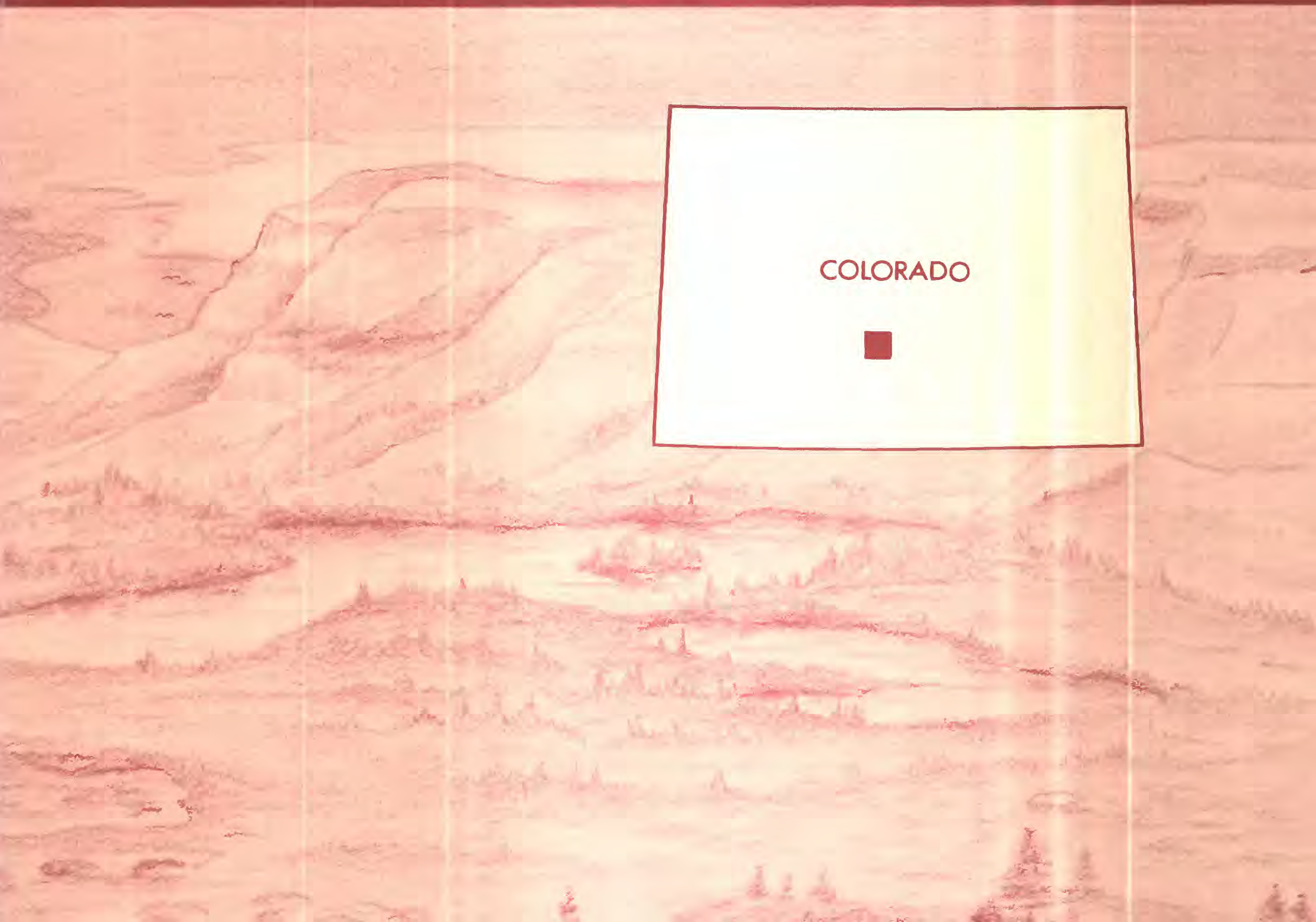
Mineral Resources of the Black Canyon and South Piney Creek Wilderness Study Areas, Saguache County, Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1716–A



DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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

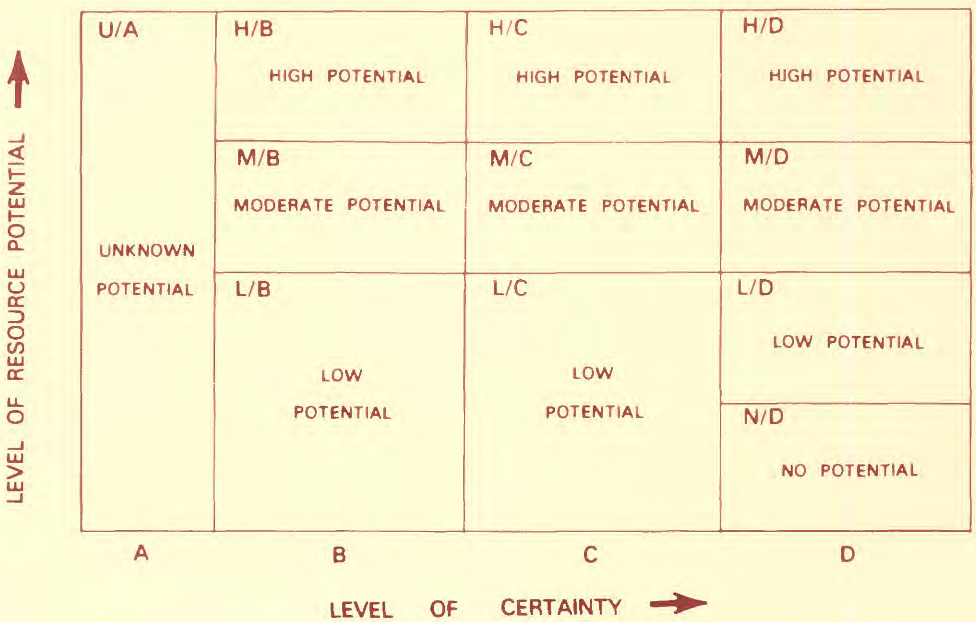
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application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

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

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

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

Levels of Certainty



A. Available information is not adequate for determination of the level of mineral resource potential.
B. Available information suggests the level of mineral resource potential.
C. Available information gives a good indication of the level of mineral resource potential.
D. Available information clearly defines the level of mineral resource potential.

Abstracted with minor modifications from:

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

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

Goudarzi, G. H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–0787, p. 7, 8.

Chapter A

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
NORTH-CENTRAL COLORADO

Mineral Resources of the Black Canyon and South Piney Creek Wilderness Study Areas, Saguache County, Colorado

By David A. Lindsey, Jerry R. Hassemer,
Gerda A. Abrams, and Richard B. Taylor,
U.S. Geological Survey and

Brian J. Hannigan,
U.S. Bureau of Mines

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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 Black Canyon (CO–050–131) and South Piney Creek (CO–050–132B) Wilderness Study Areas, Saguache County, Colorado.

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Mineral Resources of the Black Canyon and South Piney Creek Wilderness Study Areas, Saguache County, Colorado

By David A. Lindsey, Jerry R. Hassemer, Gerda A. Abrams, *and* Richard B. Taylor, U.S. Geological Survey *and* Brian J. Hannigan, U.S. Bureau of Mines

SUMMARY

The Black Canyon (CO–050–131) and South Piney Creek (CO–050–132B) Wilderness Study Areas have identified resources of agricultural limestone and dolomite; both areas have moderate mineral resource potential for base and precious metals and high potential for high-purity limestone and dolomite (fig. 1). This conclusion is based in part on an earlier report on the mineral resources of the Sangre de Cristo Wilderness Study Area (Johnson and others, 1984) and on new field studies done in 1984.

The Black Canyon (1,100 acres) and South Piney Creek (860 acres) Wilderness Study Areas are on the western side of the Sangre de Cristo Range in Saguache County, Colorado, adjacent to the Sangre de Cristo Wilderness Study Area and the Rio Grande National Forest (fig. 2, pl. 1). They are accessible by roads extending 5–6 mi (miles) east from U.S. Highway 285 and Colorado State Highway 17, south of Villa Grove, Colo. The study areas range in elevation from about 9,000 ft (feet) along their western borders to 11,536 ft in the Black Canyon Wilderness Study Area and 11,053 ft in the South Piney Creek Wilderness Study Area.

