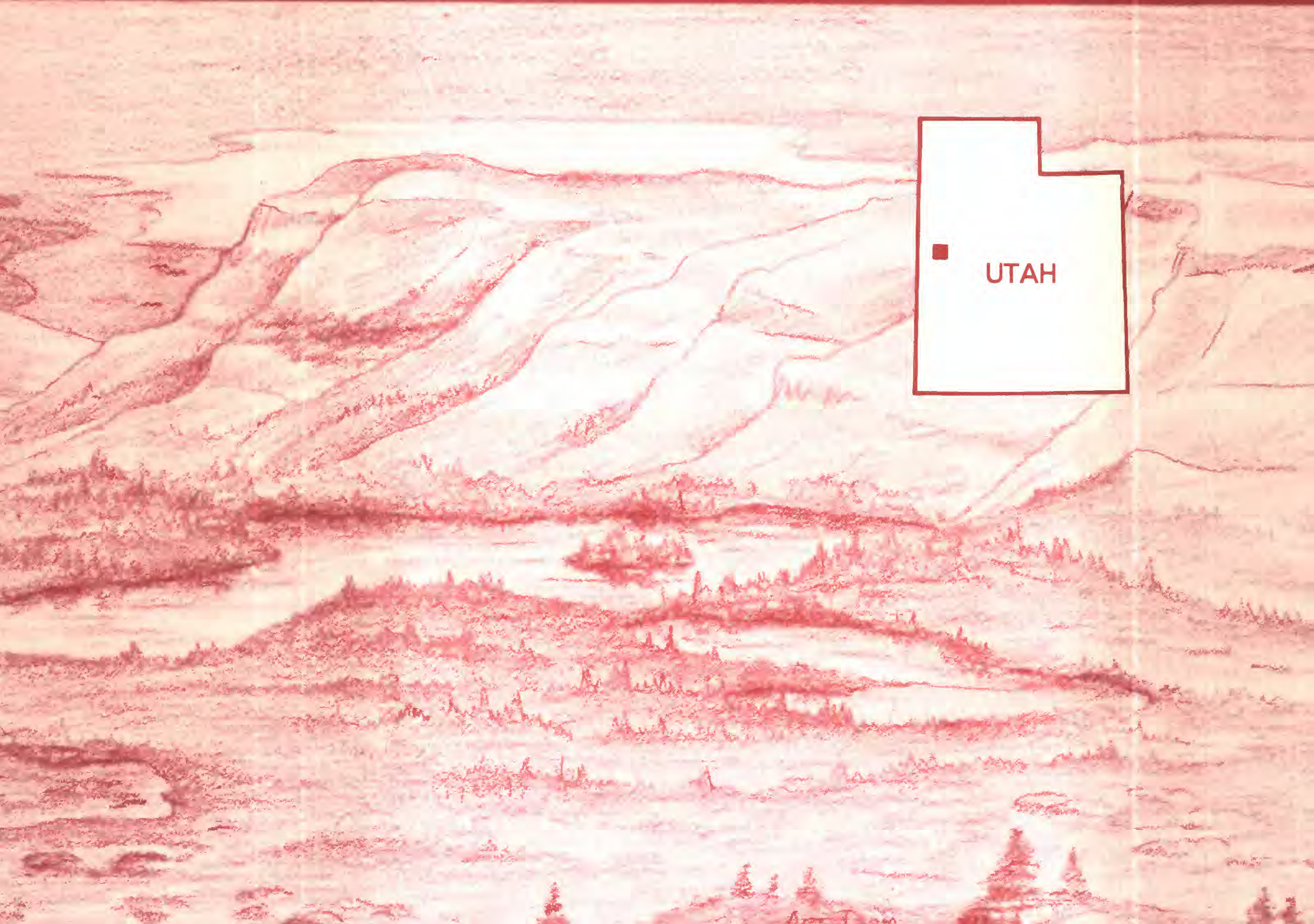
Mineral Resources of the Fish Springs Range Wilderness Study Area, Juab County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1745–A



Chapter A

Mineral Resources of the Fish Springs Range Wilderness Study Area, Juab County, Utah

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U.S. GEOLOGICAL SURVEY BULLETIN 1745

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—NORTHWESTERN 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 the Fish Springs Range (UT–050–127) Wilderness Study Area, Juab County, Utah.

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Mineral Resources of the Fish Springs Range Wilderness Study Area, Juab County, Utah

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ABSTRACT

The Fish Springs Range Wilderness Study Area (UT-050-127) includes most of the Fish Springs Range and is located north of the House Range, about 50 miles northwest of the city of Delta, Utah. A mineral resource study of the 33,840-acre area was completed in 1987 by the U.S. Geological Survey and U.S. Bureau of Mines. The northwestern and southeastern parts of the wilderness study area contain inferred subeconomic resources of high-purity quartzite. No metallic mineral resources were identified in the study area, but more than 17 million pounds of lead, 2.6 million ounces of silver, and minor copper, zinc, and gold have been produced from the Fish Springs mining district, which is immediately outside the northwest boundary of the wilderness study area. The potential for undiscovered deposits of these metals and molybdenum is high near the northern end of the study area, adjacent to the mining district, moderate near the southern end, and low in the remainder of the area. The resource potential for undiscovered deposits of high-purity limestone and dolomite is moderate throughout the study area except where quartzite is present; potential for undiscovered low-temperature geothermal resources and for oil and gas is low throughout the study area.

SUMMARY

The Fish Springs Range Wilderness Study Area is accessible by foot from dirt roads and jeep trails along the east and west sides of the Fish Springs Range (fig. 1). These roads connect to the gravel Pony Express and Sand Pass Roads north and south of the range, respectively. Within the wilderness study area, most of the crest of the Fish Springs Range is about 7,000–8,000 ft (feet) in elevation. Sparse pinon and juniper grow on steep slopes between cliffs of limestone. Coalescing alluvial fans extend from the foot of the range to the floor of Fish Springs Flat (elevation 4,300 ft) to the east and Snake Valley (elevation about 5,000 ft) to the west.

The Fish Springs Range Wilderness Study Area contains mostly Cambrian through Devonian (see geologic time chart in Appendix) sedimentary rocks. These are tilted west by the major range-bounding normal fault that extends along the east side of the range. No comparable fault is exposed on the west side of the range. Low-angle faults inferred from a deep seismic profile across the House Range to the south probably project northward into the Fish Springs Range, undercutting the entire section of Paleozoic rocks and perhaps a thick section of Precambrian rocks in the subsurface. The faults are interpreted tentatively as having moved as thrusts during the Mesozoic Sevier orogeny and as extensional detachments during Cenozoic basin-range faulting. The low-angle faults and the rocks overlying them form a gentle arch beneath the range.

The thick section of sedimentary rocks exposed in the Fish Springs Range begins in Middle Cambrian carbonate rocks. These rocks are underlain by more than 2,000 ft of Lower and Middle Cambrian quartzite and shale, exposed in the House Range to the south. In the Fish Springs Range, the Middle Cambrian carbonate rocks pass up into Upper Cambrian and Ordovician carbonate rocks and into a 250-ft-thick interval of pure quartzite, also of Ordovician age. The quartzite is in turn overlain by Ordovician, Silurian, and Devonian carbonate rocks and shale. Small plugs and dikes of Tertiary igneous rock intrude carbonate rocks in the northern part of the study area and in the Fish Springs mining district.

Geophysical surveys and drilling show that a concealed igneous intrusion underlies the Fish Springs mining district; presumably, this intrusion was responsible for the alteration of rocks and the formation of mineral deposits in the district. The surveys reveal a second concealed intrusion near Sand Pass, south of the study area, which was probably responsible for alteration and mineralization of rocks in the northern

