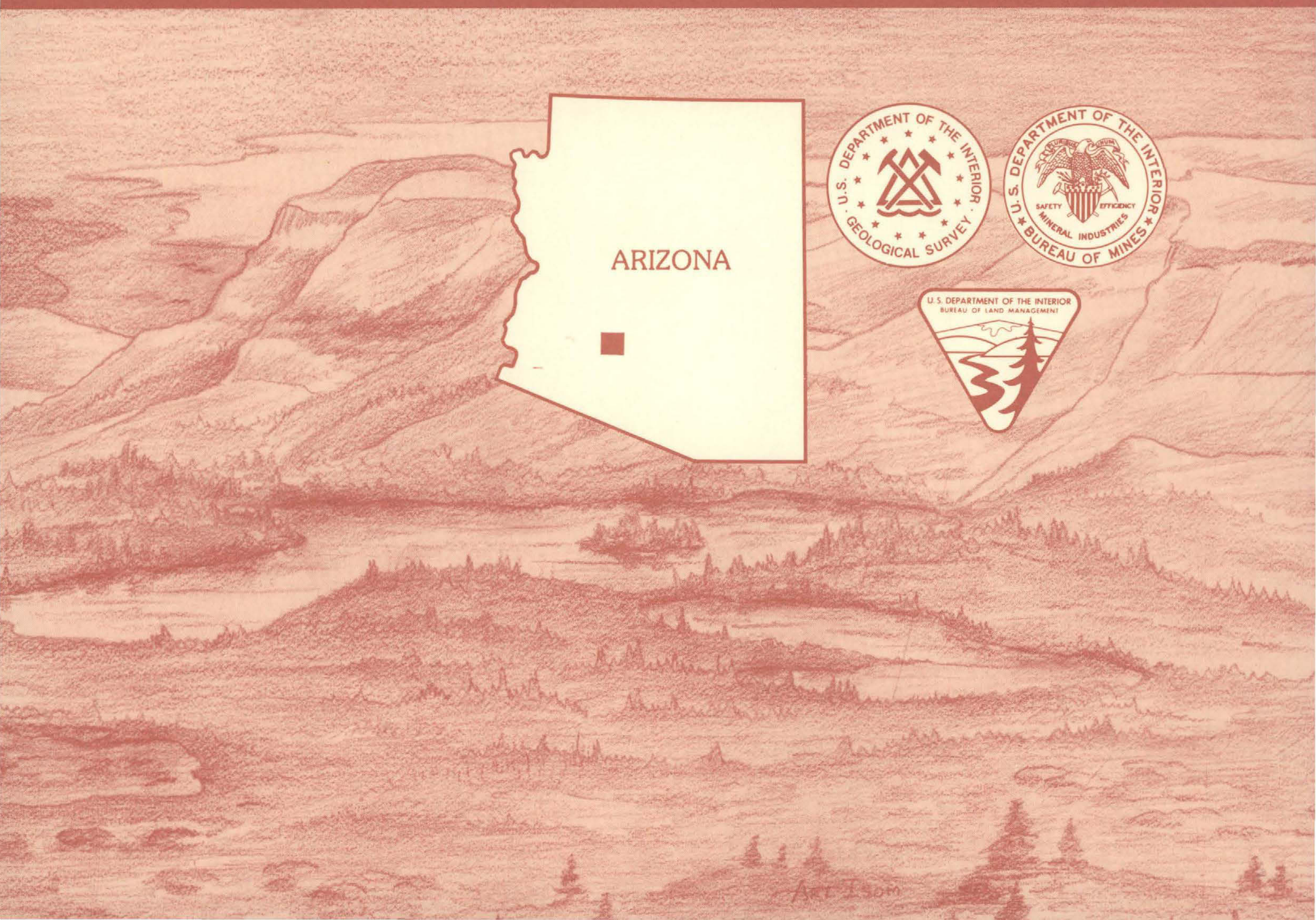
Mineral Resources of the Sierra Estrella Wilderness Study Area, Maricopa County, Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1702-I



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Chapter I

Mineral Resources of the Sierra Estrella Wilderness Study Area, Maricopa 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

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 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 be submitted to the President and the Congress. This report presents the results of a mineral survey of the Sierra Estrella (AZ–020–160) Wilderness Study Area, Maricopa County, Arizona.

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Mineral Resources of the Sierra Estrella Wilderness Study Area, Maricopa County, Arizona

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SUMMARY

Abstract

The Sierra Estrella (AZ–020–160) Wilderness Study Area is located in the Sierra Estrella of south-central Arizona. At the request of the U.S. Bureau of Land Management, 14,190 acres of the Sierra Estrella Wilderness Study Area were studied. In this report, the area studied is referred to as "the wilderness study area" or simply "the study area." Geological, geochemical, geophysical, and mineral surveys were conducted by the U.S. Geological Survey and the U.S. Bureau of Mines in 1986 and 1987 to assess the identified mineral resources (known) and mineral resource potential (undiscovered) of the study area. No resources were identified in the study area, but the results of these surveys indicate that the northeast half of the study area has low resource potential for mica in small pods (probably not over 1 ton) with concentrations that may be as much as 20 percent. An area in the lower two-thirds of the study area on the east side (west of the range crest) has low potential for gold, silver, and associated copper resources in epithermal deposits. The southwest half of the study area, which is underlain by sediments, has low potential for gold resources in placer deposits. The southwest half also has moderate potential for low-temperature geothermal resources and low potential for oil and gas resources.