The wilderness study areas are along the western side of the rugged Sangre de Cristo Range, an uplifted block that began to form by faulting along the Rio Grande rift 25–30 million years ago. The range-bounding Sangre de Cristo fault is immediately west of the study areas; it has downdropped the San Luis Valley west of the study areas. Like rocks of the rest of the Sangre de Cristo Range, those within the study areas were folded and faulted by compressional forces during Laramide mountain building, which took place about 50–70 million years ago. Rocks in the study areas are Proterozoic gneiss (1,700–1,800 million years old), Paleozoic sedimentary rocks (300–500 million years old), and a few igneous dikes (probably 25–30 million years old).

Early Proterozoic metamorphic rocks in the study areas are overlain by Paleozoic sedimentary rocks: the Ordovician Manitou Limestone, the Ordovician Harding Sandstone, the Ordovician Fremont Dolomite, the Devonian and Mississippian(?) Chaffee Formation, the Mississippian Leadville Limestone, and the Pennsylvanian Minturn Formation. Carbonate rocks are abundant in beds of Ordovician through Mississippian age and crop out in about one-third of the study areas. Fracture zones formed by folding and faulting of carbonate sedimentary rocks are the most favorable areas for deposits of base and precious metals.

Both wilderness study areas have been prospected for base and precious metals; prospect pits and caved adits are common. Small amounts of limestone were quarried for decorative stone in Quarry Creek Canyon and Steel Canyon. The Black Canyon Wilderness Study Area is 0.5 mi north of the Orient mine, formerly an important source of limonitic iron ore for the Colorado Fuel and Iron Co. of Pueblo, Colo.

The Black Canyon and South Piney Creek Wilderness Study Areas have moderate mineral resource potential for base and precious metals (fig. 1). Areas of moderate potential are outlined by the distribution of faults and fractures that cut Paleozoic sedimentary rocks, by the occurrence of limonitic iron along the faults and fractures, and by anomalously high metal concentrations in stream sediments. Limonitic iron probably was deposited in an extensive hydrothermal system that circulated metal-bearing fluids through faults and fractures. Hydrothermal fluids were heated by nearby igneous intrusions. Although any undiscovered deposits of limonitic iron probably are not extensive enough to be minable as iron ore, they may contain resources of gold, silver, copper, lead, and zinc.

The Black Canyon and South Piney Creek Wilderness Study Areas contain identified resources of agricultural limestone and dolomite and have high resource potential for high-purity limestone in the Leadville Limestone and dolomite in the Fremont Dolomite. Decorative stone also might be found in various lower Paleozoic formations. Limestone and dolomite from the study areas may not be economically competitive with large quantities of these resources where they occur adjacent to rail and highway transportation routes along the Arkansas River or near markets.

The energy resource potential of the study areas is low. Although they are near the Valley View Hot Springs Known Geothermal Resource Area (KGRA), they

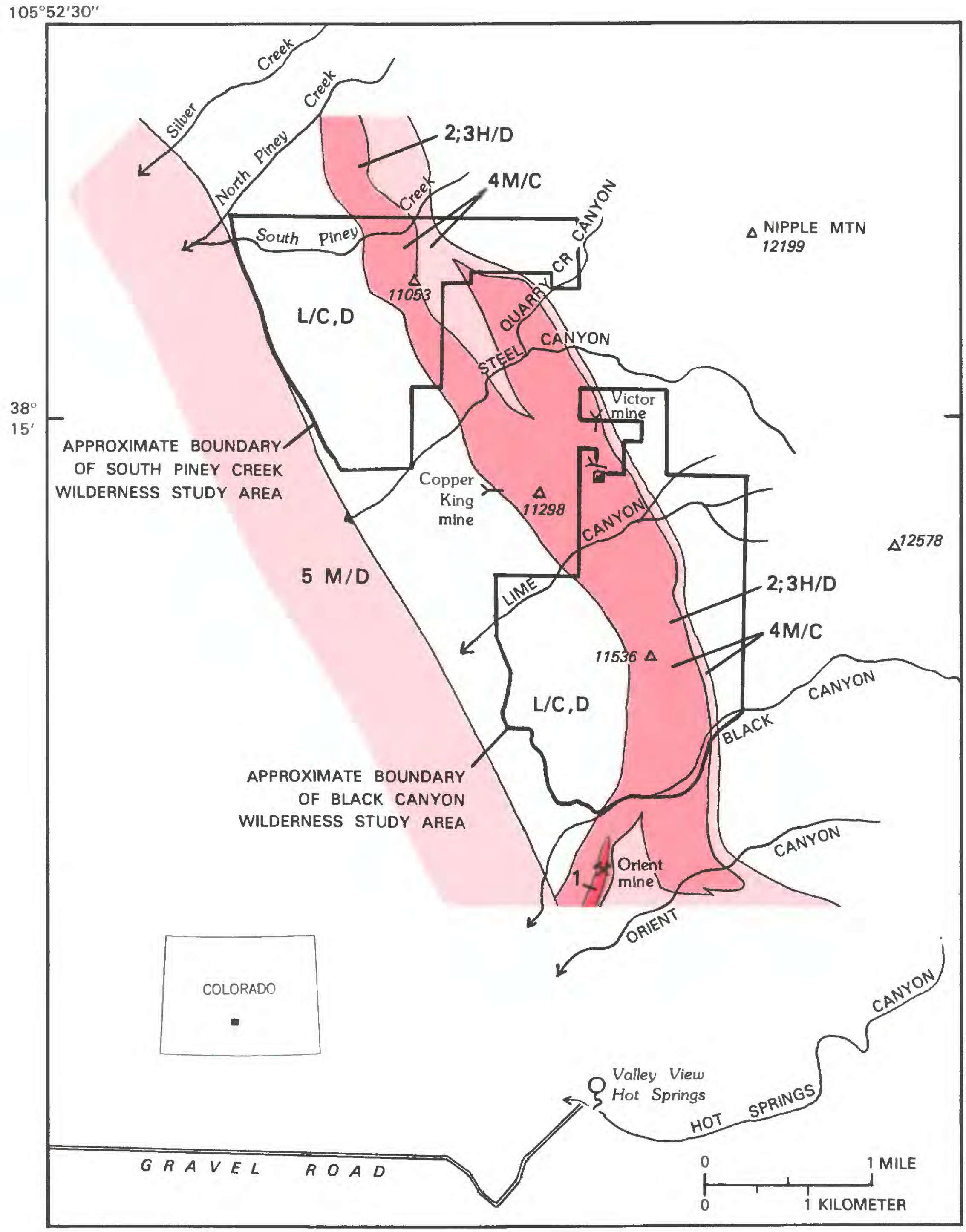

Figure 1. Summary map showing mineral resource potential and principal mines and prospects of the Black Canyon and South Piney Creek Wilderness Study Areas, Colorado.

EXPLANATION

Geologic terrane having high resource potential (commodity 3, certainty level D), moderate resource potential (commodity 4, certainty level C), and identified resources (commodity 2)

Geologic terrane having moderate resource potential (commodities 4 and 5) with certainty level C or D

Area of identified resources (commodity 1)

Commodities

1. Iron (Orient mine)
2. Limestone and dolomite for agricultural and industrial use
3. High-purity limestone and dolomite
4. Iron, gold, silver, copper, lead, and zinc
5. Low temperature ($<100^{\circ}$C) geothermal water

Levels of resource potential

H High mineral potential
M Moderate mineral potential
L Low mineral potential

Levels of certainty

A Available information not adequate
B Available information suggests level of resource potential
C Available information gives good indication of level of resource potential
D Available information clearly defines level of resource potential

Mines and prospects

Open pit
Adit
Inclined shaft

have low potential for geothermal resources because the geologic environment of the KGRA does not extend into the wilderness study areas. The geologic environment is not favorable for the occurrence of resources of coal, oil, gas, or uranium.

INTRODUCTION

The Black Canyon (CO–050–131; 1,100 acres) and South Piney Creek (CO–050–132B; 860 acres) Wilderness Study Areas are on the western side of the Sangre de Cristo Range in Saguache County, Colorado, adjacent to the U.S. Forest Service Sangre de Cristo Wilderness Study Area and the Rio Grande National Forest (fig. 2; pl. 1). They are accessible by roads extending 5–6 mi east from U.S. Highway 285 and Colorado State Highway 17, south of Villa Grove, Colo. Rough jeep and foot trails pass next to the study areas in Steel, Lime, and Black Canyons. Canyon walls are rugged and steep, especially where they have been cut through massive limestone. The elevation is about 9,000 ft at the foot of the mountains, along the western boundaries of the study areas, and reaches 11,053 ft in the South Piney Creek Wilderness Study Area and 11,536 ft in the Black Canyon Wilderness Study Area.

