Mineral Resources of the Trigo Mountains Wilderness Study Area, La Paz County, Arizona

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Chapter J

Mineral Resources of the Trigo Mountains Wilderness Study Area, La Paz County, Arizona

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U.S. GEOLOGICAL SURVEY BULLETIN 1702

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
SOUTHWESTERN AND SOUTH-CENTRAL ARIZONA

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
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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 of certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and submitted to the President and the Congress. This report presents the results of a mineral survey of part of the Trigo Mountains Wilderness Study Area (AZ–050–023B), La Paz County, Arizona.

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Mineral Resources of the Trigo Mountains Wilderness Study Area, La Paz County, Arizona

By David R. Sherrod, Richard M. Tosdal, Robert B. Vaughn, David B. Smith, *and* M. Dean Kleinkopf
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SUMMARY

Abstract

The Trigo Mountains Wilderness Study Area (AZ-050-023B) is located in La Paz County, southwestern Arizona. At the request of the U.S. Bureau of Land Management, 29,095 acres of the Trigo Mountains Wilderness Study Area were evaluated for mineral resources (known) and mineral resource potential (undiscovered). Throughout this report, reference to the "Trigo Mountains Wilderness Study Area" or to the "study area" refers only to that part of the wilderness study area for which mineral surveys were requested by the U.S. Bureau of Land Management.

An inferred subeconomic manganese resource of 210,000 long tons, having a grade of 12.7 percent, is located in the central part of the study area. Placer gold occurs along the north margin of the study area, downstream from the nearby Hart mine. Common rock and sand and gravel in the study area have no unique qualities that make them more valuable than vast quantities in the surrounding areas. There is low mineral resource potential for gold and silver associated with quartz-bearing veins near the northeast corner of the study area and in the three areas underlain by crystalline rocks in the south-central part. The north-central part of the study area has a high resource potential for manganese in deposits of limited extent. There is no potential for geothermal energy or for oil resources; the potential for natural gas is low along the northwest border of the study area.

Character and Setting

The Trigo Mountains Wilderness Study Area, which includes a large part of the Trigo Mountains, is in the southwestern part of La Paz[1] County, about 23 mi north of Yuma, Ariz. Relief in the Trigo Mountains is locally as great as 2,300 ft, although it is less than about 1,000 ft in the study area. The mountains are underlain by Proterozoic and Mesozoic gneiss and granitic rocks, and by Tertiary volcanic rocks that underwent a major episode of extensional deformation about 22 to 20 million years ago (Ma) (see geologic time chart in "Appendixes"). Sedimentary basins that bound the range were created during this time and subsequently filled by coalescing alluvial fans. An arm of the early Gulf of California briefly inundated the Palo Verde Valley northwest of the study area about 5 Ma, resulting in sandstone, siltstone, and limestone that abut the northwest edge of the Trigo Mountains. Faulting since that time enabled the Colorado River to establish its modern course in a trough along the west margin of the Trigo Mountains.

Mines that have produced gold, silver, lead, and (or) zinc are located outside the northeast and southeast boundaries of the study area. The associated mineralized rock, however, whose distribution is largely fault controlled, does not extend into the study area. Manganese has been mined in the study area and is limited to veins and fault breccia in Tertiary volcanic rocks.

Identified Resources

Manganese oxides occur as fissure fillings in faults and fractures that cut Tertiary volcanic rocks in the Trigo Mountains Wilderness Study Area. Inferred subeconomic manganese resources of about 100,000 long tons (lt) of nearly 13 percent manganese and about 110,000 lt of about 9 percent manganese were calculated for the Lopez Wash area. Of the 11 drainages in the northern part of the study area, 4 contain detectable amounts of gold in panned-concentrate samples; however, it is doubtful that a resource is present because the occurrences are scattered and the amount of gold in the samples is small.

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

Sand and gravel, and rock suitable for crushing for road surfacing, are present in the study area. These materials, however, have no unique qualities that make them more valuable than those that are closer to markets in surrounding areas.

Mineral Resource Potential

Low resource potential for gold and silver is assigned to the northeastern corner and to three areas in the south-central part of the Trigo Mountains Wilderness Study Area, all of which are underlain by Proterozoic and Mesozoic granitic rocks and their gneissic equivalents. Vigorous prospecting may lead to the discovery of gold and silver in small veins of very limited extent and probably of limited grade.

A high resource potential for manganese is assigned to the north-central part of the study area. Manganese (as manganese oxides) forms narrow veins and fracture-filling deposits. There is no resource potential for geothermal energy or for oil; the energy resource potential for natural gas is low along the northwest border of the study area.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and represents 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 is provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and 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 the U.S. Bureau of Mines and U.S. Geological Survey (1980). Studies by the U.S. Geological Survey 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. Mineral assessment methodology and terminology as they apply to these surveys were discussed by Goudarzi (1984). See "Appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Location, Physiography, and Access

The Trigo Mountains Wilderness Study Area (AZ–050–023B) is located about 23 mi north of Yuma, Ariz. (fig. 1), in the Basin and Range physiographic province of southwestern Arizona. The climate is arid, characteristic of the Sonoran Desert region of the southwestern United States and northern Mexico.