Character and Setting

Part of the study area is in the rugged Sierra Estrella, which is located in the Sonoran Desert part of the Basin and Range physiographic province, about 15 mi southwest of Phoenix (fig. 1). The topography is steep (over 2,700 ft rise in 1.5 mi) and deeply dissected. Elevations range from about 1,370 ft near the northwest corner of the study area to 4,119 ft on Butterfly Mountain in the northeastern part of the area. The study area is underlain by Precambrian (see geologic time chart in the appendixes) metamorphic rocks that are intruded by Precambrian granitic rocks. The metamorphic rocks contain pegmatite dikes of uncertain origin. The Sierra Estrella is bordered on the southwest by valley-fill sediments of Rainbow Valley (fig. 1).

Manuscript approved for publication February 22, 1989.

Identified Resources

No mineral resources were identified during field studies. Local pegmatite dikes with high concentrations of muscovite occur within the metamorphic rocks of the study area, but because of their low tonnage and sporadic distribution they cannot be considered a resource for flake mica.

Mineral Resource Potential

Part of the Sierra Estrella lying within the lower two-thirds of the study area has low potential for gold, silver and associated copper resources in epithermal deposits. The northeast half of the study area that is underlain by bedrock has low potential for mica. The southwest half of the study area has low potential for gold resources in placer deposits. The southwest half of the study area, which is underlain by sediments, also has moderate potential for low-temperature (less than 194 °F) geothermal resources and low potential for oil and gas resources, whose hypothetical source would be underlying and unexposed Tertiary sediments.

Gold and silver were detected at background levels in quartz veins and in copper-stained areas, but gold reportedly occurs in anomalous amounts in the alluvium on the southwest side of the study area. Gold concentrations in the gravels are reported to be quite low (often background levels), but clay layers within the gravels may contain as much as 0.25 ounces/short ton (oz/st) of gold. The lack of anomalous gold and silver concentrations in the veins and dikes, and the low concentrations of placer gold suggest that the resource potential for these metals is low.

The copper-stained areas are small, lenticular, and consist mostly of chrysocolla deposits on fracture surfaces. These areas are typically associated with the gold and silver concentrations. The potential for copper resources from these occurrences is low.

Local pegmatite dikes in the metamorphic rocks contain higher concentrations of coarse-grained mica (musco-