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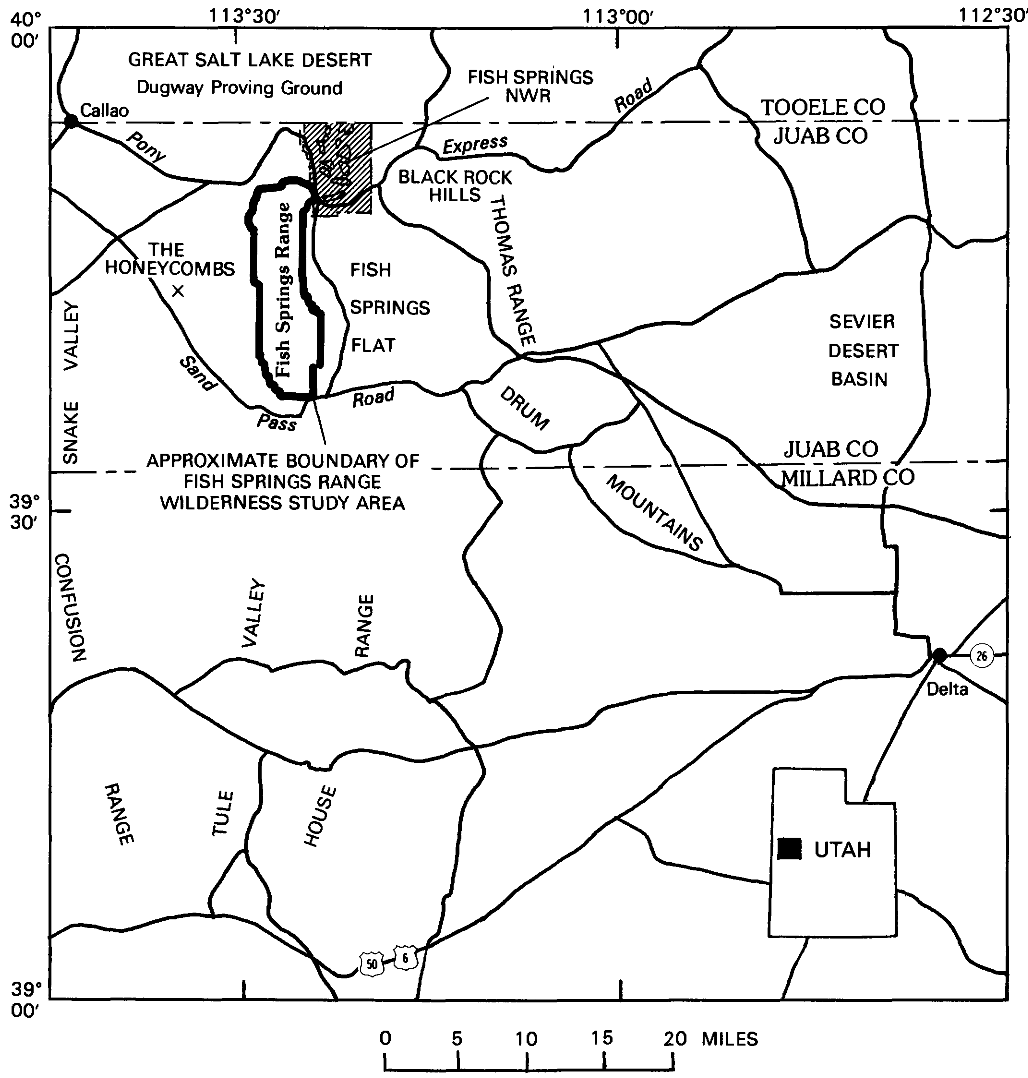

Figure 1. Location of the Fish Springs Range Wilderness Study Area, Juab County, Utah.

House Range. The occurrence of a broad aeromagnetic anomaly over the southern third of the wilderness study area suggests a third intrusion, which is more deeply buried than the others and did not produce altered or mineralized rock at the present surface.

The Fish Springs mining district, adjacent to the northern boundary of the Fish Springs Range Wilderness Study Area, produced 20,303 short tons of ore yielding 17,292,796 pounds of lead, 2,800 pounds of zinc, 5,366 pounds of copper, 507.97 ounces of gold, and 2,658,220 ounces of silver from 1891 to 1976. Prospecting continued in the district in the late 1970's, resulting in discovery of approximately 10.3 million tons of ore containing 6.03 percent zinc, 0.21 percent lead, 19.16 percent iron, 0.42 ounces of silver per short ton, 0.054 percent cadmium, and minor copper. However, no resources of these metals have been identified within the wilderness study area.

Extensive inferred subeconomic resources of high-purity quartzite occur in outcrops of the Middle Ordovician Eureka and Watson Ranch Quartzites, in the northwestern and southeastern parts of the study area (fig. 2).

The potential for undiscovered resources of lead, zinc, copper, molybdenum, silver, and gold is high at the northern end of the study area and moderate at the southern end (fig. 2). Both areas of potential are peripheral to igneous intrusions and mineralized rocks and are cut by numerous faults and fractures, which may have served as conduits for mineralizing fluids. Within the northern area, major fault systems extend east and south along the study area boundaries from the intrusive center beneath the Fish Springs mining district. The southern area is just north of the Sand Pass intrusion and is over a deeply buried intrusion suggested by aeromagnetic surveys. Geochemical anomalies in stream sediments outline both of these areas. The resource potential for lead, zinc, copper, molybdenum, silver, and gold in the remainder of the study area is low.

The study area has a moderate potential for undiscovered resources of high-purity limestone and dolomite, except in the parts of it that are underlain by quartzite.

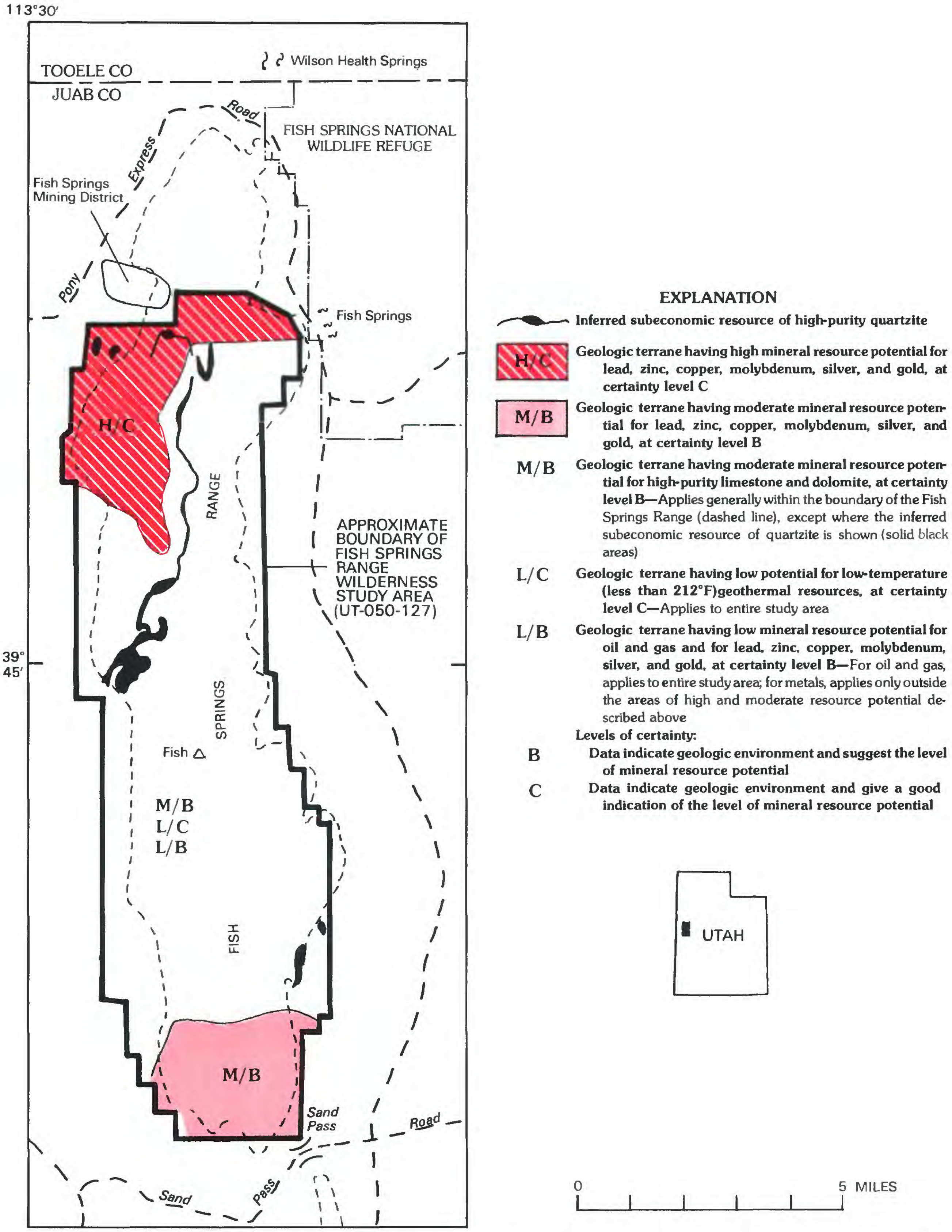

Figure 2. Identified resources and mineral resource potential of the Fish Springs Range Wilderness Study Area, Juab County, Utah.

The study area boundary is 1 mi (mile) from the warm-water Fish Springs, and 3 mi from Wilson Health Springs, both located near the north end of the Fish Springs Range. The springs produce low-temperature (less than 212 °F) geothermal water that is commonly used for recreational purposes and local heating. The potential for undiscovered low-temperature geothermal resources within the wilderness study area, however, is low.

Oil and gas resource potential in the wilderness study area is low. The occurrence of oil and gas beneath the study area would be likely only if the rocks and structures of the Sevier arch project north beneath the Fish Springs Range and are thermally mature. Such projections are tenuous. Available data on conodont alteration show that rocks in the study area have been heated to or above the upper limit of oil generation.

INTRODUCTION

The U.S. Bureau of Mines and the U.S. Geological Survey studied 33,840 acres of the Fish Springs Range Wilderness Study Area (UT–050–127). The study of this acreage was requested by the U.S. Bureau of Land Management. In this report, the studied area is called the "wilderness study area" or simply the "study area."

The Fish Springs Range Wilderness Study Area is in the Fish Springs Range, in Juab County, Utah, about 50 mi northwest of Delta (fig. 1). The Fish Springs mining district, in the northern part of the Fish Springs Range, lies immediately outside the wilderness study area. The Fish Springs National Wildlife Refuge is immediately northeast of the study area, at the north end of Fish Springs Flat (fig. 2). West of the study area, a low ridge extends north from The Honeycombs, in the middle of Snake Valley, to the Pony Express Road. To the south lies Tule Valley and the House Range. The wilderness study area can be reached by foot from dirt roads and jeep trails along the east and west sides of the Fish Springs Range. These roads connect to the gravel Pony Express and Sand Pass Roads north and south of the range, respectively.