The Trigo Mountains are barren and rocky. Winding washes in them drain to the Colorado River, which flows along the west and south margins of the range. Relief is moderate, with elevations ranging from about 2,500 ft east of the Hart mine to about 200 ft at the Colorado River near Yuma Wash (fig. 1).

Dirt roads approach the range from the north via the townsite of Cíbola (SEE-bo-la) and from the south via Martinez Lake. Four-wheel-drive trails traverse some of the larger washes. An old jeep track along the west boundary near the Colorado River was destroyed during flooding in the early 1980's. This track also connected with a jeep trail down Clip Wash, a short part of which is a tortuous bedrock channel. Access by boat from the Colorado River is possible but difficult because broad thickets of tamarisk (salt cedar) and thorny shrubs crowd the shore. The eastern part of the Trigo Mountains is closed to public access because it lies within the Yuma Proving Ground, a training center of the U.S. Army.

Previous and Present Investigations

There have been few geologic studies of the Trigo Mountains, in part because of difficult access. Until recently, writers relied upon the important regional mapping by E.D. Wilson (1933; 1960) and a handful of mine summaries and university theses (for example, Wilson and others, 1934; Wilson, 1951; Farnham and Stewart, 1958; Parker, 1966; Keith, 1978; Pietenpol, 1983; Bradley, 1986). The southern and northern fringes of the range were included in water-resource investigations of the Yuma and Blythe areas (Metzger and others, 1973; Olmsted and others, 1973). Nearby parts of the Chocolate Mountains, across the Colorado River in California, were mapped by Crowe (1978), Haxel (1977), and Morton (1977).

Investigations of the structural geology of the Trigo Mountains flourished in the late 1970's and early 1980's when students and faculty from San Diego State University pooled their efforts to understand the distribution, geometry, and mineralization of large-scale Tertiary extensional (normal) faults in the lower Colorado River region (Weaver, 1982; Garner and others, 1982). However, geologic units of the Trigo Mountains remained largely unmapped.

In 1986, the U.S. Bureau of Mines conducted a survey of the study area and investigated U.S. Bureau of Land Management mining claim and mineral lease records. U.S. Bureau of Mines field studies were directed chiefly toward the examination of known mines, prospects, and mineralized areas inside and within about 1 mi of the study area boundary.

Field studies by the U.S. Geological Survey for this assessment were conducted mainly in 1986 and 1987 and included geologic mapping and geochemical studies. Rock and stream-sediment samples were collected to supply background geochemical information and to identify areas containing anomalous concentrations of economic or indicator elements.

Acknowledgments

We gratefully acknowledge the advice and logistical support supplied by the managers and employees of the Cibola and Imperial National Wildlife Refuges (U.S. Fish and Wildlife Service) and the officers and civilian employees of the Yuma Proving Ground (U.S. Army) during the fieldwork for this study.

APPRAISAL OF IDENTIFIED RESOURCES

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U.S. Bureau of Mines

Methods of Investigation

A total of 205 samples, including 194 rocks and 11 panned concentrates, was collected from within and near the Trigo Mountains Wilderness Study Area for analysis

