Mineral Resources of the Fish Creek Mountains Wilderness Study Area, Imperial County, California

U.S. GEOLOGICAL SURVEY BULLETIN 1711–C

Chapter C

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U.S. GEOLOGICAL SURVEY BULLETIN 1711

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
SOUTHERN CALIFORNIA AND CALIFORNIA DESERT CONSERVATION AREA

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys 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 part of the Fish Creek Mountains (CDCA-372) Wilderness Study Area, Imperial County, California.

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Mineral Resources of the Fish Creek Mountains Wilderness Study Area, Imperial County, California

By Victoria R. Todd, David E. Detra, James E. Kilburn, Andrew Griscom, *and* Fred A. Kruse
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SUMMARY

Abstract

At the request of the Bureau of Land Management, 16,882 acres of the Fish Creek Mountains Wilderness Study Area (CDCA-372) were studied. In this report, the area studied is referred to as "the wilderness study area", or simply "the study area." Field work for this report was carried out between 1983 and 1985. There are no mining districts or mines in the study area. The U.S. Gypsum Company has 18 unpatented placer claims with an estimated 20 million tons of gypsum reserves inside the study area, and oil and gas leases are held in and near the area. There is high potential for undiscovered resources of the nonmetallic mineral commodities gypsum and limestone in the northwestern and central parts of the study area, respectively. A northwest-trending zone that roughly bisects the study area has low potential for undiscovered resources of the metallic minerals lead, tungsten, and molybdenum.

Character and Setting

The part of the Fish Creek Mountains Wilderness Study Area that was studied for this report occupies approximately 16,882 acres in western Imperial County, Calif. (fig. 1). The study area encompasses most of the Fish Creek Mountains, one of the easternmost ranges of the Peninsular Ranges province. The steep, rugged northeast and east faces of the range rise about 2,400 ft above the Imperial Valley, which lies partly below sea level and is part of the Salton trough, the landward extension of the Gulf of California. The Fish Creek Mountains are characterized by an arid climate, extremely high summer temperatures, and a desert flora.

The study area is underlain by Cretaceous (138 to 66 million years Before Present (Ma); see appendix for geologic time chart) plutonic igneous rocks of the Peninsular Ranges batholith; these plutonic rocks comprise much of the crystalline bedrock of the Peninsular Ranges. The batholith is composed of a variety of syntectonic (deformed) and late-tectonic to posttectonic (relatively undeformed) plutons that intruded metamorphosed Paleozoic(?) (approximately 570 to 240 Ma) sedimentary and volcanic rocks, remnants of which are exposed in tabular bodies, called screens, between the plutons. Neogene (24 to 1.7 Ma) marine and alluvial deposits unconformably overlie the uplifted and deeply eroded batholithic rocks in the study area and faults of the San Andreas system cut the batholithic rocks and sedimentary deposits.

Identified Mineral Resources

There are no mining districts or mines in the Fish Creek Mountains Wilderness Study Area. The northwestern part of the study area is underlain by bedded gypsum deposits of Miocene age that are continuous with deposits mined by the U.S. Gypsum Company at the U.S. Gypsum quarry 1.5 mi west of the study area (fig. 2). The U.S. Gypsum Company has 18 unpatented placer claims in the northwestern part of the study area. The gypsum reserves within the study area are estimated at more than 20 million tons. The Roberts Celestite mine, 3 mi northwest of the study area, produced 8,000 tons of strontium ore, mostly during World War II. Minor amounts of celestite and barite may occur within the gypsiferous strata within the study area, but no deposits of these minerals were identified.

Limestone is the major constituent of a large screen of Paleozoic(?) metasedimentary rocks in the central part of the study area. The Waters prospect (fig. 2, No. 2; table 1) encompasses large quantities of this limestone, which may be suitable for many commercial uses.

Skarns, or carbonate-rich rocks altered by the intrusion of granitic magma, and (or) clay alteration zones occur locally in a northwest-trending shear zone that bisects the study area. The shear zone follows contacts between carbonate-bearing metasedimentary screens and granitic rocks. Seven prospects in the east-central part of the study area are located in this shear zone. Samples from these prospects contained minor amounts of zinc, copper, manganese, and barium. Anomalous concentrations of tungsten, lead, molybdenum, and silver are present in sediments from streams that drain the shear zone (north half of the study area). Local metasomatism and (or) hydrothermal alteration of carbonate-bearing metasedimentary rocks in the shear zone were probably associated with the minor mineralization that produced the geochemical anomalies. A small quantity of manganese may have been produced from the Hanks Lost Mine prospect located 1,000 ft southwest of the study area (fig. 2, No. 12).

Although extensive sand and gravel deposits are present along the northeast and east boundaries of the study area, deposits outside of the study area are adequate to meet foreseeable needs.

Mineral Resource Potential

Geologic and geochemical studies indicate that the study area locally has high resource potential for gypsum and low resource potential for lead, tungsten, and molybdenum (fig. 2). Three unmined gypsum deposits are present in the northwestern part of the study area and additional deposits are inferred to underlie alluvium. The northwestern part of the study area therefore has high resource potential for gypsum. There is high resource potential for limestone in the central part of the study area in a large screen that includes the Waters prospect (fig. 2, No. 2; table 1). The northwest-trending shear zone that contains skarn and (or) clay alteration zones associated with minor mineralization has been assigned low resource potential for lead, tungsten, and molybdenum.

No potential for energy resources was identified in the study area. Oil and gas leases are held in the eastern one-third of the study area, but no potential for hydrocarbon resources was identified during this study.

