock averaging 6.05 percent manganese, and the other has an estimated 300 tons of ore averaging 16.2 percent manganese. An accurate average grade could not be determined but is probably less than 10 percent manganese.

Analytical data, with the aid of cross sections drawn through drill holes located along the west boundary of the study area, indicate that identified uranium resources near Artillery Peak may consist of 90,000 tons of rock averaging between 0.01 and 0.05 percent uranium oxide (U_3O_8), 20,000 tons averaging between 0.05 and 0.1 percent U_3O_8, and 30,000 tons having more than 0.1 percent U_3O_8. The Anderson uranium mine, approximately 1.5 mi southeast of the wilderness study area, has extensive surface excavations in part of the Chapin Wash Formation. Between 1955 and 1959, about 33,230 pounds of U_3O_8 was produced from 10,758 tons of ore with an average grade of 0.15 percent. Recent studies have shown that ore-bearing horizons are more extensive than previously recognized.

Several occurrences of gold and silver were examined within the study area. An inferred subeconomic resource of about 340 tons averaging 0.372 oz gold per ton was identified in the western part of the study area.

Table 3. Deposit types, commodities, and mineral resource potential in the Arrastra Mountain/Peoples Canyon Wilderness Study Area, Arizona

[Commodities listed in order of prominence; those in parentheses are minor. Ag, silver; Au, gold; Bi, bismuth; Ce, cesium; Cu, copper; La, lanthanum; Mn, manganese; Nb, niobium; Pb, lead; Pr, praseodymium; REE, rare-earth elements; Th, thorium; U, uranium; W, tungsten; Zn, zinc. Resource potential: H, high; L, low; M, moderate; N, none. Level of certainty: B, data only suggest level; C, data give good indication of level; D, data clearly define level]

Deposit type	Host lithology and age	Area of map (pl. 1; fig. 2)	Commodity(s)	Resource potential	Level of certainty
		Metallic commodities			
Epithermal manganese	Tertiary sandstone, minor volcaniclastic tuff.	Small southwest area.	Mn - - - - - - - - - - -	H - - - -	D
Polymetallic epithermal veins.	Tertiary sedimentary and volcanic rocks.	Southwest - - - - - -	Ag, Au, Pb, Zn - - - -	M - - - -	B
Lacustrine uranium- - - -	Tertiary fluvial and lacustrine carbonaceous sedimentary rocks.	Southwest, southeast.	U - - - - - - - - - - - -	H - - - -	D
		South - - - - - - - - -	U - - - - - - - - - - - -	L - - - -	D
Disseminated rare-earth elements.	Early and Middle Proterozoic granites	North and east-central.	Ce, La, Nb, Pr (Th)- -	L - - - -	C
Disseminated uranium and thorium.	Proterozoic granites: Early - - - - - - - - - - -	Northwest- - - - - -	U, Th - - - - - - - - - -	L - - - -	C
	Early and Middle- - - - -	East-central- - - - -	U, Th - - - - - - - - - -	L - - - -	B
Shear- or fault-controlled, disseminated gold.	Early and Middle Proterozoic granites.	North border- - - - -	Au (Ag)- - - - - - - - -	H, M - -	C
Pegmatite- - - - - - - - -	Veins in Early and Middle Proterozoic granites.	East- - - - - - - - - -	REE, quartz, feldspar.	M - - - -	C
Volcanogenic massive sulfides.	Early Proterozoic intrusive rocks.	East- - - - - - - - - -	Cu, Pb, Zn - - - - - - -	L - - - -	C
Vein tungsten	Pegmatite veins in Proterozoic gneiss and schist.	East- - - - - - - - - -	W (Bi) - - - - - - - - -	M - - - -	C
		Other commodities			
Zeolite minerals, clays, and gypsum.	Alluvial valleys, buried Tertiary fluvial and lacustrine sediments.	Northwest corner - -	Zeolite, clay, gypsum.	L - - - -	C
Geothermal energy	Alluvial basins	Northwest corner, south border.	Geothermal - - - - - - -	M - - - -	B
Coal- - - - - - - - - - - -	Chapin Wash Formation	South - - - - - - - - -	Coal - - - - - - - - - - -	L - - - -	C
Oil and gas- - - - - - - -	Chapin Wash Formation	South - - - - - - - - -	Oil, gas - - - - - - - - -	L - - - -	C

The 13 types of deposits having mineral resource potential are discussed in the following sections, and reasons are given there for the levels of potential and the certainty of assessments.

