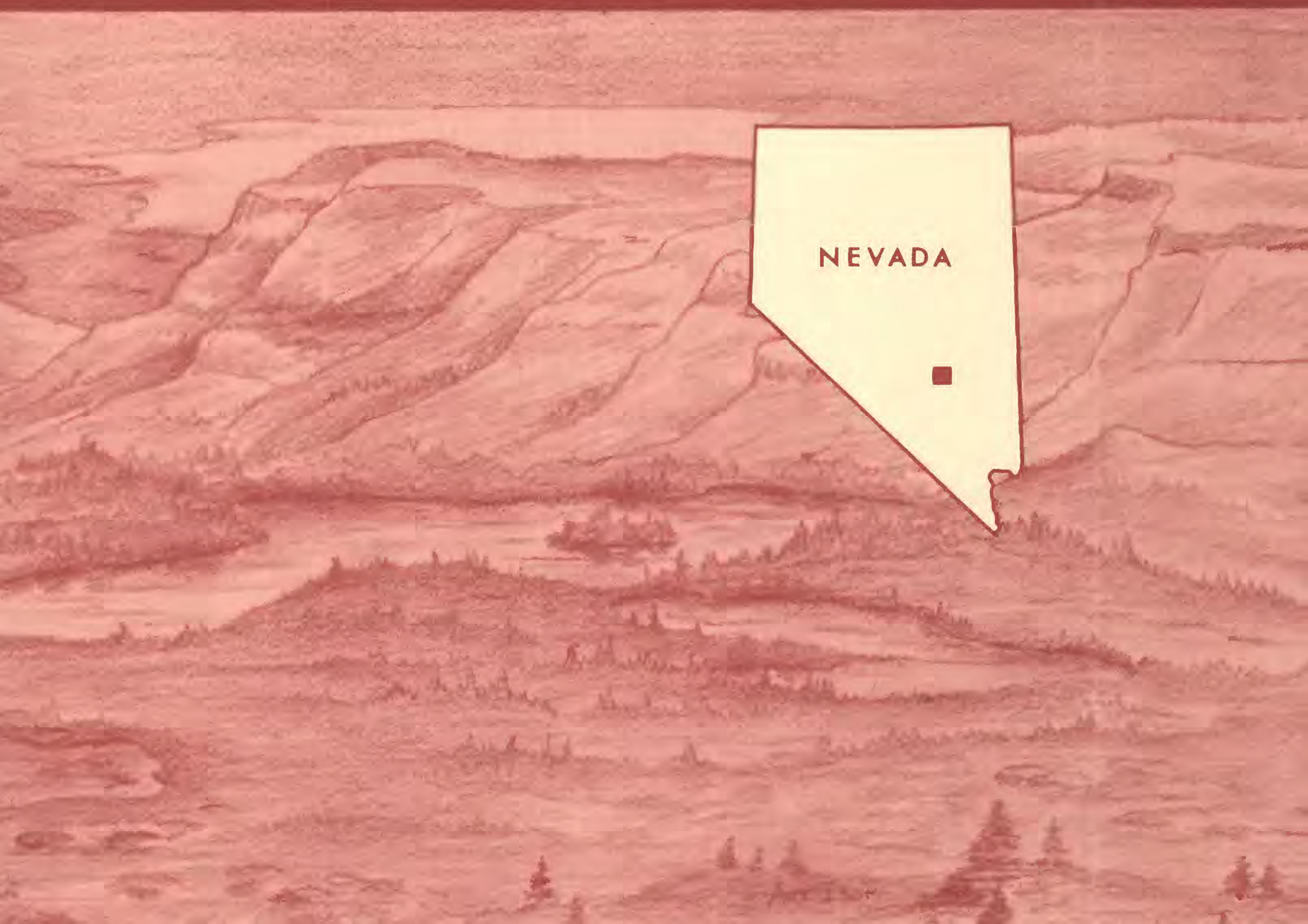
Mineral Resources, Geology, and Geophysics of the Worthington Mountains Wilderness Study Area, Lincoln County, Nevada

U.S. GEOLOGICAL SURVEY BULLETIN 1728–A



DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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 unlikely. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

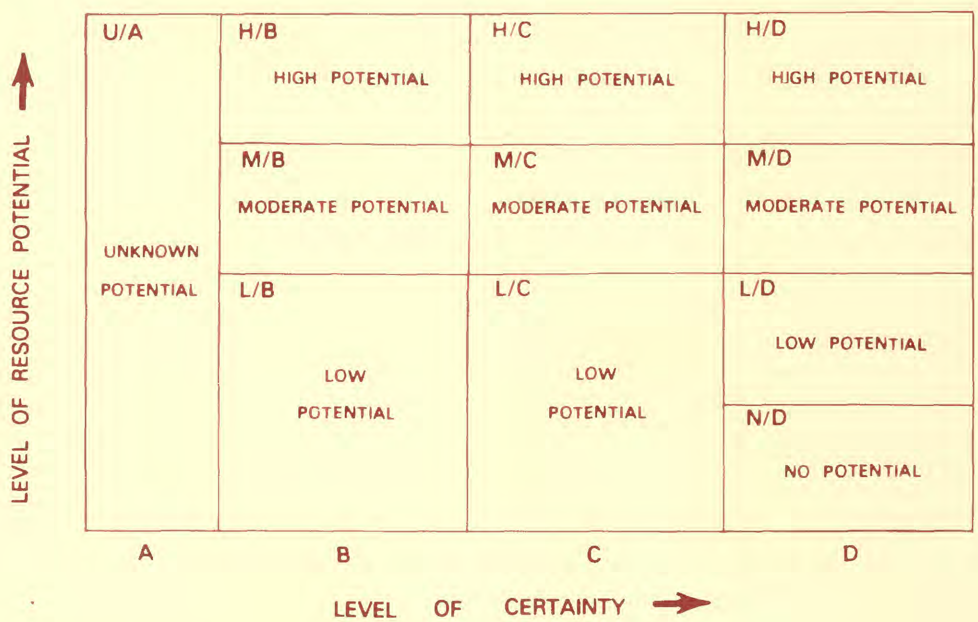
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

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

Levels of Certainty



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

Abstracted with minor modifications from:

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

Taylor, R. B., Stoneman, R. J., and Marsh, S. P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40–42.

