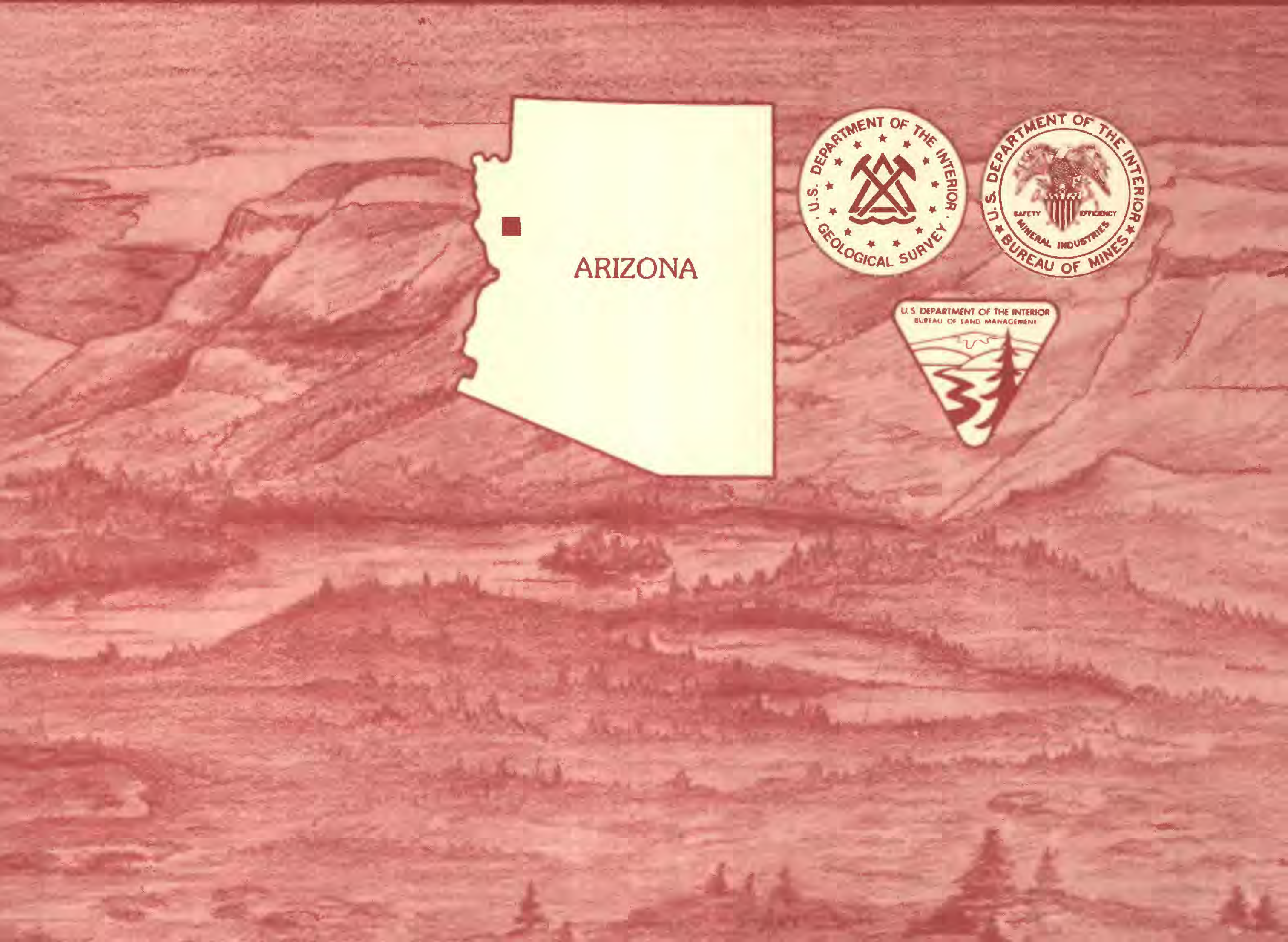
Mineral Resources of the Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

U. S. GEOLOGICAL SURVEY BULLETIN 1737–E



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On both plate 1 and figure 2: The dark-pink area in the northwestern part of the map is colored correctly in having high potential for deposit type [2]; however, it should not contain the horizontal-line pattern denoting moderate potential for deposit type [2]. This horizontal-line pattern should also not appear in the narrow strip in the northwesternmost corner of the map area; this area has moderate potential for deposit type [3], as colored, but has no potential for deposit type [2].

On both plate 1 and figure 2, the pale-pink area in the southern and central part of the map is not correct; this area should contain only the horizontal-line pattern shown, denoting moderate potential for deposit type [2].

Chapter E

Mineral Resources of the Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

By CLAY M. CONWAY, JERRY R. HASSEMER, DANIEL H. KNEPPER, JR., JAMES A. PITKIN, and ROBERT C. JACHENS
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U.S. GEOLOGICAL SURVEY BULLETIN 1737

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
BLACK MOUNTAINS REGION, ARIZONA

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

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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Wabayuma Peak Wilderness Study Area (AZ–020–037/043), Mohave County, Arizona.

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PLATE

[In pocket]

FIGURES

TABLES

ELEMENT SYMBOLS

Element symbols that are used in the text are defined below for readers who may not be familiar with chemical element symbols.

Ag	Silver
As	Arsenic
Au	Gold
Be	Beryllium
Bi	Bismuth
Cu	Copper
Fe	Iron
In	Indium
La	Lanthanum
Mo	Molybdenum
Nb	Niobium
Pb	Lead
Re	Rhenium
Sc	Scandium
Sn	Tin
Ta	Tantalum
Th	Thorium
W	Tungsten
Y	Yttrium
Zn	Zinc

Mineral Resources of the Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

By Clay M. Conway, Jerry R. Hassemer, Daniel H. Knepper, Jr., James A. Pitkin, *and* Robert C. Jachens
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SUMMARY

Abstract

The Wabayuma Peak Wilderness Study Area (AZ–020–037/043), for which a mineral survey was requested by the U.S. Bureau of Land Management, encompasses 40,118 acres in northwestern Arizona. Fieldwork was carried out in 1986–88 by the U.S. Bureau of Mines and the U.S. Geological Survey to appraise the identified (known) resources and assess the mineral resource potential (undiscovered) of the wilderness study area. Within the Wabayuma Peak Wilderness Study Area are 14 private parcels of land totaling 1,315 acres. The Wabayuma Peak Wilderness Study Area, including the 14 private parcels of land, is herein referred to as the "wilderness study area" or the "study area." The Boriana, Antler, and Copper World mines lie near the east boundary of the study area. The Boriana mine was a major tungsten-producing mine of the United States during World War II. The Antler and Copper World mines produced relatively small amounts of copper and zinc prior to 1970.

Copper and zinc were mined within 100 ft of the study area at the Antler mine. The Antler mine contains subeconomic resources of 350,000 to 400,000 short tons of copper-zinc ore; a minimum of 2,000 short tons, at grades of 1 to 4 percent copper and 1 to 2 percent zinc, lie within the study area. No other mineral resources were identified within the study area.

Four small tracts in the eastern part and one in the central part of the study area have high resource potential for copper, zinc, and minor lead, silver, and gold in massive sulfide deposits. A large central tract and two eastern tracts have moderate resource potential for the same metals. An eastern and a western tract within the wilderness study area have high resource potential for tungsten, copper, and combinations of beryllium, gold, silver, arsenic, bismuth, molybdenum, tin, indium, thorium, niobium, yttrium, lanthanum, scandium, tantalum, rhenium, lead, zinc, and iron in granite-related tungsten-polymetallic vein deposits. Most of the rest of the study area has moderate resource potential for these metals. A northern tract in the study area has moderate resource potential for gold, copper, and combinations of silver, zinc, lead, tungsten, and molybdenum in polymetallic vein deposits of several types.

Manuscript approved for publication, August 30, 1990.

Character and Setting

The Wabayuma Peak Wilderness Study Area (AZ–020–037/043) comprises 40,118 acres in the northern Hualapai Mountains of western Arizona (fig. 1). The study area is about 5 mi east of Interstate Highway 40 and 15 mi south of Kingman in rugged country that ranges from 2,600 to 7,600 ft in elevation and contains several plant and animal habitats. Primary land use is cattle grazing; the study area contains six developed springs. Recreational uses include hiking, camping, hunting, and wildlife observation.

The Hualapai Mountains are within the transition zone between the Colorado Plateau and the Basin and Range physiographic provinces. The Hualapai Mountains are bounded by a major Basin and Range fault on the west and by a downdropped fault block of the transition zone on the east, in the valley of the Big Sandy River (fig. 1). The study area is underlain mostly by Early Proterozoic plutonic and stratified rocks (about 1.7 billion years old; see geologic time chart in the "Appendixes") that have been multiply deformed and metamorphosed to a high grade. Subsequent to late Tertiary faulting that resulted in the present physiography, the Early Proterozoic crystalline complex was deeply eroded and parts were covered by a thin veneer of Tertiary to Quaternary alluvium and colluvium.

Copper-zinc deposits have been mined within 100 ft of the southeast boundary of the wilderness study area; tungsten deposits have been mined within 1 mi of the east boundary. Several granite masses in and near the study area are spatially associated with tungsten-bearing veins. Tungsten mineralization at the Boriana mine is genetically related to one of these granites. Stratified rocks in and near the study area are largely or wholly submarine volcanic and volcaniclastic rocks. These strata host volcanogenic massive sulfide deposits containing copper and zinc at the Antler mine, adjacent to the study area, and at the nearby Copper World mine. Extensive near-vertical, northwest-trending joints developed in the study area, probably during middle or late Tertiary time. A locally mineralized fault with gold and copper in the northwestern part of the study area parallels these joints.

Identified Mineral Resources

Although there has been no mineral production from the wilderness study area, there are several prospects. Identified copper and zinc resources at the Antler mine adjoin the southeast border of the study area in Boriana Canyon. Underground exploration in the Antler mine has shown that these resources extend a few hundred feet into the study area. The part of the deposit that lies in the study area constitutes subeconomic resources (see "Appendixes") with a minimum of 2,000 short tons (hereafter, "tons" denotes short tons) of ore at grades of 1 to 4 percent copper and 1 to 2 percent zinc. Other indicated subeconomic resources of the Antler deposit lie outside the study area but adjoin the southeast boundary. These

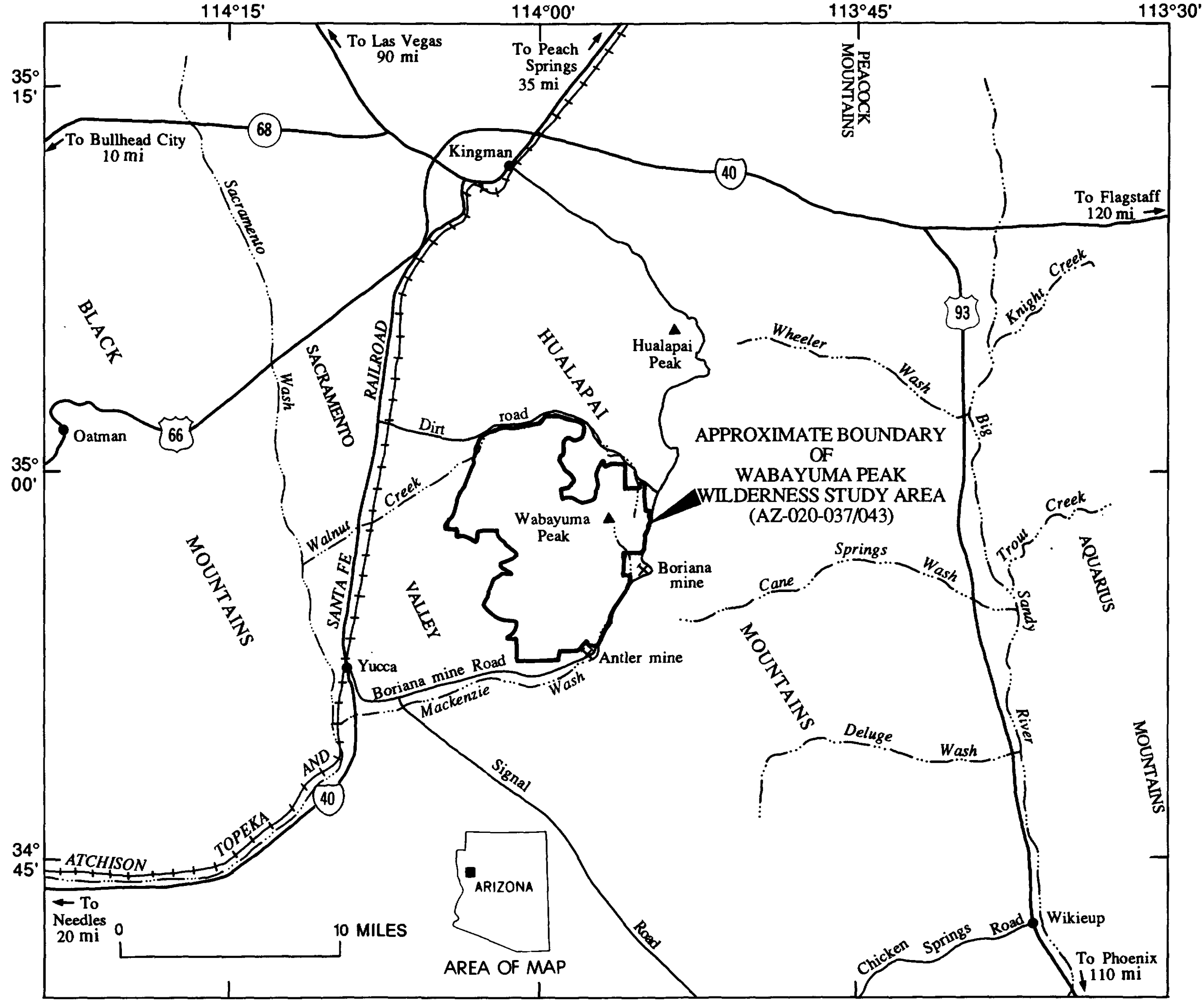

Figure 1. Index map showing location of Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. The study area contains 14 private parcels of land totaling 1,315 acres (see pl. 1 for locations).

amount to 350,000 to 400,000 tons of ore averaging 3.0 percent copper, 6.5 percent zinc, and 3.0 percent lead.

Mineral Resource Potential

The volcanogenic massive sulfide model best applies to the Antler and Copper World (1 mi east of study area) ore deposits. Two small tracts near the Antler and Copper World deposits (fig. 2, pl. 1) and three small tracts in the central and eastern parts of the study area (fig. 2, pl. 1) have high resource potential for copper, zinc, and minor lead, silver, and gold in massive sulfide deposits. High resource potential in these five tracts is based primarily on the presence of chloritized rocks and other altered rocks indicating hydrothermal alteration, pillows in basalts (amphibolites) indicating subaqueous volcanism, and chert indicating subaqueous exhalative activity. Definition of these tracts is aided by indications of altered areas from Landsat color-ratio composite images and from drainage-sediment geochemical anomalies. A large tract in the central part of the study area and two tracts along the southeast boundary of the study area (fig. 2, pl. 1) have moderate potential for copper, zinc, and minor lead, silver, and gold in massive sulfide deposits. This potential is based on the scattered presence of pillow basalts and of various volcaniclastic rocks and graywacke that were likely deposited subaqueously.

Quartz-wolframite-scheelite veins produced tungsten and copper from the Boriana and Bull Canyon mines and are genetically related to the two-mica granite in that area. Tungsten in quartz-scheelite veins in biotite schist at the Ophir and Lentz Black Rock tungsten areas, in the northwestern part of the study area, may be genetically related to nearby two-mica granite. The granite-tungsten vein model applies to these deposits, which we refer to in this report as tungsten-polymetallic vein deposits. Analyses of ore from the Boriana mine dump and drainage-sediment geochemical anomalies in the study area suggest that, in addition to tungsten and copper, there is resource potential for beryllium, gold, silver, arsenic, bismuth, molybdenum, tin, indium, thorium, niobium, and yttrium in tungsten-polymetallic vein deposits. On the basis of worldwide production from tungsten vein deposits, lanthanum, scandium, tantalum, rhenium, lead, zinc, and iron are among other possible recoverable metals. A tract along the southeast boundary of the study area and a tract along the northwest boundary of the study area (fig. 2, pl. 1) have high resource potential for these metals in tungsten-polymetallic vein deposits. The high potential is based on the presence of tungsten-bearing veins and of two-mica granite or biotite granite, and on widespread moderate to very strong drainage-sediment geochemical anomalies. Most of the rest of the study area (fig. 2, pl. 1) has moderate potential for the same metals in tungsten-polymetallic vein deposits on the basis of widespread geochemical anomalies and the presence of scheelite in all drainage-sediment samples.

A large tract along the north boundary of the study area (fig. 2, pl. 1) has moderate resource potential for gold, copper, and subordinate silver, lead, and zinc, and possibly tungsten and molybdenum in polymetallic vein deposits. This potential is based on the presence of sulfide-bearing quartz veins along a Tertiary fault and of other types of mineralized quartz veins, and on weak to moderate anomalies of metals in drainage 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 was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to a system that is a modification of that described by McKelvey (1972) and U.S. Bureau of Mines and U.S. Geological Survey (1980). U.S. Geological Survey studies are designed to provide a scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. See "Appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Location and Physiography

The Wabayuma Peak Wilderness Study Area (AZ–020–037/043) encompasses 64.7 mi^2 of rugged terrain in the northwestern part of the Hualapai Mountains, western Arizona, about 10 mi south of Kingman (fig. 1). Elevations range from about 2,600 ft in the Sacramento Valley bounding the study area on the west to 7,601 ft, the elevation of Wabayuma Peak, the second highest peak in the Hualapai Mountains, in the east-central part of the study area. The study area is bounded by Walnut Creek on the north and by Mackenzie Wash (upper part in Boriana Canyon) on the southeast. Access is by several roads from Interstate Highway 40, which runs north-south 4 to 6 mi west of the study area, or by a road from Kingman south past Hualapai Peak and into Boriana

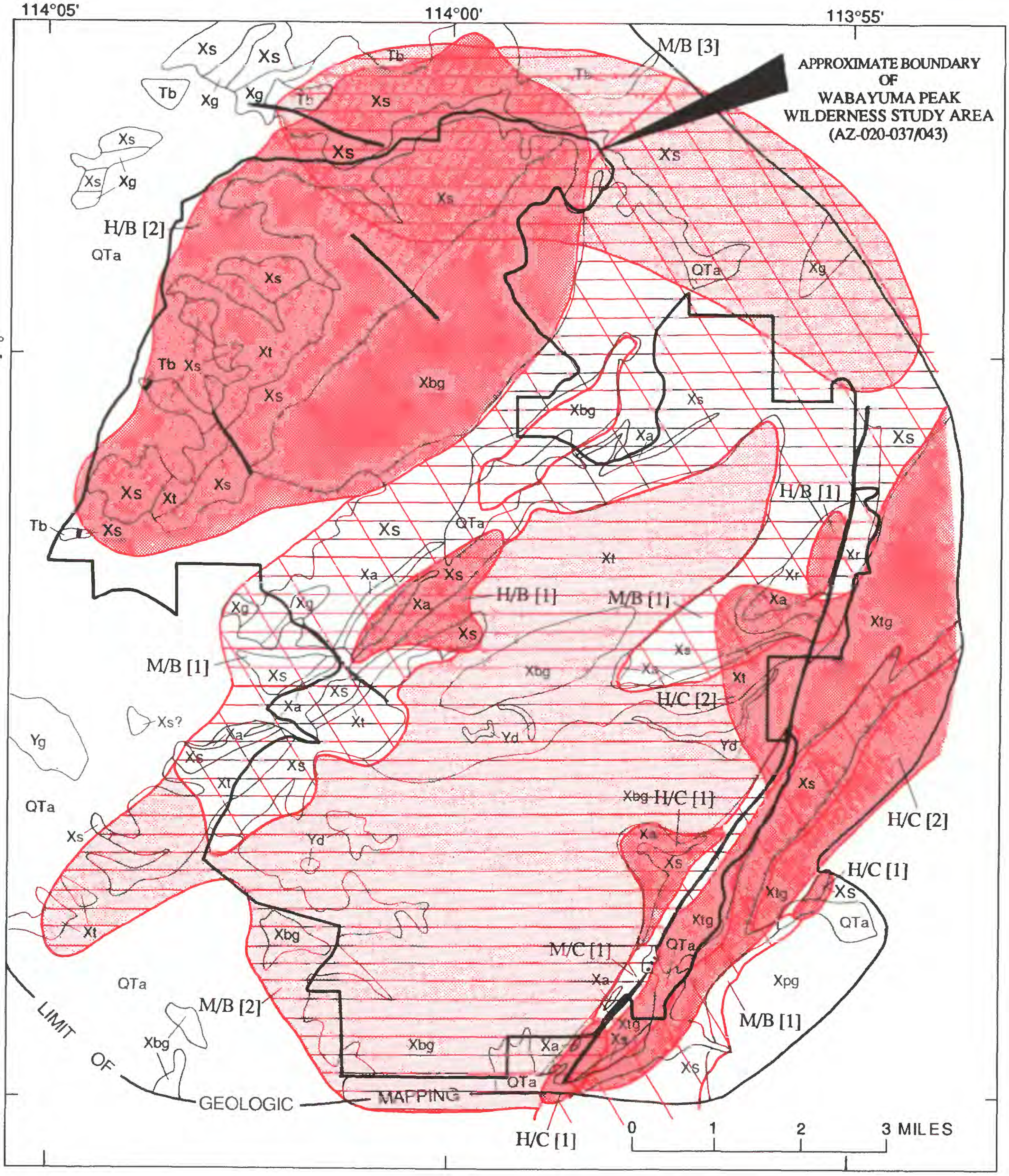

Figure 2. Mineral resource potential and generalized geology of Wabayuma Peak Wilderness Study Area, Mohave County, Arizona.

Canyon. There are 17 mi of jeep trails within the wilderness study area, parts of which are impassable even in four-wheel-drive vehicles.

EXPLANATION

Area having high (H) mineral resource potential for deposit type shown

Area having moderate (M) mineral resource potential for deposit type [3]

Area having moderate (M) mineral resource potential for deposit type [2]

Area having moderate (M) mineral resource potential for deposit type [1]

Mine having identified resources—See text for discussion

Levels of certainty of assessment

B — Data only suggest level of potential

C — Data give good indication of level of potential

Deposit types and commodities contained
[Commodities present in only minor amounts in parentheses; commodities whose presence is less certain in brackets]

[1] Massive sulfide deposits

Copper	(Gold)
Zinc	(Lead)
(Silver)	

[2] Tungsten-polymetallic vein deposits

Tungsten	[Thorium]
Copper	[Niobium]
(Beryllium)	[Lanthanum]
(Gold)	[Yttrium]
(Silver)	[Iron]
(Arsenic)	[Lead]
(Bismuth)	[Zinc]
(Molybdenum)	[Scandium]
(Tin)	[Tantalum]
(Indium)	[Rhenium]

[3] Polymetallic vein deposits

Gold	(Lead)
Copper	[Tungsten]
(Silver)	[Molybdenum]
(Zinc)	

Geologic map units

QTa	Alluvium (Quaternary and Tertiary)
Tb	Basalt (Tertiary)
Yd	Diabase (Middle Proterozoic)
Yg	Porphyritic granite (Middle Proterozoic)
Xpg	Porphyritic granite (Early Proterozoic)
Xg	Granitic rock, undivided (Early Proterozoic)
Xtg	Two-mica granite (Early Proterozoic)
Xbg	Biotite granite (Early Proterozoic)
Xt	Trondhjemite (Early Proterozoic)
Xa	Amphibolite (Early Proterozoic)
Xr	Rhyolite gneiss (Early Proterozoic)
Xs	Schist, highly variable (Early Proterozoic)

Contact

Fault—Dotted where concealed

The Wabayuma Peak Wilderness Study Area contains 40,118 acres (U.S. Bureau of Land Management, 1987, p. 5). Within the wilderness study area are 14 private parcels of land totaling 1,315 acres (pl. 1). Throughout this report, "wilderness study area" or "study area" refers specifically to the 41,433-acre area that includes both the land under jurisdiction of the U.S. Bureau of Land Management and the private parcels. We made no attempt to evaluate public and private lands separately and it is impractical to discuss them separately. The term "map area" in this report refers to the wilderness study area and bordering areas that were mapped (pl. 1) or otherwise included in parts of this study.