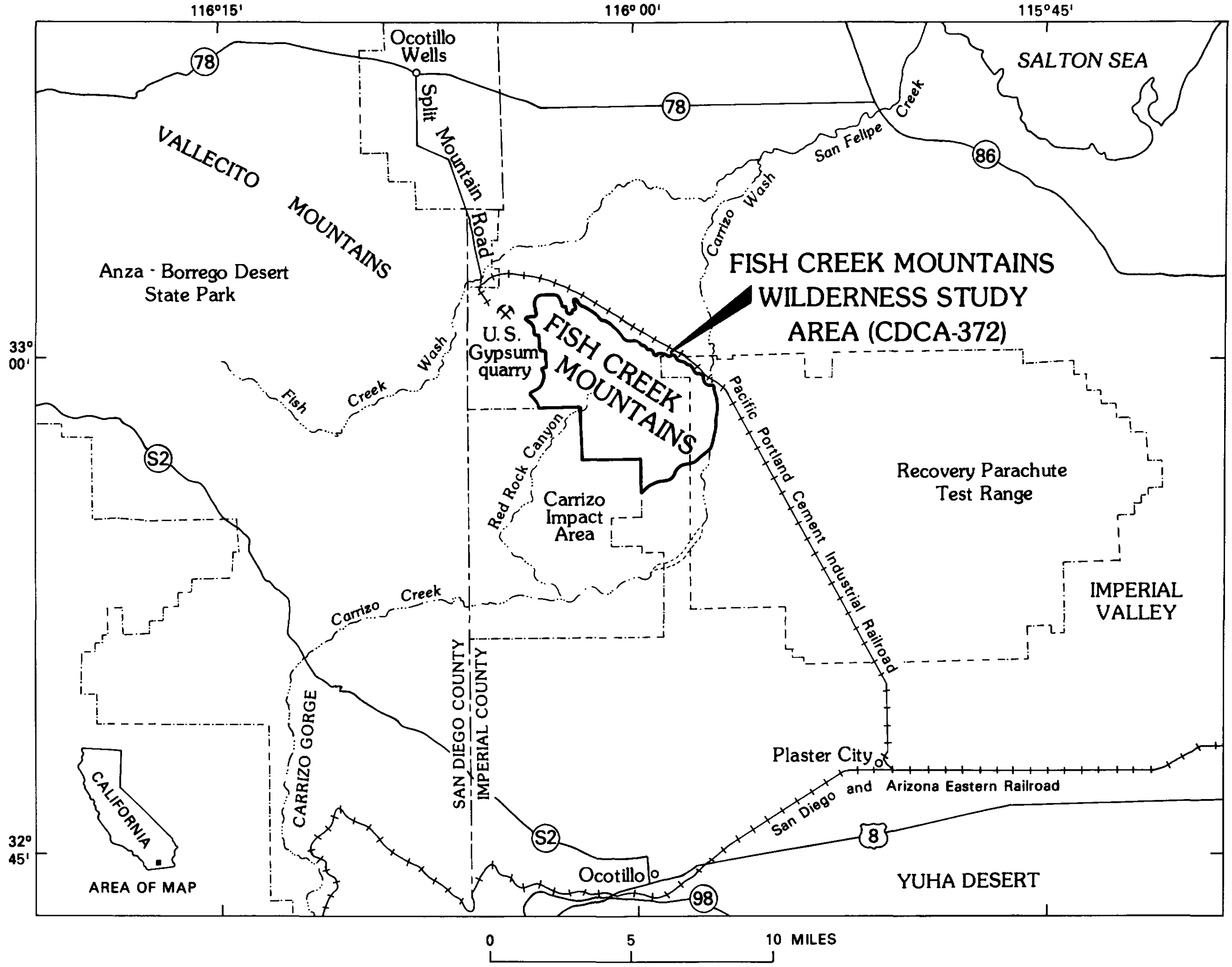

Figure 1. Index map showing location of the Fish Creek Mountains Wilderness Study Area, Imperial County, California.

TABLE 1. Prospects in and adjacent to the Fish Creek Mountains Wilderness Study Area

[*, outside the wilderness study area boundary]

Map No. (fig. 2)	Name	Summary	Workings and production	Sample and resource data
1	Gypsum prospect	A bed of massive gypsum crops out in three significant bodies (1A, 1B, 1C). Drill hole data show gypsum thickness of more than 100 ft. Interbedded shale, gypsum, and sandstone underlie massive gypsum bed.	No production or workings	A chip sample from overlying weathered zone of gypsum body 1A had 94.0 pct gypsum. A grab sample from overlying weathered zone of body 1B contained 92.4 pct gypsum. A 40-ft vertical chip sample from gypsum body 1C averaged 89.0 pct gypsum for upper 30 ft and 58.5 pct gypsum and 37.4 pct anhydrite for lower 10 ft. Deposits 1A, 1B, and 1C have 600,000 tons, 100,000 and 20 million tons of inferred gypsum reserves, respectively.
2	Waters prospect	A screen of carbonate rock about 3 mi long and 1 mi wide surrounded by granitic rocks. Exposed stratigraphic thickness of carbonate unit consists of about 1,500 ft of marble and lower 1,200 ft of dolomite with pegmatite dikes.	One prospect pit	Fourteen samples taken by U.S. Bureau of Mines and California Division of Mines and Geology had values that ranged from 54.2 pct CaO and 0.66 pct MgO (limestone) to 29.9 pct CaO and 21.7 pct MgO (dolomite).
3	Unnamed prospect	A narrow zone of alteration near marble-granitic rock contact. Altered zone contains mixture of clay and iron oxide minerals.	One pit 12 ft by 8 ft by 4 ft deep.	One grab sample of altered material from dump contained no gold or silver.
4	Unnamed prospect	Small metasedimentary screens in granitic rocks. Metasomatic replacement formed skarns along fractures in carbonate rock in small screens. Skarn minerals are predominantly quartz, garnet, pyroxene, and epidote with iron and copper oxide staining. Some alteration near skarn and narrow shear zones.	Three shafts from 8 to 12 ft deep and four prospect pits.	Five chip and one select sample contained no gold, silver, or tungsten. One sample had 0.4 pct zinc and 0.05 pct copper. Spectrographic analysis of one sample showed minor amounts of barium.
5	Unnamed prospect	A small screen exposed on ridge near head of Red Rock Canyon. Screen is mostly marble with narrow quartzite bed through center of screen. Small shear zones in marble are iron oxide stained and locally heavily altered. Epidote and siderite in shear zones.	Five prospect pits	Three chip samples contained no gold, silver, or tungsten. A spectrographic analysis of one chip sample showed minor amounts of barium and manganese.
6	Unnamed prospect	A small marble screen has skarn containing quartz, garnet, epidote, actinolite, and pyroxene.	One prospect pit	One chip sample contained no gold, silver, or tungsten.
7	Unnamed prospect	A shear zone strikes N. 40° W. and dips 65° NE. along contact between gneissic granitic rocks and foliated dioritic rocks. Gneissic granitic rocks have numerous pegmatite dikes containing quartz, feldspar, garnet, and biotite.	One 23-ft shaft with a 30-ft crosscut at bottom.	Two chip and one select sample contained no gold, silver, tungsten, or molybdenum.
8	Unnamed prospect	A skarn zone trends N. 76° W. along marble screen-granitic rocks contact. Masses of garnet are in skarn; individual garnet crystals have diameters as much as 2 in. Skarn minerals mainly quartz and garnet with some epidote and pyroxene.	Five prospect pits	One chip and one grab sample contained no gold, silver, tungsten, or molybdenum.
9	Unnamed prospect	A marble screen with outcrop diameter of about 100 ft has skarn zone that strikes N. 10° W. and dips 45° NW. along fracture in marble. Skarn minerals are quartz, garnet, epidote, pyroxene, and idocrase.	One prospect pit	One chip sample contained no gold, silver, or tungsten.
10	Unnamed prospect	A skarn zone strikes N. 80° E. and dips 45° SE. along marble screen-granitic rocks contact.	One prospect pit	One chip sample contained no gold, silver, or tungsten.
11*	Unnamed prospect	A near-vertical fault zone about 10 ft wide strikes N. 65° E. for over 3/4 mi along contact separating granitic rocks on north from sedimentary rocks on south. Fault zone contains manganese and iron oxides.	Two shafts 15 and 17 ft deep and three prospect pits.	Three chip samples had 0.1 oz/ton silver and one chip sample had a trace silver. Three chip samples contained 0.14 pct, 0.70 pct, and 0.93 pct manganese.
12*	Hanks Lost Mine prospect	A nearly vertical fault zone about 10 ft wide which strikes N. 65° E. has manganese oxide occurring as fracture fillings and disseminations in quartz veinlets.	One shaft 70 ft deep and one 30-ft adit.	One select sample contained 6.7 pct manganese.
13*	Bonanza Queen prospect	A nearly vertical fault zone that strikes N. 65° E. has azurite and malachite in shear zone 3 ft wide.	One shaft 25 ft deep	One select sample had 1.9 pct copper.