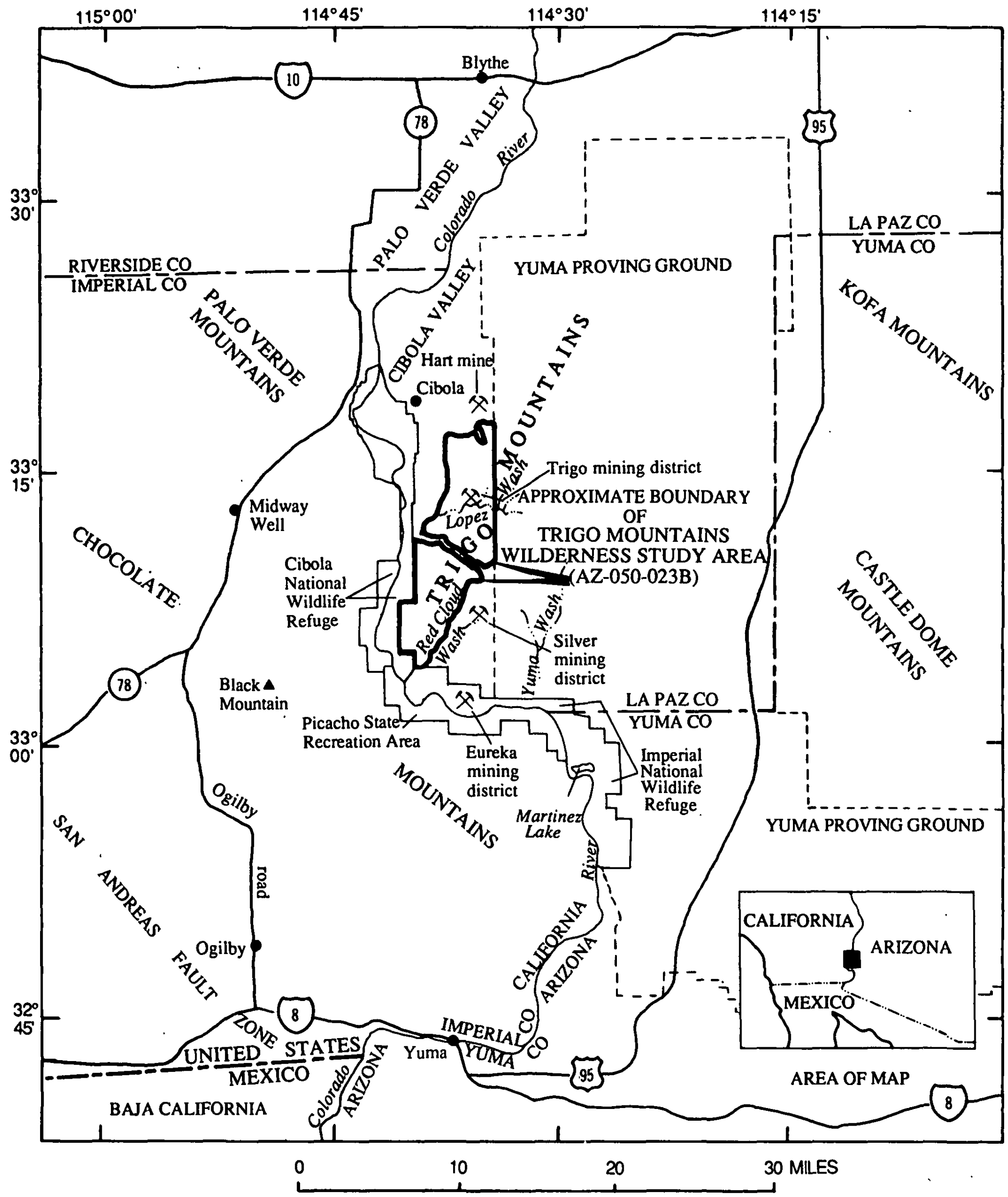

Figure 1. Index map showing location of Trigo Mountains Wilderness Study Area, La Paz County, Arizona.

(Wood, 1989). Accessible mine workings were mapped using compass and tape, and rock samples were taken across veins and other suspected mineralized structures. Panned-concentrate samples were collected from drainages in an area of known gold placers (Johnson, 1972; Krason and others, 1982) in the northeastern part of the study area. A limestone sample from the Bouse Formation was analyzed by inductively coupled plasma–atomic emission spectroscopy for oxides of aluminum, calcium, iron, manganese, phosphorus, potassium, silica, sodium, and titanium. Loss on ignition was determined gravimetrically, and sulfur was determined instrumentally. The remaining 204 samples were analyzed by fire assay for gold and silver. Of the samples from the central part of the study area, 60 were analyzed by atomic absorption (AA) for manganese, and 11 of these samples were also analyzed by AA for iron and silver. All 116 samples from the southern part of the area were analyzed by AA for lead, molybdenum, silver, vanadium, and zinc, and 17 of these samples were also analyzed gravimetrically for barium. (See Wood, 1989, for analytical details.)

Production History and Mining and Leasing Activity

The study area includes parts of the Trigo and Silver mining districts (fig. 1): the Trigo district in the central and northern part of the study area, and the Silver district extending into the southeastern part (Keith, 1978). The Eureka mining district is 5 to 6 mi southeast of the study area along the Colorado River.

Manganese oxides in the Trigo mining district occur as fracture fillings in andesitic volcanic rocks; 11 occurrences are reportedly in the study area. Approximately 25,000 long tons (lt) of 20- to 40-percent manganese ore were mined in the district during the 1950's, when the government was purchasing low-grade manganese ore (Krason and others, 1982).

Mines in the Silver mining district are all outside the study area but as near as 0.5 mi. The mineral deposits are restricted to a narrow set of veins localized along north-trending fault zones (Bradley, 1986); the Eureka district has a similar setting (Keith, 1978). Production from the Silver and Eureka districts since about 1879, when the districts were organized, is reportedly about 1.6 million ounces (oz) of silver, 1,457 short tons (st) of lead, 940 oz of gold, 15 st of zinc, and 0.75 st of copper (Keith, 1978). The largest mines in the Silver district are the Red Cloud, Clip, and Black Rock (Wilson, 1951). Extensive drilling near the Clip, Black Rock, and Geronimo mines in the early 1970's delineated reserves in excess of 5 million st containing 4 oz of silver/st and significant amounts of fluorite, barite, lead, and zinc, which may be minable by open-pit methods (U.S. Bureau of Land Management, 1985).

According to Bureau of Land Management records (as of January 1988), there are no patented claims in the study area, and unpatented mining claims are located only in the southern part. As of February 1987, about 5,000 acres in the northern part of the study area were under lease for oil and gas.

Mineral Deposits

Gold

Gold occurrences in the study area are limited to placer deposits along the north margin, downstream from mineralization in the nearby Hart mine area (figs. 1, 2). Gold at the Hart mine occurs in narrow quartz veins in Jurassic dioritic gneiss. Major faults cut off the Mesozoic rocks 1.5 mi inside the study area's northeast corner (fig. 2).

Panned-concentrate samples of stream sediments for this study were taken from dry washes in the area identified by Johnson (1972) and Krason and others (1982) as the locations of placer mining. No evidence of past or current placer mining was seen. Minor amounts of gold were detected in panned-concentrate samples from 4 of the 11 drainages sampled. The presence of gold in the panned-concentrate samples does not define a resource because of the small amount of gold detected, the absence of visible gold in the samples, and the scattered nature of the occurrences.