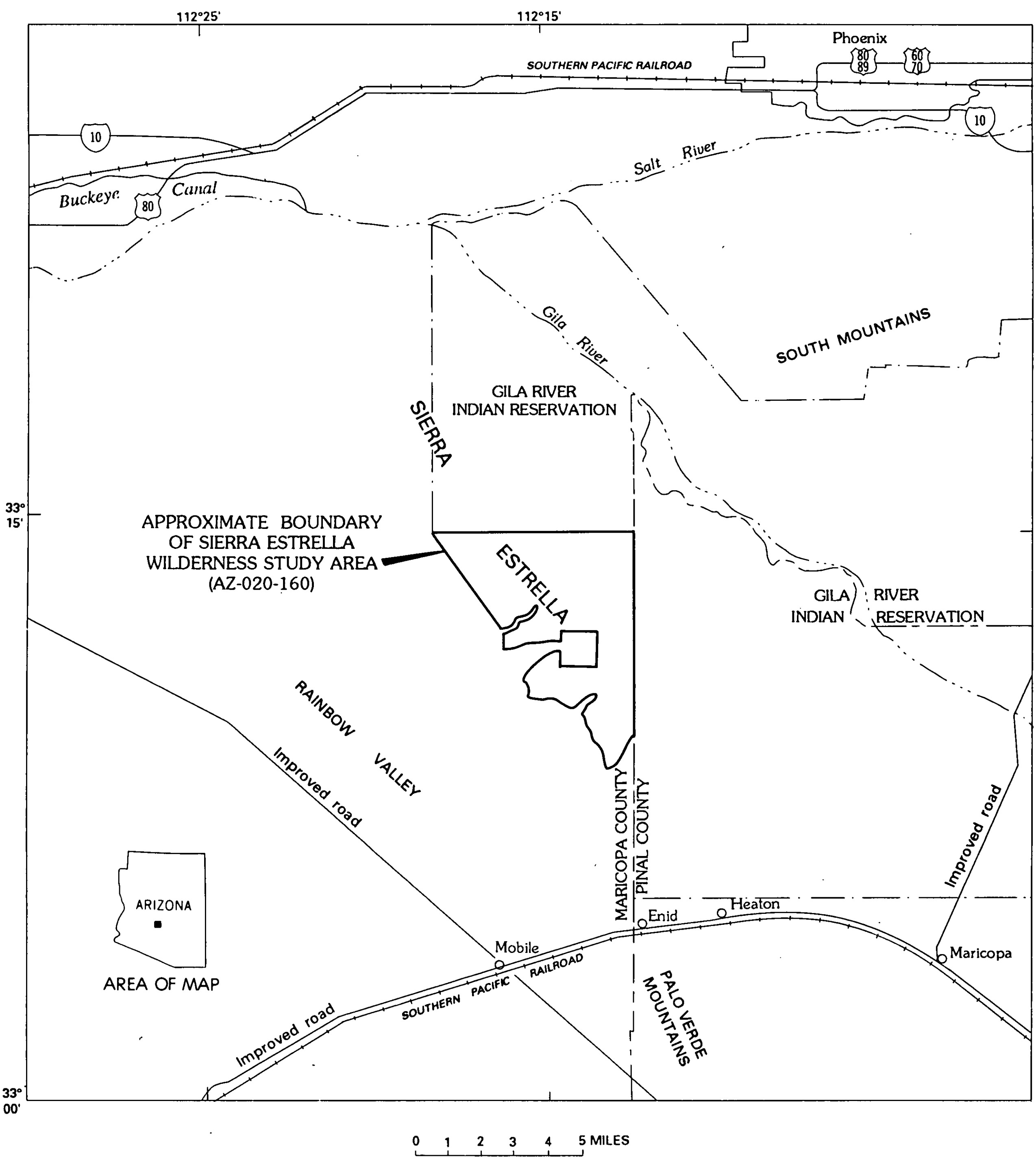

Figure 1. Index map showing location of Sierra Estrella Wilderness Study Area, Maricopa County, Arizona.

vite). It is doubtful that these dikes contain enough usable mica to make an economic mining operation feasible either now or in the near future. Potential for mica resources is low.

High heat flow and the presence of low-temperature geothermal systems within 50 mi of the study area suggest moderate potential for low-temperature geothermal energy resources in the southwest half of the study area that is underlain by sediments.

The southwest half of the study area also has low potential for oil and gas resources. Tertiary source beds may underlie the sediments in this area or hydrocarbons may have migrated laterally into these sediments.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is the result of a cooperative effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities is in Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to a system that is a modification of that described by McKelvey (1972) and U.S. Bureau of Mines and U.S. Geological Survey (1980). U.S. Geological Survey studies are designed to provide a scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Goudarzi (1984) discussed mineral resource assessment methodology and terminology as they apply to these surveys. See the appendixes for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Area Description

At the request of the U.S. Bureau of Land Management, 14,190 acres of the Sierra Estrella (AZ-020-160) Wilderness Study Area were studied. The study area consists of sparsely vegetated basin-and-range terrain in southern Maricopa County, Arizona (fig. 1). Elevations range from 4,119 ft on Butterfly Mountain to about 1,370 ft near the northwestern corner of the study area (fig. 2). It is in the northern part of the Sonoran desert and has geomorphological features typical of arid climates such as flash flood scars. Study area access on the west side is provided by unmaintained jeep roads and on the east by a gravel road through the Gila River Indian Reservation. The higher elevations are accessible only by helicopter or on foot.

The vegetation of the study area is in the Lower Colorado River Valley subdivision of the Lower Sonoran Desertscrub Biotic Community (Brown, 1982). The major shrub species are creosotebush (*Larrea tridentata*), incienso (*Encelia farinsa*), and white bursage (*Ambrosia dumosa*). Sparsely distributed throughout the area are the small paloverde trees (*Cercidium* spp). Other trees include cat-claw acacia (*Acacia greggii*), mesquites (*Prosopis* spp.) and ironwood (*Olneya tesota*). The most spectacular cactus of the Sonoran Desert, the large columnar saguaro (*Carnegiea gigantea*), also grow in the study area, as do many common cactus species.

Previous and Present Investigations

A geologic map of the study area (fig. 2) prepared by the U.S. Geological Survey in 1986 at an approximate scale of 1:48,000 provided a base for the interpretation of geochemical, geophysical, remote sensing, and mining data. The geologic map was generalized from those of Wilson (1969) and Spencer and others (1985).

Geochemical data were obtained from analyses of stream-sediment and heavy-mineral-concentrate samples collected by the U.S. Geological Survey (Rose and others, 1989) from streams draining the study area. Bedrock samples were also collected and analyzed to obtain background levels for many elements and to identify hydrothermally altered areas.

Geophysical data interpreted are from an aeromagnetic survey from the National Uranium Resource Evaluation (NURE) Program (LKB Resources, 1980) and a regional gravity study by Peterson (1968).

The U.S. Bureau of Mines studied the known prospects and claims within and adjacent to the study area to develop a model that would predict the grade and tonnage of mineral resources that might occur in the study area.

APPRAISAL OF IDENTIFIED RESOURCES

By Stanley L. Korzeb
U.S. Bureau of Mines

Mining History

The study area is not within or adjacent to any established mining district. The Sierra Estrella was probably first explored prior to 1886, due to its proximity to transcontinental travel routes. Wilson (1969, p. 21) reported that several copper mines were present in the Sierra Estrella in the late 1800's, but the locations are unknown. In 1920, nine claims were developed by open cuts but appear to have produced little ore (Wilson, 1969, p. 21).

