U.S. GEOLOGICAL SURVEY CIRCULAR 1088

The Conterminous United States Mineral Assessment Program: Background Information to Accompany Folio of Geologic, Geochemical, Remote Sensing, and Mineral Resources Maps of the Butte 1° x 2° Quadrangle, Montana

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The Conterminous United States Mineral Assessment Program: Background Information to Accompany Folio of Geologic, Geochemical, Remote Sensing, and Mineral Resources Maps of the Butte 1° × 2° Quadrangle, Montana

By JAMES E. ELLIOTT, CHARLES M. TRAUTWEIN, CHESTER A. WALLACE, GREGORY K. LEE, LAWRENCE C. ROWAN, *and* WILLIAM F. HANNA

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By JAMES E. ELLIOTT, CHARLES M. TRAUTWEIN, CHESTER A. WALLACE, GREGORY K. LEE, LAWRENCE C. ROWAN, *and* WILLIAM F. HANNA

ABSTRACT

The Butte 1°×2° quadrangle in west-central Montana was investigated as part of the U.S. Geological Survey's Conterminous United States Mineral Assessment Program (CUSMAP). These investigations included geologic mapping, geochemical surveys, gravity and aeromagnetic surveys, examinations of mineral deposits, and specialized geochronologic and remote-sensing studies. The data collected during these studies were compiled, combined with available published and unpublished data, analyzed, and used in a mineral-resource assessment of the quadrangle. The results, including data, interpretations, and mineral-resource assessments for nine types of mineral deposits, are published separately as a folio of maps. These maps are accompanied by figures, tables, and explanatory text. This circular provides background information on the Butte quadrangle, summarizes the studies and published maps, and lists a selected bibliography of references pertinent to the geology, geochemistry, geophysics, and mineral resources of the quadrangle.

The Butte quadrangle, which includes the world-famous Butte mining district, has a long history of mineral production. Many mining districts within the quadrangle have produced large quantities of many commodities; the most important in dollar value of production were copper, gold, silver, lead, zinc, manganese, molybdenum, and phosphate. At present, mines at several locations produce copper, molybdenum, gold, silver, lead, zinc, and phosphate. Exploration, mainly for gold, has indicated the presence of other mineral deposits that may be exploited in the future. The results of the investigations by the U.S. Geological Survey indicate that many areas of the quadrangle are highly favorable for the occurrence of additional undiscovered resources of gold, silver, copper, molybdenum, tungsten, and other metals in several deposit types.

INTRODUCTION

PURPOSE AND SCOPE OF STUDIES

This circular, together with a folio of maps (published separately, table 1), is part of a series of U.S. Geological Survey reports that contain information on the mineral resources and mineral-resource potential of the conterminous United States. The studies described in this circular were done for the Butte 1°×2° quadrangle as part of the Conterminous United States Mineral Assessment Program (CUSMAP). The main objective of CUSMAP is to provide information to support a sound, long-range, national minerals policy, and for Federal, State, and local land-use planning. In addition, this program will increase the geologic, geochemical, mineral deposit, and geophysical knowledge of the conterminous United States. The program also provides a regional geologic and mineral-resource framework for site-specific studies, such as wilderness investigations, and guidance for mineral exploration.

The Butte quadrangle, which contains the world-famous Butte mining district, was selected for study as part of CUSMAP because of its location in an important mineral-producing region in west-central Montana. During this study, new data on geology, geochemistry, geophysics, geochronology, mineral resources, and remote sensing were

Table 1. Principal maps of the Butte 1°×2° quadrangle folio

[See "References Cited and Selected Bibliography for the Butte 1°×2° Quadrangle" for complete references]

Map No.[1]	Subject	Author(s)(year of publication)
OF-86-292	Preliminary geologic map	Wallace and others (1986)
MF-1925	Generalized geologic map	Wallace (1987a)
I-2050-A	Limonite and hydrothermal alteration map	Rowan and Segal (1989)
I-2050-B	Linear features map	Rowan and others (1991)
I-2050-C	Mines and prospects map	Elliott, Loen, and others (1992)
I-2050-D	Mineral resource assessment map for vein and replacement deposits of Au, Ag, Cu, Pb, Zn, Mn, and W	Elliott, Wallace, and others (1992a)
I-2050-E	Mineral resource assessment map for skarn deposits of Au, Ag, Cu, W, and Fe	Elliott, Wallace, and others (1992b)
I-2050-F	Mineral resource assessment map for porphyry/stockwork deposits of Cu, Mo, and W and stockwork/disseminated deposits of Au and Ag	Elliott and others (in press)
I-2050-G	Mineral resource assessment map for Tertiary and Quaternary placer Au deposits	Elliott and others (in preparation)
I-2050-H	Mineral resource assessment map for miscellaneous deposit types of phosphate, Cu, Ag, Ba, and F	Elliott and others (in preparation)
I-2050-I	Gravity and magnetic anomaly maps	Hanna and others (in press)
I-2050-J	Geochemical anomaly maps	Lee and others (in preparation)

collected and synthesized, and a folio of maps and numerous reports were produced. This report is one of the products of the CUSMAP project and summarizes and provides background information for the folio of geologic, geochemical, remote-sensing, and mineral-resource maps.