The highest point in the Fish Springs Range Wilderness Study Area, at triangulation point "Fish," is 8,523 ft in elevation. Most of the crest of the range in the study area, however, is about 7,000–8,000 ft in elevation. Sparse pinon and juniper grow on steep slopes between cliffs of limestone. Coalescing alluvial fans extend from the foot of the range to the floor of Fish Springs Flat (elevation 4,300 ft) to the east and Snake Valley (elevation about 5,000 ft) to the west.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which also is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

In May 1986 the USBM conducted a mineral investigation of the Fish Springs Range Wilderness Study Area (Korzeb, 1986). The USBM surveys and studies mines, prospects, and mineralized areas to appraise reserves and identified resources. Records of the Utah Geological and Mineral Survey and the U.S. Bureau of Land Management were reviewed for information regarding geologic investigations, patented and unpatented claims, and Federal mineral and oil and gas leases in or near the study area. Two USBM geologists spent six days examining the study area. They collected 18 chip samples from prospects and 1 dump sample at a shaft; 3 of the samples from prospects are from inside the study area.

Analytical determinations were made at the U.S. Bureau of Mines, Reno Research Center, Reno, Nev., and by commercial laboratories. All 19 samples were analyzed by fire assay for gold and silver, atomic absorption spectrometry for arsenic, X-ray fluorescence for barium, and inductively coupled plasma-atomic emission spectroscopy for copper, lead, and zinc. In addition, 15 of the 19 samples were analyzed by semiquantitative emission spectrography for 40 elements. Analytical results for all samples are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo.

Investigations by the U.S. Geological Survey

A geologic map (pl. 1) of the Fish Springs Range Wilderness Study Area was compiled by R.A. Yambrick from 1:24,000 scale maps of the Sand Pass, Sand Pass NW, Fish Springs NW, and Fish Springs SW quadrangles (Hintze, 1980a, b, c). No new mapping was done, but geologic features of the study area were examined in 1986 to prepare this report. A stream-sediment geochemical survey was done in 1986–87 by D.R. Zimbelman, H.A. Whitney, and T.A. Delaney. Altered rocks in and near the study area were sampled by D.R. Zimbelman, H.A. Whitney, T.A. Delaney, R.A. Yambrick, and D.L. Kelley for geochemical analysis.

Aeromagnetic and aeroradiometric data were collected in 1976–78 by Texas Instruments, Inc. (1977, 1979), as part of the National Uranium Resource Evaluation program of the U.S. Department of Energy. The data were gridded and contoured by R.P. Kucks. Gravity data were compiled in 1986–87 by K.L. Cook and Viki Bankey. Vertical electric soundings were made near the study area in 1980 by R.J. Bisdorf and A.R. Zohdy. The above-described geophysical data were evaluated by D.L. Campbell. Radiometric data were processed and evaluated by J.S. Duval. Remote-sensing data were collected by the Landsat Thematic Mapper satellite and were processed and evaluated by M.H. Podwysocki and D.W. Brickey.

Acknowledgments.—Employees of the U.S. Bureau of Land Management in Salt Lake City, Fillmore, and Delta, Utah, provided information on mineral exploration and space for equipment storage. We thank L.F. Hintze of the Utah Geological and Mineral Survey for his critical review of the manuscript.

APPRAISAL OF IDENTIFIED RESOURCES

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

Mining History

The Fish Springs mining district is adjacent to the northern boundary of the Fish Springs Range Wilderness Study Area (fig. 3). Ore was discovered there in 1890, and the mining district was organized in 1891. The principal producers in the district were the Galena and Utah Mines (Butler and others, 1920, p. 465). Production from the district from 1891 to 1976 was 20,303 short tons of ore yielding 17,292,796 pounds of lead, 2,800 pounds of zinc, 5,366 pounds of copper, 507.97 ounces of gold, and 2,658,220 ounces of silver (Perry and McCarthy, 1977, p. 182–183). Prospecting, including drilling and geophysical studies, continued in the district in the late 1970's (Christiansen, 1977, p. 56). Utah International, Inc., drilled a concealed stock in the mining district (sec. 18, T. 11 S., R. 14 W.). The company reported replacement deposits in skarn adjacent to the stock containing approximately 10.3 million tons of 6.03 percent zinc, 0.21 percent lead, minor copper, 19.16 percent iron, 0.42 ounces of silver per short ton, and 0.054 percent cadmium (P.V. Hehn, Utah International, Inc., written commun., 1980).

Results of Field Investigation

No metallic mineral resources were identified in the study area. An east-striking, vertical, limonite-stained and weakly mineralized fault-fracture system extends from the Fish Springs mining district along the northern boundary of the study area (pl. 1; trace mostly concealed by Quaternary alluvium in fault-controlled valleys). Carbonate-rock formations that host fault-controlled replacement deposits in the Fish Springs district extend into the northern part of the study area. The fault-fracture system and some altered rock are exposed in prospects and shafts located along the boundary. Samples from prospects along the fault zone contain anomalously high concentrations of arsenic, barium, lead, and zinc. Analyses yielded the following, in parts per million: 13–6,500 arsenic, 23–61 lead, 180–6,200 barium, and 13–250 zinc. No gold was detected, and the silver concentration was at the detection limit of 0.1 ounce per short ton for all sampled prospects. Anomalous concentrations of arsenic, barium, lead, and zinc indicate that mineralizing fluids may have moved along the fault zone, possibly from the igneous intrusion in the Fish Springs mining district.

Limestone and dolomite are found throughout the study area. These rocks are part of a thick sequence of thin- to thick-bedded sandy and cherty limestones and dolomites interbedded with shales, sandstones, and siltstones (Kepper, 1960, p. 5–60). Interbedding of these rocks makes most of them unsuitable for commercial use. The Middle Cambrian Howell Limestone contains an identified resource of high-purity limestone (Tuftin, 1987), but the Howell crops out only in small areas at the southeast corner of the study area.

Inferred subeconomic resources of high-purity quartzite, used in glass manufacture and as smelter flux, are present in the Middle Ordovician Eureka and Watson Ranch Quartzites, which crop out in the northwestern and southeastern parts of the study area (pl. 1). These formations and their stratigraphic equivalents contain resources of high-purity quartzite elsewhere in Utah (Ketner, 1964). Testing for impurities (such as Al, Fe, Ca, Mg, and minor elements) is needed to better define high-purity quartzite resources. No testing was done for this appraisal.

Recommendations

Further investigations in the vicinity of the fault zone on the northern boundary of the study area using geophysical methods such as magnetic surveys followed by drilling are needed to verify the existence of base and precious metal deposits.

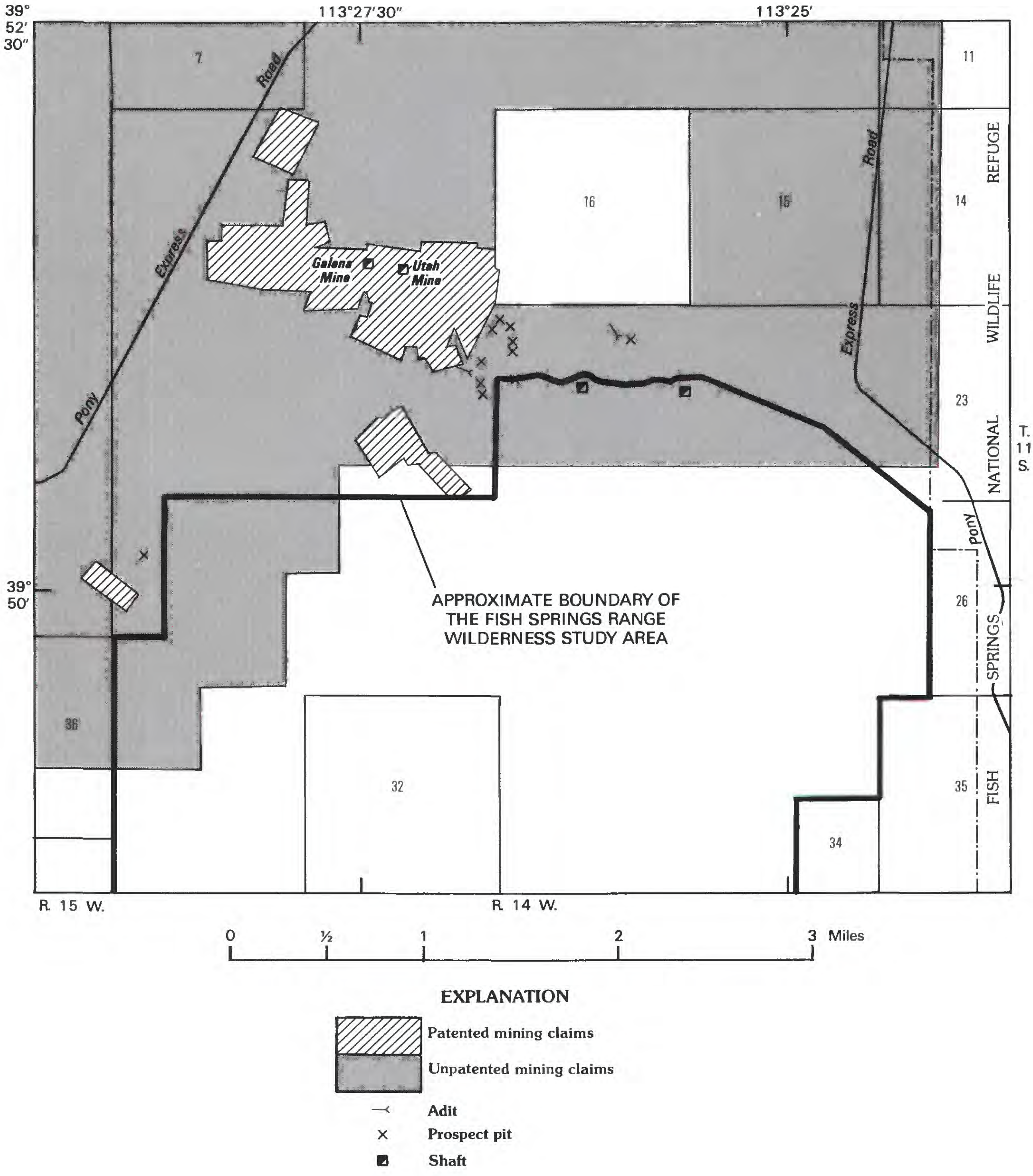

Figure 3. Mines, prospects, and mining claims in and near the northern end of the Fish Springs Range Wilderness Study Area, Juab County, Utah.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