The Crusher mica quarry, 0.1 mi outside the west-central boundary of the study area (fig. 2), was reported to be in operation in 1958 by the Arizona Department of Mines and Mineral Resources. An unrecorded amount of flake mica was produced from a pegmatite pod exposed in a 20- by 10- by 8-ft cut at the mine (Krason and others, 1982, p. 77). From 1980 to 1983, 74 placer claims were located within and adjacent to the west boundary of the study area (fig. 1). In 1980, a block of lode claims was located approximately 1 mi southeast of the Crusher mica quarry. No surface work is evident at or near any of these claims.

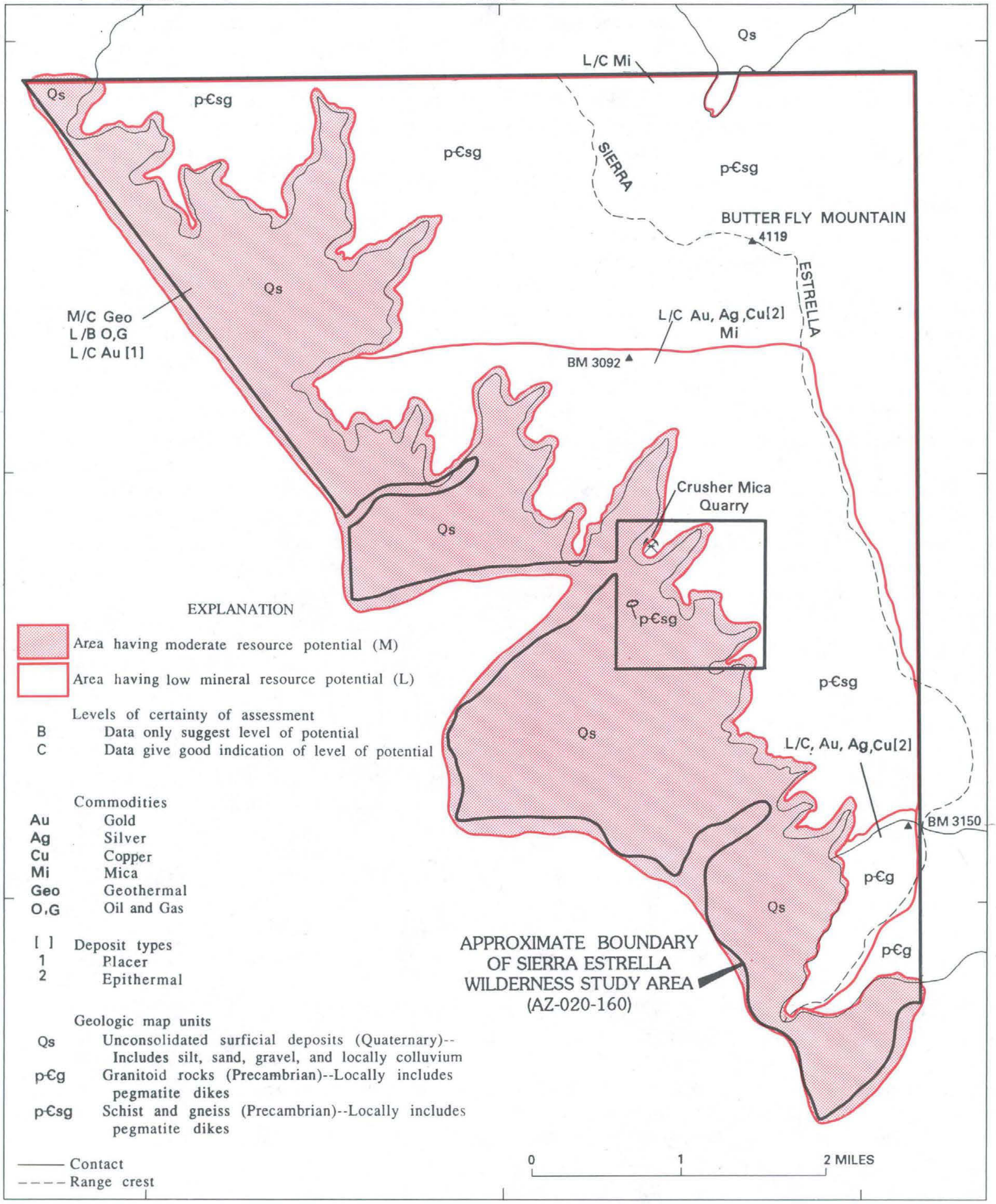

Figure 2. Generalized geologic map of Sierra Estrella Wilderness Study Area showing areas of mineral resource potential.