The present study was conducted to appraise the identified mineral resources and to assess the mineral resource potential of the Black Canyon and South Piney Creek Wilderness Study Areas, which are contiguous with the Sangre de Cristo Wilderness Study Area of the Rio Grande and San Isabel National Forests. This report supplements and refines an earlier report by the U.S. Geological Survey and the U.S. Bureau of Mines (Johnson and others, 1984) on the mineral resource potential of the Sangre de Cristo Wilderness Study Area.

Investigations by the U.S. Bureau of Mines

The Black Canyon and South Piney Creek Wilderness Study Areas were examined by the U.S. Bureau of Mines in 1983 during an investigation of the Sangre de Cristo Wilderness Study Area (Ellis and others, 1983). Prior to the field investigation, a detailed literature search was made for pertinent geologic and mining information. In January 1984, Bureau of Land Management records were checked for the location of patented and unpatented claims, and of oil and gas, geothermal, and other mineral leases in or near the study areas (Hannigan, 1984).

Field studies by Bureau of Mines personnel included investigation of prospects and mineralized areas in and within 2 mi of the study areas. Seventy-two samples were collected from two mines, an inclined adit, two shafts, five caved adits, and 24 prospects (Hannigan, 1984). All samples were analyzed by fire assay for gold and silver and for 40 elements by semiquantitative optical-emission spectrographic methods (Ellis and others, 1983). Selected samples were analyzed for base metals using atomic-absorption methods. Complete sample descriptions and analytical results are available for public inspection at the U.S. Bureau of Mines Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225.

Investigations by the U.S. Geological Survey

Since the report on the mineral resource potential of the Sangre de Cristo Wilderness Study Area (Johnson and others, 1984) was issued, new data for assessing the mineral resource potential of the Black Canyon and South Piney Creek Wilderness Study Areas has been obtained by the Geological Survey. A new geologic map at scale 1:24,000 was prepared by D. A. Lindsey in June and July of 1984; stream-sediment geochemical data used for the Sangre de Cristo report (Adrian and others, 1984) were supplemented and interpreted by J. R. Hassemer; and a new aeromagnetic survey of the northern Sangre de Cristo Range (U.S. Geological Survey, 1983) was analyzed by G. A. Abrams. A model for hydrothermal

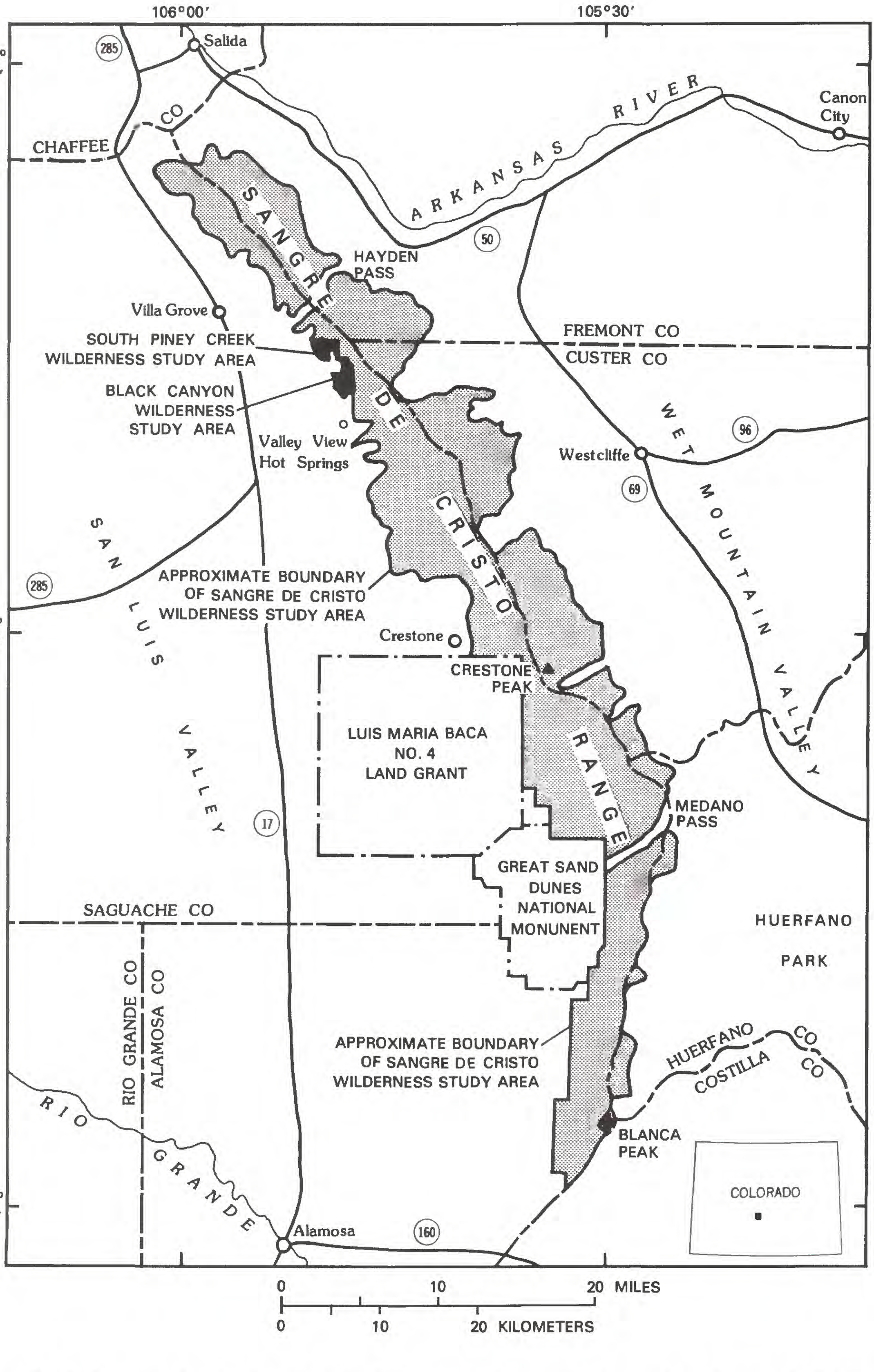

Figure 2. Index map showing location of wilderness study areas in the northern Sangre de Cristo Range, south-central Colorado.

mineralization at the Orient mine, modified for use here, was developed by R. B. Taylor. Among other sources of information, descriptions of the Orient mine (Stone, 1934) and geothermal systems in the Rio Grande rift (Swanberg, 1983) were used for assessing mineral resource potential of the study areas. In accordance with a newly devised system of mineral resource assessment (Goudarzi, 1984), the mineral resource potential of the study areas was classified as high, moderate, or low for the types of deposits likely to occur in the geologic environment there. The level of certainty of each mineral resource assessment is specified.

Acknowledgments.—We thank employees of the Bureau of Land Management in Canon City, Colo., for providing information on mineral resources from their files, and Neil Seitz of Villa Grove, Colo., for granting access to the Orient mine.

APPRAISAL OF IDENTIFIED RESOURCES By Brian J. Hannigan, U.S. Bureau of Mines

Mining and Mineral-Exploration History

The Black Canyon and South Piney Creek Wilderness Study Areas are in or near the Hayden Pass, Steel Canyon, Orient mine, and Blake mining districts (Ellis and others, 1983). Minerals have been produced from within 2 mi of the study areas, but there has been no recorded production from the wilderness study areas.

The area around Steel Canyon, which separates the Black Canyon and South Piney Creek Wilderness Study Areas, produced 5 oz (ounces) of gold, 7,000 oz of silver, 70,000 lb (pounds) of lead, and 8,000 lb of copper (Ellis and others, 1983, p. 13). The date of production is uncertain. The names of the Victor and Copper King mines (pl. 1*A*), derived from sketchy production records, may be incorrect. Decorative marble was quarried and shipped from Steel Canyon in small quantities (Argall, 1949). The Orient mine (pl. 1*A*), 0.5 mi south of the Black Canyon Wilderness Study Area, produced 1.7 million tons of iron ore between 1880 and 1931 (Stone, 1934, p. 317). The ore was shipped to Colorado Fuel and Iron Co. in Pueblo, Colo. The mine still contains identified resources estimated at 5 million tons of 43 percent iron (Carr and Dutton, 1959, p. 97).

Mining Claims and Leases

Nineteen unpatented claims exist in the South Piney Creek Wilderness Study Area, and ten unpatented claims exist in the Black Canyon Wilderness Study Area. No patented claims exist within the study areas, but 40 patented claims are within 1 mi of the boundaries.

Oil and gas leases occur within 2 mi of the South Piney Creek and Black Canyon Wilderness Study Areas (Hannigan, 1984). No oil and gas has been discovered near the study areas.