**By David A. Lindsey,
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Kenneth L. Cook,[2] Melvin H. Podwysocki,
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Geology

Geologic Setting and Structure

The Fish Springs Range is northernmost in the line of classic basin ranges originally described as the House Range by G.K. Gilbert (1875, p. 27). The range consists mostly of faulted, west-tilted Paleozoic carbonate rocks. A large normal fault separates the east front of the range from the downthrown valley of Fish Springs Flat, but no comparable fault is evident on the west side of the range. Scarps in alluvium indicate movement in late Quaternary (Holocene) time (Bucknam and Anderson, 1979). Along the north border of the wilderness study area, a major normal fault extends across the range from the Fish Springs mining district, and many smaller normal faults cut rocks within the range (pl. 1).

The entire section of Paleozoic rocks in the Fish Springs Range, as well as a thick section of Precambrian sedimentary rocks in the subsurface, probably rests on the House Range and Sevier Desert detachments. These detachments (low-angle faults) have been interpreted from the COCORP seismic profile of western Utah (Allmendinger and others, 1983; 1985). The detachments are interpreted as surfaces that resulted from thrusting during the Mesozoic Sevier orogeny and that also accommodated low-angle extension during Cenozoic basin-range faulting. Rocks overlying the House Range detachment form the gentle Sevier arch (also known as the House Range antiform). This interpretation of structures beneath the Fish Springs Range assumes northward projection of structures seen on the COCORP profile across the House Range.

Hintze (1978; 1980a, b, c) mapped and described areas of younger-over-older faulting, which he called "attenuation faulting," in much of the Fish Springs Range as well as in the House Range. He mapped attenuation faults where formations are abnormally thin or missing and, in some places, brecciated. Hintze (1978) interpreted the faults as thin-skinned detachment surfaces that formed by stretching and smearing of Paleozoic formations as the youngest units moved farthest east during the Sevier orogeny. Mapped attenuation faults in the southern part of the Fish Springs Range, however, may also be interpreted as normal faults parallel to the strike of the bedding. Other mapped attenuation faults, in the northern part of the range, may be depositional contacts between thinner-than-normal units. Hintze (1978) also described low-angle normal faults that postdate attenuation faults on the southeastern side of the Fish Springs Range; these he called "glide faults."

Description of Rocks

The Paleozoic rocks of the Fish Springs Range extend from the Lower Cambrian Prospect Mountain Quartzite to the Devonian Simonson Dolomite. The Lower Cambrian Prospect Mountain Quartzite (more than 2,000 ft thick), the Lower and Middle Cambrian Pioche Formation (600 ft of mostly shale), and the Middle Cambrian Howell Limestone (210 ft thick) are exposed only at the southeast corner of the range. In most of the Fish Springs Range, they underlie exposures of younger Cambrian rocks. Well-preserved trilobite faunas are found in a thick section of Middle and Upper Cambrian carbonate rocks (Hintze, 1980a, b, c) in the range. The reader is referred to Hintze and Robison (1975) for detailed descriptions of these rocks and fossils.

Small plugs and dikes of rhyolitic to andesitic composition intrude the main east-west fault system in the Fish Springs mining district (Oliveira, 1975; Hintze, 1980c) (pl. 1). Paleozoic carbonate rocks adjacent to the intrusions have been silicified and recrystallized. A plug of quartz latite crops out in the northern part of the wilderness study area, but no other igneous rocks have been identified in the study area. The dikes and plugs resemble late Eocene and Oligocene intermediate-composition rocks of the Thomas Range and the Drum Mountains (Lindsey, 1982). The small intrusions may be apophyses of a concealed stock of quartz monzonite to granodiorite composition discovered by drilling in the Fish Springs mining district (P.V. Hehn, Utah International, Inc., written commun., 1980). A small remnant of intermediate-composition volcanic flow rock crops out midway along the east side of the range, outside the study area.

Geochemistry

Methods

A reconnaissance geochemical survey was made in the wilderness study area and vicinity. Collected for analysis were 43 minus-80-mesh stream-sediment sam-

[2]University of Utah.

ples, 43 heavy-mineral concentrates of stream sediment, and 176 rock samples. These were evaluated as possible indicators of altered or mineralized rock. Chemical analysis of sediments provides information that helps identify those stream basins that contain unusually high concentrations of elements that have been derived from mineralized areas. The minus-80-mesh stream-sediment samples and the heavy-mineral concentrates were collected at the same sites from alluvium in the channels of first-order (unbranched) streams and second-order streams (below the junction of two first-order streams) (pl. 1). Threshold values (highest values not considered anomalous) were determined by inspection of frequency-distribution histograms for each element (table 1). Rock samples were collected in and near the study area. Rocks that appeared unaltered were sampled for information on geochemical background concentrations. Visibly altered rocks were sampled at mines, prospects, and other areas to determine suites of elements associated with mineralized and altered rock. Analytical data and a description of sampling and analytical techniques are in Arbogast and others (in press).

Analysis of the nonmagnetic fraction of heavy-mineral concentrates was the most useful geochemical method for a reconnaissance evaluation of the study area. Concentrate samples generally contain minerals that result from ore-forming processes. In mineralized areas generally, concentrates may include minerals such as pyrite (FeS_2), galena (PbS), cassiterite (SnO_2), sphalerite (ZnS), stibnite (Sb_2S_3), barite ($BaSO_4$), scheelite ($CaWO_4$), and native gold. The selective concentration of ore-related minerals permits determination of some elements that are not easily detected by analysis of bulk stream sediments. The minus-80-mesh fraction of bulk stream sediments collected from the area contained no significant geochemical anomalies and is not discussed further.

Results of Study

Anomalous concentrations of one or more of the selected elements were found in 18 of the 43 concentrate samples (table 1, fig. 4). Most of these anomalous samples contain elevated amounts of barium and (or) lead. The anomalous amounts of lead in concentrate samples from the southern part of the study area may represent a halo around the concealed pluton south of Sand Pass. Anomalous amounts of barium are widespread in the study area. The origin of the barium is unknown, although anomalous amounts of barium in carbonate rocks of the Richfield quadrangle of southwestern Utah has been attributed to iron-barite mineralized fault zones (W.R. Miller, oral commun., 1987).

Two stream drainages in the wilderness study area contain anomalous amounts of other elements as well as

Table 1. Anomalous concentrations of selected elements in nonmagnetic heavy-mineral concentrates of stream-sediment samples, Fish Springs Range Wilderness Study Area, Utah

[Only anomalous values shown here. Leaders (---) mean element concentration not considered anomalous. Elements tested (and minimum anomalous values, in parts per million) are Au (20), Ag (5), As (500), Ba (> 10,000), Be (20), Bi (20), Cd (50), Cu (500), Mo (20), Pb (500), Sb (200), Sn (20), W (100), and Zn (500)]

Field No.	Anomalous elements (parts per million)		
	Ba	Pb	Others
0013	>10,000	---	
0021	>10,000	---	
0026	>10,000	---	
0027	>10,000	---	
0030	---	500	
0031	>10,000	---	
0034	>10,000	---	
0036	>10,000	1,000	Zn 500
0039	>10,000	---	
1024	---	30,000	Ag 50 As 2,000 Zn 5,000
1025	---	1,000	
1029	---	500	Ag 10
1033	>10,000	---	
1034	>10,000	---	
1035	>10,000	---	
1051	>10,000	2,000	Mo 50
1052	>10,000	1,000	
1060	>10,000	---	

lead and barium. An unnamed drainage on the west side of the study area, about 4 mi south of the Fish Springs mining district, contains anomalous amounts of silver and lead. An unnamed drainage east of the mining district, inside the northern border of the study area, contains anomalous amounts of zinc as well as lead and barium. A heavy-mineral-concentrate sample collected for reference near the central part of the Fish Springs mining district contains anomalous amounts of silver, arsenic, lead, zinc, and molybdenum.