Sediment-Hosted Manganese, Lacustrine Uranium, and Polymetallic Epithermal Veins

Manganese, uranium, and polymetallic (silver, gold, lead, and zinc) vein mineralization has occurred in the western, southwestern and southern parts of the Arrastra Mountain/Peoples Canyon Wilderness Study Area. Manganese is found principally in the Oligocene and (or) Miocene Artillery Formation and to a lesser extent in the Miocene Chapin Wash Formation. It occurs in veins, as matrix in conglomerate, in fault zones, and as disseminations in red sandstone and boulder conglomerate. These occurrences are on the periphery of the Artillery Peak mining district, which has an estimated 75 million tons of reserves that are among the largest reserves of low-grade manganese in the United States (Laskey and Webber, 1938). A small area in the southwestern part the study area has high mineral resource potential for Tertiary sediment-hosted manganese deposits, certainty level D.

Uranium occurs in a wide band in the southern and southwestern parts of the study area. Uranium occurrences are typically found in carbonaceous zones in the lacustrine facies of the Artillery Formation west and south of Artillery Peak and in the Chapin Wash Formation, which is exposed along the southern border of the study area (figs. 2, 3; pl. 1). New information (J.K. Otton, oral commun., 1989, after plate 1 was completed) indicates that the contact between the upper part of the Artillery Formation and the Signal Granite follows the 2,200-ft contour line on the west side of Artillery Peak. Detailed aerial gamma-ray spectrometry data (flightlines spaced one-quarter mile apart, High Life Helicopters, Inc./QEB, Inc., 1983) for part of the Prescott 1° by 2° quadrangle indicate eU concentrations of 4 to 7 ppm in an area that includes the Anderson mine. These anomalous concentrations were not detected by the 1-mi-spaced aerial survey (Aero Service Division, Western Geophysical Company of America, 1979). The areas west and south of Artillery Peak and a corner near the Anderson mine have high mineral resource potential for lacustrine uranium deposits, certainty level of D. The northernmost Date Creek basin, in the southern part of the study area, has a low mineral resource potential for lacustrine uranium deposits, certainty level D.

Geologic and geochemical data indicate that areas of moderate resource potential for polymetallic vein deposits are coincident with manganese and uranium resource potential in the southwestern part of the study area (fig. 2; pl. 1). Clusters of small intrusions, plugs, and volcanic rocks in the western part of the study area have geochemical anomalies of barium, molybdenum, and uranium and scattered concentrations of lead, zinc, and silver, and gold along faults and breccia zones. These rocks and structures have moderate potential for silver, gold, lead, and zinc mineral resources, certainty level B.

Disseminated Gold

Two areas in the northern part of the study area have high mineral resource potential, certainty level C, for fault- or shear-related disseminated gold and minor amounts of silver. These areas are separated by an area of moderate resource potential, certainty level C, for gold and minor silver. All of these areas are located in an east-west-trending zone in the Poachie Range (fig. 2; pl. 1). The areas of high potential contain northeast-trending to east-northeast-trending Tertiary shear or fault zones in granitic basement rocks. The zones typically contain pulverized rock surrounded by argillically altered breccia, locally heavily stained by hematite. Argillically altered rocks in the interior of the breccia zones are cut by irregular, discontinuous quartz-calcite or calcite-hematite veins with or without quartz. Propylitically altered rocks are present locally in irregularly shaped envelopes outside of the argillic alteration area. Limonite-rich veins having a variable jarosite component are common in the eastern area. Samples of stream sediments from these three areas contain anomalous concentrations of gold; composite rock-chip samples of vein and gouge material also have anomalous gold concentrations. Gold typically occurs as micron-sized particles associated with quartz and less commonly with calcite. Several samples of gouge and vein material show that concentrations of elements typically associated with gold (antimony, arsenic, mercury, and thallium) are negligible and that barium concentrations are higher than in unaltered rock.