Geothermal leases occur in the vicinity of the KGRA west of Valley View Hot Springs and just outside the boundaries of the wilderness study areas (Hannigan, 1984).

Mineral- and Energy-Resource Occurrences

Metals

Vein-type base- and precious-metal deposits occur in fracture zones in carbonate rocks near the Black Canyon and South Piney Creek Wilderness Study Areas. Three adits and one shaft, exposing four veins, were mapped and sampled. The veins pinch and swell to 3 ft in thickness and consist of silver-bearing galena and minor chalcopyrite in gangue of quartz, calcite, and minor fluorite and barite.

The mineralized structures in the Copper King and Victor mines, on the south side of Steel Canyon (pl. 1*A*), consist of veins in fracture zones in carbonate rock. The structures dip 45–60° to the south; the veins are oxidized near the surface to gossans containing abundant hematite and limonite and minor malachite, fluorite, and barite.

Four of the fifteen rock samples taken in the Copper King mine contained from 0.006 to 0.043 oz gold per ton. Nine of the samples taken from this mine contained from 0.3 to 34.2 oz silver per ton. Copper, detected in all but two samples, was present in concentrations generally ranging from 0.01 to 0.63 percent. One sample contained 21.9 percent copper. Lead, detected in all fifteen samples, was present in concentrations ranging from 0.03 to 4.80 percent. Antimony was present in five samples and ranged in concentration from 0.04 to 0.3 percent. The mineralized structure in the Copper King mine was not traceable into the study areas because of surface cover. The structure trends toward both study areas.

The Victor mine is on a peninsula of privately owned land that is bounded on three sides by the Black Canyon Wilderness Study Area (pl. 1*A*). Six of the eight samples taken in the Victor mine contained silver; values ranged from 0.3 to 10.3 oz per ton. All eight samples contained copper, and values ranged from 0.002 to 0.20 percent. Lead was detected in all eight samples; concentrations ranged from 0.01 to 8.0 percent. Traces of nickel, chromium, and cobalt were detected in some samples. The mineralized structure in the Victor mine was not traceable into the wilderness study areas because of surface cover. The structure trends toward both areas.

An unnamed inclined adit and a shaft, south of Steel Canyon, are on the same tract of privately owned land bounded on three sides by the Black Canyon Wilderness Study Area (pl. 1*A*). The veins in the workings contained gold, silver, lead, fluorite, barite, and calcite in the matrix cementing brecciated limestone. The veins strike approximately east-west and dip 30–50° to the south (Ellis and others, 1983). Five samples were taken from the inclined adit and shaft. One sample contained 0.03 oz gold per ton; silver values ranged from 0.7 to 2.0 oz per ton in three samples. Four samples contained from 0.005 to 1.0 percent copper, and five samples contained from 0.02 to 0.5 percent lead. The mineralized structure was not traceable into the Black Canyon Wilderness Study Area because of surface cover. The structure trends toward the study area.

Lack of outcrop made it difficult to trace any of the mineralized structures past the extent of the workings. The orientation and mineral composition of the veins in the Victor and Copper King mines are similar. Although the veins in the inclined adit and shaft contain greater concentrations of fluorite than the Victor and Copper King mines, the orientation of the structures and the concentrations of gold, silver, lead, and copper are similar to those found in the mines.

A small silver-lead resource is present in veins between the Black Canyon and South Piney Creek Wilderness Study Areas (Ellis and others, 1983, p. 13). Although these structures have minor fault offsets and cannot be traced beyond the extent of the workings because of ground cover, the fracture zones containing veins are essentially continuous and trend toward the study areas.

Limestone and Dolomite

Limestone and dolomite crop out over about one-third of the study areas. Parts of the Leadville Limestone and Fremont Dolomite have been quarried elsewhere in south-central Colorado for such uses as soil conditioner, sugar refining, and lime and cement manufacture, and as flux in smelters (Vanderwilt and others, 1947, p. 244–246; Taylor and others, 1984, p. 31). The Leadville Limestone near Monarch Pass was quarried from 1930 to 1984, when operations ceased. The Fremont Dolomite is quarried at Canon City. Large quantities of limestone and dolomite occur in these formations in the Arkansas River valley about 12 mi north of the study areas but are not being quarried even though they are readily accessible by highway and railroad and are closer to market. Access to the limestone and dolomite in the study areas is not developed. Six miles of dirt road provide access to the study areas, but there are no roads to most of the limestone and dolomite in them. Although the Leadville Limestone and Fremont Dolomite in the study areas are suitable for common use, and the Leadville is probably suitable for use in cement manufacture, the large quantity of easily accessible limestone and dolomite north of the study areas is a deterrent to development of these resources in the study areas. Further sampling is necessary to delineate beds of high-purity limestone and dolomite in the study areas.

Decorative Stone

Two small decorative-stone quarries occur between the Black Canyon and South Piney Creek Wilderness Study Areas in Steel Canyon. Although Argall (1949) identified pink, yellow, black, blue, and green marble at these quarries, no marble was observed during the field investigation. The formations quarried extend into both the South Piney Creek and Black Canyon Wilderness Study Areas; however, the colorful stone reported by Argall (1949) was not observed in the study areas.

Geothermal Energy

Valley View Hot Springs, about 2 mi south of the Black Canyon Wilderness Study Area and about 4 mi southeast of the South Piney Creek Wilderness Study Area, is a KGRA (fig. 3). Mineral Hot Springs, near the center of the San Luis Valley, is about 6 mi southwest of the study areas (fig. 3). No hot springs were found in either of the study areas. Water from the hot springs has a surface temperature of approximately 30–60°C (Celsius) (Pearl, 1979). This temperature is sufficient to provide heat for local use (Coe, 1980). Drilling could discover hotter water at depth. Valley View Hot Springs ssues from the Sangre de Cristo fault. Because of the location and dip of the fault, drilling for undiscovered hot water would most likely be done west of the fault and west of the study areas.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By David A. Lindsey, Jerry R. Hassemer, Gerda A. Abrams, and Richard B. Taylor, U.S. Geological Survey

Geology

Geologic Setting

The Black Canyon and South Piney Creek Wilderness Study Areas lie on the steep western slope of the Sangre de Cristo Range (fig. 2). The Sangre de Cristo Range is separated from the San Luis Valley by the Sangre de Cristo normal fault, which passes immediately west of the study areas (fig. 3). The San Luis Valley