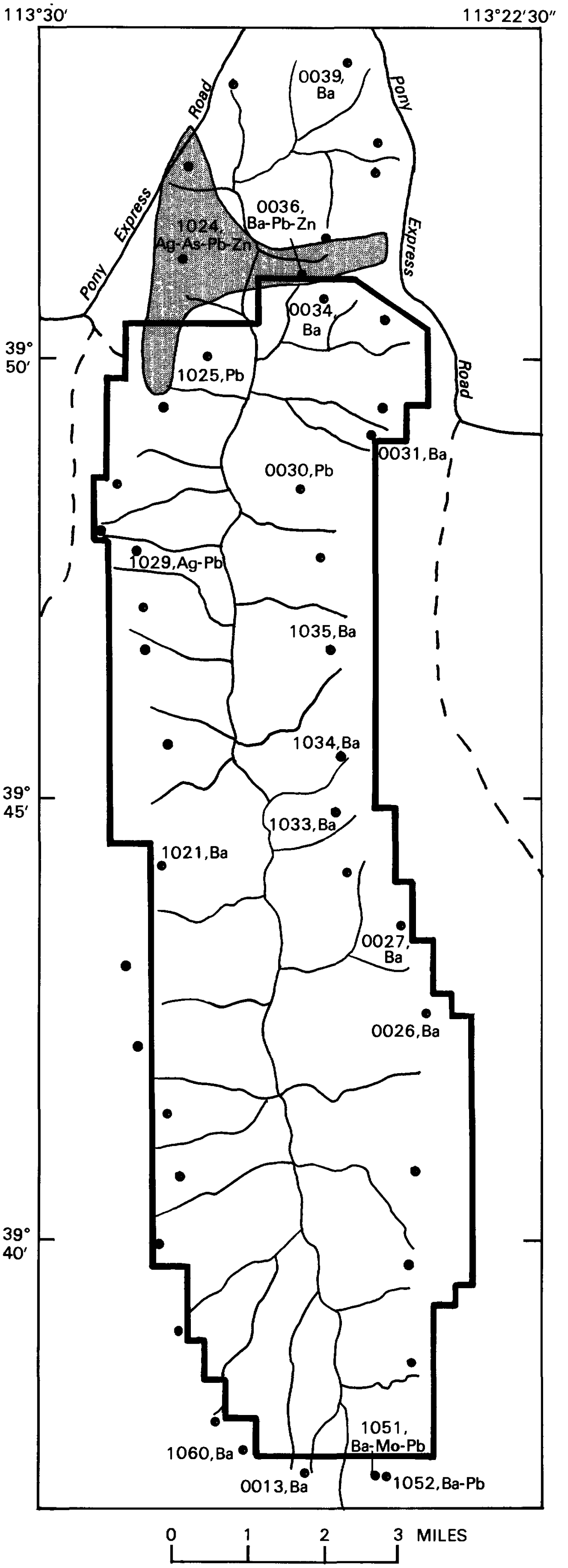
Of the 176 rock samples collected within and north of the study area, including some from the Fish Springs mining district, 86 contain anomalous concentrations of one or more of a group of selected elements. These samples contain anomalous amounts of lead (65 samples); silver (62 samples); arsenic (47 samples); zinc (47 samples); antimony (39 samples); molybdenum (35 samples); cadmium (27 samples); gold (25 samples); copper (19 samples); and bismuth, tin, tungsten, beryllium, and barium (6 samples or fewer for each) (table 2). In the base- and precious-metal mining districts of western Utah, these elements are concentrated in zones along structures that extend out from mineralized intrusive centers (Zimbelman and Campbell, 1987). In the Fish Springs mining district, two structures host strong geochemical anomalies. A major fault extends east through the mining district and across the range, and a fault zone extends north and south through the mining district. These faults are major zones of fracturing that might have channeled mineralizing fluids outward from the concealed intrusion in the mining district. Rock geochemical anomalies along these faults indicate the possibility of significant mineralized areas within the northern part of the study area.

Geophysics

Gravity

Gravity coverage of the study area (fig. 5) is too sparse to reflect local geological details. Only 12 gravity stations are located inside the study area, and 6 more are on or near the boundary.

Gravity values are high over the Fish Springs Range and low over the adjacent Snake Valley to the west and Fish Springs Flat to the east. The gravity high is probably caused by the contrast between the relatively high-density Paleozoic rocks in the range and the lower density sedimentary fill in the adjacent valleys. A gravity high having about 6-milligal closure occurs over the northern tip of the Fish Springs Range, north of the wilderness study area. This gravity high extends southwest across the northwest part of the study area and continues over a pediment developed on Paleozoic(?) bedrock west of the range. The relatively steep gradient along the east side of the Fish Springs Range reflects the basin-range boundary fault there. A similar gravity gradient overlies the valley 3–5 mi west of the Fish Springs Range and may mark a fault bounding the west side of the pediment-covered block of inferred Paleozoic strata. Alternatively, this western gravity gradient may represent the eastern edge of volcanic flows that crop out there.



EXPLANATION

● Heavy-mineral-concentrate sample site—Locality number and anomalous elements shown only for sites found to have anomalous concentrations of one or more elements

Approximate area where many rock samples were collected

Drainage divide

Approximate boundary of Fish Springs Range Wilderness Study Area

Dirt road

Figure 4. Heavy-mineral concentrate sample sites and elements detected in anomalous amounts, Fish Springs Range Wilderness Study Area, Utah. See table 1 for threshold anomalous values for each element. See plate 1 for more exact locations of sample sites.

Table 2. Anomalous concentrations of selected elements in rock samples, Fish Springs Range Wilderness Study Area, Utah

[Only anomalous values shown here. Leaders (---) mean element concentration not considered anomalous. Elements tested (and minimum anomalous values, in parts per million) are Au (.05), Ag (5), As (200), Ba (>5000), Be (10), Bi (10), Cd (20),Cu (500), Mo (20), Pb (500), Sb (100), Sn (10), W (50), and Zn (500)]

Field No.	Rock type	Anomalous elements (parts per million)									
		Ag	Au	As	Cd	Cu	Mo	Pb	Sb	Zn	Others
FS-1	Silicified limestone	150	---	---	200	500	---	2,000	---	>10,000	
FS-2	Gossan---------------	150	0.05	>10,000	100	2,000	---	20,000	2,000	>10,000	
FS-3	Gossan---------------	5,000	1.1	>10,000	10	1,000	---	10,000	2,000	>10,000	
FS-4	Quartz vein----------	500	.25	>10,000	>500	5,000	---	>20,000	1,000	>10,000	
FS-5	Dolomite-------------	7	---	500	>500	700	---	3,000	---	>10,000	
1034	Limestone------------	---	---	---	---	---	---	---	---	5,000	
1035	Limestone------------	---	---	>10,000	---	---	20	---	---	---	
5015A	Quartz latite--------	5	---	---	---	---	---	---	---	---	
5015B	Gossan---------------	7	---	---	50	5,000	---	15,000	---	>10,000	
5021A	Gossan---------------	70	---	500	500	---	100	5,000	500	10,000	
5021B	Silicified limestone	300	---	10,000	>500	---	50	>20,000	700	>10,000	
5023	Dolomite breccia-----	---	---	---	---	---	---	500	---	5,000	
5025	Dolomite-------------	200	---	1,500	200	---	---	>20,000	100	10,000	
5026A	Dolomite-------------	---	---	---	---	---	---	500	---	---	
5026B	Carbonate replacement	200	---	500	>500	2,000	---	20,000	1,000	>10,000	
5027A	Carbonate replacement	1,000	.17	5,000	>500	2,000	---	>20,000	2,000	>10,000	
5027B	Dolomite-------------	1,000	.15	7,000	>500	700	---	20,000	1,000	>10,000	
5028B	Dolomite-------------	100	---	700	>500	1,000	200	>20,000	500	>10,000	
5029A	Dolomite-------------	50	---	---	100	500	---	7,000	100	3,000	
5029B	Quartz latite--------	5	---	1,000	---	---	---	500	---	---	
5030A	Gossan---------------	50	.3	1,000	---	---	50	2,000	---	1,000	Bi 100
5030B	Gossan---------------	15	.2	5,000	---	---	---	2,000	100	1,000	Bi 15 W 200
5030C	Quartzite------------	5	---	---	---	---	---	500	---	---	
5042	Breccia--------------	150	---	1,000	---	---	50	>20,000	200	2,000	
5043A	Breccia--------------	500	---	700	---	---	100	>20,000	300	---	
5043B	Gossan---------------	200	1.8	10,000	---	---	100	>20,000	1,500	1,000	W 50
5208	Hematite nodules-----	---	---	---	---	---	70	---	---	1,000	
5347B	Carbonate replacement	---	---	3,000	---	---	---	---	---	500	
5347C	Jasperoid------------	---	---	1,000	---	---	---	---	---	500	
5350B	Quartzite breccia----	---	---	500	---	---	20	---	---	---	
5351B	Carbonate replacement	---	---	10,000	---	---	---	---	200	---	
5351C	Carbonate replacement	---	---	2,000	---	---	20	---	150	2,000	
5352	Carbonate replacement	---	---	---	---	---	100	---	---	---	Ba>5,000
5353A	Limestone breccia----	---	---	---	---	---	---	---	100	---	
5353B	Limestone breccia----	---	---	---	---	---	20	---	---	---	
5361	Marble---------------	5	---	---	---	---	---	---	---	---	
5362A	Carbonate replacement	700	2.55	>10,000	300	1,000	50	>20,000	5,000	>10,000	Bi 100 Sn 500
5362B	Carbonate replacement	500	4.55	7,000	10	---	300	7,000	1,000	10,000	Bi 20
5363A	Dolomite replacement	7	.05	---	---	---	20	---	---	---	
5363B	Dolomite replacement	10	.15	---	---	---	50	---	100	---	
5364A	Marble breccia-------	10	---	---	20	---	20	20,000	---	500	
5364B	Quartz latite--------	---	---	---	---	---	---	500	---	---	
5365C	Breccia--------------	---	---	---	---	---	---	1,500	---	---	
5366A	Carbonate replacement	---	.15	3,000	---	500	20	10,000	100	7,000	
5366B	Carbonate replacement	10	.15	2,000	---	---	30	10,000	100	5,000	Bi 70
5367A	Carbonate replacement	100	.20	3,000	---	2,000	---	>20,000	300	10,000	
5367B	Quartz latite--------	50	---	200	---	---	---	>20,000	---	2,000	