INTRODUCTION

Area Description

The part of the Fish Creek Mountains Wilderness Study Area (CDCA-372) that was studied for this report occupies approximately 16,882 acres in western Imperial County, Calif. (fig. 1). One of the easternmost ranges of the Peninsular Ranges province, the Fish Creek Mountains rise above the broad, flat, alluvium-filled Imperial Valley that lies to the northeast. The sedimentary deposits in the study area

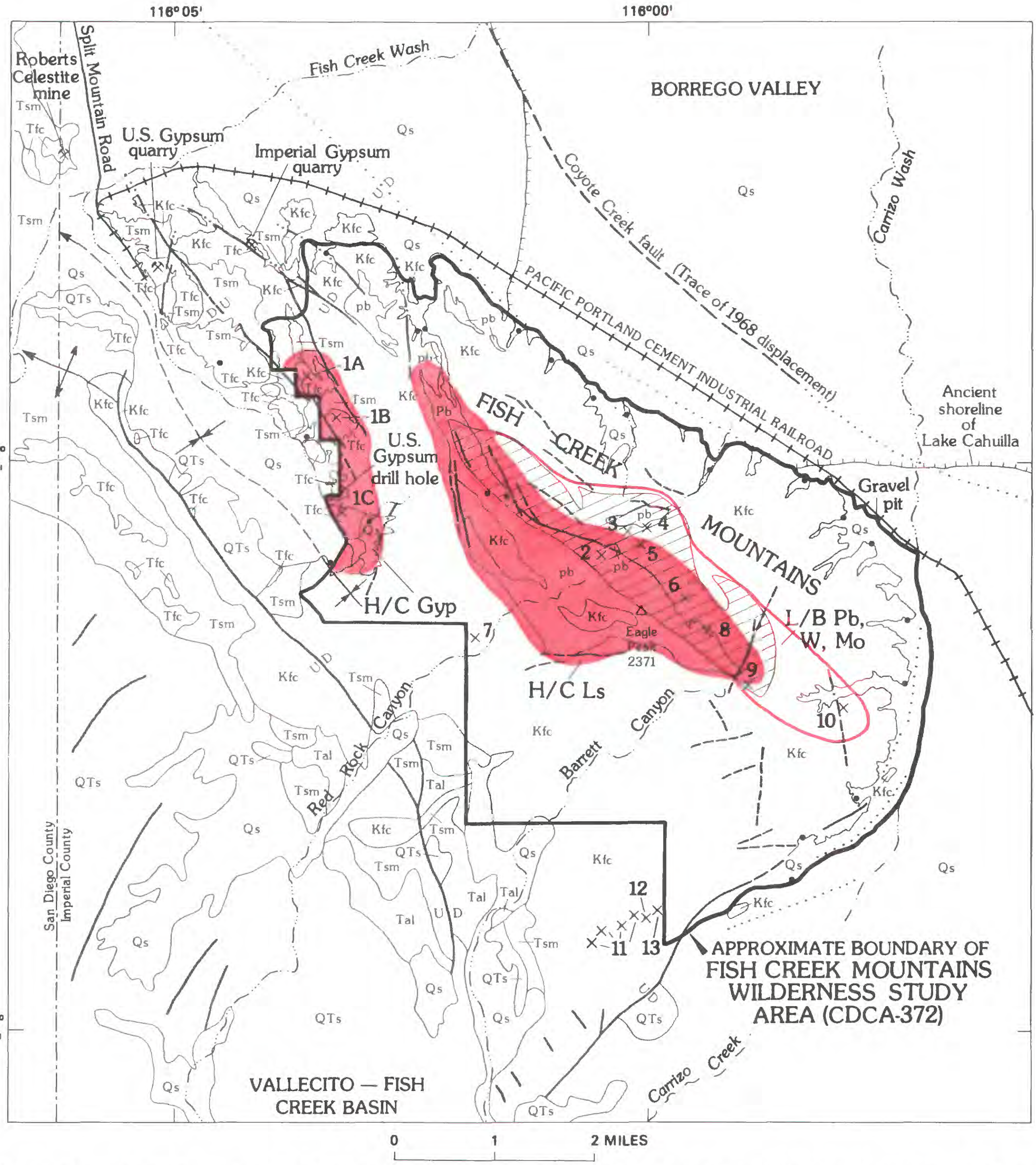

Figure 2. Mineral resource potential and generalized geology of the Fish Creek Mountains Wilderness Study Area, Imperial County, California. Geology of northeastern part of area by V.R. Todd; southeastern part from Morton (1977) and Woodard (1963).

are part of a thick accumulation of Neogene clastic sediments that filled the Imperial structural depression, or Salton trough, which was once connected to the Gulf of California (Dibblee, 1954). In this region, an irregular erosion surface that developed on the crystalline rocks of the Peninsular Ranges

EXPLANATION

Area with high mineral resource potential

Area with low mineral resource potential

See appendix for definition of levels of mineral resource potential and certainty of assessment

Commodities

Mo	Molybdenum
Pb	Lead
W	Tungsten
Gyp	Gypsum
Ls	Limestone

Geologic map units

Qs	Surficial deposits (Quaternary)
QTs	Sedimentary rocks (Quaternary and Tertiary)—Palm Spring and Imperial Formations
Tfc	Fish Creek Gypsum (Tertiary)
Tal	Alverson Andesite (Tertiary)
Tsm	Split Mountain Formation (Tertiary)
Kfc	Plutonic rocks of Fish Creek Mountains (Cretaceous)
pb	Prebatholithic metasedimentary rocks (Paleozoic?)