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Chapter A

Mineral Resources, Geology, and Geophysics of the Worthington Mountains Wilderness Study Area, Lincoln County, Nevada

By EDWARD A. DU BRAY and H. R. BLANK, JR.
U.S. Geological Survey

ROBERT H. WOOD II
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1728

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
EAST-CENTRAL NEVADA AND PART OF ADJACENT BEAVER COUNTY, UTAH

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, *Secretary*

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

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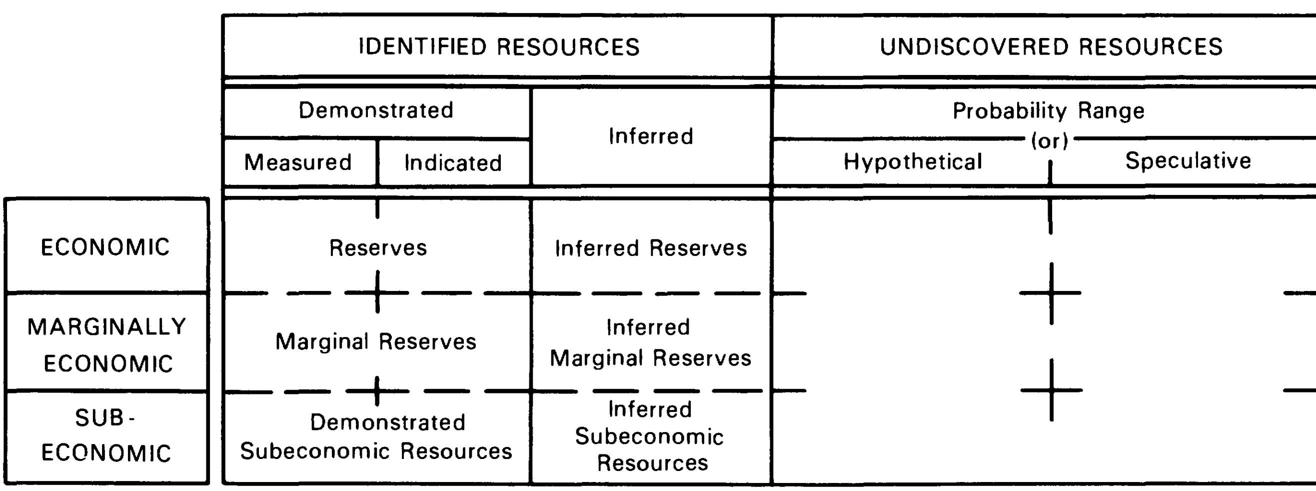
STUDIES RELATED TO WILDERNESS

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 a part of the Worthington Mountains (NV-040-242) Wilderness Study Area, Lincoln County, Nevada.

RESOURCE / RESERVE CLASSIFICATION



Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from 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.

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Mineral Resources, Geology, and Geophysics of the Worthington Mountains Wilderness Study Area, Lincoln County, Nevada

By Edward A. du Bray *and* H. R. Blank, Jr.,
U.S. Geological Survey, *and*
Robert H. Wood II
U.S. Bureau of Mines

SUMMARY

The U.S. Geological Survey and the U.S. Bureau of Mines studied 26,587 acres of the Worthington Mountains Wilderness Study Area (NV–040–242) in Lincoln County, Nevada. The study of this acreage was requested by the U.S. Bureau of Land Management. In this report, the studied area is called "wilderness study area" or just "study area." Field studies of the area were conducted during fall 1983 and spring 1984 by Bureau of Mines personnel and during fall 1984 and spring 1985 by geologists and geophysicists of the Geological Survey. Metallic-mineral (Cu, Pb, Zn, Au, Ag, W) resource potential within the study area is moderate, with level-B certainty, in the northernmost part, and it is low, with level-C certainty, in the remainder of the area (fig. 1). Identified resources of commodities with industrial applications occur in the area. Energy resources are unknown; accordingly, their resource potential is considered low, with level-B certainty.

The Worthington Mountains Wilderness Study Area is about 120 mi north-northwest of Las Vegas, Nevada (fig. 1); Caliente, about 60 mi east of the area, is the nearest population center (fig. 2). Graded dirt roads lead northward from Nevada State Route 25 to the study area. The Worthington Mountains is a 15-by-3-mi fault-block range flanked by Sand Spring and Garden Valleys on the west and east sides, respectively. Elevations within the study area range between 5,400 ft and 8,850 ft.

The Worthington Mountains are underlain by carbonate sedimentary rocks of Ordovician through Pennsylvanian age (see geologic time chart on last page of this report). A small amount of monzogranite crops out near the northern part of the map area, and Tertiary volcanic rocks crop out in the northwestern and southeastern corners of the map area. The most notable geologic structure in the area is the Freiberg thrust fault, along which are juxtaposed an allochthonous block of Ordovician Pogonip Group limestone and Ordovician Eureka Quartzite, and younger, upper Paleozoic dolomitic rocks.

Mining in the Worthington Mountains Wilderness Study Area has been restricted to very limited production of silver-lead-zinc-copper ore, which contains minor gold, from limestone replacement deposits in the Smelter shaft workings. Between 1919 and 1948, at least 12,600 lbs (pounds) of lead, 7,600 lbs of zinc, 2,359 oz (ounces) of silver, and 274 oz of gold were produced from the Freiberg mining district within and just northeast of the wilderness study area. Between the late 1970's and early 1980's the Smelter shaft dump was processed for silver (Tom Beam, oral commun., 1984). Identified metallic mineral resources in the study area are similarly restricted to the Smelter shaft workings. Additional mining has occurred in the Freiberg mining district (Kathleen shaft, Roadside and Mountain View properties, and Zinc shaft), where a small quantity of silver-lead-zinc-copper ore was mined from additional limestone replacement deposits; there is no recorded production from scheelite-bearing tactite that also crops out in this area.

Limestone metamorphosed by two monzogranite stocks is unmineralized to very weakly mineralized at the ground surface in the northern part of the study area. The Smelter shaft has identified resources of copper, lead, zinc, silver, and minor gold. An aeromagnetic survey (pl. 1) suggests that these stocks project into the study area at depth, beneath Ordovician Pogonip limestone. Thus, there is moderate mineral resource potential, with level-B certainty, for undiscovered resources of copper, lead, zinc, and silver in replacement deposits and tungsten in scheelite-bearing tactite at depth, in contact-metamorphosed limestone adjoining the granitoid stocks; the mineral resource potential of the rest of the area is low,