Disseminated Uranium, Thorium, and Rare-Earth Elements in Granite

Stream-sediment data obtained in this study (table 2) and from aerial gamma-ray surveys (Aero Service Division, Western Geophysical Company of America, 1979) indicate that anomalous concentrations of uranium and thorium occur in Proterozoic granites in the study area. The Middle Proterozoic granites in the western part of the area contain unknown uranium-bearing minerals and at least one thorium-bearing mineral—thorite. Biotite, chlorite, zircon, monazite, xenotime, and thorite can contain elevated concentrations of uranium and thorium (Silver, 1969, 1980; Silver and others, 1977, 1984). Fault gouge and composite samples of brecciated, altered granite in the study area have an average concentration of 5.8 ppm uranium oxide (U_3O_8).

The mineral resource potential for disseminated uranium and thorium is low, certainty level C, in the Signal Granite underlying the western one-third of the study area and is low, certainty level B, in the older granitic rocks underlying much of the eastern part of the study area. The certainty level B is given to the area of older granitic rocks because of a lower level of geochemical anomalies in those rocks and a lack of distinct data from gamma-ray spectrometry in that area.

Geologic and geochemical data indicate that the entire Proterozoic granitic crystalline terrane in the north and central parts of the study area has low resource potential, certainty level C, for disseminated rare-earth elements. The principal unit having this potential is a coarse-grained biotite quartz monzonite to granodiorite. Zircon, rutile, apatite, monazite, and xenotime in relatively high amounts for granitic rocks have been identified in samples of the quartz monzonite. The rare-earth and associated elements present include cerium, yttrium, terbium, lanthanum, neodymium, niobium, and praseodymium. The total rare-earth oxides in the granitic rocks may approach grades comparable to lower grades found in carbonatite deposits (Cox and Singer, 1986). Analyzed samples of the rock have 600 to 800 ppm total rare-earth elements. Metalliferous granites having widely disseminated rare-earth elements have not received much attention as sources for these elements but are here considered as having potential for resources that may be recoverable in the future by bulk-leaching techniques.

Pegmatite Minerals and Vein Tungsten

The Arrastra Mountain/Peoples Canyon Study Area lies within the major productive pegmatite belt of Arizona. This belt includes several mines (Kingman Feldspar to the west, Rare Metals to the north, and those of the White Picacho district to the southeast) that have been developed as commercial sources of feldspar, quartz, mica, beryl, lithium minerals, tungsten minerals, rare-earth elements, and other commodities (Heinrich, 1960; Jahns, 1952).

The eastern part of the study area, especially the area of Peoples Canyon, has moderate mineral resource potential, certainty level C, for tungsten in veins and for rare-earth elements, quartz, and feldspar in pegmatite bodies. The pegmatites occur in Early Proterozoic granites as two types: (1) small, complex veins typically several feet long and 0.5 ft wide containing coarse-grained micas, quartz, and feldspar, less common tourmaline, and rare spodumene, and (2) large, spatially extensive pods or sill-like bodies having a simple mineralogy of quartz, feldspar, and micas. Chemical analyses show high concentrations of tungsten and elevated values of molybdenum, bismuth, tin, and beryllium in basins that drain rocks having both types of pegmatites.

Volcanogenic Massive Sulfides (Copper, Lead, Zinc)

Leached, hematite-stained gossan found in Early Proterozoic supracrustal rocks in the eastern part of the study area may have formed from rhyolite-hosted massive sulfide deposits; however, no significant geochemical values were found in samples of the gossan. The mineral resource potential for base-metal massive sulfide deposits (such as copper, lead, and zinc) in the area is speculative and, at best, is considered low, certainty level C.