Contact

U / D — High-angle fault—Dashed where approximately located or inferred; dotted where concealed. U on upthrown side, D on downthrown side

Brittle shear zone

Anticline

Syncline—Dashed where concealed

Stream-sediment sample site

Mine or quarry with recorded past production

×11 Prospect—See table 1 for description

Figure 2. Continued.

batholith is overlain by Neogene clastic sediments derived both from the adjacent mountain ranges and from the area drained by the Colorado River to the east. These deposits represent virtually continuous deposition over the last 24 m.y. and probably attain thicknesses greater than 20,000 ft in the Imperial Valley.

The roughly triangular shape of the Fish Creek Mountains reflects the origin of the range as an upfaulted basement block. The northeast and southeast flanks of the range are bounded by faults of the San Andreas fault system along which the mountain block has been uplifted repeatedly and tilted gently to the southwest during the past 24 m.y. As a result of faulting, the northeast and southeast faces of the range are extremely steep and rugged. Relief varies from near sea level at the east boundary of the study area to 2,371 ft at Eagle Peak on the crest of the range. The climate of the region is arid with rainfall ranging between 3 and 4 in. per year (Morton, 1977), and summer daytime temperatures often exceed 110 °F.

The study area is drained on the northeast by Carrizo Creek and Fish Creek Wash and their tributaries, all of which flow into the Salton Sea (fig. 1). The study area is located about 2 mi east of the Anza-Borrego Desert State Park and is bounded on the southwest by the Carrizo Impact Area, an inactive bombing range that is administered by the Anza-Borrego Desert State Park. The study area overlaps the Recovery Parachute Test Range on the east. Access to the study area is by Split Mountain Road, which connects California Highway 78 in Ocotillo Wells with the U.S. Gypsum quarry at the northwest end of the range. An unimproved dirt road runs along the northeast flank of the range parallel to the narrow gauge Pacific Portland Cement Industrial Railroad, which runs from the U.S. Gypsum quarry to Plaster City.

Previous and Present Investigations

This mineral resource study is a joint effort by the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM). The history and philosophy of such joint mineral surveys of U.S. Bureau of Land Management (BLM) study areas are discussed by Beikman and others (1983). Mineral assessment methodology and terminology are discussed by Goudarzi (1984). Studies by the USGS are designed to provide a reasonable scientific basis for estimating the possibilities for the existence of undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, and presence of geochemical and geophysical anomalies. The USBM evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, and mineralized areas.

The Fish Creek Mountains Wilderness Study Area includes parts of the Borrego Mountain SE, Harpers Well, Plaster City NW, and Carrizo Mountain NE 7.5-minute quadrangles. Published geologic maps describe the geology of the Imperial Valley region

(Loeltz and others, 1975; Morton, 1977), while unpublished mapping was provided by T.W. Dibblee, Jr. (written commun., 1943), for part of the Fish Creek Mountains. The U.S. Geological Survey carried out field investigations in the study area between 1983 and 1985. The work included mapping, whole rock and stream sediment sampling for geochemical analysis and radiometric dating, and aeromagnetic and gravity surveys. Twenty-three panned heavy-mineral concentrates from stream-sediment samples were analyzed; the analytical data are given in Detra and Kilburn (1985).

The U.S. Bureau of Mines conducted a library search for information on mines and prospects in and adjacent to the study area. Mines and prospects near the study area were described by Tucker (1926) and Sampson and Tucker (1942). These data were supplemented by information from U.S. Bureau of Land Management mining claim and land status records and U.S. Bureau of Mines Mineral Industry Location System. Field studies by U.S. Bureau of Mines personnel were carried out in the fall of 1983 (Campbell, 1986). Rock samples were checked for radioactivity and fluorescence and were analyzed for a variety of elements by fire-assay, inductively coupled plasma, chemical, and semiquantitative spectrographic methods. Detailed sample data are presented in Campbell (1986).

Regional Geologic Setting

The Fish Creek Mountains Wilderness Study Area is part of the Peninsular Ranges batholith of southern California, U.S.A., and Baja California, Mexico. The batholith is composed of hundreds of plutons of variable compositions that range in age from about 130 to 80 Ma (Cretaceous Period) (Silver and others, 1979). The original eastern limit of the batholith is uncertain, although it probably extended at least as far as northwestern Sonora, Mexico. Beginning in Miocene time, the eastern part of the batholith was disrupted by the San Andreas fault and the opening of the Gulf of California. In Imperial County, the batholith is overlapped by marine and continental sedimentary deposits that range in age from Miocene (24 to 5 Ma) to Holocene (10,000 yr to present).

Batholithic rocks in western Imperial County were intruded during and after the last stages of regional deformation (Todd and Shaw, 1979). Deformation structures in plutons include foliation, lineation, and tight isoclinal folds whose axial planes are coplanar with foliation. Contacts between these plutons, and between plutons and screens of metasedimentary rocks, are broadly concordant with these structures. Most contacts dip steeply (60^{o} to 75^{o}).

The wallrock screens in Imperial County consist of metasedimentary rocks that were originally quartz-rich sandstone, shale, and limestone deposited in a relatively shallow continental shelf sea (Hill, 1984; Gastil and Miller, 1984). The rocks are as yet undated, but contain thick carbonate sequences that resemble carbonate rocks in the Coyote Mountains about 10 mi to the south that were dated by Miller and Dockum (1983) as Ordovician.