Table 2. Anomalous concentrations of selected elements in rock samples, Fish Springs Range Wilderness Study Area, Utah—Continued

Field No.	Rock type	Anomalous elements (parts per million)									
		Ag	Au	As	Cd	Cu	Mo	Pb	Sb	Zn	Others
5368	Quartz latite--------	10	---	---	---	---	---	1,000	---	---	
5369B	Breccia---------------	100	---	500	>500	---	20	20,000	---	>10,000	
5369C	Carbonate replacement	70	---	>10,000	---	1,000	20	>20,000	700	>10,000	Sn 10
5370A	Carbonate replacement	100	.05	>10,000	200	1,000	---	20,000	200	>10,000	
5370B	Carbonate replacement	500	2.0	>10,000	>500	500	20	>20,000	2,000	>10,000	Sn 20
5371	Limestone breccia----	5	---	1,000	---	---	---	1,000	---	1,000	
5372	Dolomite breccia-----	---	---	700	---	---	---	---	---	---	
5375A	Jasperoid------------	---	---	---	---	---	---	---	---	---	Bi 30
5378A	Quartz latite--------	---	---	---	---	---	---	---	---	---	Be 10 Sn 500
5378B	Quartz latite--------	---	---	---	---	---	---	---	---	---	Be 10 Sn 500
5379A	Dolomite breccia-----	500	1.0	10,000	>500	1,000	50	>20,000	1,000	>10,000	
5379B	Dolomite breccia-----	200	1.25	10,000	>500	1,000	20	>20,000	500	>10,000	
5380A	Jasperoid------------	100	---	500	20	---	500	>20,000	>10,000	2,000	
5380B	Jasperoid------------	20	---	---	---	---	30	7,000	200	1,000	
5380C	Jasperoid------------	100	---	500	100	---	20	>20,000	>10,000	5,000	
5381	Marble---------------	---	---	---	---	---	---	1,000	---	---	
5382A	Dolomite-------------	100	.35	---	---	---	---	---	---	---	
5383	Carbonate replacement	150	.10	1,000	500	---	---	>20,000	100	>10,000	Sn 200
5384A	Dolomite-------------	---	---	---	---	---	20	7,000	---	---	
5384B	Dolomite-------------	---	---	---	---	---	---	500	---	---	
5385A	Carbonate replacement	1,000	.50	1,500	---	---	200	>20,000	500	500	
5385B	Carbonate replacement	100	.35	1,500	---	---	100	>20,000	1,000	2,000	
5385C	Dolomite breccia-----	5	---	---	---	---	---	2,000	---	---	
5385D	Quartzite breccia----	10	---	200	---	---	---	10,000	---	---	
5385E	Quartzite breccia----	20	---	---	---	---	30	10,000	---	---	
5385F	Quartzite breccia----	1,000	.20	2,000	---	---	20	>20,000	500	1,500	
5385G	Quartzite breccia----	500	---	---	---	---	---	>20,000	---	---	
5385H	Quartzite breccia----	1,000	.20	2,000	---	---	20	>20,000	200	---	
5386A	Quartzite breccia----	100	---	3,000	---	---	---	>20,000	200	---	
5386B	Quartzite breccia----	200	---	300	---	---	100	>20,000	100	---	
5386C	Dolomite breccia-----	10	---	---	---	---	---	5,000	---	---	
5387A	Quartzite breccia----	5	---	---	---	---	---	2,000	---	---	
5387B	Quartzite breccia----	50	---	---	---	---	---	>20,000	---	---	
5387C	Quartzite breccia----	100	---	---	---	---	---	>20,000	---	---	
5387D	Quartzite breccia----	700	---	---	---	---	---	>20,000	---	---	
5387E	Dolomite breccia-----	70	---	---	20	---	---	10,000	---	1,000	
5387F	Dolomite breccia-----	100	---	---	500	---	---	15,000	---	>10,000	
5388A	Andesite-------------	---	---	---	---	---	---	500	---	---	
5388D	Dolomite-------------	5	---	---	---	---	---	---	---	---	

Aeromagnetics

Flight lines of the aeromagnetic survey were spaced (nominally) 2 mi apart over the study area (fig. 6), and the nominal flight elevation was 1,000 ft above topography. Using the rule of thumb that airborne surveys can detect anomalous bodies in a swath on the ground directly under the aircraft and about 45 degrees from vertical on either side, only about 19 percent of possible magnetic sources on the ground surface would be detected by this survey. Although the detection percentage increases for deeply buried bodies, small, shallow magnetic bodies between flight lines might remain undetected.

The busy pattern of magnetic highs and lows (feature A on fig. 6) west of the study area in Snake Valley reflects Oligocene(?) volcanic rocks that crop out there. A magnetic high and some nearby lows immediately east of the study area (feature B on fig. 6) may reflect buried volcanic rocks in the downfaulted block of

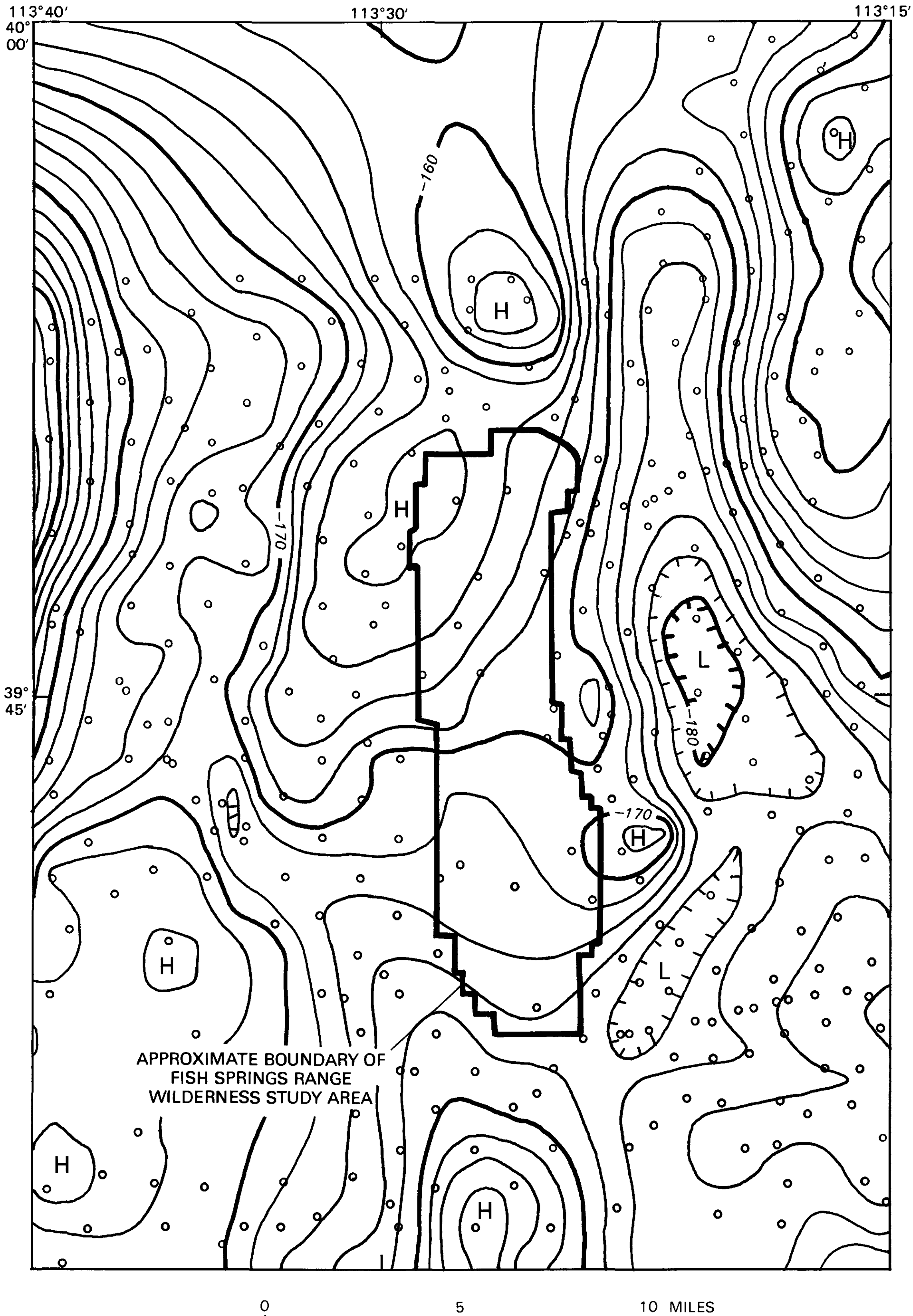


Figure 5. Complete Bouguer gravity anomaly map of the Fish Springs Range Wilderness Study Area and vicinity. Reduction density 2.67 grams per cubic centimeter; contour interval 2 milligals; H=gravity high; L=gravity low; solid dots designate gravity stations.