The terrain of the study area varies from sparsely vegetated rocky hills at the lower elevations on the west side to heavily vegetated (chapparal, pinyon, and juniper) rugged slopes surrounding Wabayuma Peak. The great topographic relief permits several vegetation and habitat zones in a small area. There are ponderosa pine stands near Wabayuma Peak and mixed conifer forest on high northern slopes. Saguaro cactus and joshua trees grow in the lower desert of the study area. Streams are intermittent, but these and numerous springs, six of which are developed, provide minor riparian habitat. The ponderosa pine-gambel oak habitat in the northern Hualapai Mountains, much of which is in the Wabayuma Peak Wilderness Study Area, is the sole habitat area for the Hualapai Mexican vole; this vole is in the endangered category on the Federal Register of Threatened and Endangered Species.

Previous Investigations

Little geologic mapping has been done in the Hualapai Mountains. The northernmost part of the Hualapai Mountains, including parts of the study area, have received the most attention because of ore deposits in this region. Several reports, published mostly during or shortly after World War II, discussed the geology around the Boriana tungsten mine and the Antler and Copper World copper-zinc mines, all of which are within 1 mi of the study area. Schrader (1909, 1917), in a review of ore deposits of Mohave County, reported little mineralized ground in the northern Hualapai Mountains in contrast to many other mountain ranges in northwestern Arizona that have numerous mines. However, Schrader failed to note the Antler and Copper World deposits, discovered in 1879 and 1882, and the Boriana and Bull Canyon deposits, discovered by 1915. These deposits in the Boriana Canyon area are some of the few known ore deposits in the range.

Important published studies about the region include a report on the geology and tungsten deposits in the Boriana district (Hobbs, 1944), a report on the Antler deposit (Romslo, 1948), and a summary of tungsten deposits, including the Boriana area, in several Arizona counties (Dale, 1961). Hobbs (1944) concluded that the tungsten mineralization is related to emplacement of the granite with which some of the quartz-wolframite veins are associated. Numerous unpublished reports provide details on the Boriana, Antler, and Copper World mines (see Chatman, 1988). More (1980) mapped Boriana Canyon between the Antler and Copper World mines at 1:6,000 scale, the only detailed geologic map available near the study area. He provided valuable descriptions of rock types and ore deposits and assembled evidence for a volcanogenic origin of the Antler massive sulfide deposit. Stensrud and More (1980) described the regional geology in the Wabayuma Peak area on the basis of More's mapping in Boriana Canyon and on Stensrud's reconnaissance mapping, largely to the west of Boriana Canyon. Their geologic sketch map (Stensrud and More, 1980, fig. 2) covers the southern one-third of the study area at approximately 1:88,000 scale. They provided good descriptions of the Proterozoic rocks and summarized characteristics and probable origins of ore deposits.

Procedures and Sources of Data

In January and February 1987, M.L. Chatman and R.E. Jeske evaluated mining history, land status, and mineral resources of the map area through a literature search, discussions with claimholders, examination of U.S. Bureau of Land Management mining claim records, and a field investigation. The field investigation consisted of examining and sampling mines and prospects in the map area and making a reconnaissance survey for additional mineralized sites. One hundred and twenty-nine samples including 104 rock, 20 drainage-sediment, and 5 panned-concentrate samples were collected and analyzed (Chatman, 1988).

C.M. Conway, D.A. Gonzales, and K.R. Chamberlain mapped the geology of the wilderness study area in the fall of 1987 and the spring of 1988. Reconnaissance mapping was done on 1:25,000-scale color and 1:24,000-scale color-infrared aerial photographs; coverage of the study area was uneven. Photogeologic interpretations were used extensively, particularly in mapping the contacts between Proterozoic and Cenozoic units and between Cenozoic units. A preliminary geologic map was compiled at 1:36,000 scale (pl. 1). Data were obtained at mines, prospects, and mineralized ground. Several areas of altered ground were discovered. Rock samples were collected for thin-section examination and for chemical analysis.

One goal of the geologic mapping was to interpret relations of geologic units to mineral deposits. This approach and the conclusions of More (1980) and Stensrud and More (1980) led to application of specific mineral deposit models in the assessment of mineral resource potential.

J.R. Hassemer collected drainage-sediment samples from the map area in November 1986. Eighty-two sieved-sediment, 80 nonmagnetic and paramagnetic heavy-mineral-concentrate, and 20 panned heavy-mineral-concentrate samples were collected from 89 locations on first-, second-, and third-order drainages (pl. 1, fig. 5). A first-order drainage is unbranched as shown on a U.S. Geological Survey 7.5-minute topographic map. A second-order drainage comprises two or more first-order drainages; a third-order drainage comprises two or more second-order drainages. Sample density is about 1 site/mi^2. Eighteen rock samples, mostly from mines and prospects outside the study area, were also collected and analyzed.

Data from the National Uranium Resource Evaluation (NURE) program (Clark, 1979; Wagoner, 1979; Qualheim, 1978; and Cook, 1981) were also used in the geochemical evaluation of the study area. Those studies provide regional geochemical information, especially for uranium and thorium.

The seived drainage-sediment samples were obtained by passing 1 to 2 lb of sediment through US Standard 100-mesh stainless-steel screens. The fine fraction was retained for analysis.

The nonmagnetic and paramagnetic heavy-mineral concentrates were prepared by panning, heavy-liquid separation, and magnetic separation. A composite sediment sample was panned to approximately 50 percent dark-colored (mostly heavy) and 50 percent light-colored (mostly quartz and feldspar) minerals using standard gold-panning techniques. The sample size was the amount of material needed to fill a 14-in.-diameter gold pan, about 8 lb. The resulting panned concentrate was further concentrated using bromoform (specific gravity greater than 2.8). The remaining heavy-mineral fraction was passed through a magnetic separator to obtain nonmagnetic and paramagnetic concentrates for analysis; the magnetic fraction, essentially magnetite, was discarded.

Another type of heavy-mineral-concentrate sample was obtained by panning about 15 lb of sediment until the sample was reduced to nearly all heavy minerals. These heavy-mineral-concentrate samples weighed from 1 to 15 oz.

Rock samples were crushed and pulverized. All sediment and rock samples were analyzed for 31 elements by a semiquantitative six-step, direct-current arc, optical-emission spectrographic method (Grimes and Marranzino, 1968). In addition, rock samples and sieved-sediment samples were analyzed for As, Sb, Bi, Cd, and Zn by inductively coupled–plasma emission spectroscopy and for Hg by atomic-absorption spectroscopy (Crock and others, 1987). Rock samples were analyzed for Au, Tl, In, and Te by atomic-absorption spectroscopy (O'Leary and Meier, 1986) and most rock samples were analyzed for Au, Pt, and Pd by atomic-absorption spectroscopy (J.R. Hassemer, unpublished method). The sieved-sediment samples were also analyzed for uranium by ultraviolet fluorescence (O'Leary and Meier, 1986). Analytical data for selected elements are shown in tables 4–7.

Digital image data acquired by the Thematic Mapper (TM) system on the Landsat–4 satellite (Scene I.D. 40174–17383) were analyzed by D.H. Knepper, Jr., to detect areas that may contain hydrothermally altered rocks. The six bands of visible and near-infrared image data were digitally processed to enhance spectral characteristics of minerals that commonly accompany alteration or are derived from the weathering of altered rocks. Those areas that have spectral characteristics suggestive of alteration-related minerals were visually mapped on 1:36,000-scale plots of the processed data.

Natural radioelement distribution in the study area was evaluated by J.A. Pitkin. Available data are from aerial gamma-ray spectrometry surveys of the Kingman, Prescott, Williams, and Needles (U.S. Department of Energy, 1979a–d, respectively) 1° by 2° quadrangles. The study area lies at the join of the four quadrangles. These surveys acquired aerial gamma-ray data along 1-mi- (Kingman, Prescott, Williams) and 3-mi- (Needles) spaced east-west flightlines at 400 ft above ground level. This combination covers about 10 percent of the study area, because an aerial gamma-ray system at 400 ft above ground level effectively detects terrestrial gamma radiation from a swath 800 ft wide along a flightline. The survey gives reconnaissance near-surface (1 to 18 in.) contents of the natural radioelements potassium (K), uranium (eU), and thorium (eTh). The prefix "e", for equivalent, denotes the potential for disequilibrium in the uranium and thorium decay series.

R.C. Jachens evaluated available aeromagnetic and gravity data. Detailed aeromagnetic data are available along east-west profiles spaced at about 0.5 mi south of lat 35° N. and west of long 114° W. (Needles 1° by 2° quadrangle) and about 1 mi for the rest of the area (Kingman, Prescott, and Williams 1° by 2° quadrangles). Aeromagnetic surveys of the Kingman, Prescott, and Williams quadrangles were flown in 1977 and compiled as part of the NURE program (U.S. Department of Energy, 1979a, b, c). An aeromagnetic survey of the Needles quadrangle was flown in 1980 (U.S. Geological Survey, 1981). Corrections were applied to the total-field magnetic data to compensate for diurnal variations of the Earth's magnetic field; the International Geomagnetic Reference Field, updated to the month that the data were collected, was subtracted to yield a residual magnetic field that primarily reflects the distribution of magnetite in the underlying rocks. Data from the Kingman and Needles quadrangles were merged by Mariano and Grauch (1988).

Gravity data were obtained from Mariano and others (1986), the National Geophysical Data Center (1984), and J.D. Hendricks (written commun., 1987). Gravity stations are scattered at 1- to 3-mi intervals and 23 stations are within the study area. The observed gravity data, based on the International Gravity Standardization net datum (Morelli, 1974), were reduced to free-air gravity anomalies using standard formulas (Telford and others, 1976). Bouguer, curvature, and terrain corrections, to a distance of 103.6 mi from each station, at a standard reduction density of 2.67 g/cm^3 were made at each station to determine complete Bouguer gravity anomalies.

Acknowledgments

R.E. Jeske assisted in the U.S. Bureau of Mines fieldwork, and D.A. Gonzales and K.R. Chamberlain assisted in geologic mapping by the U.S. Geological Survey. The senior author is indebted to H.L. Stensrud for a field introduction to the geology of Boriana Canyon. K.A. Howard, E.H. Dewitt, K.E. Karlstrom, B.H. Bryant, J.L. Wooden, and K.R. Chamberlain provided insights on matters of regional and local geology and geochronology. We are especially indebted to J.E. Elliot and W.R. Griffitts for thorough technical reviews and suggestions for further incorporation and analysis of data and for improvement of the manuscript. We also appreciate the administrative supervision, manuscript review, and editing, respectively, by M.F. Diggles, J.A. Peterson, and C.A. Donlin and the forebearance of these individuals in the belated completion of this work.

APPRAISAL OF IDENTIFIED RESOURCES

By Mark L. Chatman
U.S. Bureau of Mines

Mining History

There has been no mineral production from within the study area. Numerous small adits, pits, and shafts along Boriana Canyon were excavated to search for extensions of the Hualapai district copper-zinc ores and the Boriana district tungsten-bearing veins (fig. 3). A few prospects lie within the study area. Another prospected area in the northwestern part of the study area follows gold- and copper-bearing veins and quartz-scheelite veins.

The Hualapai District

The Hualapai copper-zinc massive sulfide mining district (Keith and others, 1983a, b) includes the Antler and Copper World mines. Extensions of the district include small prospects in the lower Boriana Canyon area (fig. 3). About 136,000 tons of sulfide ore were produced through sporadic mining at the Antler and Copper World mines from the 1890's to 1970; most was produced between 1943 and 1954 and between 1966 and 1970 (Forrester, 1963; Soulé, 1966; Still, 1974).

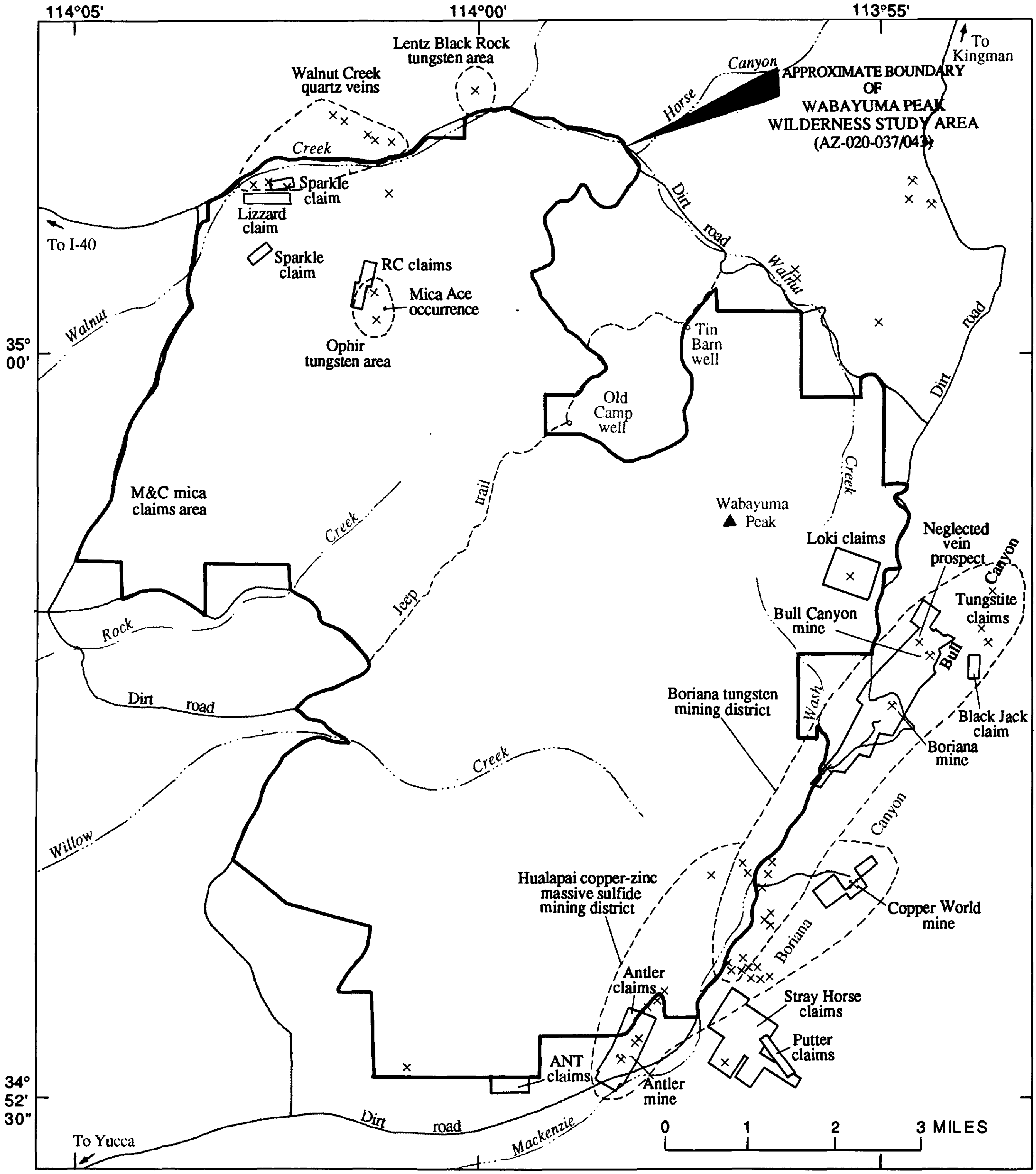

Figure 3. Mines (⚒), prospects (×), claims, and mining districts in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona.

The original Antler claim was located in 1879 on oxidized copper ore containing from 5 to 12 percent Cu (Romslo, 1948). This claim, patented in 1894 (mineral survey no. 903; Stringham, 1946), lies within the Antler claims (fig. 3) and contains the Antler mine. Eight unpatented mining claims adjoin the Antler patent; three are within the study area. These patented and unpatented claims are held by Standard Metals Corp., New York City. The ANT, Stray Horse, and Putter groups of copper-zinc-lead claims are within 1 mi of the study area, but none of these have been mined.

The Antler mine has more than 6,600 ft of drifts on eight underground levels accessed by a 650-ft-deep shaft, inclined to the west. Mining on level 7, about 460 ft below the surface, has included northward drifting to within 100 ft of the study area boundary (Still, 1974). Mine workings were inaccessible in 1987 because of toxic levels of H_2S gas, and because the hoist could not be operated. The Antler deposit yielded 78,251 tons of copper-zinc-sulfide ore, including 34,236 tons in 1970, the last year of operation. Average grades were 2.9 percent Cu and 6.2 percent Zn with 1 percent Pb, 1 oz/ton Ag, and 0.01 oz/ton Au.

The Boriana District

The Boriana tungsten mining district (fig. 3) consists of the Boriana and Bull Canyon mines, the Tungstite and Black Jack claims, the Neglected Vein prospect, and prospects mostly on quartz veins in lower Boriana Canyon that have anomalous tungsten (Chatman, 1988).

The Boriana mine was Arizona's leading tungsten producer in 1918 and from 1933 to 1937 and was one of the top producers from 1951 to 1956 (Dale, 1961). In its early years it was one of the leading producers in the United States (Hobbs, 1944). The district has been inactive since 1957. Total production from the Boriana district was 120,413 short-ton units (STU) of WO_3[1], with about 98 percent coming from wolframite- and scheelite-bearing quartz veins in fine-grained muscovite schist at the Boriana mine (Chapman, 1943; Hobbs, 1944; Dale, 1961). The Boriana mine has ore zones on nine levels and three sublevels to 1,100 ft deep and along more than 15,500 ft of drifts.

During the late 1950's, copper concentrates were produced as a byproduct of reprocessing mill tailings for some of the remaining tungsten. The copper comes from chalcopyrite present in quartz veins. Thirty to 50 tons of concentrates assaying 18 percent Cu (Dale, 1961) were produced.

None of the production of the Boriana district came from inside the wilderness study area. Production, reserves, workings, and geology are summarized in Chatman (1988, Appendix B).

Current Leases and Claims

Current oil and gas leases totaling 5,800 acres cover scattered parts of the study area. There is no record of oil or gas drilling, shows, or production in or near the study area (O'Sullivan, 1969a; Peirce and others, 1970). The study area has been assigned a "zero" potential for petroleum (Ryder, 1983). Water-well drilling records show a lack of potential petroleum source rocks (O'Sullivan, 1969b).

Mining claims in the study area include the Sparkle (two claim areas), Lizzard, and RC claims in the northwest quadrant, the Loki claims west of the Boriana mine, a southwestern part of the Boriana group of claims, and the northern part of the Antler group of claims (fig. 3).

Surface and Mineral Ownership

According to U.S. Bureau of Land Management Arizona State Office records as of January 1987, mineral rights for about 18,160 acres (45 percent) of the wilderness study area are federally held; mineral rights on the remaining acreage are privately held.

Mineral Deposits and Occurrences

Copper and zinc in massive sulfide deposits are known in the Hualapai district and a small subeconomic resource is present in the southeastern part of the study area. Other metal occurrences include tungsten-bearing quartz veins and small quartz veins with minor copper-sulfide minerals and gold; none constitute identified resources. Several industrial minerals and rock products are present, but none are identified resources.

Antler and Copper World Copper-Zinc Deposits

The Antler massive sulfide deposit is roughly tabular. It strikes N. 20° to 30° E. along its 2,000-ft strike length and dips about 70° NW. Folding deformed the body into "ore shoots" that rake N. 50° at the north end of the deposit and rake southward at the south end; this relation indicates a late overall arching of the entire deposit. The deposit extends to at least 650 ft in depth, but its total depth is not known and it continues along strike at least 300 ft into the study area (see Still, 1974; Gilmour, 1975).

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[1]Equal to about 2.4 million lb of WO_3, based on 20 lb per short ton unit (STU) (Jensen and Bateman, 1981).

Copper- and zinc-sulfide minerals along with small amounts of lead sulfide, silver, and gold are present in the Antler deposit. The identified resources of the deposit are at its north end, adjacent to but outside the study area, and below mine level 5 (Still, 1974). Still (1974) estimated the reserves as 350,000 to 400,000 tons of 3.0 percent Cu, 6.5 percent Zn, 3.0 percent Pb, 1.2 oz/ton Ag, and 0.01 oz/ton Au. Under the market conditions of late 1989, these resources would not be classified as reserves, but as indicated subeconomic resources (see "Appendixes").

Core drilling by Standard Metals Corp. verified that the deposit extends at least 300 ft north into the Wabayuma Peak Wilderness Study Area, where there is an estimated 2,000 tons of an inferred subeconomic resource with grades of 1 to 4 percent Cu and 1 to 2 percent Zn (Chatman, 1988, Appendix B). The tonnage estimate is a minimum because it is based on outermost drill intercepts of the Antler deposit. Seventy-five percent of the resource within the study area boundary is in a western mineral zone at a depth of about 1,130 ft. The remaining resource is in a zone about 175 ft farther east at a depth of about 650 ft.

Due to low tonnage, the economic viability of the copper-zinc resource within the study area is tied to the adjoining 350,000- to 400,000-ton identified subeconomic resource adjacent to the study area. At late 1989 copper and zinc prices an estimated net refinery return of $8/ton of ore mined could be realized to make the value of the deposit about $2.5 million. The expense of refurbishing the mine would, however, reduce this value considerably (Chatman, 1988). The condition of the mine is unknown; flooding and other types of deterioration are likely.

The Copper World deposit is in a small belt of stratified rock within a predominantly granitic terrane. Information in unpublished reports (cited in Chatman, 1988) suggest that Copper World is a volcanogenic massive sulfide deposit that was extensively remobilized during deformation. Reserve estimates made by mine operators in the 1950's and 1960's vary from 30,000 to 40,000 tons at grades of 3 to 3.8 percent Cu and 7 to 13 percent Zn (Chatman, 1988). More than half that material has since been mined; the remainder, as of late 1989, was subeconomic.

Copper-Zinc Occurrences in the Bulge and Lower Boriana Canyon

Prospects in an area referred to as the bulge, an embayment of stratified rocks in biotite granite (fig. 2, pl. 1) within the study area on the west side of Boriana Canyon, and other prospects on the east side of Boriana Canyon, are included here within the Hualapai mining district (fig. 3). They are copper-zinc prospects in mineralized areas similar to the Antler and Copper World deposits. There are no identified resources in these areas.

The bulge is underlain by amphibolite and quartzofeldspathic schist, similar to the host rocks of the Antler deposit. Geologic evidence suggests that the bulge, which contains several prospects, may have mineral occurrences similar to the Antler deposit (Still, 1974; More, 1980; see "Early Proterozoic Stratified Rocks" section). The area was once claimed by Standard Metals Corp., but it has never been drilled to verify the existence of mineral occurrences. The bulge remains an exploration target for copper-zinc resources.

Several prospects in lower Boriana Canyon, including a cluster 0.25 mi north of the Stray Horse claims, are in stratified rocks or adjacent porphyritic granite (fig. 3, pl. 1). These prospects have variable metal anomalies and are generally characterized by high copper concentrations, exceeding 1 percent in some cases (Chatman, 1988). The mineralization may be of the copper-zinc volcanogenic massive sulfide type.

Copper-Zinc Occurrences in Loki Claims Area

High levels of Cu, Zn, and Pb were reported by Chatman (1988) for samples from a prospect in the Loki claims area (fig. 3). The host rocks at and near the prospect are volcanic, and they show evidence of chloritic alteration. These are probably copper-zinc massive sulfide occurrences. There are no identified resources at these occurrences.

Boriana Canyon and Bull Canyon Tungsten deposits

Tungsten deposits in upper Boriana and Bull Canyons are characterized by wolframite- and scheelite-bearing quartz veins, mostly in muscovite schist but also in nearby two-mica granite (fig. 3, pl. 1). Schist and granite that host the tungsten veins lie outside but near the east boundary of the study area; however, ore zones and mineralized structures do not extend into the study area.

Economic concentrations of tungsten in the Boriana mine were found mainly in two composite lodes of quartz veins 90 to 135 ft apart. Quartz veins between these two lodes contain little tungsten. The vein system strikes N. 30° to 40° E. conforming to foliation of the schist and dips vertically to 75° SE. In addition to wolframite and scheelite, the quartz veins contain chalcopyrite, beryl, fluorite, chlorite, molybdenite, arsenopyrite, pyrite, and cuprotungstite; some gold and silver are present in an unknown form (Wilson, 1941; Kerr, 1946; Dale, 1961).

Quartz veins at the Bull Canyon mine are on strike with those at the Boriana mine and are likely part of the same system. The veins at the Bull Canyon mine are in both muscovite schist and two-mica granite. Veins in the 700-ft level of the Boriana mine also pass northeastward into granite, which contains scheelite-bearing greisen zones and small amounts of disseminated scheelite (Hobbs, 1944).