Results

There are no identified resources in the study area, but it contains pegmatites similar to those mined for flake mica at the Crusher quarry. Most of the pegmatites are small vertical dikes 6 in. to 2 ft wide, but some are pods as much as 20 ft thick. Some dikes can be traced on the surface along strike for 100 ft. The pegmatites consist mostly of feldspar, quartz, and muscovite but include minor amounts of magnetite, garnet, schorl, and chrysocolla. Muscovite is confined to the outer edges of the pegmatites and occurs in books as much as 4 in. across and 2 in. thick (Korzeb, 1988, p. 8). The muscovite books are bent, ruled, and discolored. Their condition makes them unsuitable for sheet mica but suitable for flake mica. Flake mica is ground to a mesh size ranging from less than 80 to greater than 325. The ground mica is used in the manufacture of asphalt shingles, joint cement, drilling mud, paint, rubber goods, plastic, and welding rods (Lesure, 1973, p. 416); its use depends on the mesh size to which it is ground. Flake mica is valued at about $48.00 per ton (Gene Reese, Pacer Corporation, Custer, South Dakota, oral commun., 1987). Locally, these pegmatites contain as much as 20 percent muscovite. The largest and highest grade muscovite zones may contain as much as 1 ton of mica; however, because of the sporadic distribution of these zones, the pegmatites cannot be considered a resource for flake mica.

Muscovite schist hosting the pegmatites also contains flake mica. An analysis of this schist by Wilson (1969, p. 23) showed that it contains as much as 21.8 percent muscovite. By comparison, mica schist mined for commercial use in South Dakota by the Pacer Corporation contains 78–80 percent mica. The muscovite schist throughout the study area is too low grade to be considered a resource for commercial flake mica.

Chemical analyses of the copper-stained pegmatites generally show background levels of 15 parts per billion (ppb) (0.0004 oz/st) to 40 ppb (0.001 oz/st) gold and weakly anomalous amounts of tantalum and niobium. They did, however contain up to 8,950 parts per million (ppm) copper. One quartz vein within a pegmatite contains 23 ppm gold (.662 oz/st), 13.5 ppm silver, pyrite, and limonite (Korzeb, 1988, p. 9). Pyrite and limonite do not commonly occur in pegmatites. No gold resources were identified in the pegmatites, but they could be a source of gold in the placer deposits in the southwestern part of the study area.

Alvin C. Johnson, Jr. (Sevenmile Mining Association, Tempe, Ariz., oral commun., 1987) reported that exposed gravels on the placer claims within and adjacent to the study area contain less than 0.1 oz/st gold; most samples from the gravels do not contain gold at detectable levels; beds of clay discovered by drilling under the gravels may contain as much as 0.25 oz/st gold. The placer deposits were estimated to contain 30 million yd^3 or 45 million st of gravel from an assumed thickness of 10 ft. The thickness and extent of the underlying clay and the stratigraphic distribution of the gold are unknown and there are no identified resources as a result of this study. More detailed subsurface work such as trenching and drilling is necessary to verify the presence of gold.

Sand and gravel in the study area have no unique properties and no local market. Sand and gravel are bulk commodities whose production cost depends on transportation costs. Sand and gravel at other locations, nearer markets, are better suited for local use. The sand and gravel in the study area, therefore, are not classed as an identified resource.

Conclusions

The Sierra Estrella Wilderness Study Area does not contain any identified resources. Pegmatites within the study area contain flake mica and weakly anomalous amounts of gold, but their low tonnage and sporadic distribution make them unsuitable as a resource. The muscovite schist is also too low grade to be considered a mica resource. Gold has been reported from the placer deposits in the study area, but the volume and concentration of the gold are unknown. Further investigation of the placer deposits in the southwest half of the study area, including trenching and drilling to bedrock, is necessary to determine if enough gold is present to represent a resource.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By William J. Keith, Richard J. Goldfarb, *and* Viki L. Bankey
U.S. Geological Survey

Geology

The study area is underlain mostly by muscovite schist and gneiss of various protoliths (sedimentary, volcanic, and granitic) that are not considered to be a metamorphic core complex (Spencer and others, 1985, p. 2). A rubidium-strontium age of 1.38 billion years before present (Ga) on the granitic rocks (Pushkar and Damon, 1974) intruding the metamorphic rocks suggests that both units are Precambrian. The metamorphic grade of these rocks is upper amphibolite to lower granulite facies (Sommer, 1982). The intruding granitic rocks consist largely of a porphyritic monzogranite but also include tonalite and quartz diorite. The sediments in the study area are typical valley-fill material. Rocks in the north end of the study area are cut by dioritic dikes that are probably of Tertiary age (Spencer and others, 1985, p. 10). Although these dioritic dikes appear to be randomly oriented, they are part of a regional northwest-trending system (Spencer and others, 1985, p.

10). Rocks in the central to south-central part of the study area contain pegmatite dikes ranging from 6 in. to 20 ft in thickness. These pegmatite dikes consist mostly of quartz and feldspar but include lesser amounts of muscovite, magnetite, and schorl. The pegmatites could either be related to the metamorphism or to the Precambrian igneous activity. Also contained in the central to south-central part of the study area are rare quartz veins that may be part of the pegmatite system. These veins range in thickness from 1 in. to 10 ft and are typically less than 20 ft in exposed length. The margins of these veins contain variable amounts of schorl, magnetite, muscovite, and garnet. The quartz veins appear to be randomly oriented, although Wilson (1969, p. 20) reports the occurrence of quartz veins in north-trending fractures.