Andesite and basalt were erupted in the central part of the batholith in California and in northern Baja California in Miocene time (Minch and Abbott, 1973). Volcanism was approximately contemporaneous with the inception of faulting on the San Andreas system and the opening of the Gulf of California. Folding, faulting, and localized subsidence and uplift related to these tectonic events continue to affect the regions marginal to the Gulf of California to the present time. In the study area, thick Miocene and Pliocene marine and continental clastic sediments that once filled the Imperial depression were largely eroded off the upfaulted Fish Creek Mountains block. Interbedded andesitic flows and marine and continental sediments of presumed Miocene age are exposed 2 to 3 mi southwest of the study area.

Acknowledgments

The authors gratefully acknowledge R.J. Beckman, Senior Staff Geologist, United States Gypsum Company, Chicago, Ill., for providing information concerning the Fish Creek Mountains gypsum deposits. We also thank personnel of the El Centro and Riverside district offices of the U.S. Bureau of Land Management for advice on access to the study area and for generously making their records available to us. The Anza-Borrego Desert State Park gave permission for helicopter landings in the state park adjacent to the study area.

APPRAISAL OF IDENTIFIED RESOURCES

By Harry W. Campbell, U.S. Bureau of Mines

History and Production

No mines or mining districts are present in the Fish Creek Mountains Wilderness Study Area. A large gypsum mine owned and operated by the U.S. Gypsum Company lies 1.5 mi west of the study area (the U.S. Gypsum quarry) (fig. 2). The Imperial Gypsum quarry (fig. 2) produced a small, unknown tonnage of gypsum that was marketed as a soil conditioner in the Imperial Valley (Morton, 1977). The U.S. Gypsum Company has 18 unpatented placer claims inside the study area.

Completion of the San Diego and Arizona Eastern Railroad (fig. 1) in 1920 permitted the Fish Creek Mountains gypsum deposits to be mined. Imperial Gypsum and Oil Corporation acquired a large block of gypsum claims in the Fish Creek Mountains and constructed a narrow gauge railroad from the San Diego and Arizona Eastern track to the deposit in 1922. The first shipment of crude gypsum was made in 1922. In 1924, Pacific Portland Cement Company bought the Fish Creek Mountains gypsum operations and built a calcining plant (Plaster City plant) at the junction of the narrow gauge railroad with the main line. The Plaster City plant and quarry were sold in 1945 to U.S. Gypsum Company who modernized and expanded the operation (Ver Planck, 1952, p. 71, 72; Pressler, 1984, p. 425; Burnett, 1984, p. 8). In 1971, the U.S. Gypsum quarry produced 742,000 tons of gypsum, making it the largest operating gypsum mine in the United States (Appleyard, 1975, p. 715).

About 8,000 tons of strontium ore (celestite) was shipped from the Roberts Celestite mine (fig. 2), mostly during World War II (Morton, 1977). Sand and gravel were quarried from a gravel pit east of the study area (fig. 2) and used for fill, aggregate, and ballast. A small quantity of manganese may have been produced from the Hanks Lost Mine prospect southwest of the study area (fig. 2, No. 12). Oil and gas leases are held in and near the study area (U.S. Bureau of Land Management, written commun., 1986). No other mining claims or mineral leases are known inside the study area.

Mineral Deposits

Four types of deposits were examined by the U.S. Bureau of Mines: (1) bedded gypsum deposits; (2) limestone in a large screen; (3) small carbonate bodies with skarn and (or) clay alteration zones; and (4) sand and gravel in alluvial fan and ancient lacustrine shoreline deposits. In addition, a tungsten prospect and three manganese prospects (the latter outside the study area) were examined.

Three gypsum deposits are present inside the study area (fig. 2, Nos. 1A, 1B, and 1C), although none of the gypsum has been mined. Gypsum outcrops in an area southeast of the U.S. Gypsum quarry (fig. 2) are remnants of a once-continuous bed (Ver Planck, 1957, p. 233). At this site, gypsum is preserved in the gently dipping limbs of a synclinal basin. The axis of this syncline lies under alluvium in the wash west of the quarry (fig. 2). Gypsum beds on the east and west synclinal limbs are exposed along the margins of this wash. Within the study area, gypsum in deposits 1A and 1B is present as relatively small, isolated veneers that overlie a zone of thin, interbedded gypsiferous clay and sand layers. Massive gypsum more than 100 ft thick is found in the study area at deposit 1C. The degree to which the deposit has been hydrated is unusually high (Appleyard, 1975, p. 715); however, there are lenses and layers of anhydrite in the gypsum unit. Most massive gypsum and anhydrite deposits are present as large, lenticular stratified bodies formed by the evaporation of lake or sea water in basins with restricted outlets. Results of a 174-ft hole drilled in the study area (fig. 2) by U.S. Gypsum Company in 1985 showed 117 ft of massive gypsum overlain by 36 ft of alluvium. The gypsum content of the unit ranges from 89.9 to 99.4 percent as determined by analyses of samples taken at 5-ft intervals (R.J. Beckman, written commun., 1985). Gypsum content is consistently more than 85 percent in the massive gypsum bed throughout the region. Deposits 1A, 1B, and 1C (fig. 2) contain an estimated 600,000 tons, 100,000 tons, and 20 million tons, respectively, of gypsum. Resource estimates were based on data from surface samples, outcrops, aerial photographs, topographic maps, geologic inference, and the drill hole inside the study area.

Limestone is present inside the study area at the Waters prospect (fig. 2, No. 2). The prospect covers 1,200 acres and is located near the crest of the Fish Creek Mountains. The limestone is in a large screen composed chiefly of metasedimentary rocks of Paleozoic(?) age intruded by Cretaceous(?) granitic rocks. The maximum exposed stratigraphic thickness of the limestone at the Waters prospect is about 2,700 ft. The lower 1,200 ft consists of gray- and brown-weathered dolomite with numerous granitic dikes that diminish in number upsection. The upper 1,500 ft of carbonate rock is composed of light-gray, fine- to coarse-grained marble (Morton, 1977).

Prospects 3 through 6 and 8 through 10 (fig. 2) occur along a northwest trend in the east-central part of the study area. Pits and small shafts were dug on and near carbonate bodies with skarn and (or) clay alteration zones. Samples taken from these mineral occurrences did not contain significant amounts of economic elements, but minor amounts of zinc, copper, manganese, and barium were found. The nearly linear trend of these prospects suggests that mineralization may have been related to a northwest-trending fault zone.

Prospect 7 (fig. 2) in the west-central part of the study area lies within a northwest-trending shear zone that follows a contact between granitic and dioritic rocks. Numerous pegmatite dikes are present near the prospect. Morton (1977, pl. 1) designated this site as a tungsten prospect, however, three samples from this prospect did not contain significant amounts of tungsten, molybdenum, gold, or silver.