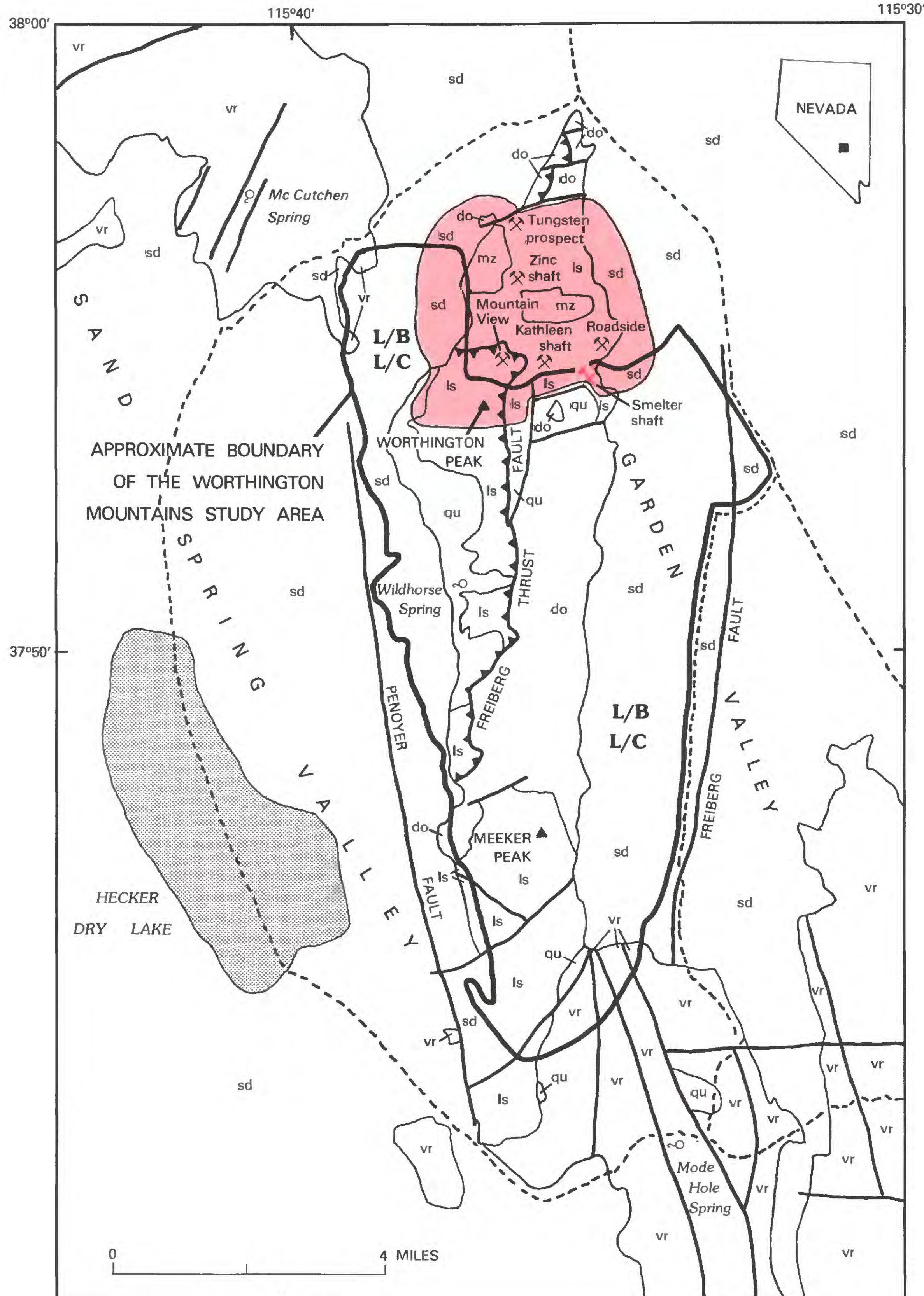

Figure 1 (above and facing page). Map showing mineral resource potential and generalized geology of the Worthington Mountains Wilderness Study Area, Lincoln County, Nevada.

EXPLANATION

[The entire study area contains identified resources of carbonate rock, quartzite, and sand and gravel, not shown on this map]

	Mine (Smelter shaft) having identified resources of copper, lead, zinc, silver, and minor gold
	Geologic terrane having moderate potential with level-B certainty for base (Cu-Pb-Zn)- and precious (Au-Ag)- metal deposits and (or) tungsten in scheelite-bearing tactite deposits
L/B	Geologic terrane having low potential for energy resources, with certainty level B—Applies to entire study area
L/C	Geologic terrane having low potential for all metallic mineral commodities, with certainty level C
vr	Volcanic rocks
mz	Monzogranite
qu	Quartzite
do	Dolomite
ls	Limestone
sd	Surficial deposits
	Contact
	Normal fault
	Thrust fault
	Mine or prospect
	Unpaved road

with level-C certainty, for metallic elements. Energy-mineral, including petroleum, coal, and uranium, and geothermal-energy resources are unknown in the area, and the geologic environment is not favorable for the occurrence of energy resources; the mineral resource potential is classified as low, with level-B certainty. The study area contains identified resources of sand and gravel, quartzite, and carbonate rock.

INTRODUCTION

The U.S. Geological Survey and U.S. Bureau of Mines studied 26,587 acres of the Worthington Mountains Wilderness Study Area (NV-040-242) in Lincoln County, Nevada (fig. 1) as requested by the U.S. Bureau of Land Management. The area is about 120 mi north-northwest of Las Vegas and about 60 mi from Caliente and is accessible by graded dirt roads that lead north from Nevada Route 25. Warm Springs and Alamo, about 40 mi northwest and southeast, respectively, are much smaller communities (fig. 2). The Worthington Mountains, like other ranges of the Basin and Range physiographic province, rise steeply from playa-lake valleys covered by sage and other desert shrubs. The range itself is sparsely forested with pinyon pine and juniper trees. Elevations within the study area range from about 5,400 ft to almost 8,900 ft; prominent high points along the crest of the Worthington Mountains are Worthington Peak (8,850 ft) at the northern end of the range and Meeker Peak (8,400+ ft) at the southern end. Travel within the area is via a few rough jeep trails and on foot.

Personnel of the U.S. Bureau of Mines made a literature search in which mining, mineral-lease, and mining-claim information were compiled. Field work by Bureau of Mines personnel entailed examination of prospects and mines in and around the study area. Accessible mine workings were mapped, and mineralized areas and mine dumps were sampled. Heavy-mineral concentrates were prepared from stream-sediment samples collected in drainages near the boundaries of the wilderness study area. Samples of selected beds of limestone and quartzite were analyzed to determine their purity. Detailed descriptions of analytical procedures and results are in Wood (1985).

Existing 1:250,000-scale geologic mapping of Lincoln County (Tschanz and Pampeyan, 1970) was examined, and a photogeologic study of the area was conducted prior to field work by U.S. Geological Survey personnel. Geologic mapping techniques appropriate to preparation of a 1:50,000-scale geologic map (pl. 1) were employed. Outcrops were examined for signs of mineralized rock. Samples of all rock units were collected for petrographic examination.