Gold resources were calculated for the gold-bearing quartz veins in two adits at the Hart mine, which is adjacent to the study area on the north (figs. 1, 2). In the upper adit, average gold concentrations are calculated to be 0.22 oz/st for about 150 st of material. In the lower adit, average gold concentrations are calculated to be 0.13 oz/st for about 10,000 st of material. The tonnages were calculated using one-half the strike length of each fault and a tonnage factor of 12.2 cubic feet per short ton. The resource is subeconomic.

Manganese

Manganese oxides, mostly pyrolusite and psilomelane, occur as fault and fracture fillings and between breccia clasts in volcanic rocks in the central and southern parts of the Trigo mining district (Farnham and Stewart, 1958; Keith, 1978). The manganese oxides were mined from surface cuts and underground stopes. Selective mining, crushing, screening, and commonly hand sorting were required to adequately concentrate the manganese prior to shipping. None of the manganese claims are currently on file with the Bureau of Land Management.

Manganese concentrations in samples collected for this study range from less than 1 percent to 36 percent.

Exposures created by workings along two of the faults in the study area provided a basis for estimating the remaining manganese resource (see Wood, 1989, for calculations). The amount of the inferred subeconomic manganese resources along the two faults is about 100,000 lt having 13 percent manganese and 110,000 lt having 9 percent manganese, or about 210,000 lt of material containing manganese worth about $3 million, using an average manganese price of $1.27/lt unit (one lt unit = 22.4 lbs) (U.S. Bureau of Mines, 1988). Bulk sampling and metallurgical testing would be required to determine if the manganese can be concentrated to the 46- to 48-percent level required to make a salable product.

Silver, Lead, and Zinc

There are no identified resources of silver, lead, or zinc in the Trigo Mountains Wilderness Study Area. Silver, lead, and zinc were mined from the Silver district, which borders the study area on the southeast. The ore minerals fill fractures along chiefly north-trending normal faults that extend into the study area north of the Clip and South Geronimo mines (fig. 2). Mineralization diminishes abruptly near the study area boundary, however.

Discontinuous barite and calcite veins occur along the faults near the Clip mine. Workings sampled north of the Clip mine are mostly prospect pits that include three adits and five shafts. Concentrations of gold and molybdenum are low in the samples, whereas concentrations of barium, silver, vanadium, lead, and zinc vary. Rocks collected along faults near the mine contain gold (as much as 0.06 oz/st), barium (as much as 38 percent), silver (0.003 to 8.0 oz/st), molybdenum (2 to 14 parts per million, ppm), vanadium (26 to 465 ppm), lead (15 to 1,900 ppm), and zinc (5 to 880 ppm). Wood (1989) gives details of sampling localities and analytical results.

The fault at the South Geronimo mine contains calcite and quartz veins. Workings along the fault include two adits, two shafts, and several prospect pits and opencuts. Rocks collected along the fault contain gold (as much as 0.06 oz/st), silver (0.12 to 11.4 oz/st), molybdenum (4 to 610 ppm), vanadium (10 to 132 ppm), lead (560 to 42,000 ppm), and zinc (440 to 8,600 ppm).

Inferred subeconomic silver resources of 70,000 st (silver grade of 5.0 oz/st), which may be mined by open-pit methods, were calculated for workings along the fault in the South Geronimo mine area (outside the study area). The in-place value of the silver resource is about $2 million, using the August 1988 silver price of $6.70 per oz (Wood, 1989).

Industrial Minerals

The washes and alluvial fans of the study area contain common-variety rock, sand, and gravel. Volcanic rocks in the study area are suitable for construction after crushing. From 1986 to 1988, sand, gravel, and rock (both volcanic and plutonic) were being quarried outside the northern boundary of the study area for use in road and levee construction along the Colorado River in the nearby Cíbola National Wildlife Refuge. There are no unique qualities (other than distance to job site) that make the sand and gravel or rock in the study area more valuable than the vast quantities available in the surrounding area. Volcanic rock from the rip-rap quarry south of Hart Mine Wash (north edge of fig. 2) is highly fractured because of its location near a major Tertiary fault. The numerous fractures may have expedited the work of quarrying.

Limestone of the Bouse Formation is exposed outside the northwest margin of the study area (fig. 2). Calcium carbonate ($CaCO_3$) content of the limestone is 69 percent, which is well below that needed for industrial applications.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By David R. Sherrod, Richard M. Tosdal,
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Geology

The Trigo Mountains are built of Tertiary volcanic and sedimentary rocks deposited nonconformably over Proterozoic and Mesozoic crystalline rocks. The mountains are near the western edge of the southern Basin and Range physiographic province, where large-scale extensional deformation between about 22 and 20 Ma broke the region into a series of fault-bounded mountains and basins. Most mineralization in the study area is structurally controlled by the normal faults and is limited to vein-forming manganese oxides emplaced in Oligocene and Miocene rocks. Scarce gold-bearing quartz veins were emplaced in Mesozoic rocks outside the study area prior to Oligocene and Miocene volcanism and sedimentation.