Prospects 11 through 13 (fig. 2) are south and west of the study area boundary. Shafts, pits, and an adit occur along a northeast-trending fault zone. A select sample from prospect 12 had 6.7 percent manganese, but manganese values were not consistent in the exposed part of the shear zone. A select sample from prospect 13 had 1.9 percent copper. Mineralization along this fault zone does not appear to continue into the study area.

Sand and gravel in alluvial fan and ancient lacustrine shoreline deposits are present along the northeast and east boundaries of the study area. These commodities were quarried just outside the east boundary of the study area (fig. 2) and used for fill, aggregate, and railroad ballast. This quarry was leased by the California Department of Transportation during the 1960's as a potential source of aggregate and fill for local road construction projects (California Department of Transportation, oral commun., 1984).

A brief description of mineral properties examined by the U.S. Bureau of Mines during this study is contained in table 1.

Appraisal of Mineral Resources

The gypsum resources within the study area (fig. 2, Nos. 1A, 1B, and 1C) are classified as "inferred reserves" (U.S. Bureau of Mines and the U.S. Geological Survey, 1980) because they are an extension of a gypsum bed that has been continuously mined since 1922, and their size, quality, and location are such that profitable extraction is possible under current economic conditions. The term "inferred" was applied because the size, shape, and mineral content of the gypsum deposits were not established well enough to assume continuity between points of observation. Although the general geologic character of the deposits is well understood, local folding and faulting introduce enough uncertainty that more accurate resource estimates cannot be made with present data. Also, subsurface sample data are not sufficient to reliably estimate the impurities within the gypsum bed, particularly the amount of anhydrite. However, the gypsum was deposited as one extensive sedimentary unit, and sample data from widely spaced sites show uniformly high purity of gypsum. This suggests that the deposits contain high-grade material that can be used with no beneficiation beyond crushing, grinding, and calcination. Inside the study area, and west of deposit 1C, are 25 acres of thick-bedded gypsum with sand and gravel overburden that could be mined economically by open-pit methods. Most of the facilities required for transport and manufacturing of gypsum are already established adjacent to the study area by the U.S. Gypsum Company.

The Waters prospect in the central part of the study area (fig. 2, No. 2) has large quantities of limestone. The deposit is large, has little overburden, and could be quarried by the relatively low-cost method of level benches driven into the hillside. Preliminary sampling suggests the limestone is suitable for many commercial purposes, including cement manufacture, and gypsum and clay also necessary for cement production are nearby. However, the deposit has not been developed because more accessible limestone deposits have been mined 19 and 13 mi south of the study area in the Dos Cabezas mining district and in the Coyote Mountains. Furthermore, igneous dikes and silicified patches in the Waters prospect limestone would hinder mining, and access to the deposit on the crest of the Fish Creek Mountains is difficult. Much of the deposit is within 2 mi of the U.S. Gypsum Company narrow gauge railroad, and the deposit is near two major marketing centers, San Diego and Los Angeles.

Sand and gravel in alluvial fan and ancient shoreline deposits are abundant along the northeast and east boundaries of the study area. Because there are adequate deposits outside the study area, it is unlikely that development of the sand and gravel deposits in the study area would be necessary.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Victoria R. Todd, David E. Detra, James E. Kilburn, Andrew Griscom, and Fred A. Kruse

U.S. Geological Survey

Geology

Dibblee (1954) described the crystalline rocks of the Fish Creek Mountains as "a series of gneisses, gneissoid granites, and scattered lentils of marble"; "hornblende-rich diorite, with facies of quartz diorite and gabbro" were the dominant intrusive rocks. Geologic mapping for the present study shows that the range is underlain by a single large composite pluton, here informally called the Fish Creek Mountains pluton, that probably is part of the late-tectonic to posttectonic intrusive sequence (Todd and Shaw, 1979). A similar pluton 20 mi west of the study area has been dated by uranium-lead zircon method at 100 Ma (L.T. Silver, personal commun., 1979). A large posttectonic pluton in the region has uranium-lead zircon ages of 98, 97, and 95 Ma (Silver and others, 1979; Clinkenbeard and others, 1986). By analogy, the Fish Creek Mountains pluton is tentatively considered to be Late Cretaceous in age. The Fish Creek Mountains pluton ranges in composition from hornblende-biotite tonalite through biotite granodiorite to muscovite-biotite granite. Abundant pegmatite dikes probably are related to the late granite phase. Areas of relatively massive tonalite and granite are present locally, but much of the pluton was strongly deformed at metamorphic temperatures, probably during and closely following its emplacement. Much, but not all, of the strong deformation fabric probably resulted from flow against abundant wallrock screens during intrusion. Fabric elements, including mineral foliation in granitic rocks and wallrock inclusions and preferred orientation of wallrock screens and granitic dikes, compose a northwest-striking, northeast-dipping structural grain in the deformed parts of the pluton. Field relations suggest that the Fish Creek Mountains pluton intruded folded metasedimentary wallrocks and that some folding continued after intrusion.

Screens and inclusions of wallrocks in the Fish Creek Mountains pluton consist of high-grade metasedimentary rocks and lesser amounts of gabbro and related fine-grained mafic rocks. The metasedimentary rocks include metaquartzite, quartz-rich pelitic schist and gneiss, and marble. These rock types represent quartz-rich sandstone, argillaceous sandstone, shale, and limestone deposited in a continental shelf environment. Gabbro in small deformed pods and sheet-like bodies may represent mafic magma that was coeval with the Fish Creek Mountains pluton. Some of these bodies are quartz dioritic in composition. Screens range in size from a few feet long to the one containing the Waters limestone prospect, which is about 16,000 ft long and 5,000 ft thick. Limestone, now marble, is present in many smaller screens in the study area but is typically interlayered with other metasedimentary rocks and intruded by granitic dikes. Marble from a similar metasedimentary sequence near Carrizo Mountain, about 8 mi south of the study area, contains Ordovician fossils (Miller and Dockum, 1983). This age and lithologic similarities among the metasedimentary rocks of the Fish Creek Mountains, Carrizo Mountain, and Paleozoic formations of the Great Basin suggest that the metasedimentary rocks of the Fish Creek Mountains are probably Paleozoic in age.