The wilderness study area was included in regional aeromagnetic and gravity surveys of the Caliente 1°×2° quadrangle (Healey and others, 1981; Saltus and Snyder, in press). In 1985, a drape-flown aeromagnetic survey, with a nominal ground clearance of 1,000 ft, was made by fixed-wing aircraft along east-west flight lines 0.5 mi apart, using a nuclear precession magnetometer with 1-nanotesla sensitivity. After correction for diurnal effects and tie-line discrepancies, the International Geomagnetic Reference Field was removed, and the residual data were contoured. The resulting aeromagnetic map (pl. 1) shows total-intensity isopleths at intervals of 20 nanoteslas.

Gravity data for the study area were obtained from a preliminary gravity map of the Caliente 1°×2° quadrangle (Healey and others, 1981) and from an updated gravity map of the same area (R. W. Saltus, U.S. Geological Survey, unpub. data, 1985), which includes data made available by the U.S. Defense Mapping Agency. Forty additional stations were metered during May 1985 (H. R. Blank, Jr., unpub. data). Gravity data were reduced by standard procedures using a Bouguer reduction density of 2.67 g/cm^3 (grams per cubic centimeter), and terrain corrections were applied between radii of 1.6 mi and 103 mi about each station.

Aerial gamma-ray spectroscopy is a radiometric technique that provides an estimate of near-surface (0–20 in. depth) concentrations of uranium, thorium, and potassium and is commonly used in exploration for

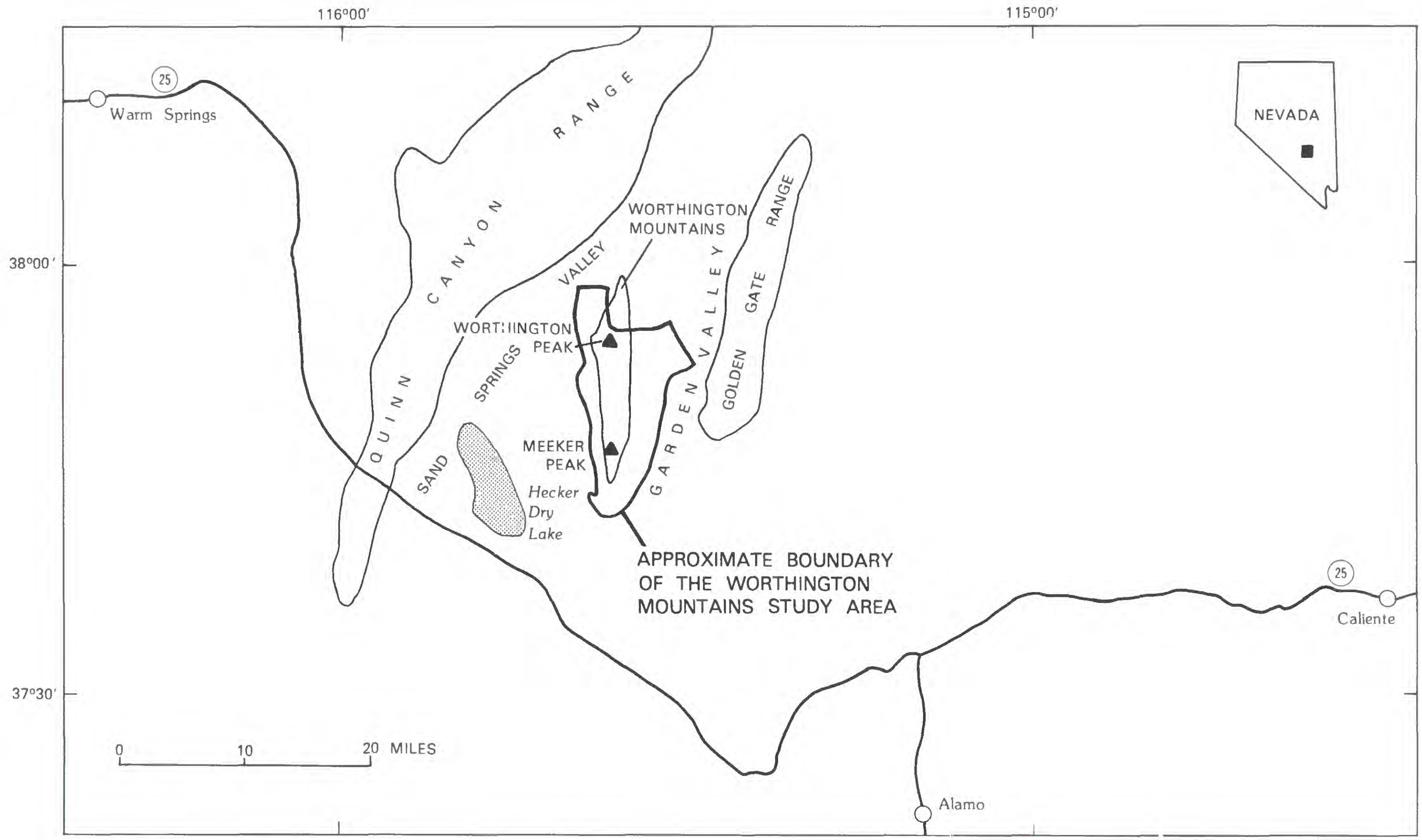

Figure 2. Index map showing the location of the Worthington Mountains Wilderness Study Area, southern Nevada.

uranium deposits. Anomalous concentrations of the elements require that an element's concentration, as well as its ratios to the other two elements, be high relative to threshold values established for the area studied. Individual measurements made in typical aerial surveys reflect the concentrations of these elements in an area of about 0.02 mi^2 (square mile). Radiometric data for the Worthington Mountains Wilderness Study Area were extracted from a 1:1,000,000-scale map of Nevada (Duval, 1983) produced from data obtained between 1975 and 1983 by contractors working for the U.S. Department of Energy.

The mineral resource potential of the Worthington Mountains Wilderness Study Area described here is based on data from many sources. Among these are the study of geology and mineral deposits of Lincoln County, Nevada (Tschanz and Pampeyan, 1970), a reconnaissance study of mineral resources in the study area (Great Basin Geology-Energy-Minerals Joint Venture, 1983), geophysical studies of the Caliente 1°×2° quadrangle (Healey and others, 1981; Snyder, 1983), a study of identified mineral resources by the Bureau of Mines (Wood, 1985), a study of geology in the Worthington Mountains (du Bray, this report), an evaluation of petroleum potential (Sandberg, 1983), an interpretation of aeromagnetic and gravity data (Blank, this report), and an interpretation of radiometric data (J. S. Duval, U.S. Geological Survey, written commun., 1985).

Acknowledgments.—The study has benefited from the cooperation and assistance of Wayne Howle and Bill Robinson in the Ely office of the Bureau of Land Management. Tom Beam, owner of the Smelter shaft claim, provided mining and geologic information about the Freiberg district and allowed access to patented mining claims.