The oldest rocks in the study area are Proterozoic gneiss and amphibolite, which crop out near Lighthouse Wash (fig. 2). The gneiss and amphibolite were intruded by Mesozoic diorite and associated pegmatite and then were metamorphosed. Late Triassic monzonite crops out in the Hart mine area (Tosdal 1986, 1988), along the north boundary of the study area. Jurassic granitic rocks intruded the Proterozoic and Mesozoic gneisses and also the Late Triassic monzonite. The Jurassic granitic rocks, consisting of diorite, granodiorite, and granite that are locally converted to gneiss and mylonitic gneiss, are

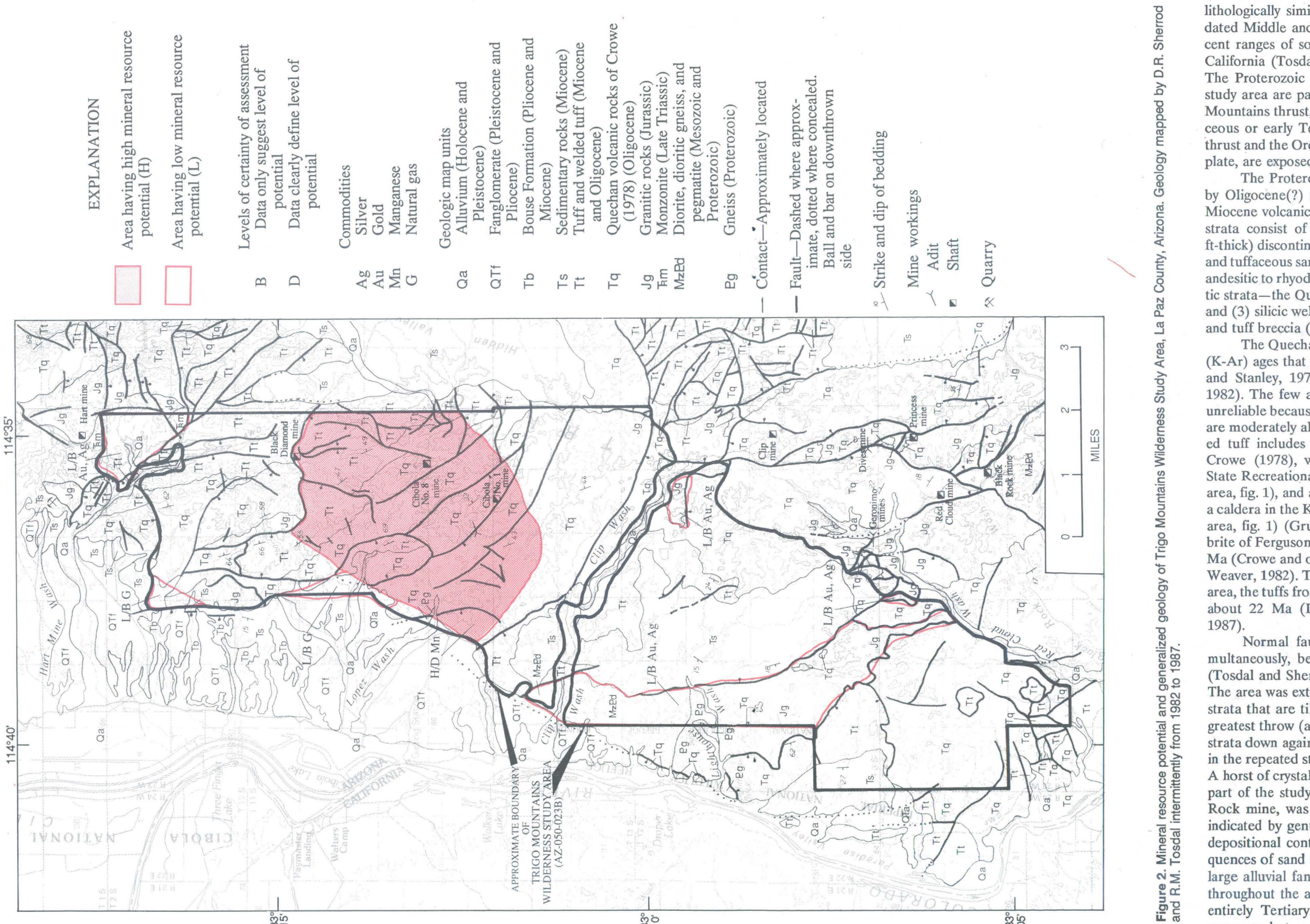

Figure 2. Mineral resource potential and generalized geology of Trigo Mountains Wilderness Study Area, La Paz County, Arizona. Geology mapped by D.R. Sherrod and R.M. Tosdal intermittently from 1982 to 1987.

lithologically similar to and correlated with isotopically dated Middle and Late Jurassic plutonic rocks in adjacent ranges of southwestern Arizona and southeastern California (Tosdal, 1988; Tosdal and others, in press). The Proterozoic and Mesozoic crystalline rocks in the study area are part of the upper plate of the Chocolate Mountains thrust, a regional thrust fault of latest Cretaceous or early Tertiary age. The Chocolate Mountains thrust and the Orocopia Schist, which occurs in the lower plate, are exposed 4 mi southeast of the study area.