Very little evidence of hydrothermal activity was observed in the study area. The only alteration observed consists of locally copper-stained areas in quartz veins, pegmatites, and schist and minor limonite after pyrite in some quartz veins. The copper staining occurred after the formation of the pegmatites and quartz veins. Fluids that deposited the copper and associated elements probably used brecciated areas or the coarse pegmatites as conduits. Similar mineralization took place on the eastern slopes of the Sierra Estrella, but exploration of these areas by early prospectors yielded little ore (Wilson, 1969).

Foliation is generally well developed in the study area and typically strikes northeast and dips vertically or steeply southeast. (Spencer and others, 1985). No faulting was observed in the study area during fieldwork, but the gravity data suggest a steeply dipping, northwest-trending fault about 3 mi southwest of the study area.

Geochemical Studies

The geochemical survey of the Sierra Estrella Wilderness Study Area consisted of the collection and analysis of 26 stream-sediment and heavy-mineral-concentrate samples, and 5 rock samples from within and immediately adjacent to the study area boundary. Stream-sediment samples were air dried and sieved to minus-80-mesh-size fractions. All concentrate samples were panned from 1.5 to 2 lb of minus-10-mesh stream sediment using a gold pan. In the laboratory, the concentrates were air dried, the lighter material was removed using bromoform, and the magnetic heavy-mineral fractions were removed using a magnetic separator. Each sediment and rock sample was analyzed for 35 elements and each concentrate sample was analyzed for 37 elements using an optical emission spectrograph according to the method outlined by Grimes and Marranzino (1968). In addition, all rock and sediment samples were analyzed by atomic-absorption spectrometry for gold and all sediments were analyzed by inductively coupled plasma-atomic absorption spectrometry for arsenic, bismuth, cadmium, antimony, and zinc. Complete analytical data and a detailed discussion of the sampling and analytical mehods are given in Rose and others (1989).

Most of the geochemical data show background levels for all elements studied. Gold was not detected in any of the concentrate, sediment, or rock samples, either by emission spectrography (lower detection limit of 10 ppm) or atomic-absorption spectrometry (lower detection limit of 0.05 ppm). Concentrate samples from washes draining the northeast side of the study area contain as much as 300 ppm molybdenum and 1,000 ppm tungsten, and microscopic scheelite and powellite were identified in many of these samples. Such concentrations, however, represent normal background levels of these minerals for the Precambrian rocks underlying the watersheds. Values of 100 ppm lead detected in some of the concentrate samples correlate with abundant apatite.

One sample from a quartz vein with visible azurite and malachite (Rose and others, 1989), collected near the Crusher mica quarry just outside the west-central boundary of the study area, contains 2 ppm silver, 20 ppm bismuth, and 10,000 ppm copper. A similar signature was obtained for a sample of a copper-stained pegmatite, collected 1.5 mi southeast of the quarry; anomalous metal concentrations consist of 15 ppm silver, 12 ppm bismuth, 20,000 ppm copper, and 7 ppm tellurium (W.J. Keith, unpub. data, 1988). Five sediment samples, all from washes draining west within the southern half of the study area, contain 2–3 ppm bismuth. Additionally, one concentrate sample in the same area contains 200 ppm copper. On the basis of these data, the portion of the study area south of BM 3092 and west of the Sierra Estrella range crest (fig. 2) has favorability for weak silver-bismuth-copper-tellurium mineralization.

Geophysical Studies

Bouguer gravity data were taken from a regional study by Peterson (1968). A density of 2.67 g/cm^3 was used and terrain corrections were applied to reduce each station to the complete-Bouguer gravity value. Gravity data reflect changes in the gravity field that are associated with varying rock densities or structural features. However, the lack of stations within the study area boundary gives these data a regional character only broad or deep features are enhanced and shallow, short-wavelength anomalies are missing.

A broad regional gravity high is associated with the Sierra Estrella. The gravity data suggest a range-front fault near the southwest side of the study area with an adjoining, parallel basin that is deepest about 4 mi southwest of the fault. The fault continues as far as the south end of the Palo Verde Mountains; the Sierra Estrella gravity high includes those mountains, which suggests that they are part of one continuous feature.

Two other deep basins appear as gravity lows southeast and north of the Sierra Estrella. To the northeast of the study area, the gravity data suggest that the Gila River Valley is shallow between the Sierra Estrella and the South Mountains. Spencer and others (1985) discuss the lithology, structure, and gravity field in these two ranges and conclude that they are probably structurally continuous. However, the northeast-trending South Mountains constitute a metamorphic core complex (Spencer and others, 1985) but the Sierra Estrella does not because it lacks evidence of post-Precambrian deformation.