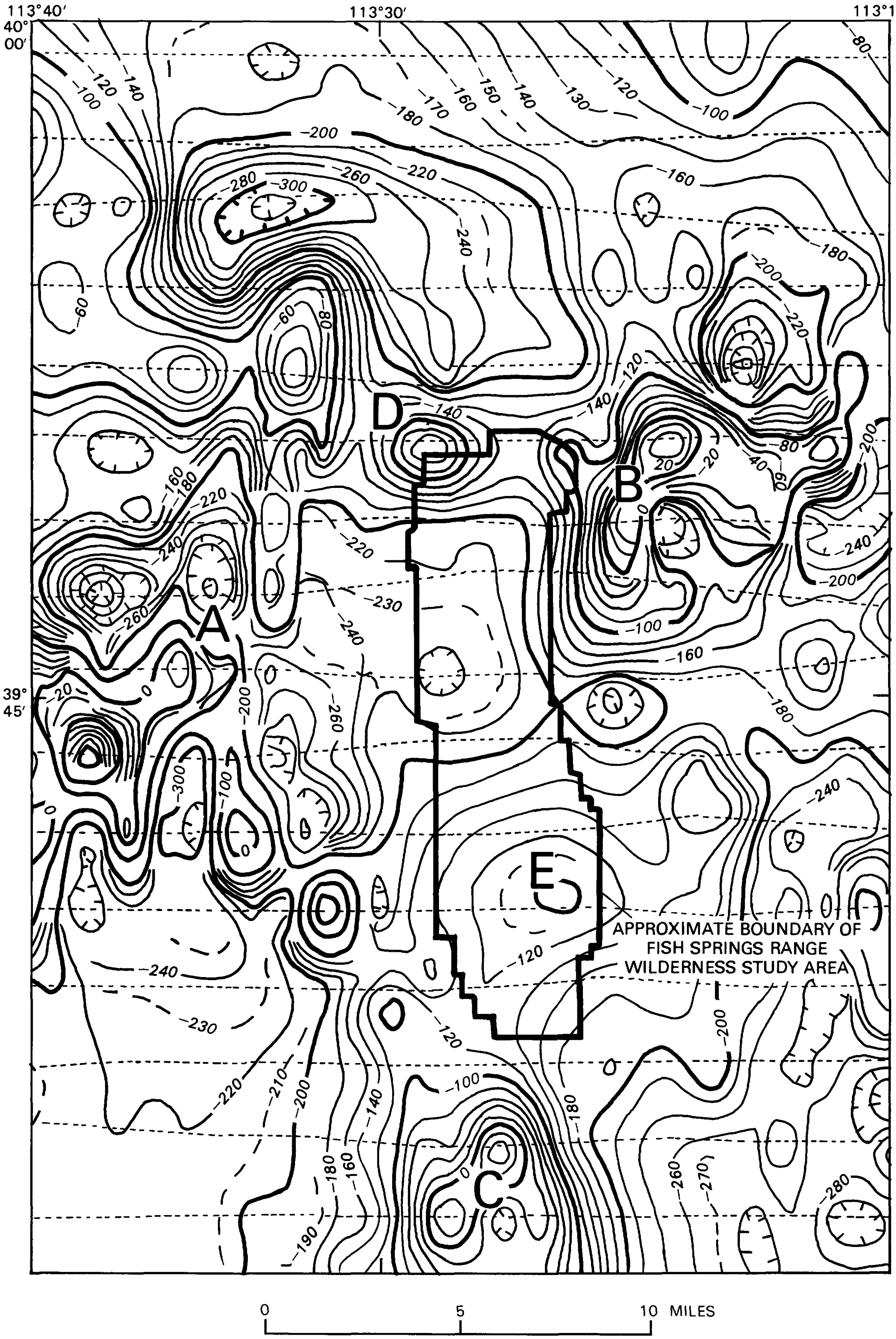


Figure 6. Aeromagnetic map of the Fish Springs Range Wilderness Study Area and vicinity. Contour interval 20 nanoteslas (solid contours) and 10 nanoteslas (dashed contours); light dotted lines show flight paths; letters A–E designate features discussed in text.

Fish Springs Flat. The amplitude and wavelength of this high and its presumed polarity low(s) suggest that any volcanic rocks there are relatively shallow, thin, and magnetic. The magnetic high south of the study area (feature C on fig. 6) may reflect a buried pluton immediately southwest of Sand Pass. This pluton may be the source of the dikes and altered rocks exposed immediately south of Sand Pass.

A strong, local magnetic high (feature D on fig. 6) is located at the northwest corner of the Fish Springs mining district, immediately north of the study area. This magnetic high may reflect a concealed stock that was discovered by drilling in the mining district. Another magnetic high (feature E on fig. 6), located over the southeastern third of the study area, may also represent a concealed pluton. This magnetic high is much broader than the others, suggesting that the source pluton is larger and probably more than a mile below the surface.

Igneous rocks beneath and near the study area probably belong to the oldest two stages of igneous activity documented in the nearby Thomas Range and Drum Mountains (Lindsey, 1982). Formations of both stages include magnetic rocks.

Aeroradiometrics

Aeroradiometric data were collected in 1976–78 along several east-west-trending lines that cross the study area (Texas Instruments, Inc., 1977; 1979). Aeroradiometric surveys detect gamma rays emitted by radioactive potassium and by daughter isotopes produced by decay of uranium and thorium. If these elements and isotopes were known to be at normal equilibrium, the parent populations of uranium and thorium could be calculated from the radiometric measurements. Because equilibrium is not certain, though, these populations are reported as equivalent uranium (eU) and equivalent thorium (eTh). Gamma rays are readily absorbed by soil and rock, so aeroradiometric data reflect only potassium, eU, and eTh within a few feet of the surface.

As part of a statewide geophysical mapping project, the gamma-ray data for Utah were compiled and processed to make a series of color-composite maps (Duval, 1983). These maps were reviewed to estimate the potassium, eU, and eTh concentrations in and near the study area and to look for anomalous concentrations of radioactive elements.

Extremely high aeroradiometric readings occur north of the study area, over Wilson Health Springs on the Dugway Proving Ground Military Reservation. The overall radioactivity within the study area is low to moderate, with concentrations of 0.6–2.2 percent potassium, 0.5–3.5 parts per million eU, and 1–8 parts per million eTh. Potassium levels are anomalously high in the south-central part of the study area.

Geoelectric Soundings

Bisdorf and Zohdy (1980) made electrical soundings in Fish Springs Flat as part of a hydrologic study there. None of the soundings was inside the study area, but several were near its northeastern and northern boundaries. The soundings detected electrical resistivities to about 900 ft depth. They showed high-resistivity (300 ohm-meters or more) rocks in the Fish Springs Range, but low-resistivity (4–150 ohm-meters) material interpreted as water-bearing sedimentary rocks in the downfaulted block of Fish Springs Flat. No resistive units that might represent volcanic flows were identified in the subsurface of Fish Springs Flat; therefore, we conclude that such flows, if present, have either undergone low-temperature chloritization (which can substantially lower the typically high resistivity of volcanic flows) or are buried at depths of more than 900 ft.

Remote Sensing

Part of a Landsat Thematic Mapper (TM) data set covering the study area (scene ID 50123–17425, July 2, 1984) was processed digitally and analyzed to delineate areas of hydrothermally altered, potentially mineralized rocks. A color-ratio-composite image was used to identify lithologies where vegetation did not obscure outcrops. Generally, vegetation cover greater than 25 percent obscures the spectral signature of rocks. Using a color-ratio composite image composed of the band ratios TM3/TM1, TM5/TM4, and TM5/TM7, rocks containing ferric iron oxides, oxyhydrides, and sulfates (these minerals are referred to here collectively as limonite) were distinguished from rocks lacking these components. In addition, rocks containing significant quantities of the Fe^{+2}-bearing minerals, such as the chlorite minerals, also were detected. Likewise, rocks containing significant quantities of hydroxyl ion (OH^-) (that is, sheet silicates such as clays and micas) were distinguished from rocks lacking this composition. Hydrothermally altered rocks commonly contain an abundance of sheet-silicate minerals and (or) ferric iron-bearing minerals.

Many other rocks may display signatures in TM data similar to those of the hydrothermally altered rocks. Such false anomalies are caused by supergene weathering of ferromagnesian minerals producing both hematite and goethite in otherwise unaltered rocks and by the presence of large quantities of micas and clays as original minerals in shale, phyllite, schist, and mica-rich igneous rocks. Likewise, bright carbonate minerals show a similar signature in TM data. Also, some silicified and altered rocks are not visible on remote sensing images. Field checking of the study area verified all three problems.

The wilderness study area contains two anomalies that may be associated with hydrothermally altered rocks (table 3; pl. 1). Anomaly L1, located outside the study area, represents recrystallized carbonate rocks (marble) in the Fish Springs mining district. Anomalies L2 and L3, in southern part of the study area, appear to represent limonite in fractures; alternatively, anomaly L3 may result from weathering of primary ferromagnesian minerals.

Mineral and Energy Resource Potential

Lead, Zinc, Copper, Molybdenum, Silver, and Gold

The model.—Deposits of lead, zinc, copper, silver, and gold in the Fish Springs mining district are consistent with a model of mineralization that incorporates several different types of mineral deposits found in western Utah (Zimbelman and Campbell, 1987). Although the Tintic mining district, 70 mi east of the wilderness study area, is the best-known example of the model (Morris and Mogensen, 1978), the Fish Springs mining district, the mineralized area south of Sand Pass, and the Detroit mining district in the Drum Mountains are other examples. The model encompasses mineral deposits found in and around mineralized intrusive centers in western Utah: porphyry copper-molybdenum deposits; skarns; vein and replacement deposits of lead, silver, zinc, manganese, gold, and clay; and disseminated gold deposits.