Subeconomic resources in the Boriana and Bull Canyon mines are 1,000 STU WO_3 indicated in veins, 47,000 STU WO_3 inferred in veins, and 2,800 STU WO_3 measured in dump material (Chatman, 1988). Grades estimated are from 0.3 to 1.5 percent WO_3.

Copper, in chalcopyrite, has been recovered from dump material, as discussed above. As a byproduct, copper could represent an inferred subeconomic resource in both the dump and unmined veins, but there are no identified resources on the basis of currently available data.

Small quantities of beryl form discontinuous aggregates of grains along the outer edges of quartz veins. Dale (1961) analyzed seven samples from the Bull Canyon mine; only one, a dump sample, contains detectable (0.02 percent) BeO. Samples analyzed from the Boriana mine dump do not exceed 0.005 percent BeO (unpub. data, U.S. Bureau of Mines, 1959). Beryl-bearing pegmatite mines in the U.S. have BeO grades of 0.04 to 1.0 percent; none operated in 1989. Currently, producing beryllium mines in North America are in epithermal(?) deposits that contain bertrandite, a beryllium silicate mineral, with grades of 0.6 to 0.85 percent (U.S. Bureau of Mines, 1987a, b). Because of low grades, beryllium does not constitute a resource at the Boriana and Bull Canyon mines.

Tungsten Occurrences in Lower Boriana Canyon

Samples from quartz veins in lower Boriana Canyon within 0.2 mi east of the study area contain as much as 1,970 ppm W (Chatman, 1988). Several prospects on such veins (fig. 3, pl. 1) are near the contact between muscovite schist and two-mica granite. The geologic relations are analogous to those at the Boriana and Bull Canyon mines and the granite-schist contact is continuous between the two areas. There are no known resources in this area.

Ophir and Lentz Black Rock Tungsten Occurrences

The Ophir and Lentz Black Rock tungsten occurrences in the northwestern part of the map area (fig. 3) are scheelite-bearing quartz veins in biotite schist (Dale, 1961).

The veins in the Ophir area are sparse and small, a few inches wide by a few feet long. Workings are limited to shallow surface cuts. No tungsten minerals were observed and tungsten was detected in only 3 of 10 samples. Concentrations do not exceed 270 ppm in vein quartz samples or 70 ppm in panned concentrates. Two unpatented claims of the RC claims currently cover some of the Ophir area. There are no identified resources at the site.

The Lentz Black Rock tungsten area is north of the study area along Walnut Creek. Veins here have higher tungsten content than those in the Ophir area. Of three samples analyzed, one contains 590 ppm W. Dale (1961) reported 15 tons of ore excavated from shallow pits in the late 1950's that yielded 1,200 lbs of concentrate containing 60 percent WO_3. Numerous shallow, sloughed-in trenches mark these claims. There is no evidence that these tungsten-bearing veins continue into the study area.

The veins at the Ophir and Lentz Black Rock areas are low grade. Ore grades at underground tungsten vein mines are 0.5 to 1.5 percent WO_3 (Anstett and others, 1985), or about 10 times greater than tungsten concentrations in these two areas. There are no identified resources at either site.

Gold- and Copper-Bearing Quartz Veins in Walnut Creek

Sulfide-bearing quartz veins in biotite schist are present both north and south of Walnut Creek (fig. 3). The veins north of Walnut Creek occupy a northwest-trending Tertiary fault; those south of Walnut Creek trend northeastward. Veins are exposed in several shallow pits, and in shafts as much as 60 ft deep. No production is known. Samples show a maximum Cu concentration of 5,810 ppm (0.58 percent). All samples contain Au—as much as 5,570 ppb (0.16 oz/ton). Average Au content is lower; four samples of vein quartz and one of gossan average 0.07 oz/ton. Assays and sample localities are in Chatman (1988). None of the veins are longer than 35 ft. There are no known resources at these sites.

Mica, Feldspar, Stone, and Sand and Gravel

Nonmetallic minerals and commodities in the map area include mica and feldspar in pegmatites, stone, and sand and gravel. None of these occurrences constitute identified resources.

Pegmatites, some deformed and some undeformed, are common in the map area. The Lizzard and Sparkle claims are staked on large quartz-albite-orthoclase pegmatites in a pegmatite swarm south of Walnut Creek (fig. 3); none of these pegmatites have been excavated. A prospect in a similar pegmatite about 1.2 mi east of the Lizzard claim contains about 5 percent biotite. Pegmatites at the Mica Ace occurrence and in the M & C mica claims area (fig. 3) contain small quantities of muscovite. There are no excavations at these sites.

Production of crushed stone from the study area is unlikely, as trucking to any market beyond about 8–10 mi is usually uneconomical. Furthermore, more than 100,000 tons of crushed stone (unpub. data, U.S. Bureau of Mines, 1959) are available at the Boriana mine dump. Crushed stone is also available at the Antler mine dump.

Sand and gravel accumulations in Walnut Creek and smaller drainages in the study area are of insufficient tonnage for classification as identified resources, and poor sorting makes them undesirable. Larger accumulations of better sorted material may be present in the Sacramento Valley, west of the study area.

Recommendations for Additional Work

An effort should be made to fully define the part of the Antler deposit that lies within the wilderness study area. Ordinarily, electromagnetic surveys would be recommended but the Antler deposit is notably unresponsive to them (A.R. Still, oral commun., 1987). Alternatives are deep drilling inside the study area or drifting and drilling northward on level 7 (460 ft below the surface) of the Antler mine. Any such work would be expensive relative to the current value of the metals sought. Drifting is the most economical approach because production revenues would partially subsidize exploration costs, but these revenues would be small at current market conditions.

Further exploration in the bulge area for massive sulfide deposits should include electrical surveys, perhaps coupled with drilling at favorable sites, if any are encountered. Electrical surveys are recommended here because they were used effectively on the Copper World deposit (Silman, 1966).

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

Geologic Setting

The wilderness study area is in the Hualapai Mountains horst, which is bounded by the downdropped Sacramento Valley and Big Sandy River blocks on the west and east, respectively (fig. 1). The Hualapai horst is part of the transition zone between the Colorado Plateau and the Basin and Range provinces because it is an unrotated, undropped crustal block similar structurally to terrane throughout the transition zone. Evidence for lack of rotation is the presence of subhorizontal Middle Proterozoic diabase sills in the northern Hualapai Mountains and subhorizontal Peach Springs Tuff (18.5 Ma, Nielson and others, 1990) near Kingman. The graben of the Big Sandy River valley is similar in character to other grabens in the transition zone.

Proterozoic igneous and metamorphic rocks underlie the entire Wabayuma Peak Wilderness Study Area (pl. 1). This basement complex is covered by a thin veneer of unconsolidated Tertiary and Quaternary alluvium and colluvium in 10 to 20 percent of the study area. There are several tiny exposures of Tertiary basalt in the westernmost part of the map area and extensive Tertiary volcanic rocks immediately north of the map area. The Proterozoic terrane, almost entirely Early Proterozoic (about 1.7 Ga), consists of approximately 50 percent plutonic and 50 percent volcanic and sedimentary rocks. These rocks were metamorphosed to amphibolite grade and subjected to polyphase deformation. Unmetamorphosed Middle Proterozoic diabase sills are present locally.

Abundant Early Proterozoic stratified rocks in the Wabayuma Peak Wilderness Study Area contrast markedly with a paucity of such rocks throughout the Hualapai Mountains (Conway, unpub. mapping, 1988–89) and throughout western Arizona. However, stratified rocks at Bagdad (Conway and others, 1986) and the Cottonwood Cliffs near Valentine (Beard, 1985) are metallogenically similar to those in the study area, which also contain massive sulfide deposits or altered rocks suggesting potential for massive sulfide deposits.

Tungsten mineralization in the map area is genetically related to Early Proterozoic plutonic rocks. This is the only place where an Early Proterozoic age is suggested for tungsten mineralization in western Arizona. Other tungsten occurrences in this region (for example, Tungstona and Black Pearl deposits near Bagdad; Schmitz and Burt, 1987, in press) are genetically related to Middle Proterozoic (1.4 Ga) plutons.

Early Proterozoic Stratified Rocks

Early Proterozoic stratified rocks in the study area are metamorphosed sedimentary and volcanic rocks. They are tectonites metamorphosed to amphibolite facies and generally lack primary sedimentary and volcanic features. However, relatively large or very coarse-grained features such as pillows and conglomerate in amphibolite are commonly poorly to well preserved. No bedding features were found in the abundant, fine-grained schistose rocks, which have shale, graywacke, or tuff protoliths. Most of these rocks show a strong penetrative foliation and a weak to strong lineation.

Lack of facing indicators and structural complexity precluded our determining a stratigraphic succession in the study area. Anderson (1986) and More (1980) reported, without stratigraphic data, that in Boriana Canyon mafic volcanic rocks are overlain by felsic volcanic rocks, which are overlain by sedimentary rocks. This hypothesis is based on the classic idea of island-arc growth from early mafic volcanism to later stages of felsic volcanism and, finally, to sedimentation. Our mapping provided no direct evidence for such a stratigraphic succession, and it is unlikely that this narrow belt preserves a complete island-arc sequence. Moreover, the mafic to felsic volcanism to sedimentation cycle is a broad idealized cycle. Irregularities on a small scale have been documented in many places, including the nearby Bagdad volcanic belt (Conway and others, 1986; Conway, 1986).

Some of the stratified units are probably largely or entirely mafic volcanic rocks. They are amphibolite units, as much as several hundred feet thick, interlayered with other rock types. Pillow structures, indicating a subaqueous origin, were recognized at many sites in three different areas of amphibolite (included in unit Xpa, pl. 1). Pillows are locally remarkably well preserved despite the high-grade metamorphism. In some places, however, they are difficult to recognize and in most exposures are unrecognizable. They are best preserved where the rocks were hydrothermally altered, as in the bulge area and the central part of the map area (pl. 1). In the bulge area, pillows were recognized in proximity to small areas of chloritized rocks, where chlorite has largely been converted to the compositionally equivalent high-grade assemblage cordierite-anthophyllite. In the central part of the map area, pillow margins (presumably originally palagonite) were altered to epidote and quartz, which preserved pillow structure because of stability of epidote and quartz during subsequent metamorphism and enhanced the texture because of the resulting color contrast with the darker plagioclase-hornblende interiors of the pillows. A few miles south of Wabayuma Peak, pillows in two layers of amphibolite that are intruded by trondhjemite are remarkably well preserved with no evidence for alteration. There, the trondhjemite caused no appreciable contact metamorphism and subsequent regional metamorphism had a minimal effect on texture. More (1980), who did not recognize pillows in the field, concluded from analytical data that the amphibolite of the bulge area and the Antler mine area was originally basalt.

The fragmental amphibolite, southeast of Wabayuma Peak, consists of pebble-to-cobble conglomerate containing a variety of mafic volcanic clasts. This unit also includes sandy interbeds of mafic composition.

The coarse amphibolite contrasts markedly with the other amphibolite units in its coarseness, absence of primary features, black rather than dark-green amphibole, and generally higher color index. It has a variable but generally coarse crystalloblastic texture that may indicate it had high volatile content. Lack of granitic texture, fairly well preserved in a nearby granodiorite, seems to preclude its being a gabbro. It may be an extensively recrystallized basalt flow or sill.

The rhyolitic gneiss unit is likely of volcanic origin. This unit, which crops out east of Wabayuma Peak, is generally massive and homogeneous but coarse clastic textures were observed in one place. Sparse, small recrystallized phenocrysts of feldspar and quartz were seen in thin section. Most of this unit is likely pyroclastic, but it may include flow rocks. It may have originally formed as subaqueous tuff that contained minor amounts of coarse-grained rock.

The pillow-flow amphibolite and rhyolitic gneiss units contain the primary evidence for Early Proterozoic sea-floor mineralization. Rock enriched in chlorite (partly converted to cordierite-anthophyllite during regional metamorphism) is present in the pillow-flow amphibolite unit in the Antler mine and the bulge areas and in the central part of the study area. Rock enriched in chlorite is also present in the rhyolitic gneiss unit near the Loki claims (fig. 3). Such rocks are typical of chlorite alteration pipes that occur beneath sea-floor massive sulfide deposits. Chert, metalliferous mudstone, and sulfide minerals, the products of sea-floor hot-spring vents, are also present at some of these localities.

The remaining stratified units are largely fine grained metasedimentary rocks that may be volcanogenic in part but the protoliths are not clearly known. We found no evidence of primary bedding but students in a Northern Arizona University summer field course reported finding graded beds in the muscovite schist unit in the southern part of Boriana Canyon (K.E. Karlstrom, oral commun., 1988). The metasedimentary units vary from pelitic to quartzofeldspathic; these compositions possibly indicate protoliths of shale, graywacke, and tuff. The extensive biotite schist in the northwestern part of the map area was probably a graywacke of intermediate composition. Most other schistose units are more felsic than is the biotite schist and contain abundant muscovite. Two areas of chloritized rocks in the variable schist unit in the central part of the study area are evidence of volcanism, or at least hydrothermal activity, during deposition of that unit.

Early Proterozoic Intrusive Rocks

Biotite granite and trondhjemite predominate among the plutonic rocks in the study area. Two-mica granite underlies small areas in the eastern part of the study area and large areas just beyond the east boundary of the study area. Numerous pegmatites, a few small rhyolite intrusions, and minor mafic intrusions are also present. Porphyritic granite is extensive east of Boriana Canyon outside the study area. All the intrusions are deformed and some appear to be folded. They commonly have a strong penetrative foliation and lineation but these structures are poorly developed in the interiors of the larger plutons. In the central part of the study area, biotite granite and trondhjemite are interlayered locally over large contact zones; this interlayering appears to be mostly a result of complex intrusion but may be partly a result of tectonism. Relative ages of the plutonic rocks were not determined but the trondhjemite may be the oldest of the large intrusions; its fine grain size may suggest shallow emplacement in the volcanic section prior to burial and subsequent intrusion of the coarser biotite granite and two-mica granite. Small rhyolite intrusions are possibly temporally related to the volcanic rocks. Porphyritic granite may be the youngest intrusion, as suggested by its low degree of deformation except near margins.

Two-mica granite (Antler granite of Stensrud and More, 1980) forms two narrow elongate bodies, the longest of which extends northeastward beyond the study area from the lower Boriana Canyon area and the second lies east of Mackenzie Wash in Boriana Canyon. The schist that hosts the Boriana and Bull Canyon tungsten deposits is flanked by the two-mica granite bodies. The granite commonly contains dark micaceous schlieren, which are "muscovite-rich to the north, biotite-rich toward the Antler mine" (Stensrud and More, 1980). The granite is medium- to coarse-grained, allotriomorphic, and seriate porphyritic with perthitic potassium feldspar phenocrysts as large as 0.3 in. Biotite generally predominates over muscovite and potassium feldspar over plagioclase.

Biotite granite makes up a large pluton in the southern part of the map area and a large sill and several small masses in the central to northwestern parts. It is homogeneous, medium grained, allotriomorphic, and has a weak to strong tectonic foliation. It is intensely foliated and locally mylonitized near its boundary with the quartzofeldspathic schist in Boriana Canyon. Essential minerals are quartz, myrmekitic plagioclase, perthitic microcline, and biotite; the sill also contains minor blue-green amphibole. Minor subhedral epidote is possibly a magmatic mineral. Accessory minerals are zircon, sphene, and apatite.

Trondhjemite is a tan, fine- to medium-grained, leucocratic rock. Unevenly dispersed anhedral magnetite and black hornblende commonly form trains or layers, which may reflect flow layering, tectonic layering, or both. The magnetite (1–4 percent) and hornblende (1–8 percent) are indistinguishable in the field except by applying a magnet to powdered sample. Optically, the amphibole is a blue-green variety. The trondhjemite consists largely of quartz and sodic plagioclase. Microcline content ranges from about 0 to 15 percent, and sphene and epidote together constitute from about 2 to 10 percent of the rock. Accessory minerals are zircon, garnet, apatite, clinopyroxene, and biotite.

Compositions of two-mica granite, biotite granite, and trondhjemite are given in table 1; sample locations are given in figure 4. The trondhjemite contrasts strongly with the other two granite types in CaO, K_2O, Rb, and Sr contents but is otherwise similar.

Field relations and distributions of drainage-sediment geochemical anomalies suggest that the two-mica granite and possibly biotite granite played a role in the tungsten mineralization. Hobbs (1944) observed tungsten-bearing veins in greisenized granite at the surface in Bull Canyon and at depth in the Boriana mine and suggested that the tungsten mineralization was genetically related to the granite. We concur and also suggest that the large biotite granite sill in the northwestern part of the study area caused the tungsten mineralization there. The biotite granite dips at 40° to 50° NW. beneath the biotite schist and may have released metallizing fluids upward into the schist. There is no known association between trondhjemite and tungsten-bearing veins, but tungsten and other rare metals (see "Rare-Metal Suite" section) are anomalous in sediments from drainages underlain by trondhjemite.

Certain tungsten and tin deposits worldwide are associated with geochemically evolved granites known as metallogenically specialized granites (Tischendorf, 1977). Specialized granites and less evolved precursor granites have distinctive geochemical characteristics (table 2). Specialized granites tend to be high-SiO_2, low-CaO granites that are unusually enriched in lithophile elements. It is especially characteristic that they are highly enriched in Li and F. They also tend to have low femic mineral contents.

Average contents of the two-mica granite, biotite granite, and trondhjemite from the wilderness study area are compared to selected specialized and precursor granites in table 2. Analyses are not yet available for Li, F, and important trace elements. By comparison with specialized granites in table 2 (columns 4, 6, 8, and 9) the granites of the wilderness study area are not specialized granites, but they have some characteristics of specialized granites and might appropriately be called precursor granites.

The two-mica granite and especially the biotite granite are similar in major-oxide content to Tischendorf's (1977) precursor granite in table 2, but they are slightly higher in CaO. Trondhjemite has far more CaO and less K_2O than the other Wabayuma granites, but its similar trace-element composition (table 2) may suggest a genetic affinity. The three Wabayuma granites generally contain more Ba, Sr, and Zr than either specialized or precursor granites but are similar in Nb and Y contents and contain as much or more La and Ce. Although the high Ba, Sr, and Zr contents in the Wabayuma granites do not suggest metallogenic specialization, the high Nb, Y, La, and Ce values do. Rubidium in trondhjemite and biotite granite is lower than in the specialized and precursor granites, but in two-mica granite it is comparable to the precursor granites.

Average trondhjemite of the study area is compared to worldwide trondhjemite classes in table 3. It is similar in major-oxide content to trondhjemites associated with amphibolites and to low-K rhyolites (extrusive equivalent of trondhjemite) but is remarkably enriched in

Table 1. Major-oxide and trace-element contents of granite samples from Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[FeO, CO_2, H_2O+, H_2O- by classical wet-chemical and rapid-rock methods; analyst: T.L. Fries. Other major oxides and trace elements by X-ray fluoresence; analysts: Judith Kent and M.L. Dyslin. S.D., standard deviation; —, not detected at the dectection limit; <, less than; -, calculation not possible or not meaningful]

	Trondhjemite						Two-mica granite					Biotite Granite					
Sample ------ (fig. 4)	25A	27A	30B	44	Mean	S.D.	17	20A	105B	Mean	S.D.	16	42	43	221	Mean	S.D.
Major-oxide contents (percent)																	
SiO_2	74.2	74.6	73.9	77.9	75.2	1.9	70.6	73.6	70.6	71.6	1.7	72.8	75.6	74.9	73.1	74.1	1.4
TiO_2	.50	.44	.26	.18	.35	.15	.40	.22	.40	.34	.10	.14	.14	10.18	.22	.17	.05
Al_2O_3	12.9	12.5	13.1	12.4	12.7	.3	14.6	13.7	14.7	14.3	.6	14.8	13.0	12.7	13.6	13.5	.9
Fe_2O_3	1.12	.73	1.62	.57	1.01	.47	—	.57	—	-	-	.39	.07	.82	.21	.37	.33
FeO	.88	1.06	1.06	.16	.79	.43	2.48	1.29	2.34	2.04	.65	.44	.98	1.17	1.61	1.05	.48
MnO	<.02	.03	<.02	<.02	-	-	.04	.03	.05	.04	.01	.04	.03	.04	.04	.04	.01
MgO	.40	.25	<.20	<.20	-	-	.40	.25	.40	.35	.09	<.2	<.2	<.2	<.2	<.2	-
CaO	3.98	2.70	1.70	3.18	2.89	.95	1.76	.96	1.70	1.47	.45	1.78	.98	.86	1.94	1.39	.55
Na_2O	3.6	4.7	4.7	4.2	4.3	.5	2.8	2.8	3.1	2.9	.2	4.3	3.0	3.6	3.7	3.6	.5
K_2O	.96	1.68	2.88	.32	1.46	1.10	5.38	4.90	5.16	5.15	.24	3.58	5.06	4.18	3.46	4.07	.73
H_2O+	.12	.11	.05	.07	.09	.03	.42	.68	.42	.51	.15	.32	.15	.17	.44	.27	.14
H_2O-	.01	.08	.02	.06	.04	.03	—	.02	.05	.02	.03	.01	.02	.02	.07	.03	.03
P_2O_5	.10	.06	.04	.02	.06	.03	.20	.10	.18	.16	.05	.01	.04	.04	.08	.04	.03
CO_2	<.1	<.01	<.01	<.01	<.01	-	<.01	<.01	<.01	<.01	-	.06	<.01	<.01	<.01	-	-
Total	98.7	98.9	99.4	99.1	-	-	99.1	99.1	99.1	-	-	98.3	99.1	98.5	98.5	-	-
Trace-element contents (parts per million)																	
Ba	410	640	920	410	595	242	780	470	600	617	156	640	1200	1400	560	950	414
Cr	<20	<20	<20	<20	<20	-	20	<20	<20	-	-	<20	<20	<20	<20	<20	-
Cu	<20	<20	<20	<20	<20	-	<20	<20	<20	<20	-	<20	<20	<20	<20	<20	-
Nb	30	36	32	36	34	3	32	22	34	29	6	<10	12	26	20	19	7
Ni	<20	<20	<20	<20	<20	-	<20	<20	<20	<20	-	<20	<20	<20	<20	<20	-
Rb	12	26	70	<10	-	-	260	290	295	282	19	166	182	132	150	158	21
Sr	245	164	134	260	201	61	140	90	118	116	25	205	100	56	76	109	66
Y	88	114	124	120	112	16	98	54	92	81	24	10	36	90	50	47	33
Zn	<20	<20	<20	<20	<20	-	40	44	50	45	5	26	22	52	40	35	14
Zr	475	485	575	375	478	82	730	172	690	531	311	140	500	420	280	335	159
La	74	46	72	78	68	15	140	74	92	102	34	<30	38	46	60	-	-
Ce	134	106	52	132	106	38	290	158	174	207	72	32	122	110	82	87	40

Nb, Y, La, and Ce compared to typical rocks from all trondhjemite classes shown in table 3. Fiji rhyolite sample H26, average Swaziland gneiss, and average Webb Canyon Gneiss also are enriched in Nb, Y, La, and Ce but, because of this, these rocks are anomalies in their own classes unexplained by the workers who have stud-

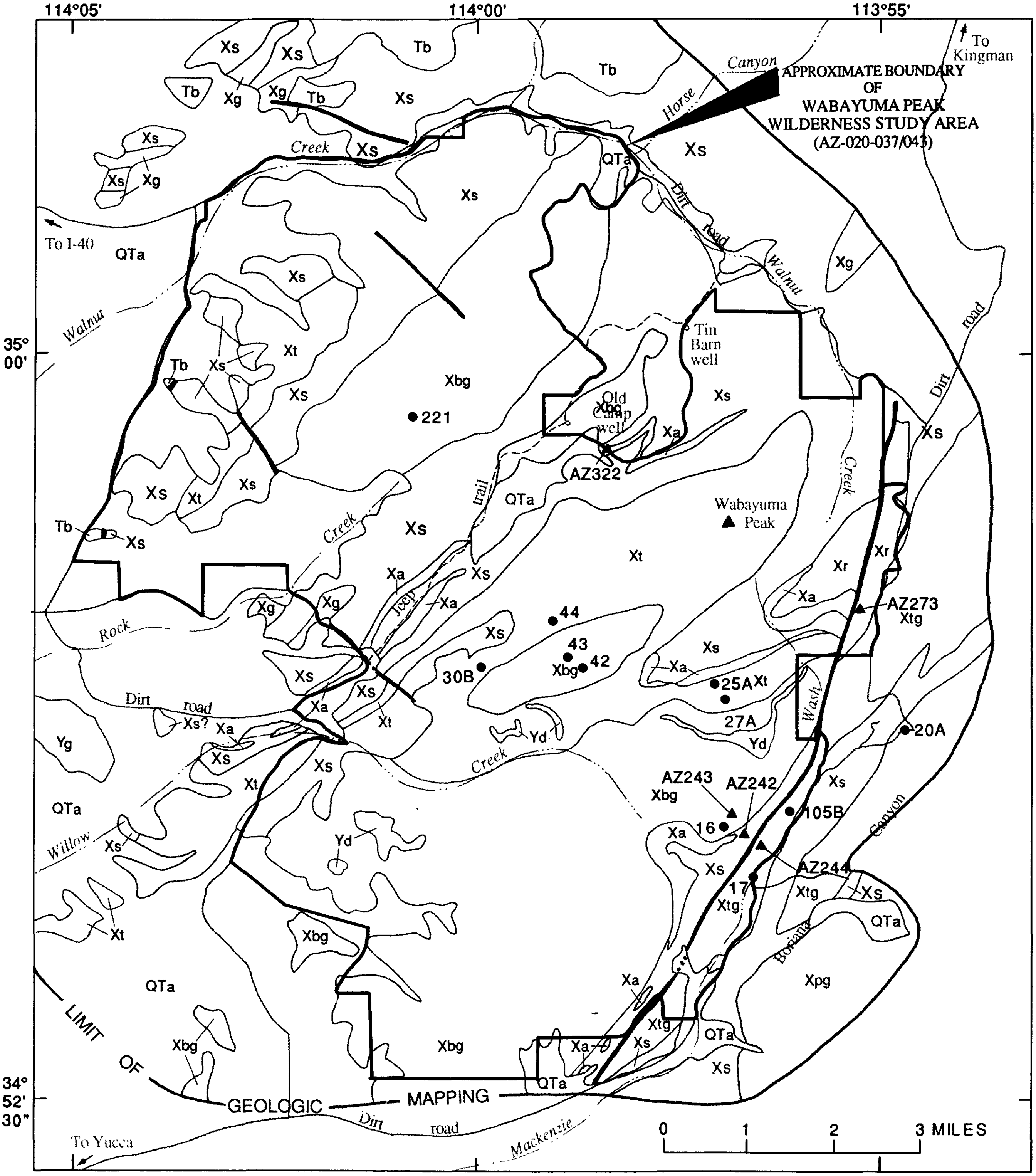


Figure 4. Locations of analyzed granite samples (●) (see table 1) and uranium-lead geochronology samples (▲) (see Chamberlain and Bowring, 1990) collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. See figure 2 for explanation of map units.