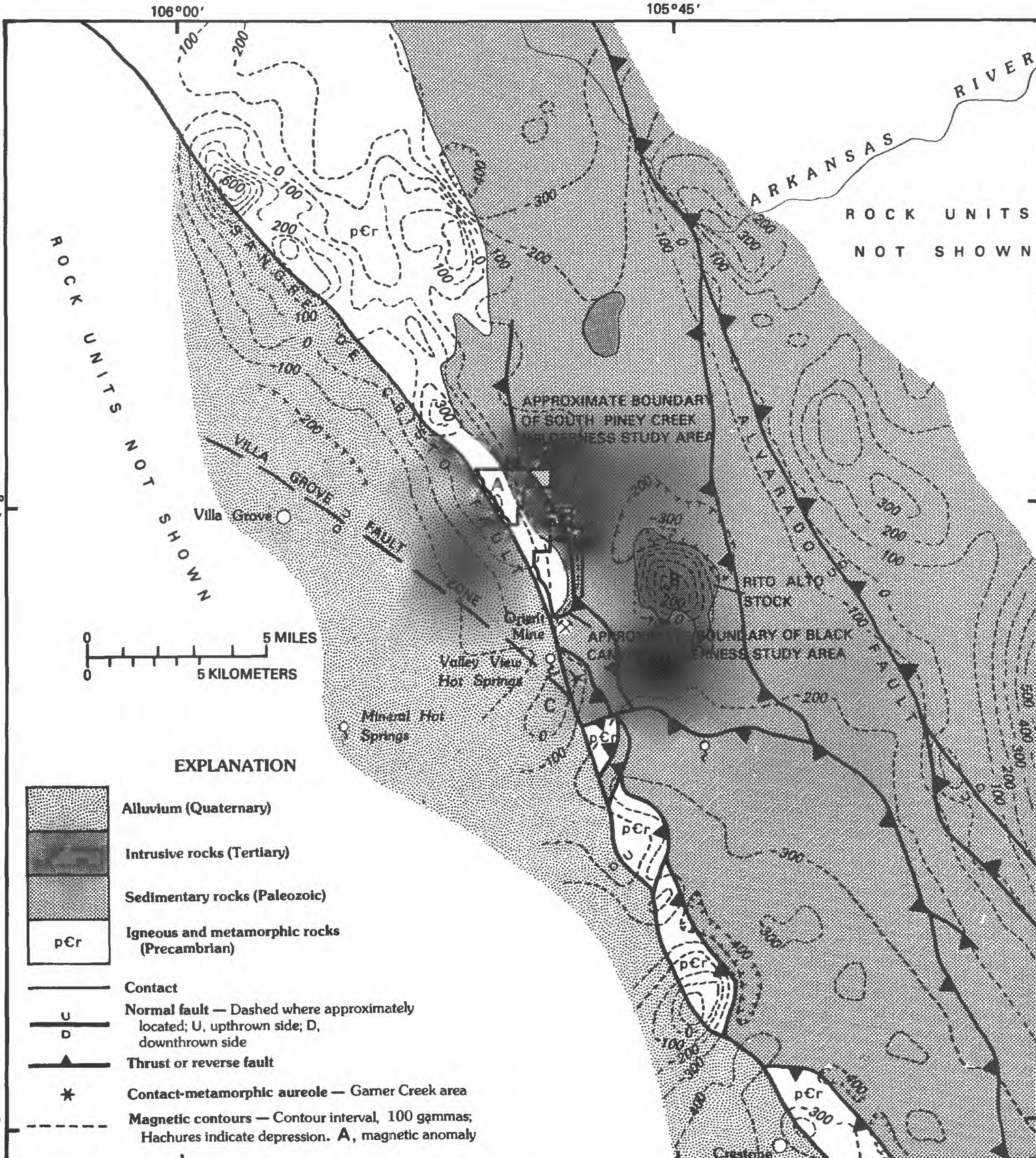

Figure 3. Map showing geologic setting, magnetic anomalies, and hot springs in the vicinity of the Black Canyon and South Piney Creek Wilderness Study Areas, Colorado. Magnetic survey from U.S. Geological Survey (1983).

adjacent to the study areas is divided into two structural blocks by the northwest-trending Villa Grove fault zone. In the northern block, the valley floor is covered by a shallow fill of late Cenozoic sediments; the southern block has been downfaulted, and the valley floor is covered by a relatively deep fill. These topographic and structural features formed during Rio Grande rifting in late Cenozoic time. Scarps of both the Sangre de Cristo and Villa Grove faults cut surficial deposits of Quaternary age in the San Luis Valley (McCalpin, 1982).

Within the Sangre de Cristo Range, an extensive system of Laramide (Late Cretaceous-Eocene) thrust and reverse faults cuts rocks of Precambrian and Paleozoic age (fig. 3) (Lindsey and others, 1983; Johnson and others, in press). In the study areas, fault blocks bounded by high-angle reverse faults have limited horizontal displacement, but south of the study areas, large thrust sheets have been displaced miles eastward over moderate- to low-angle thrust faults (fig. 3). The thrust system crosses the San Luis Valley at the approximate latitude of Valley View Hot Springs and Villa Grove. Laramide structures in downdropped rocks of the San Luis Valley are covered by late Cenozoic alluvial deposits of streams that issued from the Sangre de Cristo Range.

During Tertiary time, rocks near the study areas were intruded by stocks (fig. 3) and small sills and dikes of igneous rock (pl. 1*A*). The Rito Alto stock (tonalite and granite) of Oligocene age lies 2–5 mi east of the study areas. A contact-metamorphic aureole extends about 0.6 mi out from the stock, and parts of the stock have been mineralized and altered (Johnson and others, in press). A small stock may lie beneath the surface in the Garner Creek area, about 2 mi south of the Black Canyon Wilderness Study Area (starred locality, fig. 3). Andalusite-biotite phyllite reported there by Karig (1964) may represent a contact-metamorphic aureole; dikes of pegmatitic and felsic igneous rock crop out in the middle of the interpreted aureole. The occurrence of an aeromagnetic anomaly at the Garner Creek area is consistent with a small concealed stock.

Rocks of the entire western side of the Sangre de Cristo Range also have been regionally metamorphosed to subgreenschist grade during Tertiary time. Low-grade regional metamorphism may have occurred during deep burial beneath Laramide thrust faults.

The Black Canyon and South Piney Creek Wilderness Study Areas are underlain by folded and faulted rocks of Early Proterozoic, early Paleozoic, and late Paleozoic age (pl. 1*A*). These rocks crop out in three north-trending blocks separated by high-angle reverse faults: (1) a western fault block of Early Proterozoic gneiss and formations of early Paleozoic age, (2) a middle block composed mostly of Mississippian Leadville Limestone, and (3) an eastern block of Pennsylvanian Minturn Formation. Along the eastern side of the block of Early Proterozoic gneiss, steeply dipping beds of quartzite, carbonate rock, and shale of Ordovician to Mississippian age have been faulted against the Leadville Limestone of the middle fault block. The middle block is folded into the Steel Canyon anticline, a tight upright fold in Leadville Limestone. The Leadville Limestone of the Steel Canyon anticline has been faulted against east-dipping red and gray sandstones of the Minturn Formation. In the South Piney Creek Wilderness Study Area, this fault passes northward into the Minturn Formation, and the Minturn is in depositional contact with the underlying Leadville Limestone. A few thin igneous dikes of Oligocene(?) age crop out on ridges. Glacial deposits of Pleistocene Pinedale age cover the floor of Black Canyon.

Description of Rock Units

The following rock units were mapped in the study areas (pl. 1*A*):

Early Proterozoic gneiss (unit Xgn).—This unit consists of layered gneiss ranging from light-colored felsic gneiss to dark mafic gneiss. Felsic gneiss is composed mostly of quartz, plagioclase, and potassium feldspar; mafic gneiss contains these minerals plus abundant biotite or hornblende and accessory magnetite, apatite, and sphene. The gneiss is medium grained and well foliated, and contains migmatitic veins of quartz. Unit includes thin dikes of greenish-black hornblende-rich rock (metabasalt?) and quartz-feldspar pegmatite that cut gneiss locally.

Early Ordovician Manitou Limestone (unit Om).—It unconformably overlies Early Proterozoic gneiss along a steeply dipping contact that extends north from Black Canyon. The contact is poorly exposed in most places. At good exposures on the northern side of Black Canyon, the Manitou is gray, tan-weathering, thin-bedded, fine-grained dolomitic limestone containing sparse chert nodules, and is about 100 ft thick.

Middle Ordovician Harding Sandstone (unit Oh).—This unit consists of quartzite in the study areas; it conformably overlies the Manitou Limestone. The Harding is pale-red to light-gray, thin-bedded quartzite, composed of well-sorted, pure quartz sand. It forms prominent exposures of steeply dipping beds. The Harding is about 90 ft thick.

Late Ordovician Fremont Dolomite and Mississippian(?) to Late Devonian Chaffee Formation (unit MDO).—These rocks are limestone, dolomite, quartzite, and shale, not everywhere mappable as individual formations; they conformably(?) overlie Harding Sandstone. The Fremont Dolomite is dark-gray, mottled, massive-bedded, coarsely crystalline dolomite, about 300 ft thick. The Chaffee Formation (as described by Litsey, 1958, p. 1154–1156; and Taylor and others, 1975) consists of the Parting Quartzite Member (gray-red shale and massive gray quartzite, 14 ft thick at Steel Canyon) and the Dyer Dolomite Member (yellowish-brown-weathering, gray, cherty dolomite, about 90 ft thick).

Early Mississippian Leadville Limestone (unit Ml).—This rock is cliff-forming gray limestone. Locally, it includes the Gilman Sandstone of the Chaffee Formation. Following the usage of Taylor and others (1975), the Gilman Sandstone was mapped with the Leadville; Tweto and Lovering (1977, p. 28–30) assigned the Gilman to the Chaffee. At the Orient mine, Samsela (1980, p. 156–158) recognized: (1) the Gilman Sandstone (which he assigned to the Leadville Limestone), composed of dolomitic limestone conglomerate, thin-bedded, fine-grained limestone, and quartz sandstone, 40 ft thick; (2) a lower member of the Leadville (which he called middle member of the Leadville), composed of thin-bedded, locally stromatolitic and fossiliferous, fine-grained limestone and scattered beds of limestone conglomerate, 143 ft thick; and (3) an upper member of the Leadville, composed of medium- to thick-bedded calcarenite and fine-grained limestone, top removed by faulting, 43 ft exposed. The Leadville is mineralized locally, especially where it has been brecciated by faulting and folding. At the Orient mine, south of Black Canyon, limestone breccia in the lower member of the Leadville is strongly mineralized with limonite iron ore (Stone, 1934). The breccia extends across Black Canyon barely into the study area, where it contains small amounts of limonite. In the study areas, unfaulted sections of the Leadville are about 300 ft thick.