APPRAISAL OF IDENTIFIED RESOURCES

By Robert H. Wood II, U.S. Bureau of Mines

All mining activity in the Worthington Mountains Wilderness Study Area has occurred in the Freiberg mining district, within and just north of the study area, except for a small prospect pit at the southern end of the Worthington Mountains, about 0.5 mi west of Stink Bug Spring (pl. 1). Total recorded production from mines in the Freiberg district is $18,000 (Tschanz and Pampeyan, 1970). Between 1919 and 1948 at least 274 oz of gold, 2,359 oz of silver, 12,600 lbs of lead, and 7,600 lbs of zinc were produced (Tschanz and Pampeyan, 1970), including unspecified quantities of these metals from the Smelter shaft. Between the late 1970's and early 1980's the Smelter shaft dump was processed for silver (Tom Beam, owner, oral commun., 1984). The remains of a heap-leaching operation, probably for recovery of gold and silver, set up in the late 1970's or early 1980's, are about 2 mi north of the study area. Cored holes, probably drilled between 1980 and 1985, were identified near the Smelter shaft.

The only mineralized rock in the wilderness study area containing identified metallic mineral resources (see the resource/reserve classification chart on page IV of this report) occurs at the Smelter shaft (fig. 1). The Smelter shaft includes more than 800 ft of workings in the oxidized part of a fracture-controlled limestone-breccia replacement deposit. This mineralized zone, in Ordovician Pogonip Group limestone, strikes N. 15° W. and dips 30–50° NE. The most intensely mineralized rock is in the hanging wall of fractures where aurichalcite, calcite, galena, limonite, and malachite were identified.

Thirty-five rock-chip samples (aggregate chip length of 135.5 ft), most of which were collected across the most intensely mineralized areas in the hanging walls of fractures, contained as much as 3.3 percent copper, 10.1 percent lead, 22.1 percent zinc, 13.3 oz/ton (ounce per short ton) silver, 0.02 oz/ton gold, and anomalous concentrations of arsenic, antimony, barium, cadmium, and tin (Wood, 1985, table 1). However, abundances of copper, lead, zinc, silver, and gold (average abundances 0.99 percent, 1.95 percent, 7.4 percent, 2.9 oz/ton, and trace, respectively) were highly variable among the mineralized samples.

Wood (1985) calculated a total resource of 825,000 short tons, including an identified resource of about 550,000 short tons and an inferred resource of about 275,000 short tons. However, no valid determination of ore grade in the identified tonnage can be made because sampling was strongly biased in favor of the most intensely mineralized rock. Additional study, including systematic channel sampling and drilling of a well-defined ore-body volume, is required to realistically evaluate the value of mineralized rock in the Smelter shaft.

Current markets for and recovery rates of the metals in this complex oxide ore require evaluation. The potential for the occurrence at depth of a hypogene sulfide zone and (or) a precious-metal phase in this epithermal system must also be considered. Capitalization costs are unknown but could be adversely affected by the lack of surface water, power, and adequate roads, and by the need for a concentration facility in this remote location.

Several other prospects containing limestone replacement deposits were studied, including the Kathleen shaft, Roadside property, Zinc shaft, and the Mountain View properties, all within 0.5 mi northeast of the study area. The lack of tonnage and grade data for mineralized fractures precludes a definitive evaluation, but the small size and discontinuous nature of these deposits suggest that no mineral resources are associated with these areas. Mineralized rock samples from these areas contained anomalously high contents of copper, lead, zinc, and silver (Wood, 1985, table 3) but are not mineralized to the extent that the rock constitutes a resource. Similarly, no resource is associated with the small scheelite-bearing tactite prospect 0.5 mi northeast of the study area; tonnage and grade data are lacking.

Large quantities of carbonate rock, quartzite, and sand and gravel in the study area are identified resources with potential industrial applications. Most of the carbonate rock is suitable for use as road metal, and some beds of limestone are sufficiently pure to be considered for general chemical usage. The Eureka Quartzite is very pure and thus has high potential value for industrial usage. Sand and gravel for use as road metal or fill or as aggregate in concrete occur along the flanks and in drainages of the Worthington Mountains. However, all of these commodities have low unit value and require local markets to be economically viable; demand for these resources from the wilderness study area is unlikely.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Edward A. du Bray and H. R. Blank, Jr., U.S. Geological Survey

Geology

The Worthington Mountains are underlain by a homoclinal section of sedimentary rocks, of which the oldest are at the northern end of the range and the youngest are at the southern end. The Ordovician Eureka Quartzite occurs stratigraphically above Ordovician Pogonip Group limestone, the oldest rock exposed in the study area. A thick section of Ordovician to Devonian dolomite overlies the Eureka Quartzite and is overlain by Devonian, Mississippian, and Pennsylvanian limestone. Two small monzogranite stocks of undetermined age, probably Cretaceous or Tertiary, intrude carbonate rocks at the northern end of the range. The stocks are probably apophyses of a larger pluton at shallow depth. Two Tertiary welded ash-flow tuffs, of predominately rhyolitic composition, unconformably onlap the sedimentary section at the northern and southern ends of the range. These volcanic rocks were probably derived from several Tertiary volcanic centers. The nearby Quinn Canyon Range is an hypothesized volcanic edifice (Ekren and others, 1977) and is the probable source for the younger ash-flow tuff. The source for the older welded ash-flow tuff is unknown. Both tuffs are part of an areally extensive ignimbrite field that occurs throughout much of southern Nevada and southwestern Utah.

The structure in the area is relatively simple. The principal structure is the north-striking, west-dipping Freiberg thrust fault, which placed Ordovician Pogonip Group and Eureka Quartzite over Ordovician Pogonip Group in the northern part of the range and over younger Devonian dolomite formations in the southern part of the range. The thrust fault crosscuts bedding, accounting for the variable stratigraphic juxtaposition across the fault. A small, allochthonous block of Ordovician Ely Springs Dolomite and Eureka Quartzite was thrust over Devonian Sevy Dolomite at the extreme northern end of the range along another thrust fault, which is possibly related to the Freiberg thrust. The range is bounded by high-angle faults on the east (Freiberg fault) and west (Penoyer fault) (Tschanz and Pampeyan, 1970). The position of the Penoyer fault (pl. 1) does not agree with the location of the fault indicated by the aeromagnetic survey (see the section on "Geophysical Investigations"). This difference does not affect our assessment of the mineral resource potential in the study area. Displacement along many high-angle faults has caused small-scale stratigraphic juxtapositions within the sedimentary and volcanic rocks.

Geochemical Investigations

Ninety-two samples of variously mineralized rock were collected from mines and prospects in the Freiberg mining district. Semiquantitative spectrographic, fire-assay, and inductively coupled plasma analyses of these samples indicate that the widely distributed replacement deposits in this area contain moderately to highly anomalous concentrations of copper, lead, zinc, silver, gold, cadmium, antimony, and tin. The distribution and magnitude of these anomalous values are highly erratic. Similarly analyzed, unmineralized samples collected within the study area lack anomalous metal values.