Table 2. Average major-oxide and trace-element contents of granites in Wabayuma Peak Wilderness Study Area, Mohave County, Arizona, and of various specialized and precursor granites

[For some analyses all Fe given as Fe_2O_3 or as FeO; —, no data available]

	1	2	3	4	5	6	7	8	9	10
Locality ------	Wabayuma Peak Study Area			Saudi Arabia		Tisch. World Aves.		Colorado	New Mex.	Ariz.
Type ----------	Trond.	TMG	BG	Spec.	Prec.	Spec.	Prec.	Red. Gr.	T. C. Rhyo.	GGR
No. samples -	(4)	(3)	(4)	(6)	(9)	(962)	(226)	(13)	(17)	(18)
Major-oxide contents (percent)										
SiO_2	75.2	71.6	74.1	75.8	76.0	73.38	72.20	74.5	77.84	75.1
TiO_2	.35	.34	.17	.04	.10	.16	.24	.10	.14	.14
Al_2O_3	12.7	14.3	13.5	13.7	13.0	13.97	14.08	13.2	12.13	12.4
Fe_2O_3	1.01	.19	.37	.36	.61	.80	.48	—	1.12	1.5
FeO	.79	2.04	1.05	.50	.77	1.10	1.35	1.5	—	.6
MnO	<.03	.04	.04	.06	.03	.045	.048	.04	.05	—
MgO	<.26	.35	<.2	.11	.14	.47	.45	.05	.14	.04
CaO	2.89	1.47	1.39	.49	.70	.75	1.04	.71	.29	.5
Na2O	4.3	2.9	3.6	4.62	3.73	3.20	3.22	4.00	3.40	3.3
K_2O	1.46	5.15	4.07	4.27	4.71	4.69	4.84	4.88	4.90	5.0
H_2O+	.09	.51	.27	—	—	—	—	.27	—	—
H_2O-	.04	.02	.03	—	—	—	—	—	—	—
P_2O_5	.06	.16	.04	.02	.05	—	—	0.01	.03	—
CO_2	<.01	<.01	<.02	—	—	—	—	—	—	—
Trace-element contents (parts per million)										
Ba	595	617	950	49	80	—	—	260	39	957
Cr	<20	<20	<20	—	—	—	—	—	1.1	—
Cu	<20	<20	<20	10	17	—	—	—	—	4
Nb	34	29	19	42	44	—	—	95	45	12
Ni	<20	<20	<20	—	—	—	—	—	4.1	—
Rb	<30	282	158	557	324	580	250	460	328	127
Sr	201	116	109	26	34	—	—	25	22	51
Y	112	81	47	96	99	—	—	95	74	45
Zn	<20	45	35	—	—	—	—	70	—	—
Zr	478	531	335	92	129	—	—	210	169	304
La	68	102	48	18.9	26.3	—	—	70	41.6	63
Ce	106	207	87	46.8	60.5	—	—	160	102	137

1. Average trondhjemite from Wabayuma Peak Wilderness Study Area (table 1)
2. Average two-mica granite from Wabayuma Peak Wilderness Study Area (table 1)
3. Average biotite granite from Wabayuma Peak Wilderness Study Area (table 1)
4. Average specialized granite (Late Proterozoic) from eastern part of Arabian shield (du Bray and others, 1987, tables 2, 3)
5. Average precursor granite (Late Proterozoic) from eastern part of Arabian shield (du Bray and others, 1987, tables 2, 3)
6. Average worldwide specialized granite (Tischendorf, 1977)
7. Average worldwide precursor granite (Tischendorf, 1977)
8. Average Redskin Granite (Middle Proterozic), Colorado (Ludington, 1981)
9. Average rhyolite of tin-vein-bearing Taylor Creek Rhyolite (Oligocene), New Mexico (Duffield and others, 1987; Duffield, 1990, unpub. data)
10. Average of granite, granophyre, and rhyolite (GGR) (Early Proterozoic) in Tonto Basin, central Arizona, that have drainage sediment anomalies in tin and other rare metals (Conway and others, 1983; Conway, unpub. data)

ied them (Gill and Stork, 1979; Hunter and others, 1978). Neither can we explain these anomalies, but it may be significant in the metallogeny of the wilderness study area that the Wabayuma trondhjemite is similar in Nb, Y, La, and Ce contents to the biotite granite and the two-mica granite. The Wabayuma trondhjemite may be genetically related to the biotite granite and the two-mica granite and may be the first known trondhjemite associated with rare-metal mineralization.

Niobium, Y, and La, anomalously high in all three granites of the study area, are three of the elements in the rare-metal suite. This may suggest, in spite of the overall dissimilarity in many constituents to specialized granites, that the granites of the study area may have their own peculiar "specialized" character. This would seem especially reasonable in view of the known tungsten-polymetallic veins in the area, apparently genetically related to the two-mica granite in the Boriana

Table 3. Average contents of trondhjemite from Wabayuma Peak Wilderness Study Area, Mohave County, Arizona,

[Samples in each category were selected with SiO_2 greater than 73 percent where possible. For some analyses all Fe given as Fe_2O_3 or as gneiss; Plagio., plagiogranite; <, less than; >, greater than; —, no data available; -, calculation not meaningful].

Analysis	1	2	3	4	5	6	7	8	9	10
Locality	Wabayuma	Cenozoic island arcs			Paleozoic-Mesozoic island arcs				Amphibolite association	
Type	Trond.	Low-potassium rhyolite			Trondhjemite			Rhyolite	Tr. gn.	Tr. gn.
No. samples	(4)	(1)	(14)	(8)	(1)	(4)	(2)	(4)	(2)	(2)
Major-oxide contents (percent)										
SiO_2	75.2	75.1	75.01	74.19	73.2	73.00	73.67	76.66	76.69	78.01
TiO_2	.35	.50	.34	.46	.17	.41	.22	.20	.22	.16
Al_2O_3	12.7	13.5	12.99	12.89	14.7	12.95	13.80	11.99	11.68	10.89
Fe_2O_3	1.01	2.64	1.39	1.35	.48	—	1.13	.59	1.07	.63
FeO	.79	—	1.47	2.15	1.2	3.00	1.48	1.35	2.20	2.20
MnO	<.02	.01	.09	.07	.06	.10	.04	.04	.04	.05
MgO	<.26	.34	.58	.68	.88	.56	.49	1.22	.36	.11
CaO	2.89	2.45	2.57	3.13	3.1	2.91	2.23	1.69	1.20	1.24
Na_2O	4.3	4.71	4.17	3.90	4.01	3.79	4.18	2.99	4.44	3.50
K_2O	1.46	.64	1.18	1.11	1.52	1.32	.99	.97	1.56	2.34
H_2O+	.09	1.85	—	—	.52	1.18	1.14	1.78	.34	.34
H_2O-	.04	—	—	—	—	—	.07	.11	.03	.06
P_2O_5	.06	.14	.22	.08	.07	.05	.04	.03	.03	.03
CO_2	<.01	—	—	—	—	—	.05	.27	.04	—
Total	-	101.9	-	-	99.9	-	-	-	-	-
Trace-element contents (parts per million)										
Ba	595	90	403	289	350	—	225	361	—	1,015
Cr	<20	—	20	3	23	—	13	6.4	—	6
Cu	<20	—	2	32	—	—	—	—	—	—
Nb	34	1.2	—	—	—	—	—	—	—	—
Ni	<20	—	37	2	—	—	—	—	—	—
Rb	<30	8	—	13	35	—	20	15	60	57(5)
Sr	201	108	117	145	393	—	55	42	74	79(5)
Y	112	560	11	34	—	—	—	—	—	—
Zn	<20	—	82	49	—	—	—	—	—	44
Zr	478	177	—	95	92	—	176	127	—	495
La	68	76	6.7	4	21	7.1	3.1	2.5	79	96
Ce	106	—	22	9.8	36	18.6	9.9	7.3	170	228

Analyses:

1. Average trondhjemite from Wabayuma Peak Wilderness Study Area (from table 1).
2. Anomalous REE-enriched low-potassium rhyolite (sample H26) from Miocene Undu Volcanic Group, Fiji (Gill and Stork, 1979, p. 638, 640).
3. Average low-potassium rhyolite (SiO_2 >73%) from the Japan-Kuriles-Saipan region (Ewart, 1979, p. 112).
4. Average low-potassium rhyolite (SiO_2 >73%) from the southwestern Pacific region (Ewart, 1979, p. 112).
5. Trondhjemite (sample T1645) from Jurassic Canyon Creek pluton, Trinity Alps, California (Barker and others, 1979b, p. 424, 426).
6. Average coarse-grained trondhjemite, Triassic Sparta complex, Oregon (Phelps, 1979, p. 555, 560).
7. Average Devonian trondhjemite of Mule Mountain, West Shasta, California (Barker and others, 1979a, p. 586–537).
8. Average Devonian Balaklala Rhyolite, West Shasta, California (Barker and others, 1979a, p. 536–537).
9. Average of Archean trondhjemitic siliceous gneisses, Ancient Gneiss Complex, Swaziland (Hunter and others, 1978, p. 110, 114).
10. Average of Archean trondhjemitic quartzofeldspathic gneiss, Webb Canyon Gneiss, Wyoming (Barker and others, 1979b, p. 418–419; Reed and Zartman, 1973, p. 571).
11. Early Proterozoic trondhjemite of Rio Brazos, New Mexico (Barker and others, 1976, p. 191–192).
12. Early Proterozoic Twilight Gneiss, Needle Mountains, Colorado (Barker and others, 1976, p. 191–192).

compared to contents of trondhjemites and related rocks from worldwide localities

FeO; H_2O+ is loss on ignition or gravimetric where H_2O– is not given; Trond., trondhjemite; Tr. gn., trondhjemitic

	11	12	13	14	15	16	17	18	19	20
	Amphibolite association—Con.		Ophiolite association				Archean tonalite association			
	Trond. (6)	Tr. gn. (9)	Plagio. (1)	Plagio. (1)	Trondhjemite (4)	(3)	(16)	Trondhjemitic granite (8)	(5)	(14)
	Major-oxide contents (percent)—Continued									
	75.4	73.20	73.0	74.9	73.78	75.07	71.0	71.0	71.2	73.3
	.15	18	.47	.22	.22	.20	.29	.22	.28	.09
	13.7	13.5	13.4	13.00	13.00	13.10	15.3	15.8	15.5	15.4
	.85	.73	2.8	1.3	.79	1.31	—	—	.55	—
	1.2	2.5	.92	2.0	1.58	1.34	2.1	1.5	1.49	1.56
	.04	.10	.02	.10	.18	.06	.04	.02	.03	.05
	.33	.70	1.00	.24	.65	.19	.8	.7	.89	.4
	1.5	1.9	3.0	1.5	1.71	1.03	2.9	3.0	2.72	3.28
	4.3	4.0	5.3	2.9	5.11	6.08	4.9	5.3	4.94	4.7
	1.5	2.0	.12	.33	.58	.72	1.5	1.5	1.74	1.14
	.84	.85	.89	1.30	1.30	.87	—	—	.58	—
	—	.41	.06	.06	—	—	—	—	—	—
	.04	.06	.12	.06	.04	.01	.09	.08	.13	—
	.23	.08	.03	.05	—	—	—	—	—	—
	-	-	101.5	98.0	-	-	-	-	-	-
	Trace-element contents (parts per million)—Continued									
	617	180	64	—	53	188	232	818	305	269
	—	—	2	2	10	7	23	33	19	19
	—	—	3	—	9	9	—	—	23	—
	—	—	—	—	6	8	7	4	5	—
	—	—	9	—	—	3	5	6	10	8
	28	45	5.0	1.8	10	8	69	32	101	28
	101	217	114.0	78.0	102	80	380	562	392	277
	—	—	—	—	20	76	4	<2	—	4
	—	—	7	—	44	61	—	—	57	—
	—	—	108.0	102.0	63	225	120	124	137	103
	—	—	4	3.1	—	—	—	—	23	11
	—	—	12	9.2	—	—	—	—	41	22

Analyses:

13. Plagiogranite (sample OM-32) from Semail ophiolite, Oman (Coleman and Donato, 1979, p. 158–159).

14. Plagiogranite (sample Bcm-3) from Canyon Mountain ophiolite, Oregon (Coleman and Donato, 1979, p. 158–159).

15. Average trondhjemite (samples 02, 03, 04, and 18) from Ordovician Little Port complex, Newfoundland (Malpas, 1979, p. 476).

16. Average trondhjemite (samples 40, 41, 43) from Ordovician Bay of Islands complex, Newfoundland (Malpas, 1979, p. 477).

17. Average Amitsoq trondhjemitic gneiss (69–74% SiO_2, <2% K_2O), Greenland (McGregor, 1979, p. 183).

18. Average Nuk trondhjemitic gneiss (69–74% SiO_2, <2% K_2O), Greenland (McGregor, 1979, p. 183).

19. Average Uivak I tonalitic-trondhjemitic gneisses (70–75% SiO_2, Na_2O/K_2O<2), Labrador (Collerson and Bridgwater, 1979, p. 245).

20. Average Archean trondhjemite sheets (14) from Coll and Tiree, Scotland (Tarney and others, 1979, p. 287).

mine, and the ubiquitous rare-metal anomalies in the drainage sediments.

Structural Geology

The Early Proterozoic rocks contain two fold sets formed either from a continuum in the deformation or from two distinct orogenic episodes. We prefer the continuum hypothesis because there appears to be a simple history of accumulation of stratified rocks, with possible contemporaneous shallow plutonism, followed by pretectonic to syntectonic plutonism and deformation. Uranium-lead zircon ages (see "Geochronology" section) suggest these events occurred between 1,725 and 1,685 Ma.

Foliation, presumably axial-plane foliation from an initial folding event (f_1), is locally involved in a second stage of folding (f_2). Both a subhorizontal fold in the biotite schist in the northwestern part of the map area and a fold in the bulge area are f_2 folds (pl. 1). In the bulge area, ductile deformation may have occurred both before and after (or during) f_2. The distribution of pre-f_2 foliation attitudes in the bulge area define an f_2 axial plane, which is roughly vertical and strikes northwest. Plunge of the fold is difficult to determine, but it may plunge steeply east. The folded pillow-flow amphibolite is thick in the bulge but thins to nothing at the margins. Similar amphibolite is found in lenses within the quarztofeldspathic schist unit along strike in Boriana Canyon. Thus, the amphibolite may have been boudinaged and attenuated along strike outside the bulge. It appears that amphibolite in the bulge defines a large rootless fold and that ductile deformation has followed or accompanied f_2 folding in the bulge area.

North and south of the bulge area, contacts between biotite granite and quartzofeldspathic schist are sheared. However, within the bulge area primary contact relations are preserved; these relations show that the granite intruded the amphibolite.

A major fault, herein named the Boriana Canyon fault, extends from the southern margin of the map area northeastward along Boriana Canyon and north beyond the wilderness study area (pl. 1). Brittle fracturing was observed in several places along the length of the fault. East of Wabayuma Peak, slickensides plunge 10° to 15° north, and S–C fabrics (Lister and Snoke, 1984) and chattermarks indicate sinistral motion on the fault. K.E. Karlstrom (oral commun., 1988) reported finding indicators of sinistral movement in ductilely deformed two-mica granite in Boriana Canyon. Left-lateral brittle movement on the Boriana Canyon fault apparently followed left-lateral ductile deformation in Boriana Canyon.

Early Proterozoic tungsten and copper-zinc mineralization in Boriana Canyon and elsewhere in the map area are not structurally controlled. On the contrary, the mineral deposits predate deformation, and folding and faulting have disrupted the deposits. This is evident in the extreme boudinage of the pillow-flow amphibolite, which hosts massive sulfide deposits, and in the folding and boudinage of the wolframite-scheelite-quartz veins at the Boriana mine.

A few west-northwest-trending Tertiary faults with small offsets (pl. 1) are a subset of pronounced joints that trend west-northwest throughout the study area. One of these faults hosts the Walnut Creek gold-copper-quartz veins.

Geochronology

Isotopic studies of samples collected in and near the wilderness study area have recently been completed by Chamberlain and Bowring (1990) and Chamberlain and others (1988). Uranium-lead isotope systematics in zircon, sphene, and apatite are complicated by inheritance of isotopic characteristics from an older source terrane (about 2.2 Ga); this phenomenon results in large uncertainties in ages determined for some samples. Locations of dated samples in the map area are shown in figure 4.

Rhyolitic gneiss east of the Boriana Canyon fault has a volcanic zircon age less than 1,730 Ma (Chamberlain and Bowring, 1990). The evidence for inheritance, however, suggests to us its maximum age should be at the low end of the lead-lead ages that range from 1,728 to 1,713 Ma.

In the coarse amphibolite, zircons greater than 149 microns are probably magmatic and those less than 74 microns are probably metamorphic (Chamberlain and Bowring, 1990). The large zircons yield lead-lead ages from 1,726 to 1,721 Ma and define a well-constrained chord intersecting the concordia curve at about 1,720 Ma; there is no evidence for inherited zircon. Small zircons give lead-lead ages from 1,696 to 1,667 Ma and plot in a scattered array on the concordia diagram. Chamberlain and Bowring (1990) suggested that the protolith of the coarse amphibolite was a mafic volcanic rock; alternatively, it may have been a sill.

Biotite granite collected on the north margin of the bulge appears to have a small amount of inherited zircon and has lead-lead ages ranging from 1,718 to 1,694 Ma. Chamberlain and Bowring (1990) believe the crystallization age is between 1,710 and 1,694 Ma, but zircon fractions with the least inheritance suggest to us a maximum age of about 1,700 Ma.

A two-mica granite sample collected east of the bulge has a large inherited zircon component; some zircons contain inclusions identified by microprobe as zircon and minor aluminosilicate minerals. Isotope systematics are consequently very complicated and lead-lead ages range from 1,792 to 1,675 Ma. However, three fractions without inclusions give the youngest lead-lead ages, 1,685 to 1,675 Ma, and these fractions define a crude chord suggesting a crystallization age of 1,690 to 1,680 Ma.

Zircons from a coarse, plagioclase-rich apparent metamorphic segregation in a boudin of pillow-flow amphibolite on the northeast margin of the bulge gave an age of 1,684±4 Ma. Chamberlain and Bowring (1990) interpreted this to be near the age of peak metamorphism; this data is compatible with the lead-lead age range of small zircons in the coarse amphibolite. Lead ages on sphene and apatite from this pod are 1,660 Ma and 1,520 Ma, respectively, and are presumed to be times at which these minerals passed through blocking temperatures for lead during regional cooling.

Based on this geochronologic framework and geologic arguments for genetic associations, the volcanogenic massive sulfide deposits in the study area are approximately 1,720–1,715 Ma and the tungsten deposits are about 1,700–1,680 Ma.

There are lithologic and metallogenic similarities between strata hosting massive sulfide deposits in Boriana Canyon and at Bagdad (Conway, 1986; Conway and others, 1986; Connelly and Conway, 1987). Their ages are also similar—1,730–1,710 Ma for rhyolite and granophyre associated with the Old Dick and Bruce massive sulfides at Bagdad (Bryant and Wooden, 1986; J.L. Wooden, written commun., 1989). In contrast, strata that host massive sulfide deposits in the Jerome-Prescott region are 1,775 to 1,745 Ma (Anderson and others, 1971; Conway and others, 1987; Karlstrom and others, 1987).

Tungsten deposits in the Bagdad area are younger than those in Boriana Canyon. The tungsten at Bagdad is genetically related to the Lawler Peak Granite (Schmitz and Burt, 1987; in press), which is 1,411±3 Ma (Silver and others, 1982).

Massive Sulfide Deposits

The massive sulfide deposit of the Antler mine lies within the quartzofeldspathic schist unit and in close association with amphibolite lenses, cordierite-anthophyllite pods, talc-actinolite pods, and ferruginous chert lenses. Further subdivision of units is given in More's (1980) 1:6,000-scale map. We interpret the amphibolite lenses to be boudins of the pillow-flow amphibolite unit.

Although extreme ductile deformation and boudinage have obliterated primary stratigraphy, the positions of cordierite-anthophyllite, talc-actinolite, and ferruginous chert lenses on the west side of the ore body or on strike with it may reflect stratigraphy. The cordierite-anthophyllite and talc-actinolite pods are probably metamorphosed altered rocks originally constituting a chlorite alteration pipe in the footwall of the massive sulfide body. Although tectonically disrupted, the chloritized rocks are on the west side of the sulfide body; their position suggests that east is stratigraphically up. This hypothesis is consistent with a model presented by More (1980) suggesting that massive sulfide lenses were deposited above the pillow-flow amphibolite and beneath the quartzofeldspathic schist. More (1980) recognized that the cordierite-anthophyllite and talc-actinolite rocks were metamorphosed chlorite, but he thought the chlorite was exhalative, ponded on the sea floor, rather than a product of footwall alteration. The ferruginous chert lenses are nearly on strike with the massive sulfide body and were probably deposited contemporaneously with sulfides on the sea floor as a result of exhalative activity.

Sulfide minerals in the Antler deposit, in order of abundance, are pyrrhotite, sphalerite, chalcopyrite, pyrite, and galena (More, 1980). The abundance of the high-temperature iron sulfide, pyrrhotite, is a reflection of high metamorphic grade.

Cordierite-anthophyllite pods and ferruginous chert lenses in the bulge area lie mainly along the contact between pillow-flow amphibolite and quartzofeldspathic schist, analogous to relations at the Antler deposit. Massive sulfide deposits are not known to be present in the bulge area, but key target areas based on the presence of these assemblages have not been explored.

The Copper World deposit is hosted in a screen of muscovite schist between two-mica granite and porphyritic granite (pl. 1). Schist in this area is intruded by many small granite dikes and sills. More (1980) reported that metamorphosed alteration zone and sulfide assemblages at the Copper World mine are similar to those at the Antler mine.