Middle Pennsylvanian Minturn Formation (unit ℙ*m).*—This unit consists of interbedded sandstone, siltstone, and shale. The lower part is gray to red, contains coaly shale in places, and may be correlative in part with the Middle Pennsylvanian Belden Formation. About 6,000 ft thick, the Minturn makes up the main part of the Sangre de Cristo Range east of the study areas.

Oligocene(?) intrusive igneous rocks (unit Ti).—These rocks are dikes and sills of felsic to mafic composition. Gray to tan and porphyritic, the dikes and sills are as much as 10 ft wide and 100 ft in exposed length.

Quaternary surficial deposits (units Qpt, Qpf, Qrg, Ql, and Qal)—These deposits include glacial till (Qpt) and alluvial-fan deposits (Qpf) of Pleistocene Pinedale age and rock-glacier deposits (Qrg), landslide deposits (Ql), and alluvium (Qal) of Holocene age.

Geochemistry

Analytical Methods

Stream-sediment samples were collected from first- and second-order drainages in and near the Black Canyon and South Piney Creek Wilderness Study Areas (pl. 1*A*). Sampling was conducted in 1982 as part of a larger reconnaissance geochemical survey of the Sangre de Cristo Wilderness Study Area (Adrian and others, 1984). For each sample locality a heavy-mineral concentrate and a minus-80-mesh sample were analyzed. Except for ubiquitous low-level boron enrichment, minus-80-mesh samples were found to contain subdued values compared to concentrate samples. Selected data for the concentrate samples are presented in tables 1 and 2. A few rock samples were also analyzed in 1984 (table 3).

Each heavy-mineral concentrate was collected by panning a composite sample of stream sediment to an approximate composition of half dark minerals and half light minerals, using a 16-in. gold pan. Samples were processed through bromoform and an isodynamic separator to obtain nonmagnetic, heavy-mineral concentrates for analysis.

All samples were analyzed semiquantitatively for 31 elements by a six-step, direct-current arc, optical-emission, spectrographic method (Grimes and Marranzino, 1968). Of the 31 elements analyzed, anomalous concentrations of antimony, barium, bismuth, boron, copper, lead, molybdenum, niobium, silver, tin, tungsten, and zinc may indicate areas of mineral resource potential.

Results of Study

Samples from the Black Canyon Wilderness Study Area are enriched in a mixture of base metals, tin, tungsten, and silver derived from a variety of mineralized features that may be of related origin. These mixed-metal anomalies were noted in stream sediments in Black Canyon, west of the Rito Alto stock, and in Orient Canyon near the Orient mine.

Stream sediments from the upper reaches of Black Canyon contain highly anomalous amounts of tin and tungsten, probably derived from quartz-molybdenite veins in the Rito Alto stock. Limited geochemical data (Adrian and others, 1984) show that the most intense anomalies in stream sediments are derived from the western side of the stock, nearest the study areas. Zoning of metals around the stock may be indicated by the high base-metal content of rock sample RX9402 (1,000 ppm (parts per million) zinc, table 3) and stream-sediment-concentrate sample 4052 (1,500 ppm lead, table 1) from streams draining the flank of the stock, compared to the high tin and tungsten content of sample 4054 (100 ppm tin and 1,000 ppm tungsten, table 1) from a stream draining the central part of the stock.

Mixed base-metal, tin, and silver anomalies represented by geochemical samples from the lower reaches of Black Canyon and Orient Canyon could represent a telescoped element suite caused by several pulses of metal-rich hydrothermal fluids along the highly permeable fault zones mapped there (pl. 1*A*). Or, the mixed-metal suite could represent near-surface deposition, where sharp changes in physical and chemical conditions caused rapid precipitation of all metals from mineralizing fluids. The mixed-metal suite could have been derived from the Rito Alto stock and its country rock.

An alternative interpretation of the mixed-metal anomalies at Orient Canyon is that they represent two overlapping mineralizing systems operating in permeable fault zones of the study areas. This interpretation includes (1) deposition, around the periphery of the stock, of base and precious metals derived from the mineralizing system of the stock, and (2) deposition of base metals, tin, and

Table 1. Selected elements in heavy-mineral concentrates, Black Canyon Wilderness Study Area.

[Data from Adrian and others (1984). Values in ppm; limits of detection in parentheses. Analyzed by six-step spectrographic method by B. M. Adrian and B. F. Arbogast; sample 0037 analyzed by D. E. Detra. ND, not detected; <, less than; >, more than; do., ditto]

Sample No.	Location	Ag (0.5)	B (20)	Ba (50)	Bi (20)	Cu (10)	Mo (10)	Nb (50)	Pb (20)	Sb (200)	Sn (20)	W (100)	Zn (500)
0562	Orient Canyon	100	50	3,000	20	200	ND	100	5,000	<200	>1,000	<100	500
0560	----do.------	ND	100	200	ND	200	ND	70	20	ND	300	ND	ND
0558	----do.------	ND	50	200	ND	100	ND	70	20	ND	<20	ND	ND
0037*	Black Canyon-	ND	200	500	50	70	<5	20	50	ND	ND	ND	ND
4052	----do.------	ND	200	200	ND	100	ND	100	1,500	ND	70	ND	ND
4054	----do.------	ND	1,000	150	ND	100	20	100	20	ND	100	1,000	ND
4056	----do.------	ND	300	100	<20	150	10	70	20	ND	30	100	ND
0556	Lime Canyon--	ND	100	500	ND	100	ND	70	100	ND	20	<100	ND
0554	----do.------	ND	100	500	ND	100	ND	100	70	ND	<20	ND	ND

*Concentrate sample lost. Data presented is for minus-80-mesh sample. Limits of detection are one-half those of other samples.

Table 2. Selected elements in heavy-mineral concentrates, South Piney Creek Wilderness Study Area.

[Data from Adrian and others (1984). Values in ppm; limits of detection in parentheses. Analyzed by six-step spectrographic method by B. M. Adrian and B. F. Arbogast; sample 4318 analyzed by D. E. Detra. ND, not detected; <, less than; >, more than; do., ditto]

Sample No.	Location	Ag (0.5)	B (20)	Ba (50)	Bi (20)	Cu (10)	Mo (10)	Nb (50)	Pb (20)	Sb (200)	Sn (20)	W (100)	Zn (500)
4320	Steel Canyon-	100	<20	>5,000	ND	70	ND	<50	7,000	ND	ND	ND	ND
4318*	----do.------	0.5	150	300	ND	50	<5	20	100	ND	ND	ND	ND
4316	----do.------	5	70	500	ND	150	ND	50	200	ND	ND	ND	ND
4314	----do.------	20	50	3,000	ND	200	ND	100	5,000	ND	20	ND	ND
4310	----do.------	700	20	>5,000	ND	1,000	ND	50	>20,000	200	30	ND	ND
4312	Quarry Creek-	50	50	5,000	ND	200	ND	100	10,000	ND	ND	ND	ND
H001	Between South Piney and Steel Creeks.	ND	20	700	ND	ND	ND	300	100	ND	100	<100	ND
5026	South Piney Creek.	ND	100	2,000	ND	100	ND	70	70	ND	50	ND	ND
5024	----do.------	ND	150	1,000	ND	200	20	70	500	ND	30	ND	ND
5022	----do.------	ND	200	3,000	ND	100	<10	100	100	ND	50	ND	ND
5030	North Piney Creek.	ND	100	200	ND	100	30	70	100	ND	30	200	ND
5154	Silver Creek-	ND	100	300	ND	300	50	50	300	ND	20	150	ND

*Concentrate sample lost. Data presented is for minus-80-mesh sample. Limits of detection are one-half those of other samples.

tungsten derived from concentrations of massive-sulfide minerals in Early Proterozoic rocks. Geochemical anomalies of copper, zinc, tin, and tungsten are similar to the geochemical signature of Precambrian stratabound (massive-sulfide) deposits north of the study areas (Taylor and others, 1984, p. 15). These deposits are typically small and difficult to find; none was found in or near the Black Canyon Wilderness Study Area during this study.