Heavy-mineral concentrates were prepared, using an 18-in. gold pan and standard gold-panning techniques, from 21 samples of stream sediment collected in the major drainages of the study area. Semiquantitative spectrographic, fire-assay, and inductively coupled plasma analyses of these samples (Wood, 1985) show very few anomalous values and imply that undiscovered mineralized rock is not present in the study area. In general, elemental abundances in these samples approach the average abundances of the elements in carbonate rocks (Turekian and Wedepohl, 1961). However, boron, lithium, molybdenum, and niobium values in seven of the samples are high relative to the average carbonate rock, and they show correlated covariation. The lack of spatial relationship and correlation with bedrock lithology precludes definitive interpretation of this data, and their anomalous character may not be meaningful. The anomalous values in these samples may be a function of metal adsorption by oxide minerals during secondary processes. Alternatively, the anomalous values may have resulted from concentration of metals by insoluble chert grains prior to incorporation in the carbonate sediments.

Geophysical Investigations

Aeromagnetic Survey

The magnetic character of the northern half of the wilderness study area is quite different from that of the southern half. The character of the northern half is dominated by a broad positive anomaly which culminates in two local maxima, whereas the character of the southern half is relatively subdued. This contrast results from the relatively shallow magnetic basement underneath the Freiberg mining district. Two stocks of monzogranite coincide with the northern and eastern shoulders, respectively, of the eastern of the local highs (anomaly A, pl. 1), suggesting that moderately polarized monzogranite is the source of this anomaly. By extrapolation, monzogranite may also be the source of anomaly B, a similar feature whose apex is only 2 mi to the west. The southern margin of the concealed source of anomaly B lies somewhat to the north of the apex, in the region of the steep gradient, and is at least partly within the study area. Although the anomaly is incompletely delineated on its northern side and is distorted by variations in flight altitude, the gradient allows a rough estimate of the depth to the source. Estimates based on the horizontal extent of the steepest gradient indicate that the source is 1,200±200 ft beneath the detector or 200 ft below the ground surface, because the mean ground clearance here was 1,000 ft. Ash-flow tuff (unit Tto, pl. 1) crops out in this vicinity; a thick basal vitrophyre could account for the anomaly. If monzogranite (or an intrusion of similar magnetic susceptibility) is the source, then anomaly B may indicate a western extension of the Freiberg mining district.

The two local magnetic highs may indicate structurally elevated domains, or cupolas, on a larger parent body that produces the main long-wavelength component of the regional positive anomaly. The upper surface of this postulated deeper source could extend southward from the mineralized area and terminate near a subtle step in the north-south regional gradient (anomaly C). The step may be the expression of one of the many east- to northeast-trending faults that traverse the range. Alternatively, the broad anomaly could be due to relief on a Proterozoic metamorphic basement complex, although this explanation seems less tenable.

Other features of the aeromagnetic map are less relevant to assessment of mineral resource potential. The very intense anomaly in the northwestern corner of the area (anomaly D) is associated with volcanic rocks in the foothills of the Quinn Canyon Range. A complex short-wavelength anomaly at the southern tip of the study area (anomaly E) is associated with exposed volcanic rocks. The north-northeast-trending belt of relatively steep gradient east of the wilderness study area (aeromagnetic lineament, pl. 1) (anomaly F) reflects a concealed structural lineament. The only other strong field disturbance is a long-wavelength positive anomaly between the western edge of the study area and Hecker Dry Lake (anomaly G); here, too, the source is concealed by alluvium.

Less conspicuous magnetic features include weak disturbances of the field by the Freiberg thrust (pl. 1), possible perturbations caused by diabase dikes (although in general these are too narrow and short to be detected), and weak lineaments that can be correlated with previously mapped range-front faults.

The ground clearance must be considered in evaluation of the aeromagnetic survey, especially in interpretation of anomalies of shallow origin. Ground clearance was as little as 500 ft over the crest of the Worthington Mountains and greater than 2,500 ft over adjacent valleys (H. R. Blank, Jr., unpub. data).

Regional Gravity Survey

A pronounced north-trending gravity high delineates the Worthington Mountains structural block; lesser highs extend from the range proper into the volcanic terranes to the southeast and northwest (fig. 3). The Worthington Mountains high is bordered on the west by a steep gradient leading to a low in the western part of Sand Spring Valley, and on the northeast by a steeper gradient leading to a low centered on the dry lake in Garden Valley. The nearly circular low in the southeastern corner of the map area (fig. 3) occurs over Tertiary lake beds in upper Cold Springs Wash. Total anomaly relief across the range exceeds 46 mGal (milligals).

An east-west gravity profile across the northern part of the Worthington Mountains was modeled by Snyder (1983) in a general interpretation of the gravity-anomaly map of the Caliente $1° \times 2°$ quadrangle. A reasonable fit with observed anomaly values was obtained using a density contrast of 0.4 g/cm^3 between alluvial fill of the flanking valleys and pre-Cretaceous sedimentary rocks, which were assumed to constitute both the range and its deep core. More than 11,500 ft of relief in the pre-Cenozoic surface between Sand Spring Valley and the crest of the Worthington Mountains were indicated.

The gradient bounding the Worthington Mountains high on the west may represent the northern extension of a range-front normal fault (the Penoyer fault) mapped along the southeastern margin of Sand Spring Valley (Tschanz and Pampeyan, 1970). The median of the gradient belt should nearly coincide with the trace of the causative structure if it is a high-angle fault and should be offset somewhat to the west if the structure is west dipping. Tschanz and Pampeyan (1970) suggested a northern extension of the Penoyer fault whose trace closely follows the western boundary of the study area;