Tungsten Deposits in Upper Boriana Canyon and Bull Canyon

Tungsten deposits in Boriana and Bull Canyons are in near-vertical wolframite-scheelite-quartz veins that strike northeast parallel to the strike of the host schist and roughly parallel to its contacts with the two-mica granite (pl. 1). Some quartz veins intersect the two-mica granite (Hobbs, 1944). The numerous quartz veins vary from 1 to 10 in. in thickness and have strike lengths of many tens of feet. The veins of the Boriana mine form composites 3 to 10 ft wide, each with two or more quartz veins and stringers. Of the three or four lodes in the 200-ft-wide mineralized zone, two, the "east" and "west" lodes, were especially productive (Hobbs, 1944).

Hobbs (1944) argued that these tungsten deposits are likely genetically related to a leucocratic, greisenized "northern granite prong" in Bull Canyon that was continuous with and part of the granite immediately north of the Boriana mine. He described the granite as foliated biotite-bearing granite. It also contains muscovite and is part of our two-mica granite unit. Hobbs' arguments for genetic connections to the two-mica granite are sound because the tungsten-bearing quartz veins cut granite that is greisenized and contains scheelite disseminated in both altered and unaltered parts. There is also an apparent mineral zoning in the quartz veins away from the granite (Hobbs, 1944).

The granite, metasedimentary host rocks, and mineralized quartz veins have all been deformed, apparently by the same event. Veins in and near the uppermost adits of the Boriana mine have been folded and boudinaged. This tectonism presumably accompanied the metamorphism that occurred about 1,685 Ma.

The Boriana tungsten deposit is older than previously thought. Dale (1961) and Keith and others (1983a, b) suggested a Laramide (early Tertiary) age. Others (for example, D.M. Burt, oral commun., 1986) have considered the mineralization to be Middle Proterozoic because the only other tungsten deposit of known age in northwestern Arizona is that at Bagdad, which is 1,411 Ma.

Northwestern Mineralized Area

Several deposit types are found near Walnut Creek (fig. 3), including Early Proterozoic scheelite-bearing quartz veins, Early Proterozoic pegmatites, sulfide minerals in Tertiary faults, and quartz-sulfide veins of unknown age.

Prospects in the Ophir and Black Rock Lentz tungsten areas are in quartz veins hosted by biotite schist. The Ophir veins (Chatman, 1988, pl. 1, localities 29 and 35) are several inches wide and several feet long and reportedly contain sparse amounts of scheelite, although we found none. Evidence that the quartz veins predated regional metamorphism indicates the tungsten mineralization is Early Proterozoic; margins of the quartz veins are intergrown with metamorphic minerals from the host schist.

Mineralization on the west-northwest-trending fault just north of Walnut Creek apparently occurred in Tertiary time. The mineralization postdated faulting, which we tentatively conclude offset Tertiary basalt. This fault is parallel to several other faults and pronounced joints in the study area and to numerous Tertiary faults in surrounding regions of northwestern Arizona. Mineralized breccia and vein samples along the fault contain anomalous amounts of W, Mo, Hg, Cu, Au, and Zn (Chatman, 1988; J.R. Hassemer, unpub. data) in a predominantly hematitic matrix. Thus, tungsten enrichment occurred in Tertiary as well as Early Proterozoic time.

Quartz-sulfide veins in the Lizzard and northern Sparkle claims areas contain anomalous amounts of Au, Cu, and Ag but not W (Chatman, 1988). These veins with strikes of N. 50° E. to N. 80° E. have attitudes similar to the quartz-scheelite veins in the Ophir area. These veins contrast both geologically and geochemically with the Tertiary fault north of Walnut Creek.

A swarm of pegmatites is present in the northwestern part of the study area south of Walnut Creek (pl. 1). They are Early Proterozoic and could be related to the biotite granite in this area. They are mineralogically simple, containing quartz, albite, orthoclase, and small amounts of biotite and (or) muscovite. Prospects in several of them may have been for mica, in spite of small amount and small crystal size, or for small amounts of metals. J.R. Hassemer (unpub. data) and Chatman (1988) found varying amounts of Pb, Zn, and Cu and weak anomalies of Au and Bi but not W in some of these pegmatites, which may suggest that these pegmatites represent an outer mineralized zone (Tischendorf, 1977; Rundquist, 1982; Moore, 1982) related to the biotite granite.

In Whiskey Basin there appears to be a broad low-grade altered area (outlined on pl. 1) in biotite granite. A few small greisen zones are present. Drainage-sediment anomalies here are not notably different from surrounding areas. Detailed mapping and geochemical study should be done in this area.

Mineralization in the northwestern part of the study area is mixed, in both metals present and age. Copper and gold are the most prevalent metals but localized, anomalous amounts of Ag, Pb, Zn, W, and Mo are also present. Quartz-vein tungsten mineralization took place in the Early Proterozoic, but tungsten may have been subsequently mobilized into Tertiary fault breccia along with other metals. A sample from the Tertiary andesite plug in this area (pl. 1) contains anomalous W (140 ppm). It may have picked up tungsten by contamination from Early Proterozoic tungsten-enriched zones, although a deep magmatic source is also possible.

Drainage-Sediment Geochemistry

This section discusses the results of a drainage-sediment geochemical survey and analysis of mineralized rocks. Analyses for 10 important elements in the drainage-sediment sample types are given in tables 4–7. Localities for these samples are shown in figure 5.

Anomalous concentrations of Sb, As, Ba, Be, Bi, Bo, Cd, Cr, Co, Cu, Ga, Au, In, Fe, La, Pb, Mn, Hg, Mo, Nb, Ag, Te, Tl, Th, Sn, W, U, Y, and Zn were detected in the geochemical survey. Anomalous, as used here, means an amount greater than background concentrations, as arbitrarily deduced from other studies in Arizona (for example, DeWitt and others, 1988; Theobald and Barton, 1983; Watts and Hassemer, 1988) and from values in similar terranes worldwide. The explanation on plate 1 quantifies anomaly levels for 8 elements and table 8 defines anomaly levels for 18 elements.

Samples from individual sites contain 4 to 17 anomalous elements, average 8, and usually have one or more strongly anomalous elements. Most of the strongly anomalous elements are found only in nonmagnetic concentrate samples (table 4) and rock samples (J.R. Hassemer, unpub. data). Sieved-sediment samples (table

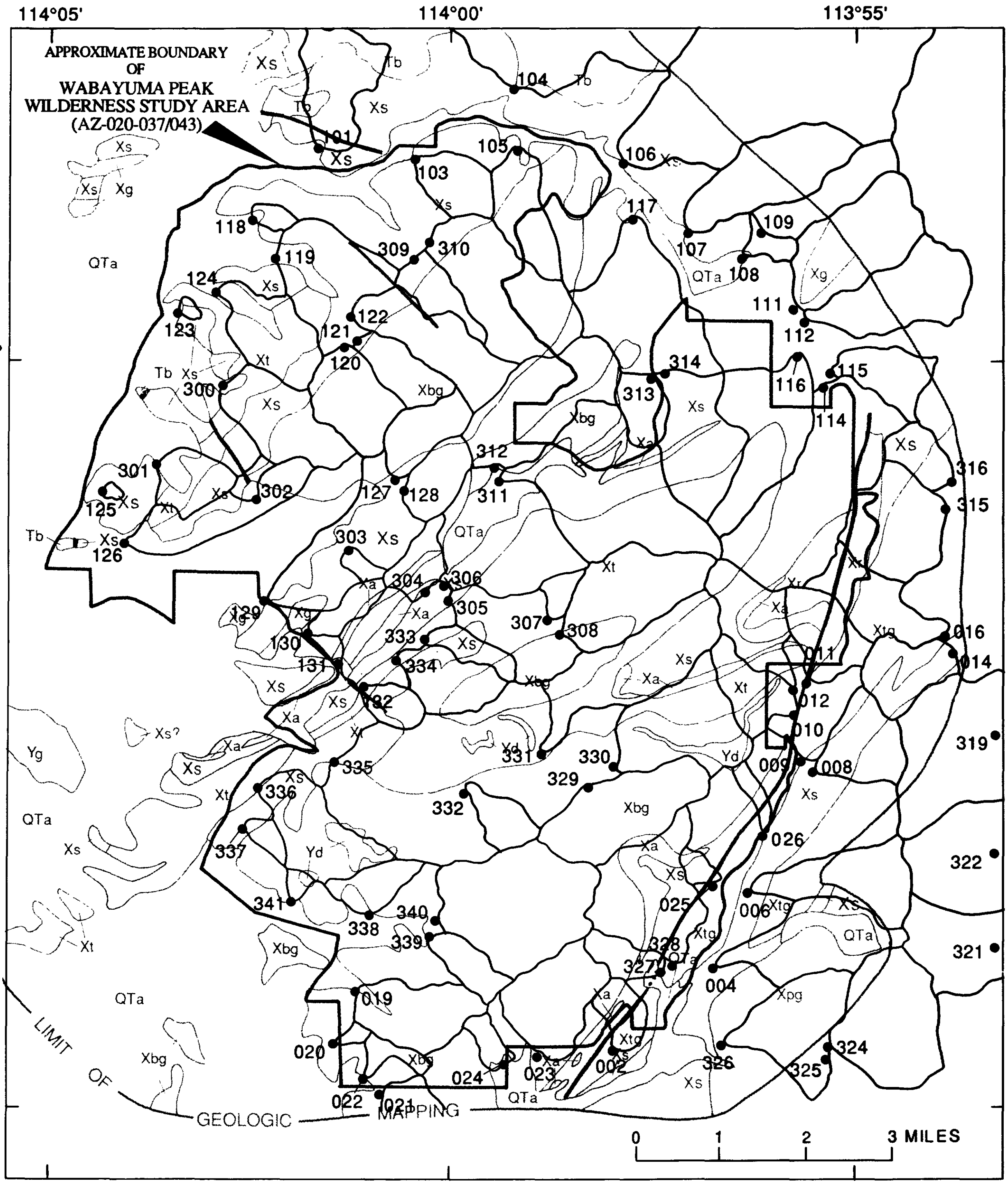


Figure 5. Sample locality map for drainage-sediment samples showing drainage basins sampled in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. Drainage areas and sample sites correspond to those shown on plate 1. Analytical data given in tables 4–7. See figure 2 for explanation of map units.

7) generally present only weak anomalies, if any, in two or three elements—a relation also seen in the NURE data for a broad region in western Arizona (Clark, 1979; Wagoner, 1979; Qualheim, 1978; Cook, 1981).

The relation of drainage-sediment anomalies and anomaly strength to geologic map units is summarized in table 8. This qualitative approach is useful to evaluate whether certain elements may be preferentially derived from certain geologic units. The table was compiled by studying single-element geochemical maps superimposed on the drainage-basin and geologic maps. Many basins could not be evaluated easily because they drain several rock units; others, however, drain only one or two rock types and allow, together with evaluations of surrounding drainages, reasonable estimates as to the rock unit source of a given anomaly.

Ubiquitous anomalies, composited sources (rock units), and several applicable mineral deposit models allow only generalized interpretations of the drainage-sediment survey. In assessing mineral resources, the presence or absence of an element may be as or more important than the intensity of an anomaly. Geochemical surveys show only that metal-enriching processes may have occurred, not the economic significance of an event. For example, a weak anomaly caused by an economically significant buried deposit cannot be distinguished from a weak anomaly caused by a near-surface uneconomic mineral deposit. Reconnaissance geochemical surveys cannot define specific mineral deposit models because several models could be indicated by the geochemical data.

Rare-Metal Suite

The dominant feature of the geochemical survey is the nearly ubiquitous presence of anomalies of a rare-metal suite of elements and elements commonly associated with such a suite. For this study, we define the rare-metal suite to consist of W, Bi, Mo, Sn, Th, Nb, La, and Y; we obtained no data for other rare elements, such as Li and Ta. We use the term rare metals in a broad or general sense (Thrush, 1968; Condensed Chemical Dictionary, 1987). Levinson (1974) included Li, Be, Sn, W, Ta, and Nb as "rare metals," whereas Tischendorf (1977) considered these six elements plus Mo to be concentrated in "rare-element mineralization" associated with specialized granites. These definitions rely on analyses of granite samples whereas our rare-metal suite is based on analyses of drainage sediments.

Widespread anomalies of the rare metals in the study area are accompanied by intermittent anomalies of Be, Mn, Pb, and Ag in nonmagnetic heavy-mineral concentrates (table 4). These elements are also anomalous in paramagnetic (table 5) and panned concentrates (table 6), but the anomalies are generally weaker and less common than in the nonmagnetic heavy-mineral concentrates. Weak, sparse anomalies of As, Ba, Cu, Cr, Ga, and U are also present, primarily in sieved-sediment samples (table 7).

Mineralogy of some samples and sites of rare metals have been determined by X-ray diffraction (S. Sutley, written commun., 1988). Bismuth is present in bismutite, Mo in powellite and scheelite, Th in thorite, and W in scheelite. Scheelite was recognized optically in all nonmagnetic concentrates and panned heavy-mineral concentrates. Wolframite, the principal tungsten ore mineral, was identified optically in the paramagnetic heavy-mineral concentrates; some wolframite grains have interstitial or surface-coated scheelite. Molybdenite was detected by laser spectroscopy (S. Sutley, oral commun., 1988) in samples from Boriana and Bull Canyons. Cassiterite, a tin mineral, was tentatively identified by microscope.

Niobium and Y in the nonmagnetic heavy-mineral concentrates are likely contained in zircon, sphene, rutile, anatase, and fluorite, all found or tentatively identified in most samples. These minerals can accommodate appreciable amounts of Nb and Y (Rankama and Sahama, 1950). In the paramagnetic fraction, Nb and Y can be present in sphene, wolframite (probably as inclusions of the niobium ore mineral columbite), monazite, and xenotime (Rankama and Sahama, 1950). The source of anomalous Be in the heavy-mineral concentrates is unknown because beryl (present in the area, Chatman, 1988) is not sufficiently dense to be concentrated in heavy liquids.

Fluorite, common to many of the samples, may come from veins or from disseminations in the granites. Its presence is noteworthy because a high volatile content in granitic magma, especially fluorine, is essential for rare-element mineralization (Tischendorf, 1977).

All or most of the eight rare metals are present in anomalous amounts in most of the drainage-sediment samples (pl. 1) but the strongest anomalies, dominated by tungsten (fig. 6), are concentrated in Boriana Canyon and the northwestern part of the study area (fig. 7). Lanthanum, which has local strong anomalies but far fewer widespread anomalies than the other rare metals, is not plotted in figure 7. Anomalies in Boriana Canyon are related to the known tungsten enrichment, which is related to the two-mica granite. The rare-metal anomalies in the northwestern part of the map area may be from scheelite-bearing veins, perhaps genetically related to the northwestern body of biotite granite. In contrast, strongest rare-metal anomalies (fig. 6, pl. 1) are not closely associated with trondhjemite and biotite granite in central and southern parts of the study area (table 8). There are differences in rare-metal drainage-sediment anomalies between the Boriana Canyon area and the northwestern part of the study area. For example, Mo is moderately anomalous in the northwestern part and not anomalous in Boriana Canyon. Such differences may reflect different rare-metal proportions in biotite granite and two-mica granite

Table 4. Values of selected elements in nonmagnetic heavy-mineral-concentrate samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[All values in parts per million by semiquantitative spectrographic analysis. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Bi	Co	Cu	Mo	Nb	Pb	Sn	Th	W	Y	Zn
002	20	300	70	5,000	<10	200	15,000	70	1,000	700	2,000	1,500
004	5	200	150	3,000	<10	<50	2,000	500	1,500	1,000	2,000	N
006	30	N	200	30,000	N	50	1,500	70	N	1,500	100	7,000
010	N	N	N	15	50	100	50	70	5,000	5,000	1,000	N
011	N	1,000	N	50	2,000	100	50	70	N	5,000	300	<500
012	N	1,000	N	300	30	70	30	20	1,500	3,000	700	N
014	10	1,500	<20	7,000	50	500	20	<20	N	>20,000	500	N
016	<1	1,000	N	100	N	200	N	N	N	20,000	300	1,000
019	N	N	N	10	N	200	150	150	5,000	N	1,000	N
020	N	2,000	N	70	<10	<50	3,000	50	>5,000	1,000	1,500	N
021	N	200	N	10	N	70	300	100	3,000	N	1,000	N
022	N	N	N	15	15	50	500	100	>5,000	1,000	1,500	N
023	N	N	N	<10	30	70	200	100	5,000	150	2,000	N
024	N	N	N	10	N	50	500	200	>5,000	N	2,000	N
025	N	300	N	<10	70	200	2,000	50	N	1,000	700	N
026	N	500	N	10	<10	200	5,000	100	1,000	2,000	1,000	N
101	N	150	N	N	20	50	<20	300	N	10,000	700	N
103	<1	N	N	N	15	200	100	1,000	N	20,000	1,000	<500
104	N	>2,000	N	N	70	150	300	1,500	N	15,000	700	N
105	N	1,500	N	N	30	100	100	70	3,000	3,000	1,500	N
106	<1	20	150	N	10	<50	20	<20	N	1,500	500	N
107	N	N	N	N	N	<50	20	20	N	150	500	N
108	<1	20	<20	N	N	70	20	<20	N	2,000	300	N
109	<1	N	20	N	N	<50	150	<20	N	1,000	500	N
111	N	30	50	5,000	N	<50	<20	N	N	200	300	N
112	<1	N	100	15	70	100	150	50	N	20,000	100	N
114	<1	N	N	10	N	<50	N	N	N	150	70	N
115	N	N	N	<10	<10	50	N	N	N	15,000	100	N
116	N	2,000	N	N	N	70	50	<20	N	500	300	N
117	<1	100	N	<10	10	200	2,000	N	N	>20,000	1,500	N
118	N	500	N	50	15	150	70	100	N	20,000	1,500	N
120	N	N	N	<10	100	100	300	200	5,000	1,500	5,000	N
121	N	300	N	N	70	150	50	150	300	5,000	3,000	N
122	<1	200	N	<10	300	200	3,000	>2,000	3,000	20,000	1,500	N
123	N	N	N	N	150	200	50	>2,000	500	20,000	2,000	N
124	N	150	N	N	70	100	500	200	300	10,000	2,000	N
125	1	>2,000	N	10	N	100	500	150	500	300	1,500	3,000
127	N	50	<20	10	70	100	70	200	700	2,000	5,000	N
128	N	N	N	<10	300	200	70	30	5,000	20,000	1,500	N
129	N	N	N	<10	<10	150	70	200	5,000	1,000	3,000	N
130	<1	700	N	300	70	150	<20	20	300	20,000	700	N
131	<1	N	N	N	20	100	200	50	1,000	10,000	1,000	N
132	N	N	N	N	20	200	50	100	700	700	1,500	N
300	<1	300	N	N	<10	100	200	150	500	300	2,000	N
301	1	500	N	N	200	150	30	500	200	20,000	1,500	N
302	N	200	N	N	100	150	70	200	300	15,000	2,000	N
303	<1	70	N	N	20	50	70	100	2,000	2,000	1,500	N
304	N	70	N	N	15	1,000	20	50	N	10,000	700	N
305	<1	<20	N	N	N	100	30	50	N	70	1,000	N
306	N	N	N	N	15	150	30	70	N	1,000	1,500	N

Table 4. Values of selected elements in nonmagnetic heavy-mineral-concentrate samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona—Continued

[All values in parts per million by semiquantitative spectrographic analysis. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Bi	Co	Cu	Mo	Nb	Pb	Sn	Th	W	Y	Zn
307	N	N	N	N	<10	<50	70	30	200	700	1,000	N
308	N	N	N	N	10	50	150	50	700	1,000	1,500	N
309	<1	N	N	<10	50	150	100	1,000	5,000	10,000	3,000	N
310	N	20	N	N	70	200	150	100	700	5,000	3,000	N
311	N	N	N	N	10	70	50	70	N	700	1,500	N
312	N	150	N	N	70	100	70	100	<200	1,500	2,000	N
313	N	500	N	N	100	50	200	>2,000	1,000	2,000	1,500	N
314	<1	N	N	N	30	150	20	50	N	1,500	1,000	N
315	<1	100	N	N	N	200	50	2,000	N	300	1,500	N
316	<1	N	N	N	N	100	<20	N	N	500	500	N
317†	N	N	N	N	N	<50	30	200	<200	150	1,500	N
319*	N	N	N	N	20	50	50	N	<200	1,000	1,500	N
320†	<1	N	N	<10	10	50	100	200	3,000	1,500	1,000	N
321*	1	N	N	N	10	50	30	N	500	1,000	700	N
322*	<1	20	N	N	<10	70	50	30	N	1,500	1,500	N
324	N	N	N	N	N	100	30	150	300	N	2,000	N
325	N	N	N	N	N	100	30	150	1,000	150	2,000	N
327	<1	100	N	N	20	70	150	200	1,000	2,000	1,500	N
328	<1	N	N	N	N	100	100	150	700	1,000	700	N
329	N	N	N	<10	<10	100	300	200	5,000	1,000	1,000	N
330	N	N	N	<10	N	70	100	100	5,000	<50	1,000	N
331	<1	N	N	N	100	<50	30	50	N	1,500	700	N
332	N	N	N	N	N	50	150	100	1,500	N	700	N
333	N	<20	N	N	15	70	150	50	200	1,500	1,000	N
334	N	N	N	N	N	100	100	100	<200	150	2,000	N
336	N	N	N	N	N	70	70	100	1,000	200	1,500	N
337	N	N	N	N	N	<50	150	30	1,500	150	1,500	N
338	N	N	N	N	N	50	100	100	700	N	1,000	N
339	<1	200	N	N	15	70	100	100	2,000	2,000	700	N
340	N	N	N	N	N	100	100	150	1,500	50	1,000	N
341	N	N	N	N	N	50	150	100	500	100	700	N

*Actual sample locality downstream (off map) from locality shown in figure 5.
†Sample locality off map (fig. 5)

magmas, the potential metal sources in the two areas. The strongest Th anomalies and the only strong to moderate La anomalies are associated with the southern biotite granite and may indicate an analogous magma contrast.

Many metals are commonly produced in major Sn and W deposits worldwide. For example, the granite-related Shizhuayuan deposit in China, possibly the world's largest tungsten deposit, also produces Sn, Mo, Bi, Be, Fe, Cu, Pb, and Zn and byproduct Nb, Ta, Sc, Au, Ag, and Re in a multizone, multiphase mineralized complex (Yang, 1982; Wang and others, 1982). Widespread anomalies of rare metals and associated anomalies of other metals (listed above) are consistent with the potential for granite-related tungsten-polymetallic vein deposits in the Wabayuma Peak Wilderness Study Area.

Drainage-sediment samples in Boriana and Bull Canyons have strong As, Bi, Mo, Nb, Sn, and W anomalies and weak to moderate anomalies of Be, Co (source unknown; a Boriana mine dump sample was not anomalous in Co), Cu, Mn, Y, and Zn. Presumably these anomalies are attributed to the tungsten-polymetallic veins in these areas. Similar suites, with fewer elements and less intense anomalies, are common to many of the drainages in the study area; these suites suggest similar mineralization.