Zeolite Minerals, Clay, and Gypsum

Small lenses of zeolite minerals, clay, and gypsum occur in alluvial valleys of the Big Sandy and Santa Maria Rivers in the wilderness study area, and somewhat higher grade accumulations are found within several miles northwest of the study area in the Tertiary Big Sandy Formation (Sheppard and Gude, 1971; Sheppard, 1973). A low resource potential, certainty level C, is assigned these commodities in the northwest corner of the study area. No evidence of deposits of high purity was found within or near the study area, and the occurrences of these minerals found in the study area are not of great thickness or lateral extent.

Coal, Oil, and Gas

Source beds and reservoir rocks suitable for the accumulation of hydrocarbons underlie the southern part of the Arrastra Mountain/Peoples Canyon Wilderness Study Area. The exposed Tertiary sedimentary deposits in the study area at the north edge of the Date Creek basin are permissive of a low potential for petroleum and natural gas resources. Resource potential for coal, oil, and gas is rated low, certainty level C, in the southern part of the study area. Impure lignite and associated carbonaceous mudstones present locally within the Chapin Wash Formation have no value as a fuel.

Geothermal Energy

Several thermal springs and thermal well sites occur in basins near the study area. Two parts of the study area—the northwest corner and along the south border—are considered to have moderate potential certainty level B, for low-temperature geothermal resources. The areas are defined on the basis of thermal springs, thermal wells, and ground-water, geologic, and geophysical surveys (Muffler, 1979; Witcher and others, 1982). A well near Alamo Reservoir (1,620 ft deep) had an average discharge temperature of 47 °C; several thermal springs near the northwestern part of the study area yielded temperatures of 37 °C. Heat-flow measurements (milliwatts of heat energy flowing across a square meter—mW/m^2) from just beyond the west border of the area study are greater than 103 mW/m^2 and, just east of the area, 74 to 85 mW/m^2. Anomalous heat resources can include molten rocks in the crust, unusually highly radioactive crystalline rocks, and a geothermal convection system. Background heat sources are mainly the mantle rocks and radioactive minerals in crystalline rocks of the crust. It is likely that the heat source for the high heat flow results from unusually highly radioactive rocks in the area.

Sand and Gravel

Sand and gravel deposits suitable for construction use occur in the wilderness area, particularly in the Quaternary alluvial deposits of Government Wash and tributaries of the Big Sandy River. Because similar materials of equal or better quality are abundant closer to local markets, and because the probable costs of mining exceed the present market value of these materials, their future development is unlikely.

Recommendations For Future Work

Further studies in the Arrastra Mountain/Peoples Canyon Wilderness Study Area are needed to resolve several problems not answered in our studies. (1) Detailed geologic mapping and sampling in the area between Arrowhead Spring and the Dunlap mine (fig. 1) to obtain a better understanding of the structural setting of the gold in the granitic rocks. (2) Detailed sampling of the Signal Granite and petrographic examination of its radiogenic mineral assemblage, focusing on the temporal and petrogenetic character of the granite. (3) Ground geophysical investigations of the Signal Granite using a portable, quantitatively calibrated gamma-ray spectrometer in conjuction with geologic studies to locate areas of anomalous radioelement concentrations indicated by aerial surveys. (4) Detailed examination of the Proterozoic pegmatitic rocks to determine the significance of tungsten, bismuth, and rare-earth element mineralization. (5) Sampling to determine grade, mineralogical nature, and distribution of disseminated rare-earth elements in the granitic rocks. (6) Detailed sampling for placer deposits of gold and rare-earth elements in areas designated to have moderate to high potential for those elements. (7) Detailed sampling of areas having high potential for disseminated uranium and thorium.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

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

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

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

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

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

LEVELS OF CERTAINTY

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

LEVEL OF RESOURCE POTENTIAL →

A	B	C	D
U/A UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL

LEVEL OF CERTAINTY →

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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.

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