The wallrock screens contain as much as 50 percent concordant fine- to medium-grained granitic dikes that emanate from the surrounding Fish Creek Mountains pluton. The pluton and its dikes are heterogeneous because they were variably chilled and contaminated near metasedimentary and mafic screens. Leucocratic dikes commonly were emplaced at a later time into the contact zones. Skarns are present locally where limestone was intruded by the tonalite pluton and (or) associated granitic dikes.

The eroded Paleozoic(?) and Cretaceous crystalline rocks of the Fish Creek Mountains are overlain on the northwest and southwest by Tertiary and Quaternary sedimentary deposits. These deposits are remnants of a thick (about 20,000 ft) sequence of terrestrial and marine sediments deposited in, and adjacent to, the Salton trough. The Salton trough is a complex rift valley that has been tectonically active since Miocene time, and is the landward extension of the Gulf of California. The Vallecito-Fish Creek basin, located southwest of the Fish Creek Mountains, is one of several pull-apart basins that formed in the rift valley (Gibson and others, 1984). Present-day tectonic activity is expressed by movement on the right-lateral San Jacinto fault zone, the most active strand of the San Andreas system, which includes the Coyote Creek fault (fig. 2).

The stratigraphic nomenclature for the Tertiary rocks in the study area is from Morton (1977). The Split Mountain Formation of Miocene age crops out in the northwestern part of the study area (fig. 2). The Split Mountain Formation formed as a series of coalescing alluvial fans during the early phase of uplift of the Fish Creek and adjacent ranges (Gibson and others, 1984). The formation interfingers with andesite about 1.5 mi southwest of the study area. The Salton trough was flooded by marine waters in latest Miocene and earliest Pliocene time (Bell-Countryman, 1984). The Fish Creek Gypsum, here considered Miocene in age, depositionally overlies the Split Mountain Formation and formed as a lagoonal evaporite deposit near the shoreline of the advancing sea. Although the age of the Fish Creek Gypsum remains controversial, the formation is considered to be part of the Split Mountain Formation by Woodard (1974) and is interpreted as Miocene in age by Dibblee (1984). As the basin continued to subside, a shoaling series of alluvial fan, shoreline, and deep-water marine deposits were deposited rapidly. These deposits form the Imperial Formation of Pliocene age (Bell-Countryman, 1984), which includes silts and clays carried by the ancestral Colorado River from the continental interior. Gradationally overlying these predominantly marine deposits is the Palm Spring Formation of Pliocene and Pleistocene age (Quinn and Cronin, 1984), a sequence of brackish water to lacustrine sediments with marine interbeds. The Imperial and Palm Spring Formations, shown as the Quaternary and Tertiary sedimentary rocks unit in figure 2, form a southwest-dipping homocline southwest of the study area.

In late Pliocene(?) time, the Vallecito-Fish Creek basin underwent broad east-west folding and 35° clockwise rotation as a result of right-lateral shear in the San Andreas fault system (Gibson and others, 1984). The homocline southwest of the study area is part of a large northwest-trending syncline that probably formed during late Pliocene folding. The smaller northwest-trending syncline that underlies the U.S. Gypsum quarry (fig. 2) probably formed during the same episode of folding. These folds are broken by high-angle faults with northwest and northeast trends. The Fish Creek Mountains probably began to rise as a large northwest-trending anticlinal uplift sometime during Pliocene time, and continued to be elevated by complex high-angle faults along the northeast and southeast flanks of the range. The range-bounding faults may still be active, as suggested by movement on the Coyote Creek fault during the Borrego Mountains earthquake (magnitude 6.4 Richter) in 1968 (Clark, 1972).

One of the most recent geologic features in the region was ancient Lake Cahuilla whose high shoreline bounded the northeast flank of the Fish Creek Mountains. A thin coating of travertine on the mountain front, a gravel beach, and finer-grained, nearshore lake deposits are preserved in this area. The lake originated by periodic overflow and diversions of the Colorado River into the Salton trough (Morton, 1977). Although it probably existed as recently as several hundred years ago, the lake's highest level occurred much earlier--possibly during Wisconsin glacial time or shortly thereafter.

Geochemical Investigations

A reconnaissance geochemical survey of stream sediments was conducted in the study area by the U.S. Geological Survey. Heavy mineral concentrates were derived from twenty-three samples collected in major washes near the range fronts (fig. 2). The washes drain basins ranging in size from less than one to several square miles. Red Rock and Barrett Canyons (fig. 2), which drain the most heavily mineralized part of the brittle shear zone (prospects 3, 4, 5, 7, 8, and 9), were not sampled because they lie within the Carrizo Impact Area, a former Naval bombing range. Each sample was sieved through a No. 10-mesh screen to remove the coarsest material and divided into light and heavy fractions using a bromoform mineral separation technique. The heavy fraction was further separated using a magnetic separator. All samples were analyzed by a six-step semiquantitative emission spectrographic method (Grimes and Marranzino, 1968) for 30 elements. A complete listing of the analytical techniques and results can be found in Detra and others (1985). In addition, concentrates were analyzed for mineral identification.

Geochemical anomalies detected within and adjacent to the Fish Creek Mountains Wilderness Study Area may reflect diverse mineralizing processes. The collective trace-element suite includes barium, tin, tungsten, molybdenum, lead, strontium, and silver. The anomalies are limited to the north half of the study area with the exception of barium and tin. In addition, widespread scheelite and barite as well as localized occurrences of celestite, anglesite, and cerussite were identified optically in the concentrates.

Anomalous tungsten concentrations and scheelite are probably related to skarn deposits that are commonly present along contacts between metasedimentary rocks and intrusive phases of the Fish Creek Mountains pluton. Lead and molybdenum are found coincident with tungsten anomalies at two sites in the north-central part of the study area. These two elements are common constituents of tungsten-bearing skarns and may be related to skarn mineralization. Laser microprobe studies of metallic inclusions in dolomite grains from these sites, however, revealed anomalous concentrations of lead, zinc, and copper. Conceivably, the lead and molybdenum anomalies may also have originated from such metallic inclusions in dolomitic rocks of screens. Anomalous concentrations of lead and molybdenum are found in streams that drain the northwest corner of the Fish Creek Mountains. These differ from the previously mentioned lead and molybdenum anomalies by the absence of tungsten at both localities, and the presence of silver at the southern site. Anglesite and cerussite, both alteration products of galena, were identified optically in this sample. These geochemical anomalies and associated lead minerals may reflect minor hydrothermal systems and (or) local metasomatism.