A sulfide-rich composite sample from the Boriana mine dump contains ore- and near-ore-grade amounts of

Table 5. Values of selected elements in paramagnetic heavy-mineral-concentrate samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[All values in parts per million by semiquantitative spectrographic analysis. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Bi	Co	Cu	Mn	Mo	Nb	Pb	Th	W	Y	Zn
002	N	N	30	50	1,500	N	N	<20	N	N	30	N
004	N	N	N	150	10,000	N	200	30	300	1,000	1,500	N
006	20	N	20	30,000	5,000	N	N	700	N	70	50	20,000
010	N	N	30	100	1,000	N	<50	<20	<200	N	200	N
011	N	N	70	70	2,000	N	50	N	N	N	30	N
012	N	N	30	20	5,000	N	N	N	N	N	70	N
014	<1	200	<20	2,000	10,000	150	200	20	N	10,000	100	N
016	N	N	50	100	1,500	N	100	<20	<200	300	1,000	2,000
019	<1	N	30	50	700	N	<50	20	<200	<50	50	N
020	N	N	30	50	500	N	N	70	700	N	30	N
021	N	N	20	20	700	N	<50	50	200	N	70	N
022	N	N	30	20	1,500	N	<50	70	1,500	N	70	N
023	5	N	30	70	1,000	N	<50	70	1,000	N	200	N
024	N	N	30	30	700	N	50	50	500	N	150	N
025	N	N	30	N	1,000	N	N	N	N	N	30	N
026	N	N	<20	50	1,500	N	50	<20	N	N	100	N
101	N	N	150	15	1,500	N	<50	N	N	300	100	N
103	N	N	50	20	>10,000	N	N	N	N	50	100	<500
104	N	20	100	15	1,000	N	N	<20	N	70	20	N
105	N	N	20	50	10,000	N	200	<20	200	200	300	500
106	N	N	50	70	1,500	N	N	N	N	N	20	N
107	N	N	30	50	1,000	N	N	N	N	N	20	N
108	N	N	50	70	1,000	N	N	N	N	N	<20	N
109	N	N	50	100	1,500	N	N	N	N	N	<20	N
111	N	N	150	150	2,000	N	N	N	N	N	<20	N
112	N	N	20	30	>10,000	N	N	N	N	N	50	N
114	N	N	30	50	2,000	N	<50	N	N	N	20	N
115	N	N	50	50	10,000	N	<50	30	<200	50	1,500	N
116	N	N	50	15	1,000	N	N	N	N	N	70	N
117	N	<20	20	100	7,000	15	300	150	N	1,500	150	500
118	N	N	<20	50	>10,000	N	50	30	N	50	700	N
120	N	N	20	10	5,000	N	200	50	1,500	N	500	<500
121	N	N	<20	<10	2,000	N	150	<20	<200	N	300	N
122	N	N	20	30	7,000	N	150	<20	200	N	200	N
123	N	N	<20	<10	5,000	N	700	200	N	N	1,000	N
124	N	N	20	20	3,000	N	100	30	N	N	700	500
125	N	<20	20	70	>10,000	<10	N	30	300	N	2,000	1,500
128	N	N	<20	<10	2,000	70	300	30	500	1,000	1,000	N
129	N	N	30	10	5,000	N	70	N	N	<50	150	N
130	N	N	30	20	10,000	N	N	N	N	N	300	N
131	N	N	50	15	2,000	N	N	N	N	N	30	N
132	N	N	30	15	1,500	N	100	N	N	50	700	N
300	N	N	20	30	5,000	N	3,000	50	300	N	1,000	<500
301	N	N	N	50	>10,000	N	700	20	N	N	500	<500
302	N	N	30	50	3,000	N	3,000	20	500	N	700	<500
303	N	N	30	20	10,000	N	50	70	1,500	N	700	N
304	N	N	50	30	3,000	N	N	N	N	N	100	N
305	N	N	30	10	1,000	N	100	N	N	N	150	N

Table 5. Values of selected elements in paramagnetic heavy-mineral-concentrate samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona—Continued

[All values in parts per million by semiquantitative spectrographic analysis. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Bi	Co	Cu	Mn	Mo	Nb	Pb	Th	W	Y	Zn
306	N	N	<20	30	3,000	N	N	N	N	N	150	N
307	N	N	30	<10	700	N	<50	30	N	N	100	N
308	N	N	30	10	1,000	N	70	<20	200	N	200	N
309	N	N	<20	50	5,000	N	200	20	500	N	700	N
310	N	N	<20	15	2,000	N	300	<20	200	N	500	N
311	N	N	30	15	1,000	N	N	N	N	N	30	N
312	N	N	30	20	2,000	N	50	N	N	N	150	N
313	N	N	20	15	700	N	<50	N	700	1,000	100	N
314	N	N	30	10	1,500	N	N	N	N	N	50	N
315	N	N	50	70	7,000	N	100	20	N	50	300	N
316	N	N	50	70	>10,000	N	150	50	300	N	1,500	N
317†	N	N	30	50	1,500	N	70	100	500	N	1,000	N
319*	N	N	20	70	5,000	N	150	20	200	N	1,500	N
320†	N	N	100	70	7,000	N	2,000	100	500	N	500	N
321*	N	N	20	50	7,000	N	1,500	<20	N	N	500	500
322*	N	N	30	70	5,000	N	1,000	20	<200	N	700	N
324	N	N	20	50	3,000	N	1,000	N	N	N	150	N
325	N	N	20	70	2,000	N	700	N	N	N	100	N
327	N	N	50	30	1,500	N	500	30	200	50	200	N
328	N	N	30	<10	1,500	N	N	N	N	N	<20	N
329	N	N	30	10	1,000	N	<50	<20	500	N	50	N
330	N	N	30	15	700	N	N	N	N	N	<20	N
331	N	N	30	20	1,000	N	50	N	N	N	70	N
332	N	N	20	70	1,000	N	50	<20	N	N	30	N
333	N	N	30	30	1,500	N	<50	N	N	N	70	N
334	N	N	<20	15	1,500	N	1,500	<20	N	N	150	N
336	N	N	50	15	1,000	N	N	N	N	N	20	N
337	N	N	30	30	1,000	N	N	N	N	N	20	N
338	N	N	50	30	700	N	N	N	N	N	100	N
339	N	N	<20	10	700	N	N	<20	<200	N	30	N
340	N	N	50	70	1,000	N	70	20	N	N	150	N
341	N	N	30	50	700	N	50	N	<200	N	100	N

*Actual sample locality downstream (off map) from locality shown in figure 5.
†Sample locality off map (fig. 5).

Au (0.53 ppm), Ag (200 ppm), As (7,000 ppm), Bi (3,000 ppm), Cu (greater than 20,000 ppm), Mo (1,000 ppm), and W (1,000 ppm). The sample also contains In (7 ppm) and Sn (200 ppm), which are potentially recoverable byproducts. Other metals have commonly been obtained as byproducts in tungsten mines elsewhere and, using modern methods, could possibly be recovered from Boriana ore. Malaysian tin mines are the world's greatest source of Y (Vijayan and others, 1989). Large amounts of Nb and Ta are obtained from the Malaysian tin slags (Cunningham, 1983). In the Shizhuayuan deposit, wolframite is the principal host for Sc (0.03 percent Sc_2O_3), Nb (0.28 percent Nb_2O_3), and Ta (0.05 percent Ta_2O_5) (Yang, 1982). At these levels, Sc, for example, is recoverable at about 20 ppm in ore containing 1 percent wolframite, or 0.76 percent WO_3. Tungsten deposits commonly contain between 0.3 and 2 percent WO_3 (Hosking, 1982); Boriana mine tungsten grades are 1 to 2 percent WO_3 (Hobbs, 1944).

The foregoing discussion brings up several points. These are: (1) the Boriana and Bull Canyon deposits could potentially produce several metals, (2) the numerous pathfinder elements in the Boriana and Bull Canyon areas may be pathfinders to similar tungsten-polymetallic vein deposits elsewhere in the study area, (3) even

Table 6. Values of selected elements in panned heavy-mineral-concentrate samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[All values in parts per million by semiquantitative spectrographic analysis. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Bi	Co	Cu	Mo	Nb	Pb	Sn	Th	W	Y	Zn
002	N	N	100	200	N	<20	20	N	N	N	500	1,000
006	50.0	10	700	>20,000	10	<20	1,000	150	N	1,000	500	>10,000
008	100.0	>1,000	300	>20,000	1,500	2,000	20	1,000	N	>10,000	100	2,000
009	N	<10	50	70	N	N	N	N	N	30	70	700
023	.5	N	100	50	N	N	30	N	200	N	150	500
106	N	N	15	50	N	N	10	N	N	<20	70	N
114	N	<10	70	70	N	N	100	N	500	N	500	2,000
117	N	N	100	70	N	N	<10	N	N	N	150	<200
119	N	N	50	50	N	<20	<10	70	N	150	500	1,000
126	N	N	20	70	N	200	70	70	200	30	1,000	500
129	N	N	30	70	<5	20	10	30	100	100	500	500
131	N	N	70	100	N	N	N	N	N	N	100	500
305	N	N	30	50	N	<20	N	10	N	N	200	700
306	N	N	30	50	N	<20	<10	N	N	N	150	N
318†	N	N	50	70	N	20	100	N	150	20	1,500	<200
319*	N	N	50	70	N	<20	10	N	N	N	200	700
323†	N	N	20	50	N	20	N	N	N	N	150	N
326	N	N	30	70	N	100	N	N	N	N	150	N
335	N	N	50	50	N	N	N	N	100	N	100	700
340	N	N	50	70	N	N	15	20	<100	N	150	<200

*Actual sample locality downstream (off map) from locality shown in figure 5.
†Sample locality off map (fig. 5).

though some elements are only weakly anomalous (or not anomalous), they might still be recoverable, and (4) our evaluation is limited; further work is needed to determine sources of certain anomalous metals and analyses need to be obtained for additional elements, including Li, Ta, Se, and most rare-earth elements.

Lead and Th are weakly to strongly anomalous in the southern part of the study area underlain by biotite granite, where there are no prospects, known altered rock, or observed sulfide minerals in nonmagnetic heavy-mineral concentrates. The Th is from thorite, but the Pb source is unknown. Their presence in evolved granitic magmas (Tischendorf, 1977) suggests that the anomalies are of magmatic origin. Future studies, including isotopic studies, should address the source of the Pb and its role in ore-forming processes.

There is potential in the study area for large-scale metal zoning (Tischendorf, 1977) that causes the regular distribution of several elements around mineralized centers. Lead, for example, is deposited in outer zones (Stone, 1982). Lead is not anomalous in the Boriana Canyon, Bull Canyon, or Ophir veins, but it is anomalous elsewhere, as in the southern biotite granite. In the northwestern mineralized area, one pegmatite about 1.5 mi west of the Ophir veins (Chatman, 1988) contains 2,700 ppm Pb and 1,000 ppm Zn, but no W. Some Cu- and Au-enriched quartz-sulfide veins nearer the Ophir veins lack Pb and W anomalies (Chatman, 1988), and quartz-scheelite veins in the Ophir area are not anomalous in Pb, Cu, or Zn. Similar chemical associations and distributions have been documented around tin deposits in the Cornwall district of England (Moore, 1982). Moore has developed a polyascendant model (variable mineralizing solutions ascending in different places) to explain the zoning at Cornwall where mineralized veins in outer zones are several miles from the centers of mineralization. Detailed studies in the northwestern mineralized area, including the Whiskey Basin greisen, might reveal a pattern of metal zoning and, possibly, the location of a buried mineralized center.

Several mineralized rocks and sieved-sediment samples anomalous in rare-metal elements have Zr/Sn and V/Nb ratios meeting criteria for granites that possibly contain rare-metal deposits (Beus and Grigorian, 1977). The criteria set by Beus and Grigorian are for data on granite itself, but these ratios might also be applicable to mineralized rocks associated with granite and sediments derived from granite. If so, mineralized rock and sieved-sediment samples from upper Boriana and Bull Canyons and sieved-sediment samples from near the head of Rock Creek have appropriate Zr/Sn and

Table 7. Values of selected elements in minus-80-mesh drainage-sediment samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[All values in parts per million; Ag, Be, Co, Cu, Mo, Pb, W, Zn by semiquantitative spectrographic analysis; As, Cd, and Zn by atomic-absorption spectroscopy; U by fluorimetry. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Be	Co	Cu	Mo	Pb	W	Zn	As	Cd	Zn	U
002	N	1.5	10	70	N	30	N	<200	<5	0.7	130	1.6
004	N	5.0	10	70	N	50	N	N	5	.8	84	2.6
006	10.0	3.0	150	5,000	N	700	50	10,000	1,500	15.0	7,300	12.0
010	N	1.5	<10	70	N	30	N	<200	200	.4	48	8.6
011	N	2.0	20	70	5	20	N	N	64	.5	67	6.9
012	N	1.5	20	50	N	15	N	N	21	.4	43	2.5
014	<.5	50.0	20	200	<5	50	300	<200	8	<.1	<2	6.4
016	N	3.0	20	50	N	20	<20	<200	38	.6	91	9.3
019	N	<1.0	10	30	N	30	N	N	7	.3	50	3.3
020	N	1.0	15	50	N	30	N	N	9	.6	57	3.4
021	N	1.0	10	30	N	50	N	N	9	.4	49	2.1
022	N	1.0	15	70	N	30	N	N	12	.5	67	1.9
023	N	1.0	10	50	N	20	N	N	<5	.1	46	3.5
024	N	1.0	10	50	N	30	N	N	<5	.5	47	6.1
025	N	1.5	30	70	N	10	N	N	<5	.5	49	2.9
026	N	2.0	10	100	<5	30	50	N	7	.4	62	7.6
101	N	3.0	50	100	N	15	N	<200	27	.8	61	2.0
103	N	2.0	10	50	N	20	N	<200	<5	.5	90	1.6
104	N	1.5	30	70	N	15	N	<200	8	.6	61	12.0
105	N	3.0	10	50	N	20	N	N	14	.4	74	1.3
106	<.5	2.0	20	100	N	20	N	N	21	.8	68	1.9
107	N	1.5	10	70	N	15	N	N	39	.7	62	1.6
108	N	1.5	30	100	N	15	N	N	53	.9	63	2.1
109	15.0	1.5	30	100	N	15	N	N	62	1.0	72	2.6
111	N	2.0	30	100	N	20	N	<200	24	.7	70	1.9
112	N	2.0	20	70	N	20	N	<200	46	.7	87	2.2
114	N	1.5	15	50	N	30	N	N	11	.3	59	24
115	N	2.0	20	50	N	30	N	N	20	.4	60	1.9
116	N	3.0	20	70	N	20	N	N	7	.5	43	3.2
117	N	5.0	15	50	70	50	N	N	8	.4	69	18.0
118	N	2.0	<10	50	N	30	N	N	<5	.7	85	2.1
120	N	3.0	10	50	N	50	N	N	<5	.8	89	9.4
121	N	3.0	10	20	N	30	N	N	<5	.8	82	8.1
122	N	5.0	10	50	N	50	N	<200	6	.6	88	3.9
123	N	1.5	<10	10	N	15	N	N	<5	.5	34	1.4
124	N	1.5	N	15	N	15	N	N	<5	.8	46	2.4
125	N	3.0	<10	50	N	50	N	N	<5	.4	79	.9
126	N	3.0	10	50	N	50	N	N	<5	.6	77	1.7
127	N	5.0	10	30	N	30	N	N	<5	1.2	77	18.0
128	N	5.0	<10	30	N	30	N	N	<5	.6	110	4.7
129	N	3.0	10	70	N	30	N	N	<5	.6	74	4.2
130	N	2.0	<10	30	N	20	N	N	<5	.5	47	1.4
131	.5	2.0	30	50	N	20	N	<200	<5	.5	46	1.5
132	N	2.0	10	50	N	20	N	N	<5	1.1	67	2.9
300	N	2.0	N	10	N	15	N	N	<5	.5	62	3.3
301	N	2.0	<10	30	N	20	N	N	<5	.4	49	1.5
302	N	3.0	10	50	N	50	N	N	<5	.6	93	5.7
303	N	2.0	10	50	N	30	N	N	<5	.5	54	3.1
304	N	2.0	15	50	N	20	N	N	<5	.6	45	1.9

Table 7. Values of selected elements in minus-80-mesh drainage-sediment samples collected in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona—Continued

[All values in parts per million; Ag, Be, Co, Cu, Mo, Pb, W, Zn by semiquantitative spectrographic analysis; As, Cd, and Zn by atomic-absorption spectroscopy; U by fluorimetry. N, not detected; <, detected but less than value shown; >, greater than value shown]

Sample (fig. 5)	Ag	Be	Co	Cu	Mo	Pb	W	Zn	As	Cd	Zn	U
305	N	2.0	15	50	N	50	N	N	<5	.5	59	4.0
306	N	1.5	10	30	N	15	N	N	<5	.9	44	4.1
307	N	3.0	15	30	N	15	N	N	<5	.4	56	12.0
308	N	3.0	15	50	N	20	N	N	<5	.5	57	17.0
309	N	5.0	<10	30	N	50	N	N	6	.6	82	7.3
310	N	5.0	10	30	N	20	N	N	<5	.7	79	5.7
311	N	2.0	15	50	N	10	N	N	<5	.5	60	3.6
312	N	2.0	<10	50	N	15	N	N	<5	.5	68	2.9
313	N	2.0	10	50	N	15	N	N	<5	.6	67	7.1
314	N	1.5	30	50	N	15	N	N	<5	.5	62	4.5
315	N	3.0	15	70	<5	20	N	200	12	.5	57	8.6
316	N	3.0	10	30	N	50	N	N	11	.6	74	8.3
317†	N	1.5	15	50	N	50	N	<200	<5	.5	75	3.7
319*	N	3.0	<10	30	N	30	N	N	7	.5	73	11.0
320†	N	3.0	20	50	N	30	N	N	6	2.7	66	18.0
321*	N	3.0	20	70	N	30	N	N	<5	.9	110	6.3
322*	N	2.0	<10	50	N	20	N	N	<5	.7	110	3.7
324	N	3.0	30	70	N	30	N	N	<5	1.2	90	4.4
325	N	2.0	20	50	N	30	N	N	<5	1.0	80	12.0
327	N	1.5	15	50	N	30	N	N	<5	.5	59	6.1
328	N	1.0	20	50	N	<10	N	<200	<5	.7	33	2.3
329	N	1.5	70	50	N	20	N	N	<5	.5	55	6.5
330	N	1.0	<10	20	N	20	N	N	<5	.4	40	1.7
331	N	1.5	20	70	N	20	N	N	<5	.5	64	3.3
332	N	1.0	20	70	N	50	N	N	11	.6	58	7.7
333	N	3.0	10	50	N	15	N	N	6	.4	65	12.0
334	N	3.0	10	30	N	10	N	N	<5	.6	58	3.2
336	N	1.5	30	50	N	15	N	N	<5	.5	35	2.1
337	N	2.0	30	50	N	15	N	N	<5	.3	51	2.0
338	N	1.5	15	50	N	20	N	N	<5	.4	58	1.6
339	N	1.0	20	50	N	20	N	N	<5	.5	68	4.7
340	N	1.0	10	30	N	20	N	N	<5	.5	62	1.9
341	N	2.0	15	70	N	20	N	N	<5	.6	78	1.8

*Actual sample locality downstream (off map) from locality shown in figure 5.
†Sample locality off map (fig. 5).

V/Nb ratios to indicate rare-metal potential. However, sediments collected downdrainage of greisen in the Whiskey Basin do not meet the criteria, suggesting the greisen may be barren. Fine grain size of the sieved samples and dilution by multiple rock types decrease the potential effectiveness of this method. Coarser material would incorporate more scheelite and wolframite, which are in the medium- to coarse-grained sand range as seen in heavy-mineral concentrates.

Uranium anomalies are surprisingly low and few given that uranium is commonly enriched with rare metals in granitic magmas. A spring in the northwestern part of the study area contains 29 ppb U (Qualheim, 1978), and weak U anomalies (less than 20 ppm) are present in drainage-sediment samples scattered through the study area. These U anomalies may be attributed to organic material in the drainage sediments rather than uranium present in the source rocks. The data do not suggest significant accumulations within the study area but do suggest the area could be a potential source area for unknown sediment-hosted uranium in the Sacramento Valley to the west.

In summary, the widespread rare-metal anomalies and the presence of veins, griesens, and moderately evolved granites means that the entire wilderness study area is permissive for mineral deposits of a wide variety of metals but that specific targets cannot yet be established.

Massive Sulfide Suite

Ideally, to evaluate the potential for mineral deposits, sediments downdrainage from known deposits should be analyzed to determine a suite of anomalous elements. Because only one such sample was collected in the map area (sample 006, fig. 5), in the Copper World drainage below mine tailings, compositions of mineralized samples from the Antler and Copper World mines and published data on the ore deposits are the primary basis for determi-

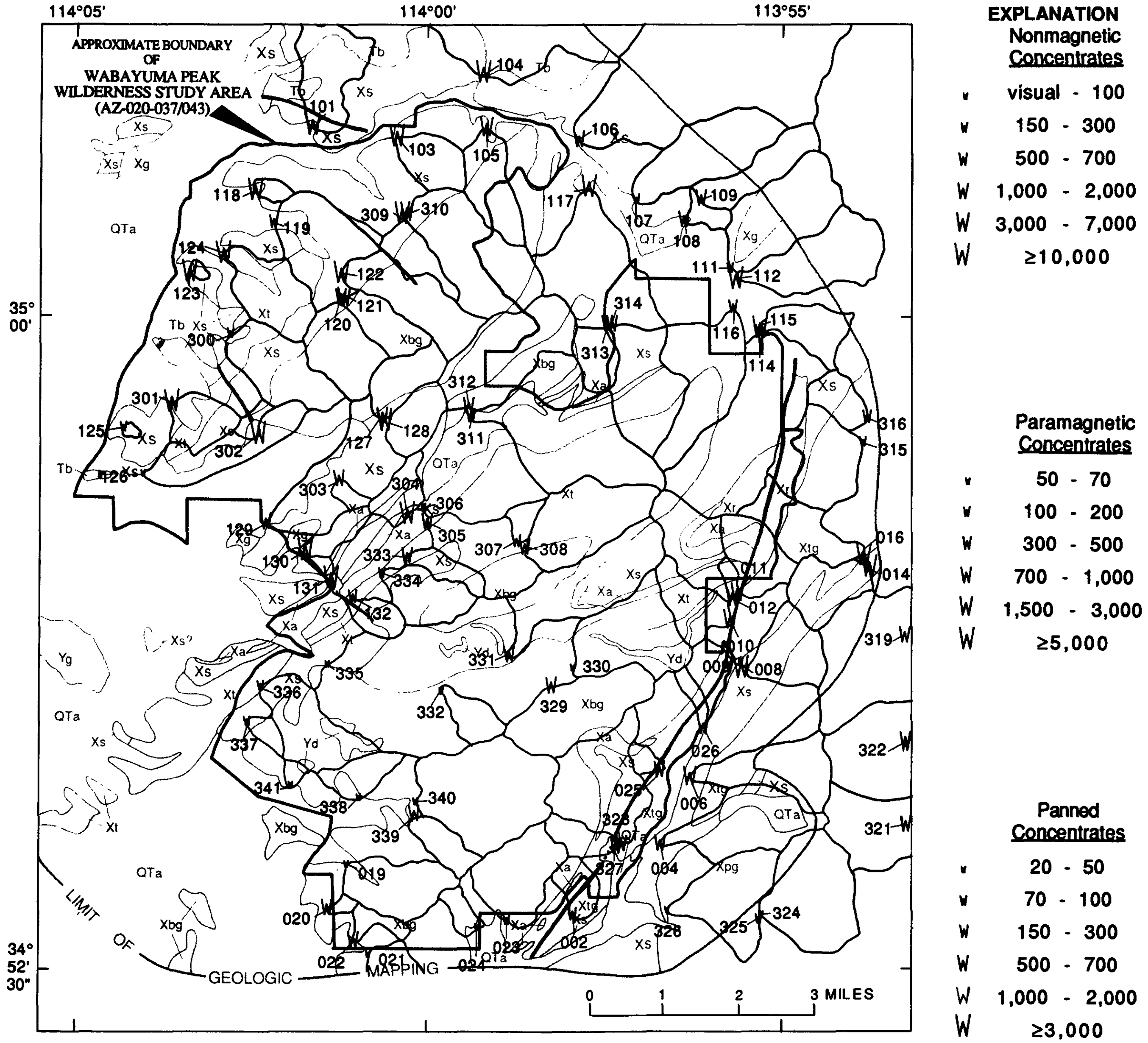


Figure 6. Tungsten anomaly levels (in parts per million) in nonmagnetic and paramagnetic heavy-mineral-concentrate samples and in panned-concentrate samples collected in drainage basins (outlined) in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. Size of tungsten symbol, W, indicates the highest level of anomaly among the three sample media. See tables 4–7 for detailed results of analyses, and figure 2 for explanation of map units.

nation of the massive sulfide suite. These data were augmented by drainage-sediment data in areas considered to have potential for massive sulfide deposits on the basis of geologic evidence (for example, chloritized rocks).