An aeromagnetic map (fig. 3) of the study area was compiled from an existing survey flown in 1979 as part of the National Uranium Resource Evaluation (NURE) Program. This survey (LKB Resources, 1980) was flown using a fixed-wing aircraft at a nominal ground clearance

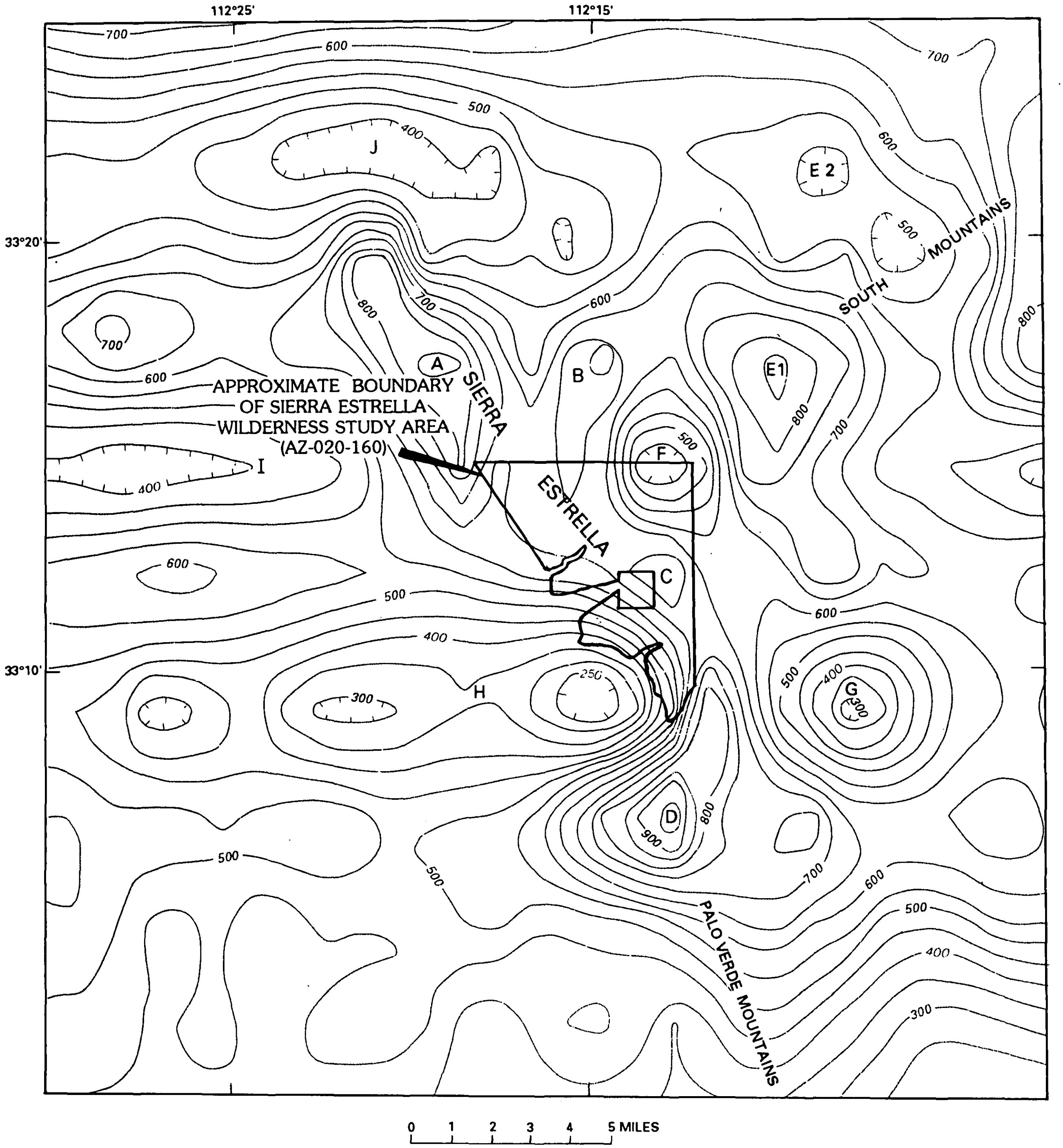

Figure 3. Total intensity aeromagnetic anomaly map of Sierra Estrella Wilderness Study Area, Maricopa County, Arizona. Contour interval 50 nanoteslas; hachures indicate magnetic low. Anomalies labeled A–J; see text for discussion.

of 400 ft, and east-west traverses were flown 3 mi apart. Aeromagnetic data are useful in delineating concealed intrusive rocks that could be associated with mineralization, or they can be used to map buried extensions of magnetic rocks. In this area, Precambrian gneiss and schist as well as possible Tertiary intrusions are magnetic and have the same aeromagnetic expression. Therefore, these data can only suggest areas of interest that may be overlooked in geologic mapping, but they do not allow the distinction between rocks that have no mineral significance and intrusions that are more favorable for the development of mineralized zones.

The aeromagnetic data show a magnetic high over most of the gneiss and schist of the Sierra Estrella, but the anomalies (labeled A–J, fig. 3) are not always contained within known structural boundaries. Positive anomalies A–D generally follow the trend of the mountains, and these local maxima probably reflect the varying composition of gneiss and schist across the study area. Anomaly D, south of the study area, is not definitively associated with the Sierra Estrella but trends east-west and crosses the range-front fault. The source of this magnetic high is not reflected by the gravity data, but it may be buried Precambrian gneiss or schist, or perhaps a younger buried intrusion.