The South Piney Creek Wilderness Study Area contains two geochemical anomalies. On its southern border, Steel Canyon, all concentrate samples are enriched in silver and lead (table 2). Anomalous amounts of barium, copper, and antimony occur in some samples. The anomaly is a continuation of that found in the Black Canyon Wilderness Study Area. The northern anomaly, represented by samples from South Piney Creek (samples 5026, 5024, and 5022), North Piney Creek (sample

Table 3. Selected elements in rock samples, Black Canyon and South Piney Creek Wilderness Study Areas.
[Values in ppm; limits of detection in parentheses. Analyzed by six-step spectrographic method by L. A. Bradley and P. H. Briggs. ND, not detected; do., ditto; >, more than]

Sample No.	Description and location	Ag (0.5)	B (10)	Ba (20)	Bi (10)	Cu (5)	Mo (5)	Nb (20)	Pb (10)	Sb (100)	Sn (10)	W (50)	Zn (200)
RX9402	Mineralized sandstone, Black Canyon.	ND	20	100	ND	70	ND	ND	200	ND	ND	ND	1,000
RX9430*	Limonitic iron, Steel Canyon.	ND	20	200	ND	150	ND	ND	50	ND	ND	ND	1,000
RX002	Quartz-rich zone in pegmatite, South Piney Creek.	ND	ND	ND	ND	7	ND	ND	ND	ND	ND	ND	ND
RX002	----do.---------------	ND	ND	70	ND	7	ND	100	30	ND	15	ND	300
RX003†	Limonitic iron, Orient mine.	ND	ND	ND	ND	7	ND	ND	ND	ND	ND	ND	ND
SC1254	Intrusive dike, peak 11,053.	ND	ND	1,500	ND	30	ND	ND	30	ND	ND	ND	ND
SC1257	Intrusive dike, 0.5 mi south of peak 11,053.	ND	ND	1,000	ND	15	ND	ND	20	ND	ND	ND	ND

*Sample contains >20 percent Fe.

†Sample contains 7 percent Fe and 5,000 ppm Mn.

5030), and Silver Creek (sample 5154), consists of anomalous amounts of copper, lead, molybdenum, tin, and tungsten (table 2). This geochemical suite in Precambrian rocks suggests the occurrence of massive-sulfide minerals there, but no deposits of these minerals have been found.

Rock samples (RX002A, RX002B; table 3) from open cuts at the mouth of South Piney Creek were barren of metals. The open cuts explore a pegmatite dike in gneiss. Samples of mafic dike rock from the ridge north of Steel Canyon were also barren.

Geophysics

Methods

A map of magnetic features in the vicinity of the study areas was prepared from an aeromagnetic survey of the Sangre de Cristo Wilderness Study Area (U.S. Geological Survey, 1983). The aeromagnetic survey was flown under contract by High Life-QEB, Inc. in 1981 with a nominal terrain clearance of 1,000 ft and a flight-line spacing of 0.25 mi. Such surveys are adequate for defining large geologic features and the general distribution of rock units. The surveys are helpful in mapping favorable environments for mineral resources.

Results of Study

The eastern and western sides of the northern Sangre de Cristo Range are marked by large linear magnetic anomalies; between these anomalies, the center of the range has a gentle, uniform magnetic gradient interrupted only by the strong dipole anomaly of the Rito Alto stock (fig. 3). Linear magnetic anomalies along the western side of the Sangre de Cristo Range are parallel to the system of Laramide reverse and thrust faults in the range and to the range-bounding Sangre de Cristo normal fault.

Anomaly A is a linear magnetic high over Precambrian gneiss in the study areas (fig. 3). East of anomaly A, the magnetic gradient decreases abruptly where Early Proterozoic gneiss and early Paleozoic sedimentary rocks have been faulted against the Middle Pennsylvanian Minturn Formation. The magnetic gradient also decreases to the west along the range front, where the Sangre de Cristo fault has downdropped Early Proterozoic gneiss into the San Luis Valley. The gradient is not as abrupt as that on the eastern side of anomaly A, suggesting that downdropping of the valley floor beneath Cenozoic sediments is distributed among multiple strands of the Sangre de Cristo fault and the Villa Grove fault zone. Anomaly A continues more than 15 mi northward over Early Proterozoic gneiss in the range but ends abruptly to the south where Early Proterozoic gneiss is covered by folded and thrust-faulted Paleozoic sedimentary rocks at the latitude of the Orient mine.

Anomaly B is a circular magnetic high centered over the Rito Alto stock east of the study areas (fig. 3). It is accompanied by a pronounced magnetic low centered over altered rocks in the northern part of the stock. This magnetic dipole probably is an expression of the sharp contrast between high mafic-mineral content of unaltered tonalite in the southern part of the stock and low mafic-mineral content of hydrothermally altered tonalite and granite in the northern part. The steep magnetic gradients and circular pattern suggest an upright, cylindrical shape for the unaltered part of the stock.

Anomaly C is an oval magnetic high centered over valley fill and sedimentary rocks near the mouth of Garner Creek (fig. 3). The northeastern end of the anomaly coincides with felsic and pegmatitic dikes inside a possible contact-metamorphic aureole of metamorphosed sedimentary rocks near the mouth of Garner Creek. Interpretation of the anomaly as the magnetic expression of a buried stock is complicated by the crosscutting Sangre de Cristo fault, which is not expressed in the anomaly, and by the lack of data (end of flight lines) nearby.

Mineral and Energy Resource Potential

Metal Deposits Associated with Faults and Fractures

The Model (Orient mine)

Limonitic iron occurs at many places along faults and fractures on the western side of the Sangre de Cristo Range. Although most of these deposits may not be large enough to be mined for iron, they may contain resources of gold, silver, copper, lead, and zinc. The Orient mine, 0.5 mi south of the Black Canyon Wilderness Study Area, is taken here as the point of departure for describing a model of fault- and fracture-controlled metal deposits in the vicinity of the study areas. The following description is modified from Stone (1934) and Taylor and others (1984, p. 25–26).

The Orient iron deposit occurs in the lower part of the Leadville Limestone just east of the Sangre de Cristo fault (fig. 3; pl. 1*A*). The mined ore occurred as pipelike and lenticular bodies of limonite as much as 210 ft long and 80 ft thick, mostly elongate parallel to bedding. Most of the mined ore was in the lower part of the Leadville Limestone, but iron is present near the mine in most other formations of Paleozoic age. Limonitic iron was probably localized by fractures in the Leadville near the Sangre de Cristo and other faults. Near the mine, limonitic iron is common along reverse faults and in sheared axial zones of folds.

The ore mined at Orient was hard, cavernous to slaggy limonite, with soft yellow-to-red ochre and some hematite; the interiors of mined ore bodies were nearly pure limonite. Minor amounts of barite, pyrolusite, ankerite, calcite, and chalcopyrite accompanied limonite. Grab samples from dumps of the mine contain as much as 0.6 ppm gold and 4 percent copper (D. R. Shawe, written commun., 1984). Gold assays of 0.01–0.04 oz per ton were reported by Stone (1934, p. 325). Average gold values of 0.094 oz per ton were reported from limonitic iron prospects in Major Creek canyon, 3 mi south of the Orient mine (Ellis and others, 1983, p. 16). In the Victor mine and a nearby unnamed prospect on the southern side of Steel Canyon (pl. 1*A*), limonitic breccia is cut by narrow (less than 3 ft) veins of fluorite, barite, and calcite. The veins contain silver, copper, lead, and zinc (Hannigan, 1984).

Iron deposits like that at the Orient mine produce a strong geochemical anomaly in stream sediment. Geochemical surveys show anomalous amounts of barium, copper, lead, silver, tin, and zinc in stream-sediment concentrates from Orient Canyon (table 1). The Orient iron deposit has no expression on aeromagnetic maps, owing to its small size relative to flight-line spacing and to the nonmagnetic mineral content of the ore. No magnetic anomaly that might indicate hydrothermal alteration was identified.

The Orient deposit and nearby occurrences of limonitic iron probably formed by hydrothermal fluids that circulated through the many faults and fracture zones along the western side of the Sangre de Cristo Range. Although the Orient deposit itself does not lie in a mapped fault zone, the host beds are steeply dipping, sheared, and brecciated. Comparison of thicknesses of formations at the Orient mine with other nearby localities suggests that the Leadville Limestone and underlying Chaffee Formation have been thinned by tectonic shear. Near the mine, most limonitic iron occurs in reverse faults and thrusts and in sheared axial zones of folds, suggesting that these structures were important conduits for mineralizing fluids. All of the mapped mineralized structures are connected with one another and with the Sangre de Cristo normal fault. Although most formations have been mineralized, the Leadville Limestone and underlying carbonate rocks may be particularly favorable hosts for metal deposits because they are more reactive than siliceous formations.