The Proterozoic and Mesozoic rocks are overlain by Oligocene(?) sedimentary rocks and Oligocene and Miocene volcanic rocks. From oldest to youngest, these strata consist of (1) a thin (generally less than 100-ft-thick) discontinuous sequence of arkosic fanglomerate and tuffaceous sandstone too thin to show on figure 2, (2) andesitic to rhyodacitic lava flows with minor volcaniclastic strata—the Quechan volcanic rocks of Crowe (1978), and (3) silicic welded tuff with minor lava flows, domes, and tuff breccia (unit Tt on figure 2).

The Quechan volcanic rocks have potassium-argon (K-Ar) ages that range from about 32 to 27 Ma (Eberly and Stanley, 1978; Crowe and others, 1979; Weaver, 1982). The few ages older than 32 Ma are considered unreliable because the rocks or minerals that were dated are moderately altered. The overlying sequence of welded tuff includes the ignimbrite of Ferguson Wash of Crowe (1978), which probably erupted near Picacho State Recreational Area, Calif. (3 mi south of the study area, fig. 1), and at least two ash-flow tuffs erupted from a caldera in the Kofa Mountains (30 mi east of the study area, fig. 1) (Grubensky and others, 1986). The ignimbrite of Ferguson Wash has K-Ar ages of about 25 to 24 Ma (Crowe and others, 1979; Olmsted and others, 1973; Weaver, 1982). The youngest volcanic rocks in the study area, the tuffs from the Kofa Mountains sources, erupted about 22 Ma (L.G. Pickthorn, in Bagby and others, 1987).

Normal faulting and sedimentation occurred simultaneously, beginning sometime after about 22 Ma (Tosdal and Sherrod, 1985; Sherrod and others, 1987). The area was extended 10 to 40 percent, as indicated by strata that are tilted as much as 60°. Faults having the greatest throw (at least 1 mi) place the capping volcanic strata down against subjacent crystalline rocks, resulting in the repeated stratigraphic sequences seen on figure 2. A horst of crystalline rocks, exposed in the southwestern part of the study area from Lighthouse Wash to Black Rock mine, was uplifted with only minor rotation, as indicated by gently dipping Tertiary rocks preserved in depositional contact along its upper surface. Thick sequences of sand and gravel (in unit Ts) accumulated as large alluvial fans in isolated grabens and half grabens throughout the area. Lithologically, these rocks contain entirely Tertiary volcanic clasts at the base of each sequence but range upsection to mixtures of Tertiary volcanic and pre-Tertiary crystalline clasts in their upper parts as a result of increasingly widespread exposure of crystalline rocks along moderately dipping faults. Tilting and large-scale faulting had ended by 13 Ma, when subhorizontal basalt lava flows and fanglomerate were deposited at Black Mountain, 9 mi southwest of the study area (Crowe, 1978).

Many of the faults in the study area probably merge at depth along a deep-seated regional detachment fault. Garner and others (1982), however, suggested that the detachment fault is arched up and breached by erosion wherever Proterozoic and Mesozoic crystalline rocks are exposed. In their model, the crystalline rocks (including the two plates of the Chocolate Mountains thrust) form the lower plate of the detachment and are everywhere in fault contact with Tertiary units. Our mapping, however, shows that the crystalline rocks are overlain depositionally by the Tertiary strata in many places.

Marine water from the proto-Gulf of California invaded what is now the Palo Verde Valley about 5 Ma, creating a complex setting of estuaries and deltas that are recorded by the limestone, siltstone, and sandstone of the Bouse Formation (Metzger, 1968; Smith, 1970; Buising, 1987). The Bouse Formation dips gently west and northwest along the northwest edge of the study area and underlies the Palo Verde Valley at depths at least as great as 400 ft, where it is penetrated by water wells. The Bouse Formation and the underlying sandstone and sedimentary breccia (unit Ts) in the Palo Verde Valley are downdropped against pre-Tertiary and Tertiary rocks along normal faults at the west margin of the Trigo Mountains.

The Colorado River established itself through the Yuma-Blythe area sometime in the Pliocene (Dillon, 1976; Buising, 1987). It originally exited the Palo Verde Valley area via Midway Well (approximately along the route of California Highway 78 and the Ogilby road, 10 mi west of its present course; fig. 1) by following the previous Bouse seaway (Dillon, 1976). The river's modern course between the Trigo and Chocolate Mountains is probably the result of late Pliocene or Quaternary faulting that provided a new escape route for Colorado River water along the troughlike depression from Cíbola Lake to Picacho State Recreational Area (fig. 1). Intermittent deposition from Pliocene to modern time in the study area has left poorly consolidated to unconsolidated sand and gravel (units QTf and Qa) as terrace-forming fanglomerate and alluvial fill.

Geochemical Studies

Methods of Investigation

A reconnaissance geochemical survey was conducted in the Trigo Mountains Wilderness Study Area in 1986–87. Minus-80-mesh stream sediments and heavy-mineral concentrates derived from stream sediments were selected as the primary sample media because they represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Chemical analysis of the sediment samples helps to identify basins containing unusually high concentrations of elements that may be related to mineral occurrences. Heavy-mineral concentrates are a useful sample medium in arid environments or in areas of rugged topography, where mechanical erosion predominates over chemical erosion (Overstreet and Marsh, 1981; Bugrov and Shalaby, 1975; Zeegers and others, 1985).