Anomalies E1 and E2 are a dipole pair associated with magnetic rocks in the South Mountains, but positive anomaly E1 also outlines a magnetic source beneath the Gila River valley. Magnetic lows F and G separate the magnetic highs of the Sierra Estrella from the anomaly pair E1–E2, but these lows follow the topographic edge of the mountains rather than the valley, as would be expected. Together, these anomalies suggest, as do the gravity data, that the Sierra Estrella and South Mountains are structurally related or continuous.

Tertiary intrusions that could affect the mineral resource potential are possibly buried beneath the study area and are delineated by any of anomalies D, E1, F, or G. However, these same anomalies could also represent older buried metamorphic rocks. Broad magnetic lows H–J border the Sierra Estrella to the north and west, where gravity data suggest deep basins.

Mineral and Energy Resource Potential

There is low potential (certainty level C) for gold and silver in epithermal deposits and associated copper resources in the lower two-thirds of the study area on the east side (west of the range crest). The northeast half of the study area has low potential (certainty level C) for mica in pegmatite dikes in Precambrian rocks underlying that area. There is low potential (certainty level C) for gold in placer deposits that would be contained in the sediments of the southwest half of the study area. This area also has moderate potential (certainty level C) for low-temperature (less than 194 °F, Muffler, 1979) geothermal resources and low potential (certainty level B) for oil and gas resources.

Combined data from the U.S. Bureau of Mines and the U.S. Geological Survey show that gold and silver occur in weakly anomalous amounts in veins and in copper-stained areas in veins, pegmatite dikes, and metamorphic rocks south of BM 3092 and west of the range crest (fig. 2). Concentrations are typically less than .05 ppm for gold and 15 ppm for silver (Korzeb, 1988, table 1; Rose and others, 1989). The veins and copper-stained areas are typically small (inches to a few feet), randomly oriented, and sparse. Some of the stream sediments and heavy-mineral concentrates from the area south of BM 3092 and west of the range crest show anomalous concentrations of bismuth and copper, and some of the copper-stained areas also show anomalous concentrations of tellurium. Magnetic anomaly D south of the study area (fig. 3) suggests the possibility of a buried pluton. The scarcity and small size of the veins and copper-stained areas and the low concentrations of gold, silver, bismuth, copper, and tellurium suggest low potential (certainty level C) for gold-silver resources in small epithermal-type deposits and also for copper resources in the southern part of the study area. Similar mineralization on the east side of the range has been explored with poor results due to low grade and small quantity. Wilson (1969, p. 21) summed up the potential quite well: "Commercially, the copper-gold deposits in the Sierra Estrella range do not seem to offer much future promise; besides being difficult of access, they are small, lenticular, and not of high grade."

The southwest part of the study area has low potential (certainty level C) for gold resources in small placer deposits. Clay layers in the sediments of this area reportedly contain concentrations of gold as high as 0.25 oz/st, although most of the gravel samples do not contain detectable gold (Korzeb, 1988, p. 9). The unknown lateral extent of the clay beds and the sporadic nature of gold concentrations are the basis for this potential assignment.

Pegmatite dikes occurring sporadically throughout the metamorphic rocks in the study area typically contain mica. Some of these dikes form pods as much as 20 ft thick, where the concentration of mica can be as high as 20 percent (Korzeb, 1988, p. 8). The muscovite in these pods occurs in books as large as 4 in. in diameter and 2 in. thick that are typically bent, ruled, and discolored (Korzeb, 1988, p. 8). One of these pods (Crusher mica quarry) has been mined for flake mica. It is possible that other minable pods exist, but it is doubtful that enough of them exist to make an economic mining operation feasible, either now or in the near future. Low potential (certainty level C) for mica resources is assigned to the northeast half of the study area.

Low-temperature geothermal systems occur within 5 to 50 mi of the study area (Krason and others, 1982, p. 42; Muffler, 1979), with temperatures ranging from 77 to 104 °F (Sammel, 1979, p. 104). Also, heat flow in this area is greater than 60 milliwatts/square meter (Muffler, 1979). On the basis of these data, the southwest half of the study area has moderate potential (certainty level C) for low-temperature geothermal energy resources.

The southwest half of the study area also has low potential (certainty level B) for oil and gas resources. Source beds may underlie the sediments in this area or hydrocarbons may have migrated laterally into the basin. Grabens in this part of Arizona typically contain Tertiary sediments less than 5,000 ft thick (Oppenheimer and Sumner, 1981) and Ryder (1983, p. C20) is of the opinion that "These shallow basins are the only part of cluster 11 where commercial hydrocarbons could be found" (cluster 11 includes the study area). However, no known oil shows occur in or near the sediments of the study area. Therefore, it is unlikely that there are any hydrocarbon deposits in the study area. The potential is only given a certainty level of B because of the unlikely possibility that Tertiary source rocks are buried beneath the study area.

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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
UNKNOWN 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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