Anomalous concentrations of strontium are found in the north-central and northwestern parts of the study area. Celestite is present in the samples and probably originates from known celestite deposits that occur as thin beds and erosional remnants that overlie massive gypsum deposits in the region (Morton, 1977).

Ubiquitous anomalous concentrations of tin appear to be a regional characteristic associated with the late-tectonic to posttectonic intrusive sequence. Although no mineralogic or lithologic host was determined, it is possible that much of the tin occurs in accessory minerals disseminated throughout the late-tectonic to posttectonic granitic rocks. Locally, skarns and pegmatites may have contributed to the anomalies.

The mineral host for the widespread anomalous concentrations of barium is barite, which was identified in most of the samples. The origin of the barite is uncertain. High barium values (more than 10,000 ppm) coincide with the anomalous concentrations of strontium mentioned above and may indicate a sedimentary origin for barite in the northern part of the Fish Creek Mountains.

An isolated anomalous concentration of lead found on the east edge of the study area probably came from contaminating lead shot.

Geophysical Investigations

Five aeromagnetic and gamma-ray spectrometer profiles (High Life Helicopters, Inc., and QEB, Inc., 1980a and 1980b; LKB Resources, Inc, 1980) cross the study area. The data were collected along east-west and north-south traverses by helicopter at a height of 400 ft above ground. The magnetic data are nearly featureless because none of the rocks within the study area are particularly magnetic. One radioactivity profile (line 11 of High Life Helicopters, Inc., and QEB, Inc., 1980a) shows a uranium anomaly (anomaly 3, Ibid., 1980a) that meets the minimum statistical requirements of the NURE program for a uranium anomaly. The anomaly is located near (but probably about 0.4 mi beyond) the west side of the study area in section 4 of T. 14 S., R. 9 E. The associated rocks are Tertiary sediments, and the cause of the anomaly is unknown. The anomaly does not significantly affect the mineral potential of the study area because the geology of the study area is here restricted almost entirely to pre-Tertiary crystalline rocks.

Gravity data available for the study area (Oliver and others, 1980; Roberts and others, 1981) represent only about 5 stations and do not contribute significantly to the mineral resource appraisal of the area.

The limonite mineral group has unique spectral reflectance characteristics that can be detected on Landsat images using a color-ratio compositing technique described by Rowan and others (1974). This technique was used to look for areas of limonite in the Fish Creek Mountains Wilderness Study Area. Limonite occurrences in exposed bedrock are considered anomalous and may indicate the presence of hydrothermal alteration. Two large limonite anomalies were identified in the study area and one large area was identified just to the west of the study area. A linear anomaly that extends from the north boundary of the study area southeast to the head of Red Rock Canyon (just northwest of BM2371) corresponds to the northwestern part of the large metasedimentary screen that contains the Waters prospect (fig. 2, No. 2). A second anomaly with a total area of approximately 4 square miles occurs in granitic rocks containing abundant pegmatite dikes near the east end of the Fish Creek Mountains. A curvilinear alignment of limonite anomalies just west of the western boundary of the study area appears to be associated with exposures of Tertiary volcanic rocks.

Conclusions

Geologic, geochemical, and geophysical studies indicate that the Fish Creek Mountains Wilderness Study Area contains three main types of mineral occurrences, one associated with Tertiary sedimentary deposits and the other two with pre-Cenozoic plutonic and metasedimentary rocks.

Miocene strata in the region locally contain bedded gypsum deposits of high purity, such as those mined by the U.S. Gypsum Company at the U.S. Gypsum quarry 1.5 mi west of the study area. Known but unmined gypsum deposits and additional gypsum are present under alluvium in the northwest part of the study area. The northwestern part of the study area is assigned high resource potential, certainty level C, for gypsum (fig. 2). See appendix for definition of levels of mineral resource potential and certainty of assessment.

Metasedimentary strata of Paleozoic(?) age that are present as screens within the Fish Creek Mountains pluton contain relatively abundant carbonate (now marble). There is high resource potential, certainty level C, for limestone in the large northwest-trending metasedimentary screen in the central part of the study area that includes the Waters prospect (fig. 2). Limestone in smaller screens in the study area does not have resource potential.

Seven prospects in the east-central part of the study area are located in skarn and (or) clay alteration zones along a northwest-trending brittle shear zone. Rock samples from these prospects contained minor amounts of zinc, copper, manganese, and barium. The northwest-trending shear zone consists of a number of subparallel faults that follow northwest-trending Cretaceous structures. The zone is localized along the margins of the large central screen and can be traced to the northwest corner of the range where numerous smaller, carbonate-bearing screens are present (fig.

2). Local metasomatism and (or) hydrothermal alteration with minor mineralization of the metasedimentary rocks in this shear zone probably are responsible for the anomalous concentrations of lead (in cerussite and galena), tungsten (in scheelite), and molybdenum in stream sediments in the north half of the study area. Lead and molybdenum were also detected locally in metallic inclusions in dolomite grains. The part of the study area that is underlain by this shear zone has a low resource potential, certainty level B, for lead, tungsten, and molybdenum in skarns of metasomatic and (or) hydrothermal origin (fig. 2). Included in this area of low resource potential is a zone of north-trending faults and small carbonate-bearing bodies in the eastern part of the study area.

Anomalous concentrations of strontium (in celestite) and barium (in barite) in stream sediments in the north-central and northwest parts of the study area probably are associated with the gypsiferous Miocene strata, as indicated by bedded celestite containing minor gypsum in the Roberts Celestite mine, 3 mi northwest of the study area. Barite and barium anomalies are ubiquitous in the Fish Creek Mountains, suggesting that the mineral may also have formed small replacement bodies in crystalline rocks from hydrothermal solutions moving through fault zones. However, no deposits of celestite or barite are present within the study area, and no resource potential is assigned for these minerals.

Oil and gas leases are held in the eastern one-third of the study area, but no potential for hydrocarbon resources exists because this area is underlain by crystalline rocks. Relatively abundant sand and gravel deposits extend into the study area from Borrego Valley and Carrizo Wash (fig. 2), but these deposits do not have resource potential.

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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><th rowspan="4">LEVEL OF RESOURCE POTENTIAL →</th><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></td><td>A</td><td>B</td><td>C</td><td>D</td></tr>
</table>

LEVEL 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.

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GEOLOGIC TIME CHART

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

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES (in Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~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 Ma also called Precambrian, a time term without specific rank.

[2]Informal time term without specific rank.

GPO 785-048/77388

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849