The principal features of the model are (1) shallow intrusive centers, (2) concentric zones of mineral deposits, and (3) localization of alteration and mineralization along fractures. (1) Shallow intrusive centers provide a heat source for convection of mineralizing fluids. Features associated with shallow intrusive centers include stocks, plugs, dikes, radial and concentric faults, pebble dikes, altered rocks, and geochemical and aeromagnetic anomalies. (2) Concentric zones of mineral deposits around the intrusive center suggest fluid movement, cooling, or physical and chemical gradients around the center. The zoned deposits may extend outward along faults and fractures. The complete sequence of mineral deposits from the intrusive center outward consists of porphyry copper and molybdenum deposits; skarns bearing tungsten, tin, and other metals; copper- and gold-bearing veins; lead, zinc, and silver veins and replacement deposits; zinc, lead, and manganese veins and replacement deposits; and gold with jasperoid. Some zones are incompletely developed and some overlap in the mining districts of western Utah. (3) In most districts, rock alteration and mineralization have been localized along faults and fractures. On a regional scale, the intrusive centers may have been localized by intersecting structural features such as major fault systems and transfer zones. On a local scale, individual ore deposits may occur in intensely shattered and brecciated rock in faults and zones of solution collapse.

Disseminated gold deposits are the target of current (1988) exploration near the wilderness study area. Although the disseminated gold deposits and occurrences in western Utah broadly resemble other sediment-hosted disseminated gold deposits in the western United States (Berger, 1986; Tooker, 1985), they differ in their characteristic association with shallow intrusive centers and zoned mineralized systems and in their complex geochemical assemblage of incompatible elements.

Mineral resource potential.—The potential for undiscovered resources of lead, zinc, copper, molybdenum, silver, and gold is high in the northern end of the study area, in a zone that extends south and east from the Fish Springs mining district along the northern and western boundaries of the study area. The level of certainty is C. The eastward extension of the zone of high potential is in extensively faulted carbonate rocks south of a major fault that crosses the range east of the mining district. The

Table 3. Anomalous areas determined from Landsat Thematic Mapper data for the Fish Springs Range Wilderness Study Area, Utah

Map No. (Pl. 1)	Location	Anomaly	Interpretation
L1	Sec. 18, T. 11 S., R. 14 W.	Nonlimonitic rocks with strong OH or CO_3 signature.	Areas of carbonate rocks altered to white marble. Site of Fish Springs mining district.
L2	NE¼SW¼SE¼ sec. 4, T. 13 S., R. 14 W.	Weakly limonitic rocks with moderate OH or strong CO_3 signature.	Moderately bright carbonate rocks with goethite staining and goethite along fracture planes.
L3	SW¼NW¼SE¼ sec. 3, T. 14 S., R. 14 W.	Limonitic rocks or FE^{+2}-rich rocks with moderate OH or strong CO_3 signature.	Phyllite and phyllitic quartzite with much goethite staining. Possible alteration by hydrothermal fluids.

southern extension follows a zone of faults that may be parallel to a concealed bounding fault northwest of the Fish Springs Range. The two extensions meet at the shallow concealed stock that underlies the Fish Springs mining district. Faults may have served as conduits for mineralizing fluids in the study area. The area of high mineral resource potential is defined by geochemical anomalies at mines and prospects immediately outside the study area and anomalies in sediments from streams draining the study area.

An area in the southern part of the wilderness study area has a moderate resource potential, at certainty level B, for lead, zinc, copper, molybdenum, silver, and gold. The area contains intensely fractured and faulted carbonate rocks of Cambrian and Ordovician age and is defined by low-level geochemical anomalies of lead and barium. The area lies north of the shallow concealed intrusion south of Sand Pass, inferred from geophysical surveys. Rocks on the eastern periphery of the concealed intrusion, outside the study area, contain surface evidence of mineralization (Chidsey, 1978). At the surface, the principal features of the mineralized area are (1) small plugs of altered igneous rocks containing secondary muscovite and clay minerals, (2) north-striking high-angle faults that appear to have localized igneous plugs and mineralizing fluids, (3) laterally extensive breccia zones that intersect the faults and provided conduits for mineralizing fluids, (4) numerous rusty, silicified masses (jasperoid) in breccia zones, and (5) anomalous concentrations of gold, arsenic, and other metals detected in samples of the jasperoid. Although no such mineralized areas are known at the surface within the southern part of the Fish Springs Range Wilderness Study Area, they may be concealed beneath unaltered rock or alluvium. All of the study area outside the zones of high and moderate resource potential has low mineral resource potential for lead, zinc, copper, molybdenum, silver, and gold, with a certainty level of B.

High-purity Limestone and Dolomite

The model.—Limestone and dolomite have been quarried for metallurgical flux from several formations in Utah (Morris, 1964), including Cambrian rocks in the Cricket Mountains, southeast of the study area, and the Ordovician Fish Haven and Silurian Laketown Dolomites in the Stansbury Range, north of the study area. All of these formations crop out in the study area; some may contain intervals of sufficient purity to provide a resource of metallurgical flux.

Mineral resource potential.—All of the Fish Springs Range Wilderness Study Area not underlain by quartzite has a moderate potential, at certainty level B, for undiscovered deposits of limestone and dolomite that could be used as metallurgical flux and for other industrial purposes. Carbonate rock in the study area would need to be tested for purity in order to predict resource potential with a higher level of certainty and to identify resources within the thick section of carbonate formations. No testing was done for this study.

Geothermal Energy

The model.—The study area extends to within 1 mi of the Fish Springs (fig. 2). According to Goode (1979), several of the springs yield warm water, and Wilson Health Springs, 3 mi north of the study area at the north end of the Fish Springs Range, discharges about 100 gallons per minute of salty water at a temperature of 141 °F. These springs are in valley fill above concealed faults east and north of the range-bounding fault (Hintze, 1980c). Regional ground-water flow in carbonate rocks is mostly from the west and southwest (Gates, 1987); local flow in the valley fill is from the south (Bolke and Sumsion, 1978).

The Wilson Health Springs may be typical of low-temperature (less than 212 °F) geothermal water in rift basins where ground water descends into sedimentary fill and becomes heated in response to the geothermal gradient (Swanberg, 1983). Such low-temperature geothermal water is commonly used for recreational purposes and for local heating. The area of ground-water recharge in the Fish Springs Range is probably small.

Fish Springs is the discharge point for a large ground-water flow system that drains from Tule Valley and beyond through the carbonate rocks of the Fish Springs Range (Gates, 1987). This water probably follows shallow faults and fractures through the Fish Springs Range, and thus it may never become heated enough to be considered a low-temperature geothermal resource. The discharge at Fish Springs may be focused by large concealed faults and impermeable sediment along the northwest side of Fish Springs Flat.

Energy resource potential.—The resource potential for low-temperature geothermal water in the wilderness study area is low, with a certainty level of C.

Oil and Gas

The model.—Exploration for oil and gas in western Utah has involved wildcat drilling of a variety of targets, including (1) asymmetric anticlines and thrusts within shaly source rocks in the Confusion Range synclinorium to the southwest, (2) gravity lows and seismic features that might indicate anticlines in basin fill of Tertiary age, and (3) subthrust oil-bearing structures including those in sandstone of Mesozoic age. Target 1 is illustrated on the interpretative sections of the COCORP line (Allmendinger and others, 1985). Targets 2 and 3 are illustrated by the drilling of the Argonaut Energy No. 1 Federal wildcat in the Sevier Desert basin (Mitchell, 1979).

A variant of target 3, oil- and gas-bearing structures associated with the Sevier arch (House Range antiform), was proposed by Allmendinger and others (1985). Although such structures may occur in Precambrian rocks above the House Range detachment fault, their most likely location is in Paleozoic rocks that might lie below the detachment. Structures that might trap oil and gas within the arch, although highly speculative and ill-defined, are probably the only place where oil and gas might be discovered in the vicinity of the wilderness study area.

Energy resource potential.—Oil and gas potential in the wilderness study area is rated with respect to the proposed structures in the Sevier arch. The potential is low at certainty level B.

For an oil and gas resource to occur in the study area, the Sevier arch must extend north beneath the Fish Springs Range, and the region beneath the arch must contain permeable zones capable of hosting oil and gas deposits, must either contain or be updip from source rocks, and must be thermally mature. The presence of permeable host rocks is inferred through a correlation by seismic lines with test holes and outcrops 60 mi to the south and east (Mitchell and McDonald, 1986; 1987). No information is available on suitable source rocks. Available data on conodont alteration indicates that rocks in the range have been heated to the upper limit or above the limit of oil generation (Molenaar and Sandberg, 1983).

Recommendations for Further Study

An extensive structural analysis of seismic profiles in the vicinity of the Fish Springs and House Ranges is needed to correlate structures and potential host rocks from the House Range northward into the Fish Springs Range.

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APPENDIX

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

<table>
<tr><td rowspan="5">LEVEL OF RESOURCE POTENTIAL ↑</td><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>
<tr><td>A</td><td>B</td><td>C</td><td>D</td></tr>
<tr><td></td><td colspan="4">LEVEL OF CERTAINTY →</td></tr>
</table>

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:

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	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, 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 in this report

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.

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