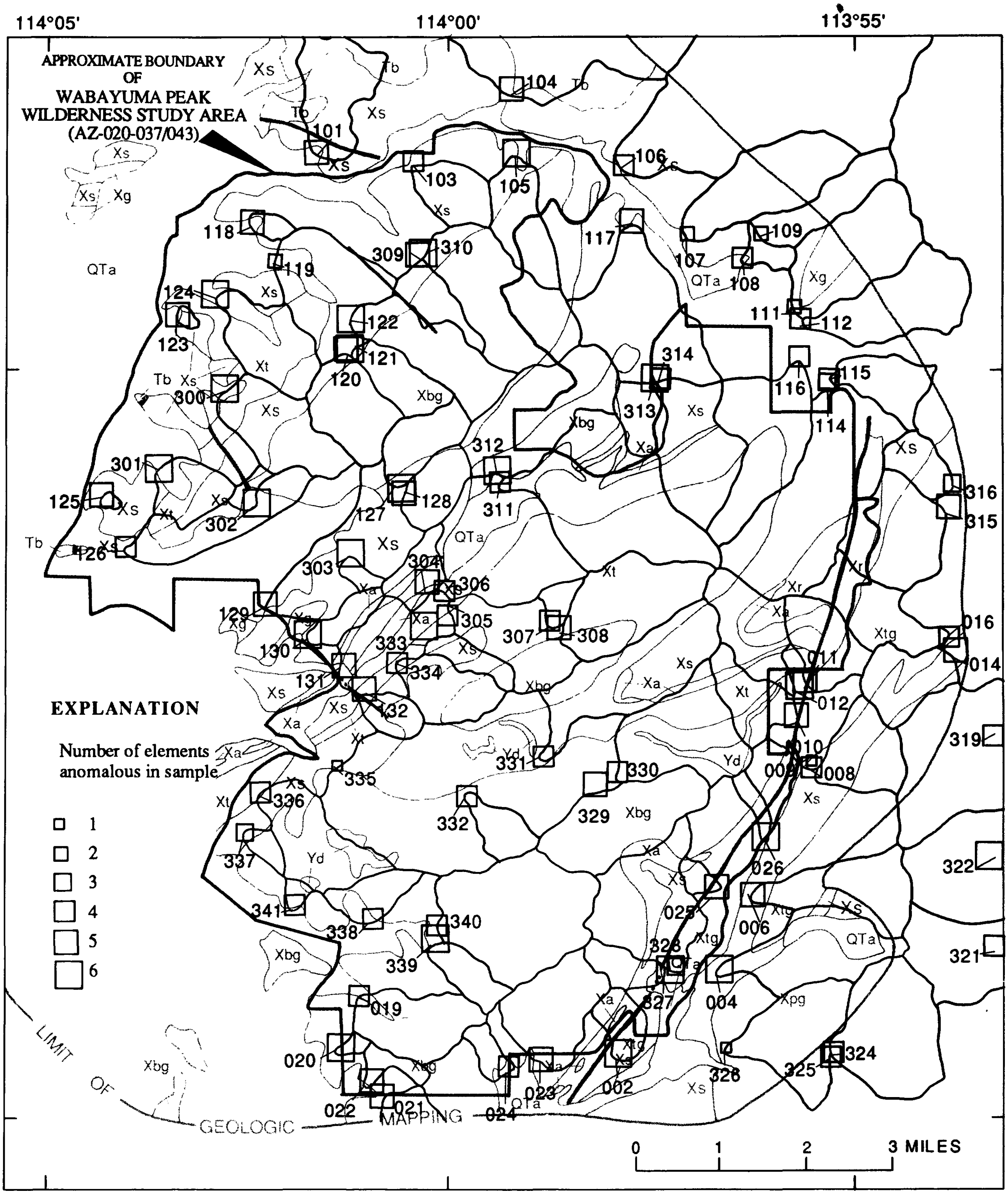
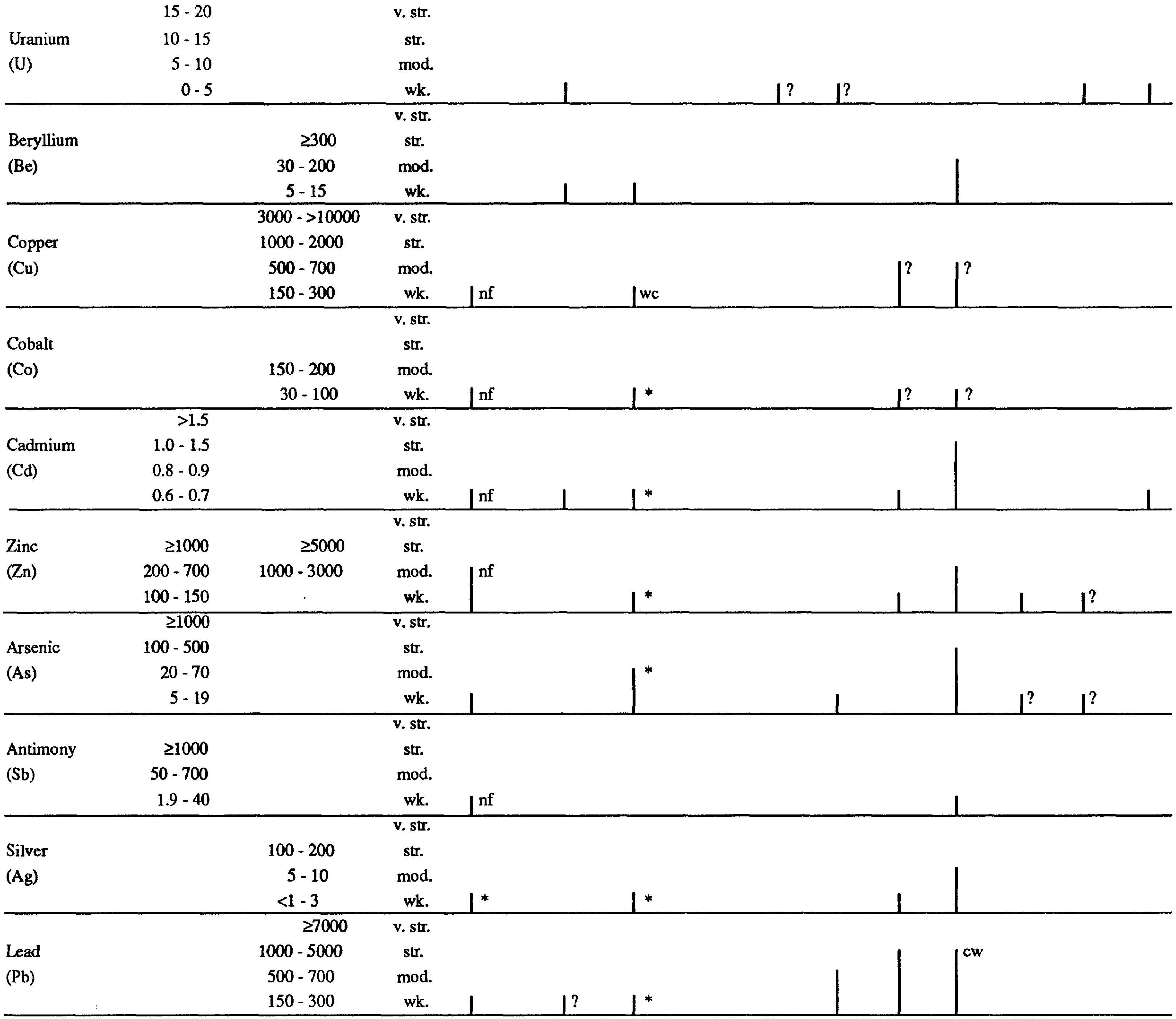


Figure 7. Anomaly incidence of the rare metals W, Bi, Mo, Sn, Th, Nb, and Y in nonmagnetic and paramagnetic heavy-mineral-concentrate, panned-concentrate, and sieved-sediment samples collected in drainage basins (outlined) in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. La not included owing to lack of widespread anomalies. See tables 4–7 for detailed results of analyses, and figure 2 for explanation of map units.

Table 8. Relation of anomaly strength to map units for drainage-sediment analyses in Wabayuma Peak Wilderness Study Area, Mohave County, Arizona

[All values in ppm; N, not detected at value shown; >, greater than; <, less than; v. str., very strong; str., strong; mod., moderate; wk., weak; nf, north of fault in lower Walnut Creek; wc, Walnut Creek area; cw, Copper World mine; *, local only; ?, anomaly questionably attributed to unit; ital., italics; sch., schist; trond., trondhjemite; Bio., biotite; Bor., Boriana; Wab., Wabayuma; 2, two; Porph., porphyritic; Pan.; panned; conc., concentrate; sed., sediment; Nonmag., nonmagnetic]

Element	Sieved sed. or Pan. con. (ital.)	Nonmag. conc.	Anomaly strength	Biotite schist	NW Bio. granite	Central sch. belt	NW Trond.	Central Trond.	S Bio. granite	W Bor. strata	E Bor. strata	Strata E Wab. Pk	2-mica granite	Porph. granite
		5000 - >20,000	v. str.		●									
Tungsten		1500 - 3000	str.	●	●	●					●		●	
(W)		500 - 1000	mod.	●	●	●					●		●	
		N50 - 300	wk.	●	●	●		●	●		●		●	●
		1000 - >2000	v. str.											
Bismuth		300 - 700	str.	●							●			
(Bi)		150 - 200	mod.	●	●	●			●*	●	●		●	
		<20 - 100	wk.	●	●	●			●	●	●		●	●
		>700	v. str.											
Molybdenum		200 - 500	str.											
(Mo)		70 - 150	mod.		●		●				●			
		<10 - 150	wk.	●	●	●	●	●	●		●			●
		1000 - 2000	v. str.											
Tin		200 - 500	str.	●	●	●								
(Sn)		100 - 150	mod.	●	●	●			●				●	●
		<20 - 70	wk.	●	●	●		●	●				●	●
			v. str.											
Niobium	*>1500*		str.										●	
(Nb)	*700 - 1000*	100 - 200	mod.		●								●	
	100 - 500	<50 - 70	wk.	●	●	●							●	●
			v. str.											
Lanthanum		>2000	str.						●*					
(La)		2000	mod.						●					
		1000 - 1500	wk.			●			●			●		●
			v. str.											
Yttrium		3000 - 5000	str.		●									
(Y)		1500 - 2000	mod.		●	●								●
		N20 - 1000	wk.	●	●	●			●				●	●
		>5,000	v. str.						●					
Thorium		2000 - 3000	str.		●*				●					
(Th)		1000 - 1500	mod.		●				●					●
		<200 - 700	wk.		●	●	●?	●?	●					●


Uranium
(U)
15 - 20
10 - 15
5 - 10
0 - 5
v. str.
str.
mod.
wk.
?
?
Beryllium
(Be)
≥300
30 - 200
5 - 15
v. str.
str.
mod.
wk.
Copper
(Cu)
3000 - >10000
1000 - 2000
500 - 700
150 - 300
v. str.
str.
mod.
wk.
nf
wc
?
?
Cobalt
(Co)
150 - 200
30 - 100
v. str.
str.
mod.
wk.
nf
*
?
?
Cadmium
(Cd)
>1.5
1.0 - 1.5
0.8 - 0.9
0.6 - 0.7
v. str.
str.
mod.
wk.
nf
*
Zinc
(Zn)
≥1000
200 - 700
100 - 150
≥5000
1000 - 3000
v. str.
str.
mod.
wk.
nf
*
?
Arsenic
(As)
≥1000
100 - 500
20 - 70
5 - 19
v. str.
str.
mod.
wk.
*
?
?
Antimony
(Sb)
≥1000
50 - 700
1.9 - 40
v. str.
str.
mod.
wk.
nf
Silver
(Ag)
100 - 200
5 - 10
<1 - 3
v. str.
str.
mod.
wk.
*
*
Lead
(Pb)
≥7000
1000 - 5000
500 - 700
150 - 300
v. str.
str.
mod.
wk.
?
*
cw

Rock samples from the Antler and Copper World mines are strongly enriched in Cu, Hg, Pb, Ag, and Zn and moderately to weakly enriched in As, Bi, Cd, Au, In, Fe, Mo, Tl, and Sn. The Antler sample, a gossan veinlet, also contains weakly anomalous concentrations of Co, Ga, Ni, Te, and V, whereas the Copper World sample, composited from mine dump material, contains weakly anomalous concentrations of Sb, B, Ge, and Mn.

Both mine samples contain anomalous values of Hg (6.4 and 0.7 ppm), detected elsewhere only in the Tertiary fault vein near Walnut Creek. Sieved-sediment samples are not anomalous in Hg except for the one collected below the Copper World mine. Mercury may not have been initially concentrated in volcanogenic deposits; it may have been introduced during faulting. Both deposits are tectonically disrupted.

The massive sulfide suite overlaps with the rare-metal suite and with the elements anomalous in Walnut Creek (see next section). However, rare metals are not characteristically anomalous in massive sulfide deposits, and some elements common to massive sulfide deposits are not associated with the rare-metal anomalies.

Silver, Cd, Co, Cu, Pb, and Zn anomalies were used to determine areas permissive for massive sulfide deposits. The number of these elements that is anomalous at each sampling site is shown in figure 8. Numerous strong anomalies suggest potential for the area north and northwest of the Antler mine just inside the study area. Samples collected downdrainage from the bulge area indicate that this area is also favorable. Several samples in Boriana Canyon and along Walnut Creek are anomalous in all or most elements of the massive sulfide suite. Stratified rocks in these areas are permissive for massive sulfide deposits, but the anomalies in upper Walnut Creek could also indicate the presence of Tertiary veins. Samples taken downdrainage from chloritized zones in the central part of the study area have weak massive sulfide signatures.

Geochemistry of Mineralized Tertiary Fault near Walnut Creek

Rock samples from the mineralized Tertiary fault north of Walnut Creek contain anomalous concentrations of Hg, W, As, Cu, Au, Zn, Sb, Be, Co, Mo, Te, and Tl but lack Pb and Ag (Chatman, 1988; J.R. Hassemer, unpub. data). This group overlaps with both the rare-metal and massive sulfide suite. It may be distinctive, however, in lacking most elements in the rare-metal suite and Cd, Ag, and Pb of the massive sulfide suite. The mineralized fault occurs in a drainage basin (sample 101, fig. 5) that is anomalous in most of the elements of the massive sulfide suite (fig. 8). We made no attempt to define a geochemical suite for this type of deposit; there is too little geological and geochemical data, no obvious deposit model, and the possibility of overprinting by other suites of elements.

Drainage-sediment geochemistry is of limited use in identifying areas of potential for mineralized Tertiary faults alone. On the other hand, sediments in the greater Walnut Creek area yield anomalies that suggest potential for one or more of the following: mineralized Tertiary faults, massive sulfide deposits, or quartz-sulfide veins similar to those at the Lizzard and Sparkle claims.

Recommendations for Further Work

In further exploration for tungsten-polymetallic vein deposits drainage-sediment sampling should be more closely spaced to minimize the number of rock types in each drainage. Additionally, in the absence of detailed rock sampling, analysis of a minus-35-mesh or coarser sieved-sediment sample would more closely approximate the actual composition of rocks in the drainage basin. This would allow more effective use of metal ratios indicative of granites with potential for rare metals (Beus and Grigorian, 1977). These approaches might locate evolved granite cupolas, greisen, or mineralized veins. In areas of known greisen or other alteration, closely spaced rock sampling in conjunction with detailed geologic mapping is recommended (Taylor, 1979).

Lead and Th anomalies suggest that further exploration in the southern biotite granite is warranted. Contact zones, pegmatites, and veins should be sampled and analyzed for additional elements such as the rare-earth elements. The relation of the metals to the granites, veins, and sample mineralogy should be determined.

Further geochemical exploration for massive sulfide deposits would require closely spaced rock sampling in conjunction with detailed geologic mapping. Chatman's (1988) sampling in the bulge area suggests the host rocks may have been depleted in some metals during sea floor hydrothermal activity that accompanied deposition of the massive sulfides. Further detailed studies near known massive sulfide deposits and in areas having potential for massive sulfides may reveal systematic patterns of depletion in some elements and enrichment in others that may provide direction to massive sulfide deposits (for example, see Conway and others, 1986, and Conway, 1986).

Geochemical exploration for Tertiary mineralized rocks would concentrate on examining the extensive Tertiary joints and faults and accompanying rock and soil sampling. Joints and faults extrapolated beneath alluvium or colluvium should be evaluated by mercury or other soil-gas analysis. Determining chemical zones in the fractures might help locate mineral deposits, if present.

Landsat Remote Sensing

Background

A digitally processed Landsat Thematic Mapper (TM) color-ratio composite image was used to locate areas whose spectral-reflectance characteristics suggest the presence of minerals associated with hydrothermally altered rocks. The spectral bands of the TM system are too broad to allow individual minerals to be identified;

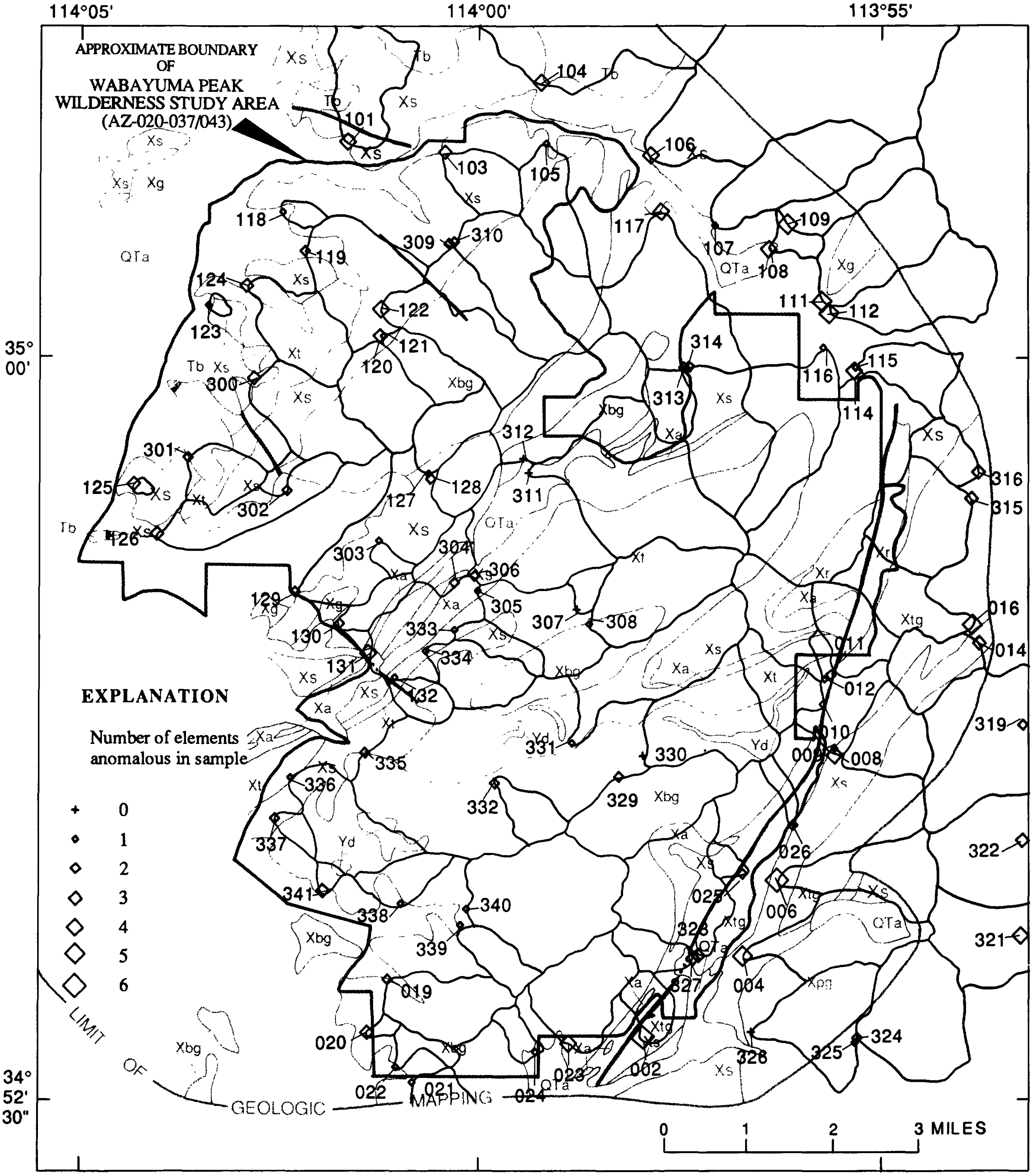


Figure 8. Anomaly incidence of the massive sulfide suite (Ag, Cd, Co, Cu, Pb, and Zn) in nonmagnetic and paramagnetic heavy-mineral-concentrate, panned-concentrate, and sieved-sediment samples collected in drainage basins (outlined) in and near Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. See tables 4–7 for detailed results of analyses, and figure 2 for explanation of map units.

however, two different groups of minerals (groups 1 and 2) can be distinguished on the basis of their spectral-reflectance characteristics (Knepper, 1989).

Group 1 minerals consist of the common ferric iron-oxide, -hydroxide, and -sulfate minerals hematite, goethite, lepidocrocite, and jarosite. They commonly form during the weathering of pyrite and, consequently, are associated with many oxidized hydrothermally altered rocks. The group 1 minerals, however, are not diagnostic because they can form by oxidation of iron-bearing minerals in unaltered rocks as well (Knepper, 1989), but group 1 minerals can signal the presence of altered rocks.

Group 2 is diverse and includes hydroxyl-bearing and (or) hydrated minerals (clay minerals, micas, gypsum, alunite, and jarosite) and carbonates (calcite and dolomite) that are spectrally similar in the TM bands. Jarosite shares common spectral characteristics with both group 1 and group 2 minerals and is included in both. Although the group 2 minerals are not restricted to altered rocks, they are commonly important constituents of or are derived from the weathering of altered rocks (Knepper, 1989).

Interpretation

Potentially hydrothermally altered rocks were determined from the Landsat color-ratio composite image by visually outlining distinct areas of unique colors related to group 1 or group 2 minerals or a combination of both (Knepper, 1989). Areas clearly related to the lithology of unaltered rocks or to sediments were excluded. The remaining areas are considered anomalous and may reflect local exposures of hydrothermally altered rocks. Field studies are necessary to characterize the altered rocks associated with the anomalies and eliminate possible false anomalies.

Moderate to dense vegetation obscures the rocks and soils of much of the study area. Eastern parts are particularly densely vegetated and little information could be obtained from the Landsat TM image. In addition, the rugged topography combined with a relatively low solar elevation angle at the time the TM data were acquired (25°) resulted in parts of the study area being in deep to moderate shadow on the TM image. Vegetation and shadows together eliminated about one-third of the study area from effective analysis. Even so, several anomalous areas were identified but may represent only part of more extensive areas.

Possible Areas of Hydrothermally Altered Rocks

Areas that might contain hydrothermally altered rocks on the basis of Landsat color-ratio composite image are shown on plate 1. Areas containing only group 1 minerals are labeled "1;" those containing only group 2 minerals are labeled "2;" and those containing both groups are labeled "3."

The Antler and Boriana mine areas are anomalous in both group 1 and group 2 minerals (pl. 1), either in altered host rock or dumps and tailings, and illustrate how exposed hydrothermally altered rocks appear on the image. Additional group 1 anomalies extend northeast from the Antler mine for about 2 mi and are associated with chloritized rocks and copper-zinc prospects. Another group 1 anomaly is associated with an area of chloritized rock in the central part of the study area. Prominent group 1 anomalies in central to northern parts of the study area are associated with weathered debris of Middle Proterozoic diabase.

Other areas of potential for hydrothermally altered rocks are scattered through the wilderness study area (pl. 1). Most areas have not been examined and should be evaluated during follow-up studies. In particular, a group of these anomalies on a northeast trend in the variable schist unit northeast of the upper reaches of Rock Creek should be field checked. These and other anomalies may indicate the presence of chloritized rock associated with massive sulfide deposits.

Gamma-ray Spectrometry

Interpretation

Distributions of the radioelements potassium (K), uranium (eU), and thorium (eTh) in and near the study area are shown in figures 9, 10, and 11; data for these figures are from NURE reports for the Prescott, Williams, Kingman, and Needles 1° by 2° quadrangles. The prefix "e" (for equivalent) denotes the potential for disequilibrium in the uranium and thorium decay series. Generally the study area is characterized by relatively low radioelement concentrations with lowest concentrations in the southern part and highest concentrations in the northern part. The southern part of the area, correlated with an aeromagnetic high, has K of 1 to 2 percent, eU of 2 to 3.5 ppm, and eTh of 8 to 10 ppm. The source rocks are biotite granite, trondhjemite, and variable schist. A subtle variation in radioelement content in relation to lithology is shown by 2 to 3 ppm eU in biotite granite and 3 to 3.5 ppm in trondhjemite. The northern part of the map area has 2 to 2.4 percent K, 3 to 5 ppm eU, and 10 to 18 ppm eTh where the source rock is biotite granite and biotite schist. The Tertiary basalt north of the study area has notably lower concentrations of 1 percent K, 3 ppm eU, and 7.5 ppm eTh. Biotite granite has 1.4 to 2 percent K in the southern part of the study area but 2 to 2.4 percent K in the northern part, suggesting different radioelement contents for the same lithologies.