In this study, the nonmagnetic fraction of the heavy-mineral concentrates was analyzed. This fraction concentrates ore and ore-related minerals such as pyrite, galena, cassiterite, sphalerite, chalcopyrite, stibnite, free gold, barite, and scheelite, permitting determination of some elements that are not easily detected in bulk stream-sediment samples.

Stream-sediment samples and heavy-mineral concentrates were collected from active alluvium in first-order (unbranched) and second-order (below the junction of two first-order) streams, as shown on U.S. Geological Survey topographic maps (scale 1:24,000). Rock samples for geochemical analysis were collected both in and near the study area. Unaltered samples were analyzed to provide information on geochemical background concentrations, whereas samples from mines, prospects, and altered areas were analyzed to determine suites of elements associated with mineralization and alteration. All samples were analyzed for 31 elements including arsenic, antimony, barium, bismuth, cadmium, cobalt, chromium, copper, gold, iron, lead, magnesium, manganese, molybdenum, nickel, silver, thorium, tin, titanium, tungsten, vanadium, and zinc by semiquantitative emission spectroscopy. This method allows the rapid and economical analysis of many elements in numerous samples, but the lower limits of determination for a few elements are somewhat high. Therefore, the following elements were analyzed by atomic absorption, which lowers the determination limit (shown in parentheses for each element): antimony (2 parts per million, ppm), arsenic (10 ppm), bismuth (2 ppm), gold (0.05 ppm), and zinc (5 ppm). Rock samples were also analyzed for mercury (0.02 ppm), fluorine (100 ppm), and tungsten (0.5 ppm). Analytical data, sampling methods, sample preparation procedures, analytical techniques, and sampling sites are presented in Bullock and others (1989).

Comparison with Nearby Mining Districts

The Silver mining district, which comprises several mines that produced silver, lead, some gold, and minor zinc and copper (Keith, 1978) near the southeast edge of the study area, was sampled in order to compare its geochemical signature with that of the stream-sediment samples and heavy-mineral concentrates from within the study area. Rocks collected from mines and prospects within the district contain high concentrations of silver (as much as 500 ppm), lead (as much as 2 percent), zinc (as much as 1 percent), and molybdenum (as much as 2,000 ppm). Heavy-mineral concentrates collected downstream from some of these mineralized zones also contain anomalous concentrations of metals: silver (as much as 70 ppm), lead (as much as 5 percent), zinc (as much as 7,000 ppm), and molybdenum (as much as 200 ppm). This geochemical signature was not observed in any samples from within the study area, which supports the field evidence that this mineralization does not extend into the study area.

Analyses of rock samples from the Hart mine area, which is located approximately 0.5 mi north of the study area, show high concentrations of gold (as much as 59 ppm), mercury (as much as 2.4 ppm), and silver (as much as 5 ppm). No geochemical or geologic evidence for this type of mineralization was found within the study area.

Summary of Results

One area of geochemical anomalies was defined from the geochemical reconnaissance survey in the northern part of the study area. This area, which was delineated on the basis of anomalous manganese (1,500 to 10,000 ppm) and silver (as much as 10 ppm) in the heavy-mineral concentrates, contains many small manganese mines and prospects (Farnham and Stewart, 1958; Keith, 1978). All the manganese deposits are hosted by Tertiary volcanic rocks. Rock samples collected from mines and prospects within this area contain concentrations of manganese as high as 5,000 ppm, the upper limit of determination.

Smaller manganese anomalies (1,500 to 2,000 ppm) defined by minus-80-mesh stream-sediment samples were noted from sites in the southern part of the study area. The area of these sites is geographically distinct from the area defined by the heavy-mineral concentrates, and the anomalies probably indicate low levels of manganese mineralization in calcite veins that cut the Tertiary volcanic rocks.

Samples from several sites scattered throughout the study area have anomalous amounts of tin (generally 100 to 300 ppm but locally greater than 2,000 ppm) in the heavy-mineral concentrates. Tin at the sites south of Clip Wash is associated with bismuth (mainly about 50 ppm but locally greater than 1,500 ppm). Wilson (1933, p. 51) noted minor showings of copper and bismuth in this same area, which lies north of the Silver mining district. The drainage basins containing these tin-bismuth anomalies are underlain primarily by Tertiary dacite and rhyodacite or rhyolite in the Quechan volcanic rocks (fig. 2), much of which was emplaced as shallow intrusions in that area. Tin (cassiterite) associated with Tertiary rhyolite was deposited at high temperatures in veins less than 3 in. wide and commonly only a few inches long (Reed and others, 1986). The tin in these types of deposits apparently was mobilized as the rhyolite cooled, as indicated by whole-rock analyses from similar occurrences elsewhere in the southwestern United States where vitrophyric (glassy, quickly cooled) rocks at the margins of a rhyolitic mass have slightly greater concentrations of tin than rocks in the interior have (W.A. Duffield, oral commun., 1988).