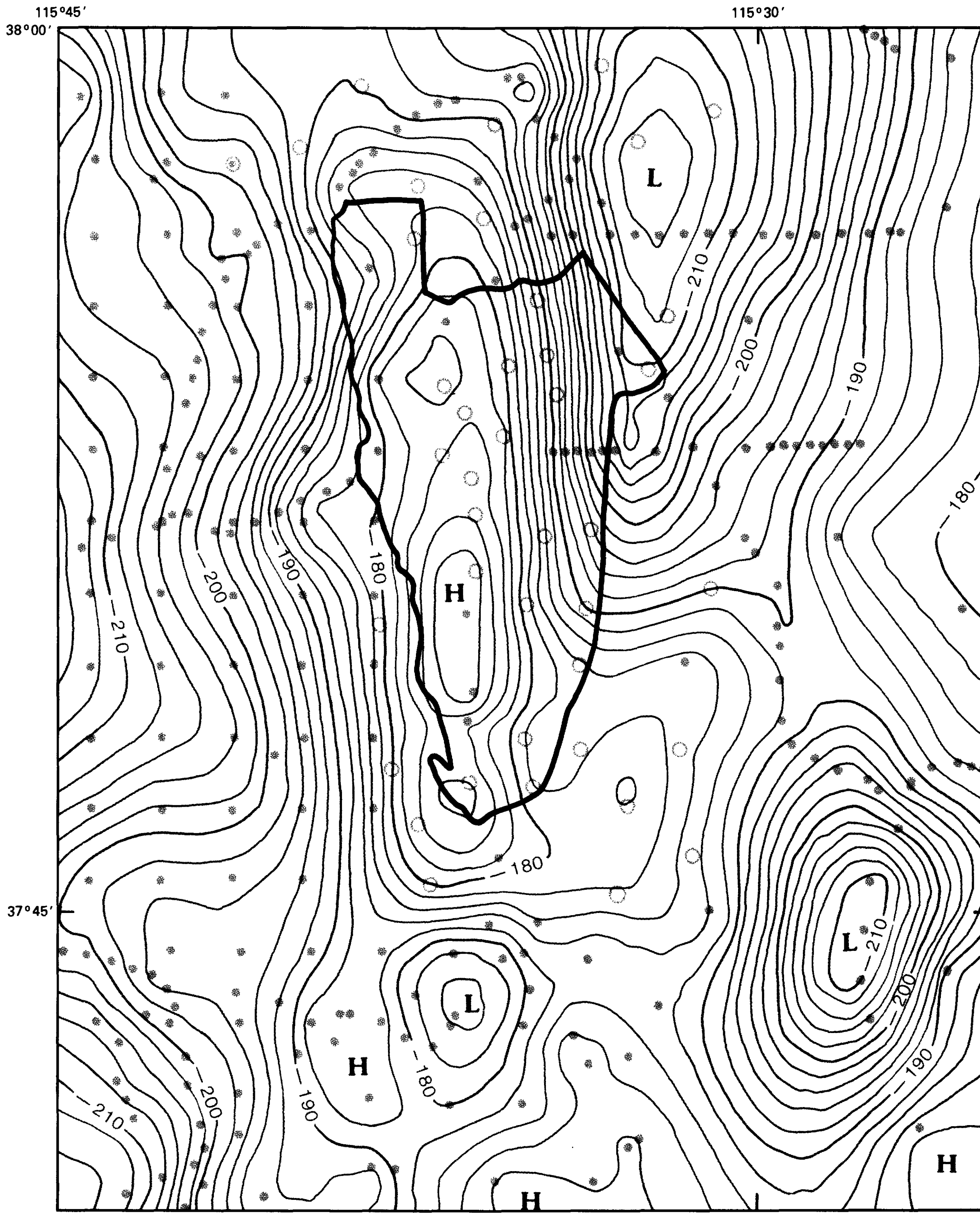

Figure 3 (above and facing page). Bouguer gravity anomaly map of the Worthington Mountains and vicinity, Nevada (Healey and others, 1981). Reduction density 2.67 grams/cubic centimeter; terrain corrections applied between 2.6 and 166 km from gravity station.

EXPLANATION

- - - 180 **Isopleths of Bouguer gravity anomaly—** Isopleth interval 2 mGal

• **Gravity station —**Defence Mapping Agency

○ **Gravity station —** This study

H **Anomaly high**

L **Anomaly low**

▬▬ **Approximate boundary of Worthington Mountains study area**

along the northwestern flank of the range, west of aeromagnetic anomaly B (pl. 1), the mapped trace and the gravity gradient (as well as the aeromagnetic pattern) closely agree, suggesting a high-angle, steeply west-dipping structure. Further south, however, the gradient belt parallels the fault's mapped trace but is about 2 mi west of it. Thus, either the actual position of the Penoyer fault extension is west of the position indicated by Tschanz and Pampeyan, or the Penoyer is not the fault represented by the gravity gradient, and it is not the principal structural discontinuity at the western margin of the Worthington Mountains block except north of anomaly B. Even if the Penoyer fault is listric (concave upward) with a shallow westerly dip along the southern flank of the range, it is unlikely to account for the measured gravity gradient.

Between the latitudes of aeromagnetic anomalies B and G (pl. 1), contours of the western steep gravity gradient trend north-northeast and closely approach the range front. This flexing of the gradient could reflect offset of the concealed causative structure along a north-northeast-trending fault, although apparently no such fault projects into the range (pl. 1).

Regardless of where range-front and transverse structures are best located from the combined geophysical data, it is clear that rocks of the Worthington Mountains block are not appreciably downthrown to the west within the study area, and that alluvium concealing the source of aeromagnetic anomaly B is essentially pediment veneer.

On the northeastern flank of the Worthington Mountains, the steepness of the gravity gradient implies the presence of a range-front fault about where inferred by Tschanz and Pampeyan (1970). This fault strikes nearly north, passing about 2 mi east of the apex of aeromagnetic-anomaly A (pl. 1) and well east of its zone of steepest gradient. The fault probably forms the eastern margin of the source of the broad anomaly on which aeromagnetic-anomalies A and B seem to be superimposed. Thus, in this area the principal structural discontinuity between the Worthington Mountains block and its adjacent depression (Garden Valley) lies well within the wilderness study area. South of about lat 37°52′30″ N. the gravity contours turn sharply east, reflecting the southern limit of thick fill in Garden Valley; the range-front fault (Freiburg fault) of Tschanz and Pampeyan (1970) has a relatively weak gravity expression, and the Bouguer anomaly levels drop only about 10 mGals from the crest of the range to the valley floor. Aeromagnetic anomaly F coincides with a slight rise in anomaly level to the east, over exposed volcanic rocks, and examination of the regional aeromagnetic map (Saltus and Snyder, in press) shows that this aeromagnetic feature continues to the north-northeast and marks the western limit of short-wavelength magnetic anomalies associated with the volcanic rocks on the western side of the Golden Gate Range. It also marks the western limit of steep gravity gradient between the Garden Valley low and the Golden Gate high. Therefore, the gravity gradient is interpreted as a west-dipping surface of Paleozoic rocks on which volcanic rocks of Tertiary age are resting. The surface could be either an unconformity or a low-angle normal fault.

Aerial Radiometric Survey

The Worthington Mountains Wilderness Study Area has low overall radioactivity. The aerial radiometric survey indicated values of 0–2.5 ppm (parts per million) equivalent uranium, 0–10 ppm equivalent thorium, and 0–2.0 percent potassium (J. S. Duval, U.S. Geological Survey, written commun., 1985). No anomalies are within the area; however, a uranium anomaly is northwest of the area, and a thorium anomaly is southeast of the area (J. S. Duval, written commun., 1985). These anomalies are associated with Tertiary volcanic rocks whose radioactivity is greater, because of greater radioelement concentrations, than that of the Paleozoic sedimentary rocks exposed throughout much of this region.