A discrete eTh anomaly of 24 ppm in the northeast corner of the study area immediately east of the Tin

Barn well (pl. 1) correlates with a K anomaly of 2.4 percent, both within a larger area of 3 ppm eU, and has a source rock of variable schist.

Following the northeast trend along Boriana Canyon, steep gradients for all radioelements (figs. 9, 10, and 11) portray the change from the low concentrations in the southern part of the study area to higher concentrations in more radioactive two-mica granite and porphyritic granite southeast of the study area. The radioelement data differentiate the two types of granite, as two-mica granite has maximum concentrations of 9 ppm eU and 24 ppm eTh, and porphyritic granite has 6 ppm eU and 30 ppm eTh; both have 2.6 percent K maximum.

West of the study area on the east side of Sacramento Valley, a strong anomaly of 2.6 percent K, 6.5 ppm eU, and 40 ppm eTh closely coincides with an outlier of Middle Proterozoic porphyritic granite. This association is consistent with high radioactivity known for such granites elsewhere in western Arizona, for example, the Lawler Peak Granite at Bagdad and the Signal Granite in the Arrastra Mountains (U.S. Department of Energy, 1979b).

Implications for Mineral Resources

The radioelement data include low K concentrations in the north-central part of the study area where 1 percent K coincides (fig. 9, area A) with an area of chloritized rocks (pl. 1) and in the bulge area where 1.4 percent K (fig. 9, area B) corresponds, in part, with amphibolite. Low K in both areas may represent the presence of altered rocks depleted in K, which are commonly associated with massive sulfides. The anomaly in the bulge area, however, may be due largely to normally low-K amphibolite. Likewise, the low eTh concentration of 10 ppm for the bulge area (fig. 11) may represent normal Th content in mafic rocks.

Aeromagnetic Data

A large positive magnetic anomaly dominates much of the central to southern half of the study area. It is truncated on the east by the Boriana Canyon fault (pl. 1) and on the north by a line between the points lat 34° 57.5' N., long 114° 2.5' W. and lat 35°00' N., long 113° 55' W. The anomaly coincides closely with trondhjemite, which contains 1 to 4 percent magnetite. The magnetic anomaly extends southward over biotite granite where it is relatively weak except 1 mi northeast of the bulge where it is strongest. The extension of the strong anomaly over part of the biotite granite may be due to trondhjemite at depth, because the biotite granite contains only 0 to 2 percent magnetite.

The magnetic field over the north half of the study area shows only weak magnetic anomalies, a fact which suggests the intrusive and stratified rocks there are, at most, weakly magnetic.

The Antler deposit and prospects between it and the bulge are spatially correlated with a strong magnetic gradient that forms the southeast flank of the magnetic high, but this gradient probably represents the faulted southeast edge of the trondhjemite and biotite granite rather than rocks hosting massive sulfide bodies. The Boriana, Bull Canyon, and Copper World mines lie along a weak magnetic gradient, which may reflect a gradual northward increase of magnetite in the two-mica granite, but more likely is the north flank of a polarization low centered near the Copper World mine. This low may be caused by a large magnetic body to the south in the area of porphyritic granite. Such lows are found north of magnetic bodies at this latitude and are related to the geometries of those bodies and not to variations of magnetization in the surrounding rock.

Gravity Data

The Bouguer gravity field over the map area reflects both shallow density distributions related to near-surface geology and deep-crustal density distributions. To isolate the near-surface part of the gravity field, an isostatic residual gravity map was constructed from the Bouguer gravity data by removing the regional gravity field (Jachens and Griscom, 1985).

The residual gravity background level in the vicinity of the study area is about −12 mGal, which is typical for Proterozoic rocks in western Arizona. Superposed on this background level is a poorly defined gravity high centered on the southern part of the northwestern mass of biotite granite. The high is elongate roughly north-south, is about 6 mi long and 3 mi wide, and has a maximum amplitude of about 10 mGal. The source of this anomaly is difficult to identify. This anomaly is associated with several geologic units, although it is centered on biotite granite. A prong of the high extends southeast into an area that is underlain by trondhjemite.

No recognizable gravity features are associated with the mineral deposits in Boriana Canyon. The small number of stations and irregular distribution of gravity data make the data adequate for addressing regional structural and tectonic settings of the study area but do not permit assessment of mineral resource potential at a deposit scale.

Mineral Resource Potential

Volcanogenic Massive Sulfide Deposits

The known volcanogenic massive sulfide deposits in the map area, the Antler and Copper World deposits, contain copper, zinc, and minor lead, silver, and gold. Undiscovered deposits are expected to contain these same metals.

We concur with More (1980) and with Stensrud and More (1980) that the Antler and Copper World deposits are massive sulfides produced by sea-floor hot-spring exha-

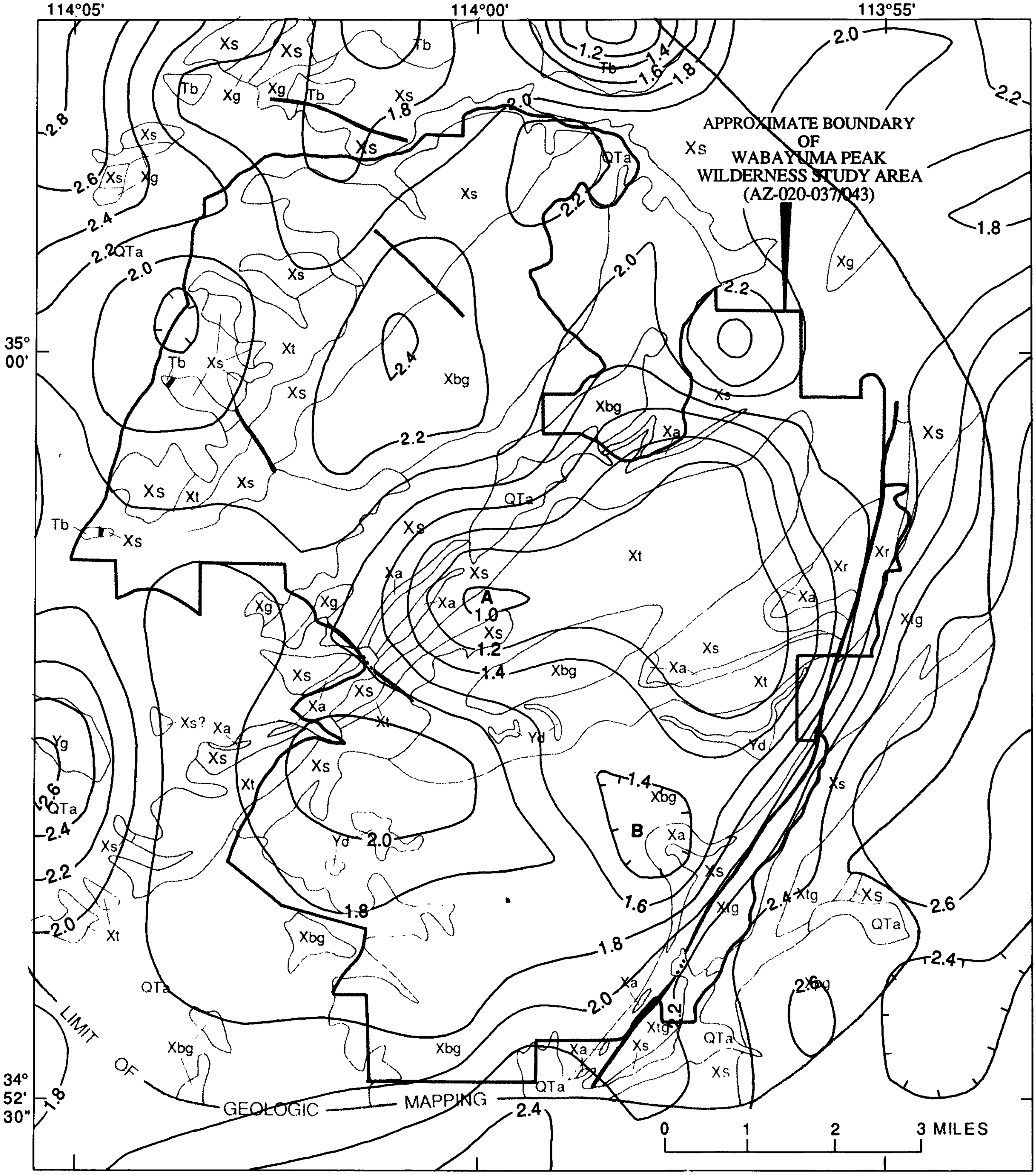


Figure 9. Gamma-ray potassium (K) distribution in Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. Contour interval, 0.2 percent K. Hachured in direction of lower values. See text for discussion of areas labeled A and B. See figure 2 for explanation of map units.

lations. The volcanogenic massive sulfide descriptive model, as summarized by Singer (1986), applies to these deposits. The following are criteria for this deposit type: (1) a typical lens-shaped body composed of more than 50 percent sulfide minerals that alters to massive gossan in the weathering environment, (2) subaqueously erupted volcanic

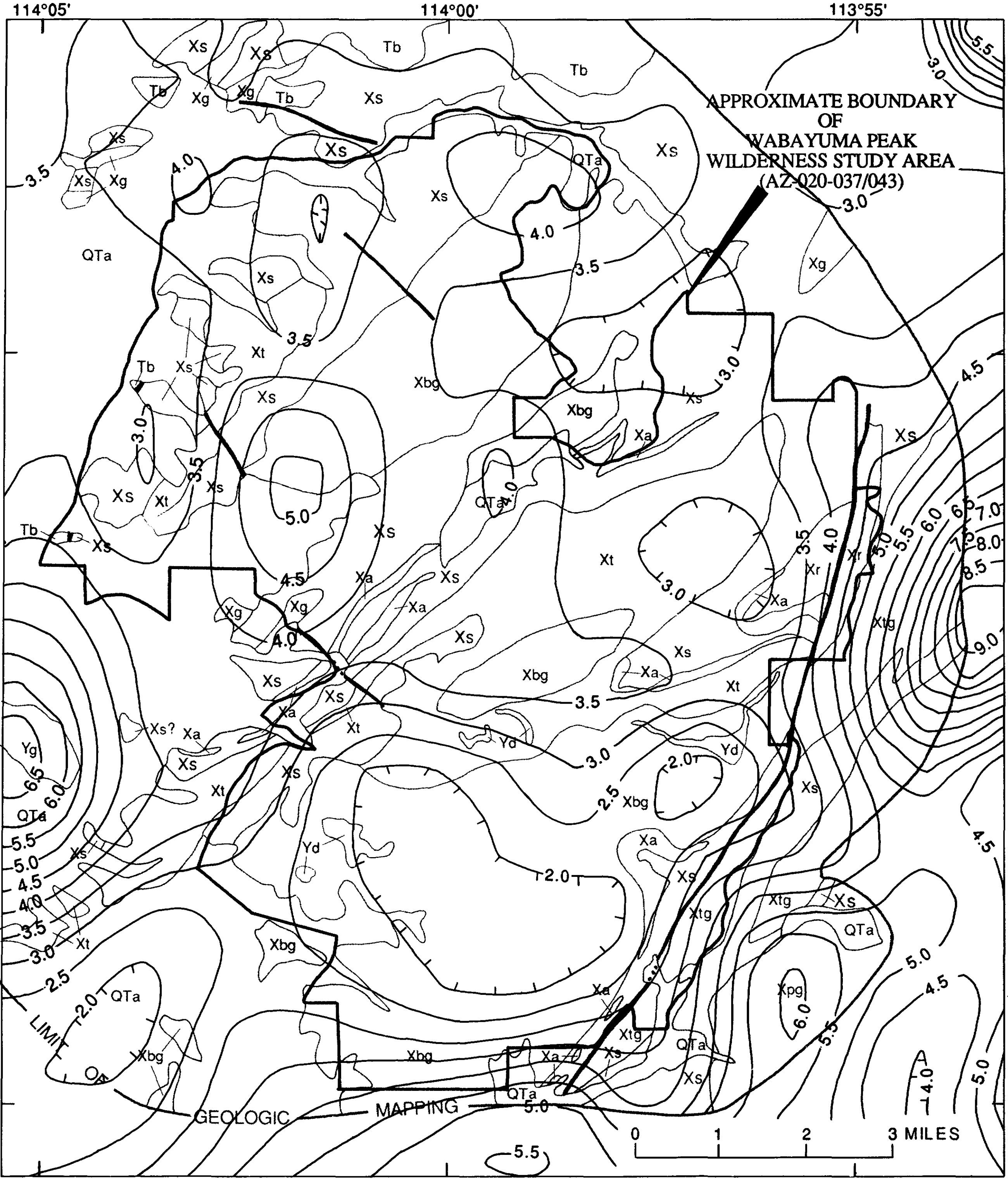


Figure 10. Gamma-ray uranium (eU) distribution in Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. Contour interval, 0.5 ppm eU. Hachured in direction of lower values. See figure 2 for explanation of map units.

and volcaniclastic rocks, as demonstrated by features such as pillow lavas, chert pods, and graded beds, (3) altered rocks in the immediate stratigraphic footwall, usually enriched in chlorite (cordierite-anthophyllite rocks in high-grade metamorphic terranes), (4) rocks enriched in albite, epidote, or silica widespread in host strata as evidence of

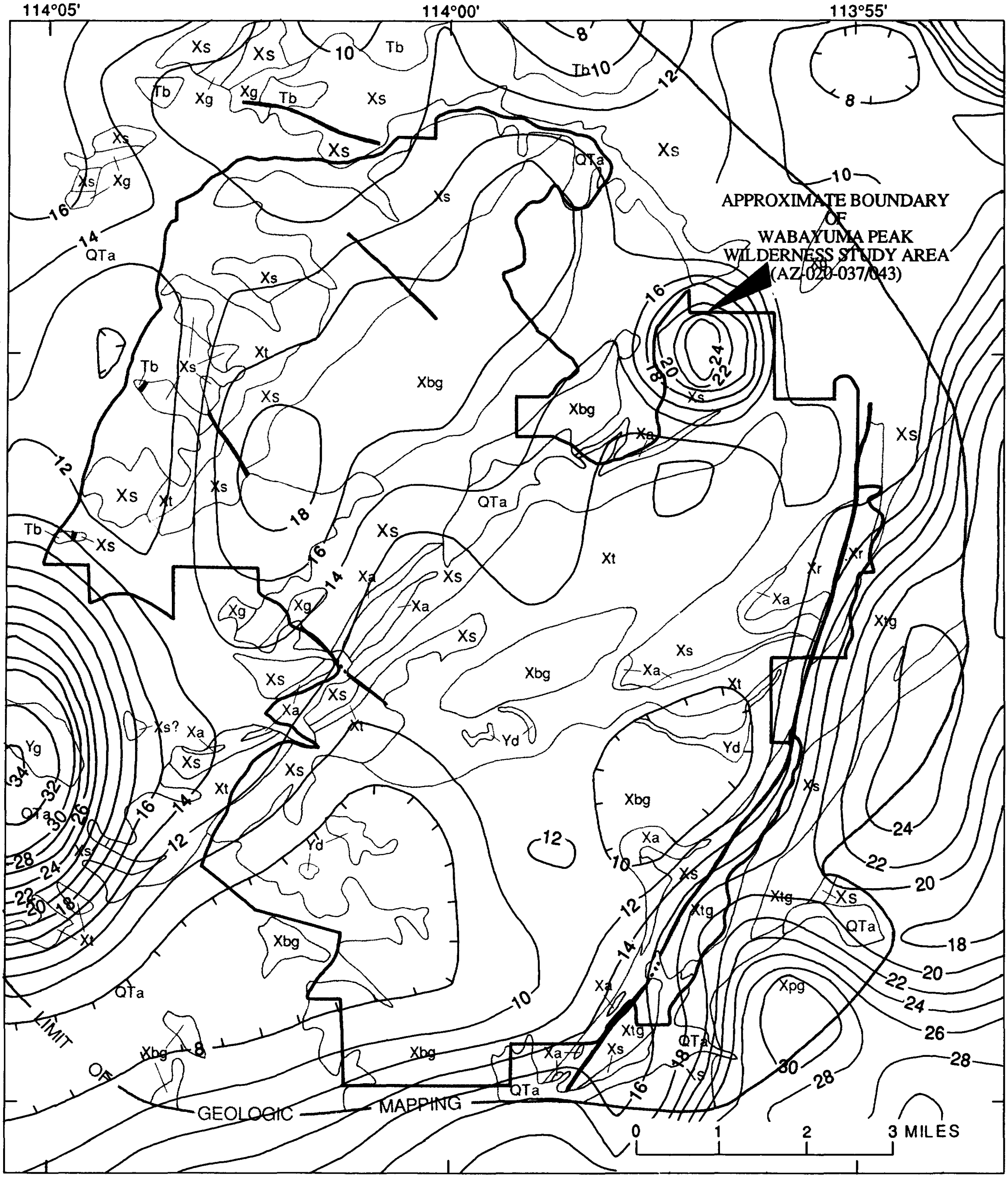


Figure 11. Gamma-ray thorium (eTh) distribution in Wabayuma Peak Wilderness Study Area, Mohave County, Arizona. Contour interval, 2 ppm eTh. Hachured in direction of lower values. See figure 2 for explanation of map units.

semiconformable alteration affecting large rock volumes, usually in the stratigraphic footwall, and (5) exhalative chemically precipitated rocks such as chert, carbonate, tourmalinite, taconite, and clays. All of these criteria, except perhaps (4) which was not investigated, are met at the Antler mine.

The gossanous cap of a massive sulfide body and associated altered rocks are geochemically anomalous in certain elements that can be detected in geochemical exploration. Gossans and especially associated altered areas can be detected by Landsat photospectrometry methods. Gamma-ray spectrometry can locate areas low in K that may indicate hydrothermal alteration related to massive sulfide deposition. These reconnaissance methods were useful in outlining areas where the massive sulfide criteria may apply and where detailed surface examination and mapping permit further application of the criteria. Massive sulfide bodies are unusually dense and have anomalous electromagnetic properties. Unfortunately, gravity and aeromagnetic surveys, at the scale applied in this study, cannot detect massive sulfide deposits that are typically the size of the Antler body or several times larger.

The wilderness study area has potential for massive sulfide deposits in several localities. Pillow structures in some amphibolite units imply a subaqueous basalt protolith. Rocks enriched in chlorite and chert lenses are present in these amphibolites and other stratified rocks. Small amounts of gossan were found in some altered areas. Semiconformable alteration has not been discovered in the study area but is commonly subtle and difficult to identify. Two photospectrometry low-K and two Landsat alteration anomalies coincide with sites of geologic criteria for massive sulfide deposits.

Four tracts within or partly within the wilderness study area (fig. 2, pl. 1) have high resource potential for massive sulfide deposits because they are associated with combinations of the following: rocks enriched in chlorite (including cordierite-anthophyllite), chemical sedimentary rocks, gossan, Landsat anomalies, photospectrometry low-K anomalies, and appropriate drainage-sediment anomalies. Two of these, near the Antler mine and in the bulge area, have high resource potential, certainty level C. Two others, east of Wabayuma Peak and between Rock and Willow Creeks, have high resource potential, certainty level B. Additionally, outside the wilderness study area, a tract near the Copper World mine has high resource potential, certainty level C (fig. 2, pl. 1).

Large areas underlain by stratified rocks in and near the study area have moderate resource potential for massive sulfide deposits because of the presence of pillow basalts and probable volcaniclastic rocks, Landsat anomalies, and drainage-sediment anomalies indicative of massive sulfide deposits. An elongate tract in the study area between the Antler mine area and upper Boriana Canyon, has moderate resource potential, certainty level C. Another elongate tract outside the study area in Boriana Canyon and a large tract in the central part of the study area have moderate resource potential, certainty level B.

Tungsten-Polymetallic Vein Deposits

The Boriana and Bull Canyon mines produced tungsten and copper. Analysis of ore samples from these mines indicates potential for Be, Au, Ag, As, Bi, Mo, Sn, and In. Tungsten, Bi, Mo, Sn, Th, Nb, La, and Y, the rare metals anomalous in the drainage-sediment survey, may be derived from tungsten-polymetallic veins. Byproduct metals in tungsten-polymetallic veins worldwide include Sc, Ta, Re, Zn, Pb, and Fe. Undiscovered tungsten-polymetallic vein deposits in the wilderness study area may contain combinations of the metals listed above.

Drainage-sediment anomalies for W and other rare metals throughout the study area are strongest where underlain by Early Proterozoic granite, particularly the two-mica granite and the northwestern mass of biotite granite. Tungsten-bearing veins in Boriana Canyon appear to be genetically related to two-mica granite; those in the northwestern part of the study area may be related to the biotite granite. An appropriate model is for tungsten veins related to granitoid rocks (Cox and Bagby, 1986). Quartz-wolframite or quartz-wolframite-scheelite veins associated with granite is the primary criterion for this model. Other criteria include rare-metal drainage-sediment anomalies and evolved granite compositions.

Application of these criteria in this study come mainly from geochemical methods, geologic mapping, and petrology. Gamma-ray spectrometry aided, particularly in defining Th distributions. Other methods were of limited value.

A large tract (fig. 2, pl. 1), underlain by two-mica granite and nearby stratified rocks in Boriana Canyon, has high resource potential, certainty level C, for tungsten-polymetallic vein deposits. Although the two-mica granite lies entirely east of the Boriana Canyon fault, an area west of the fault was included in this tract because of its strong drainage-sediment anomalies in W, Bi, Mo, and Th. This tract includes both the Boriana and Bull Canyon areas with known tungsten-bearing veins and the lower Boriana Canyon area with tungsten prospects.

A tract in the northwestern part of the study area that includes the Ophir and Black Rock Lentz tungsten areas has high resource potential, certainty level B, for tungsten-polymetallic vein deposits (fig. 2, pl. 1). Early Proterozoic quartz-scheelite veins, Tertiary fault veins, and a Tertiary andesite plug in this area contain anomalous W and other metals, and drainage sediments have pronounced rare-metal anomalies. Because the drainage-sediment anomalies coincide closely with the biotite granite and biotite schist, the tract includes virtually all the area underlain by these units.

Generally weak to moderate rare-metal drainage-sediment anomalies are present throughout most of the rest of the study area, which has moderate resource potential for tungsten-polymetallic vein deposits, certainty level B (fig. 2, pl. 1). This potential is based on these anomalies and the presence of widespread granite. Intensities of the anomalies are roughly similar in drainages underlain by stratified rocks and the trondhjemite, but they are somewhat higher in those underlain by the large biotite granite mass in the southern part of the study area. The rare-metal suite from the southern biotite granite contrasts somewhat with that from the biotite granite in the northwestern part of the study area and with that from the two-mica granite. The southern biotite granite has the strongest Th anomalies (accompanied by Pb), and it is the only one of these three granites to contain strong to moderate La anomalies (pl. 1).

The rare-metal anomalies throughout the study area might not all be derived from granite-related tungsten deposits. Placer, diagenetic, or syngenetic tungsten deposits such as volcanogenic deposits (Moench and Erickson, 1980; Fulp and Renshaw, 1985) possibly are present in the area. The veins in the Ophir and Black Rock Lentz areas are possibly a result of volcanogenic mineralization. We do not prefer this model because graywacke is the probable protolith for the schist and the tungsten has a simple quartz-vein setting. We found no evidence to support a placer or volcanogenic model, but these possible origins should be considered in subsequent studies.

Polymetallic Vein Deposits

Metals expected to be present in undiscovered polymetallic vein deposits are Au, Cu, and minor amounts of Ag, Zn, and Pb; W and Mo might also be recovered.

A tract largely outside the northern part of the study area has moderate resource potential, certainty level B, for polymetallic vein deposits (fig. 2, pl. 1). This tract is defined by mineralized quartz veins along the Tertiary fault north of Walnut Creek, by veins in the upper Walnut Creek area, and by drainage-sediment anomalies in this region. The veins in eastern parts of the tract were only briefly examined, but some may be related to Tertiary faults. We tentatively suggest that a group of veins throughout this tract may be related to west-northwest Tertiary faulting, which may also have controlled the course of Walnut Creek.

There may be a diversity of metals in these deposits as suggested from vein analyses and from the drainage-sediment geochemistry. Rare-metal contents are likely due to overprint in an area mineralized in Early Proterozoic time.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

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

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

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

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

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

LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.

B Available information only suggests the level of mineral resource potential.

C Available information gives a good indication of the level of mineral resource potential.

D Available information clearly defines the level of mineral resource potential.

LEVEL OF RESOURCE POTENTIAL →

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

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

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

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RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART

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

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

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