Geophysical Studies

Limited gravity and magnetic data were utilized to determine the mineral resource potential of the Trigo Mountains Wilderness Study Area. The data consist of widely spaced surveys made for regional geologic studies and mineral resource evaluation (LKB Resources, Inc., 1980; U.S. Geological Survey, Denver, Colo., unpublished gravity files, 1987). Fifteen gravity stations were located in and immediately adjacent to the study area. The magnetic data result from a survey flown 400 ft above terrain; north-south flightlines were spaced 3 mi apart, and east-west tielines cross the study area near its north and south ends.

The Bouguer gravity anomaly map shows a north-trending high with relief of 10 to 14 milligals that generally corresponds to the physiographic Trigo Mountains. In the vicinity of Clip Wash (near lat 33°10′ N.), low gravity values form a saddle across the regional gravity high. The central part of the saddle correlates with a closed negative magnetic anomaly of amplitude 40 nanoteslas. These anomalies reflect source rocks of lower density and magnetization relative to adjacent rocks and may arise from lithologic contrasts within the Jurassic granitic rocks or from subsequent deformation and alteration. The detail of the gravity and magnetic anomaly data is insufficient to geophysically evaluate the extent or nature of mineralization in the study area.

Mineral and Energy Resources

Gold and Silver

Low mineral resource potential for gold and silver, certainty level B, is assigned to Mesozoic intrusive rocks in the northeast corner of the Trigo Mountains Wilderness Study Area. This assignment is based on the proximity of vein mineralization at the Hart mine, the extension of Mesozoic rocks into the study area, and the localization of placer gold (Johnson, 1972; Krason and others, 1982). Major faults cut off the Mesozoic rocks 1.5 mi inside of the study area's northeast corner (fig. 2).

The occurrence of gold- and silver-bearing quartz veins in pre-Tertiary rocks north and south of the study area indicates the possibility of similar mineralization in those rocks within the study area. During the geologic mapping a few small exploration pits were noted, either along fault zones or where traces of secondary copper minerals had left minor stains on the crystalline rocks. Our geochemical studies failed to define any particular area for further investigation, but the signs of limited exploration and alteration indicate a low mineral resource potential, certainty level B, for gold and silver in the pre-Tertiary rocks extending from Clip Wash to Red Cloud Wash in the south-central part of the study area and in a small inlier of pre-Tertiary rocks along each of those washes along the southeast side of the study area.

Manganese

There is high mineral resource potential, certainty level D, for fault-controlled deposits of manganese in the north-central part of the Trigo Mountains Wilderness Study Area. The area of high potential is centered on abandoned mines in the Lopez Wash area (part of the Trigo mining district) and is further delineated by the limited number of stream-sediment samples having anomalous manganese concentrations.

Manganese production from the Lopez Wash area was economic only from 1953 to 1959, a period of U.S. Government price supports for the strategic metal. The manganese occurs in narrow vein- and fracture-filling deposits that are volumetrically limited and currently considered to be a subeconomic resource.

Other Commodities

Sand and gravel are high-volume, low-unit-value commodities that require a local market for economic development. The occurrences in the Trigo Mountains Wilderness Study Area have no unique properties that make them more valuable than other deposits closer to markets.

The study area was assigned a low to zero resource potential for oil and gas by Ryder (1983). Most of the study area is underlain by volcanic and crystalline rocks and has no hydrocarbon resource potential, certainty level of D.

There is, however, low potential for natural gas, certainty level B, along the northwest border of the study area. The Palo Verde Valley northwest of the study area is a large Tertiary sedimentary basin. The Bouse Formation, an upper Miocene and Pliocene sequence of sandstone, siltstone, and limestone, forms a broad structural depression in the Palo Verde Valley. It is exposed as high as 500 ft above sea level around the valley's margin; on the basis of water-well data, the top of the formation is at least 200 ft below sea level in the valley center. Gravity data suggest that the Bouse Formation and other Tertiary sedimentary fill in the Palo Verde Valley are more than 3,000 ft thick. Gas conceivably may have been generated from organic debris in Bouse or older sedimentary strata. If so, the structural configuration of (at least) the Bouse and younger sedimentary rocks of the basin could be conducive to up-dip migration of gas toward the basin margin and up-structure migration along basin-bounding faults that coincide with the northwest boundary of the wilderness study area.

Warm-water wells near Blythe (22 mi northwest of the study area) have temperatures of about 30 to 45 °C, defining an area "known or inferred to be underlain at shallow depth (less than 3,000 ft) by thermal water of sufficient temperature for direct heat applications" (Martin and Higgins, 1980). The geologic and hydrologic conditions are appropriate for deep circulation of ground water along the major basin-bounding faults of the Palo Verde Valley. Near the study area these faults separate Miocene and older volcanic and crystalline rocks of the Trigo Mountains from Quaternary and Tertiary sedimentary strata at the southeast end of the Palo Verde Valley (fig. 2). As the sedimentary basin of the Palo Verde Valley is adjacent to but outside of the study area, the Trigo Mountains Wilderness Study Area is considered to have no potential, certainty level D, for geothermal energy.

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

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.
Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40-42.
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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, V.E., 1972, Mineral resource estimates and public policy: American Scientist, v. 60, p. 32-40; and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	[1]~570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				(3800?)
pre-Archean[2]					4550

[1]Rocks older than 570 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.

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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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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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