Ore-Deposit Models

Characteristics of the deposits in the wilderness study area resemble two ore-deposits models. These models are for epithermal gold-silver vein deposits and contact metasomatic tungsten deposits.

Epithermal gold-silver-base metal vein deposits form in near-surface environments at low to moderate temperature in the upper parts of geothermal systems (Berger, 1982). They occur in all host-rock types, but the most important deposits of this type are replacement and vein deposits in sedimentary sequences and vein, stockwork, and replacement deposits in volcanic rocks. Ore minerals include native gold and silver or electrum; telluride minerals; and sulfide minerals of arsenic, antimony, mercury, and base metals. Alteration and alteration zonation are the keys to understanding epithermal deposits. Altered rocks and ore deposits are strongly zoned both laterally and vertically along veins. Structures such as faults and folds can localize ore deposition.

Contact metasomatic tungsten deposits occur at a contact between an intrusive mass, commonly granodiorite or monzogranite, and a reactive host rock, commonly a sedimentary carbonate rock (Elliott, 1982). Scheelite is the principal ore mineral in this deposit type. Mineralogic zonation is well developed in most deposits in tactite. The highest ore grades are generally close to the contact with the intrusive body and are associated with anhydrous iron-rich garnet-pyroxene assemblages. Folds and faults may localize or channel ore-forming fluids that emanate from the intrusive body and thereby promote development of high-grade ore zones. Because iron-rich minerals are major constituents of tactite, large-magnitude magnetic anomalies are commonly associated with deposits of this type (Elliott, 1982).

Characteristics of Known Deposits

Replacement deposits such as those in the Freiberg mining district are an integral part of epithermal ore systems. Magma, represented by the two monzogranite stocks at the northern end of the range, was the probable heat source for genesis of the epithermal system. Base-metal sulfide minerals, including galena, sphalerite, and chalcopyrite, occur in replacement deposits of the district. Alteration of rocks in most of the district was weak. The highest ore grades occur in the hanging walls of mineralized fractures and faults. Additional detailed study of veining, alteration zonation, and zonation of precious and base metals is necessary to determine what level of the epithermal system is currently exposed and to determine the potential for the occurrence of metallic mineral resources at depth.

Scheelite-bearing tactite 0.5 mi northeast of the wilderness study area has characteristics typical of contact metasomatic tungsten deposits described by Elliott (1982). Significant quantities of tungsten, silver, and zinc have been produced from mines in tactite of the Tem Piute district, about 15 mi south of the Freiberg district, where two small Cretaceous stocks intruded upper Paleozoic carbonate rocks (Tschanz and Pampeyan, 1970). The geologic environment in the Freiberg district is similar, though not identical, to that of the Tem Piute district. Carbonate rock such as limestone of the Ordovician Pogonip Group, which was intruded by stocks in the Worthington Mountains area, is a demonstrated host to tungsten deposits in this type of geologic environment. Magma which formed the western of the two granitoid stocks was the probable source of heat and chemical components necessary for tactite genesis. Limestone was converted to marble in narrow contact metamorphic aureoles surrounding the two granitoid stocks. The complex mineral assemblages and strong mineralogic zonation characteristic of scheelite deposits in tactite are absent in this area. The nature of the aeromagnetic anomaly just southwest of the eastern monzogranite stock suggests that potentially mineralized, iron-enriched tactite may exist at shallow depth in this area.

Potential for Undiscovered Resources

Accumulated evidence suggests that there is moderate mineral resource potential for undiscovered, unexposed metalliferous deposits within the wilderness study area. Gold-silver-base metal epithermal ore systems and scheelite-bearing tactite are the most likely deposit types in this area. Geophysical studies suggest that granitoid rock, which provided heat for the Freiberg mining district epithermal system, also occurs in the subsurface along the northern border of the study area. Faults are a major control of epithermal ore-deposit distribution (Berger, 1982). Thus the favorability of the geologic environment for occurrences of epithermal ore deposits in the study area also depends on the existence of appropriate structural features. Numerous replacement deposits, containing ore minerals like those found in many epithermal systems in the area, are along the northern boundary of the wilderness study area. These deposits and the hypothesized subsurface geology indicate moderate mineral resource potential for gold-silver-base metal deposits in this area, with level-B certainty (Goudarzi, 1984; see inside front cover of this report).

The occurrence of scheelite-bearing tactite 0.5 mi northeast of the study area and the hypothesized subsurface configuration of the stocks suggest moderate mineral resource potential for tungsten deposits in the northern part of the study area. The very limited mineralized tactite associated with the western stock and the absence of exposed, mineralized tactite associated with the eastern stock suggest that favorable beds do not crop out in this area. However, the steep-gradient magnetic high associated with the eastern stock suggests that potentially mineralized, iron-rich tactite may exist in the shallow subsurface near here. Thus, the likelihood for unexposed, mineralized tactite in the northern part of the study area is considered to be moderate, with level-B certainty.

Several factors suggest that mineral resource potential in all but the northern part of the study area is low. Except for the northern area, the geologic environment appears to be unfavorable for metallic deposits, mineralized rock was not identified at the surface during geologic field work, meaningful anomalous values are absent in the geochemical data base, and geophysical data do not indicate the existence of either mineralized rock or favorable geologic environments. These findings suggest that mineral resource potential for metallic minerals in the remainder of the study area is low, with level-C certainty.

Energy-mineral resources, including petroleum, coal, and uranium, are unknown in this region, and the geologic environment is not favorable for the occurrence of undiscovered resources of these commodities or of geothermal energy resources within the wilderness study area. Paleozoic sedimentary rocks, which are possible source rocks for petroleum, are present in the study area. However, the thermal maturity of these rocks suggests that the potential for petroleum resources is low, with level-B certainty (Sandberg, 1983). Tschanz and Pampeyan (1970) did not report the existence of coal within Lincoln County. Radiometric data indicate that no significant, near-surface uranium deposit exists within the area (J. S. Duval, written commun., 1985). The ages of igneous rocks in Lincoln County (Ekren and others, 1977) and the absence of geothermal phenomena in this region indicate that potential for geothermal resources in the area is low, with level-B certainty.

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GEOLOGIC TIME CHART

Terms and boundary ages used by the U. S. Geological Survey, 1986

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
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	~ 570[1]
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 m.y. also called Precambrian, a time term without specific rank.

[2] Informal time term without specific rank.

* U.S. Government Printing Office 1986: 773-047/46007