Possibly iron and other metals were deposited by an extensive convective system of hydrothermal fluids and hot springs driven by the heat of nearby cooling plutons in Oligocene time. The Oligocene Rito Alto stock, about 3 mi east of the Orient mine, may have been the principal source of heat; an unexposed stock near the mouth of Garner Creek, about 2 mi south of the Orient mine, may have provided a second source. The presence of a buried stock near Garner Creek is indicated by dikes of igneous rock, by andalusite-biotite phyllite interpreted as a contact-metamorphic aureole, and possibly by aeromagnetic anomaly C (fig. 3).

Resource Potential

Both the Black Canyon and South Piney Creek Wilderness Study Areas have areas of moderate mineral resource potential for gold, silver, copper, lead, and zinc in limonitic iron deposits of the Orient type (pl. 1*B*). Areas of moderate potential meet the following criteria: (1) intensely faulted and folded strata, (2) carbonate rock at the surface or possibly in the shallow subsurface, (3) scattered limonitic iron at the surface, and (4) anomalous quantities of metals in stream sediment. Some areas of moderate resource potential do not have mineralized rock at the surface but are assigned moderate potential because they share geologic features with mineralized areas. The remainder of the study areas, including that underlain by Early Proterozoic gneiss west of the faults and by Minturn Formation east of the faults, is judged to have low resource potential for metals.

Assignment of moderate resource potential for iron, gold, silver, copper, lead, and zinc in the study areas is made with a certainty level of C; available data give good indication of potential but are not fully adequate. More detailed mapping and geochemical sampling are required to be sure of the extent of areas having moderate resource potential. Exploration would be required to identify resources.

High-Purity Limestone and Dolomite

The Model

High-purity limestone and dolomite have been quarried from the Leadville Limestone and the Fremont Dolomite, respectively, in south-central Colorado (Carter, 1968). Both formations extend south from the Arkansas River valley into the northern Sangre de Cristo Range and through the study areas. South of the study areas, the distribution of limestone and dolomite in the Sangre de Cristo Range is spotty.

High-purity (high-calcium) limestone in the Leadville of south-central Colorado is confined to the vicinity of Salida and Colorado Springs and south of those cities, including the region of the study areas (Vanderwilt and others, 1947, p. 245). A bed of high-calcium limestone 100 ft thick has been mined from the lower part of the Leadville Limestone near Monarch Pass, west of Salida (Carter, 1968). The Leadville at Wellsville, along the Arkansas River east of Salida, contains a bed of high-calcium limestone 20–25 ft thick. High-purity dolomite is mined from a 130-ft thick interval of Fremont Dolomite near Canon City (Carter, 1968). No other details are available to better define occurrence models for high-purity limestone and dolomite in south-central Colorado.

Resource Potential

The study areas are judged to have high resource potential for high-purity limestone and dolomite (pl. 1*B*). The Leadville Limestone and Fremont Dolomite crop out over about one-third of the study areas. Although these formations have been mineralized locally in the study areas, unmineralized rocks occur over sufficiently large areas to support quarries. Neither formation has been quarried for high-purity limestone or dolomite in the study areas. No chemical analyses are available to test the purity of beds in these formations in the study areas.

The certainty level is D because the favorable host formations crop out in the study areas.

Geothermal Energy

The Model (Valley View Hot Springs)

The study areas lie within 1–2 mi of Valley View Hot Springs, a KGRA (fig. 3). A second KGRA, Mineral Hot Springs, lies near the topographic axis of the San Luis Valley, about 6 mi southwest of the study areas. The springs are typical of low-temperature (less than 100°C) geothermal water that is common throughout the Rio Grande rift (Swanberg, 1983). Both Valley View and Mineral Hot Springs have been used for recreation; Mineral Hot Springs has been developed for heating livestock pens (Coe, 1980).

Valley View Hot Springs consists of four separate springs that discharge about 250 gallons per minute from the Sangre de Cristo fault (Barrett and Pearl, 1978, p. 124–127; Pearl, 1979). The water temperature is 32–37°C at the surface and probably 40–50°C below the surface. Water entering the alluvial fill of the San Luis Valley probably is forced up along the Sangre de Cristo fault by hydrostatic pressure.

Mineral Hot Springs discharges 70–167 gallons per minute mostly from a well in the eastern of three groups of springs (Barrett and Pearl, 1978, p. 120–123; Pearl, 1979). The springs have surface temperatures as high as 60°C; subsurface temperatures may reach about 90°C. Water entering the alluvial fill of the San Luis Valley is probably heated at depth and forced up along an upfaulted block in the subsurface of the San Luis Valley.

A third hot spring is along the northern side of Cotton Creek, within the Sangre de Cristo Range and about 5 mi southeast of the study areas. This spring issues from a thrust in Paleozoic rocks and deposits calcareous tufa on talus. It evidently represents ground water that flows from recharge areas high in the range and ascends along faults after heating in response to the geothermal gradient.

Low-temperature geothermal resources in rift basins occur where ground water descends into the sedimentary fill of basins like the San Luis Valley and is heated in response to the geothermal gradient (Swanberg, 1983). Hot springs issue from the basin and the basin margin where the regional hydraulic gradient forces heated water over a barrier or through a constriction to flow. Both Valley View and Mineral Hot Springs fit this model. Small hot-spring systems also may occupy fault systems in ranges adjacent to rift basins.

No hot springs occur within the study areas, but mineralized rock along faults there may represent the conduits of fossil hot springs. Widespread limonitic iron near the study areas may indicate numerous hot springs in the geologic past. The most likely time of hot-spring activity was during the Oligocene, when the heat source of the Rito Alto stock was present. Such hot-spring systems driven by the heat of intrusive magma may have been much hotter than the low-temperature geothermal water of the present San Luis Valley, but they would have dissipated when the intrusive magma cooled.

Resource Potential

Geothermal water in the San Luis Valley is a low-temperature (less than 100°C) energy source suitable for local industrial and agricultural uses (Coe, 1980). The study areas have low resource potential for occurrences of geothermal water of the type present in the San Luis Valley. Parts of the valley adjacent to the study areas have a moderate resource potential for low-temperature geothermal water (pl. 1*B*). Because the study areas are entirely within the Sangre de Cristo Range and do not extend beyond the Sangre de Cristo fault onto the sedimentary fill of the San Luis Valley, they are unlikely to contain subsurface geothermal water.

Geothermal resource potential both inside and outside the study areas is estimated with a certainty level of D because the area of potential is well defined by the geothermal model.

Energy Resources Except Geothermal

Resource potential for coal, oil, gas, and uranium is rated as low. Coaly shale occurs locally in the lower part of the Minturn Formation, but the shale has no value as fuel; the lower part of the Minturn is missing by faulting in much of the study area. Although conditions for oil and gas accumulation have been regarded as favorable in other parts of the San Luis Valley (Gries, 1980), oil and gas resource potential of the study areas is regarded as low. Any oil and gas that might have accumulated in the study areas probably has escaped through the many faults along the western side of the Sangre de Cristo Range or has been driven out of the rocks by metamorphism. A small amount of uranium was mined from a fracture zone in Harding Sandstone about 8 mi southeast of the study areas (Nelson-Moore and others, 1978, p. 388), but no evidence of uranium has been found within the study areas.

Energy-resource assessments are made with a certainty of D because favorable geologic conditions are not present in the study areas.

Recommendations for Future Work

The resource potential for base and precious metals in the vicinity of the wilderness study areas could be assessed with more confidence if the limonitic iron deposits in the folded and faulted terrane of the western side of the Sangre de Cristo Range had been studied from the perspective of developing a genetic model of ore deposition. The distribution of limonitic iron and the structural and lithologic controls of mineralization have been established by geologic mapping for this assessment, but little is known about trace-element and isotope composition of the limonite and its host rocks and whether these vary systematically within the mineralized area. Isotopic dating is needed to better establish the relation between mineralization, folding and faulting, igneous intrusion, and metamorphism in the area. A well-defined model of mineralization, when compared to models of mineralization elsewhere, might indicate whether limonitic iron near the study areas is likely to contain significant resources of gold and other metals. A better model is required to guide the exploration and sampling needed to define resources.

Occurrence models for high-purity limestone and dolomite in south-central Colorado need development. Chemical analyses of rocks from measured sections of Leadville Limestone and Fremont Dolomite are needed to determine the relation between resource occurrence and other geologic features. A regional survey of the geological controls of high-purity limestone and dolomite beds in the Leadville and Fremont Formations would greatly assist assessment of resource potential of local areas. Possible controls that might be useful for resource assessment include paleogeographic features and regional depositional and diagenetic facies in carbonate rocks. Carbonate facies have been described for some formations (Samsela, 1980), but information is lacking about possible relationships to resource occurrence.

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