LOCATION AND GEOGRAPHY

The Butte 1°×2° quadrangle, which covers an area of approximately 6,550 mi^2, is located in west-central Montana and is bounded by latitudes 46° and 47° and longitudes 112° and 114° (figs. 1 and 2). The quadrangle includes several major and minor mountain ranges separated by intermontane valleys. Major ranges include the Garnet, Flint Creek, and Anaconda Ranges and the John Long, Boulder, and Sapphire Mountains. The valleys are generally at elevations of 3,500 to 5,500 ft and mountain peaks at elevations of 7,000 to 10,500 ft. The highest point in the quadrangle is Mount Evans, at 10,641 ft, in the Anaconda Range, in the south-central part of the quadrangle.

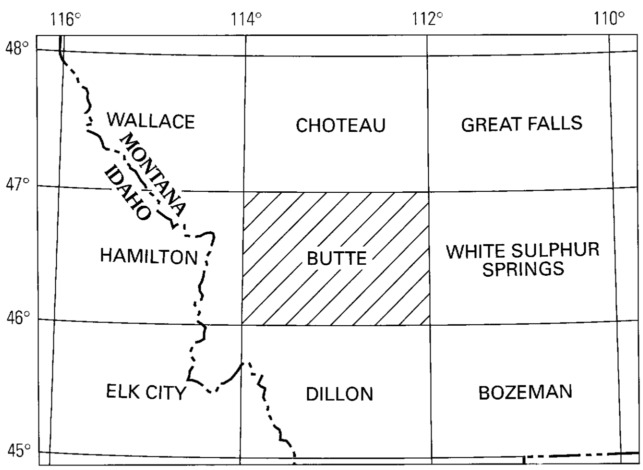

Figure 1. Index map showing locations of the Butte and adjacent 1°×2° quadrangles, Montana and Idaho.

The Continental Divide trends nearly south through the eastern part of the quadrangle. The divide forms the southern part of the boundary between Powell and Lewis and Clark Counties and the boundary between Jefferson County and the counties of Powell, Deer Lodge, and Silver Bow. The Continental Divide also follows the crest of the Anaconda Range in the south-central part of the quadrangle. East of the divide, the major drainages are the Boulder River and Little Prickly Pear Creek, which are tributaries to the Missouri River. West of the divide, the major drainage is the Clark Fork of the Columbia River. Major tributaries to the Clark Fork include Rock and Flint Creeks and the Blackfoot and Little Blackfoot Rivers.

The principal population centers in the quadrangle are Butte, in the southeastern part; Helena (State capital of Montana), on the eastern edge; and Missoula, near the northwestern corner of the quadrangle. Several other smaller towns, which include county seats of several counties, occur in the quadrangle. Most of the quadrangle is in Granite, Powell, Lewis and Clark, and Jefferson Counties, and smaller parts are in Missoula, Ravalli, Deer Lodge, and Silver Bow Counties.

Approximately one-half of the quadrangle is covered by National Forests, which include parts of the Deerlodge, Lolo, Bitterroot, Beaverhead, and Helena National Forests.

MINING HISTORY

The quadrangle has been a major producer of ores and mineral commodities since the 1860's. The largest and most famous mining district in the quadrangle is the Butte or Summit Valley district, one of the most productive mining districts in the world. The Butte district produced more than $6 billion (value of metals at the time of production). Other mines and districts in the quadrangle have a combined total production of about $400 million. Early prospectors discovered many placer-gold deposits in the quadrangle, such as Last Chance Gulch at Helena, and placers were rapidly developed and mined during the 1860's and early 1870's. About the same time, or within a few years after the discovery of placer-gold deposits, many of the principal lode deposits in the Helena, Marysville, Wickes, Garnet, Cable, and Philipsburg districts were also found. These lode deposits included rich gold, silver, silver-lead, silver-gold, silver-gold-lead-zinc, and gold-copper deposits.

During the early period of mining, before 1883, the development of lode deposits was hampered by the lack of milling and smelting facilities and the remoteness of supply centers. Only ores of highest grades could be mined because of the high costs of shipping to mills and smelters. The completion of a transcontinental railroad through the quadrangle in 1883 stimulated the mining industry and lead to the peak period (about 1883 to 1900) of production of silver and gold in most mining districts. Since 1900, except for the Butte district, mining activity has generally declined and most districts have not reached the high pre-1900 production levels.

The Butte district is known primarily as a copper district but, before the discovery of rich copper deposits, the district was first, a placer-gold district and later, one of the most important silver-producing districts of the U.S. The first major discovery of copper at Butte occurred in 1882. By the early 1900's, Butte was the most important mining center in the U.S. and has continued, with short interruptions, to be major producer to the present. Copper was the principal commodity produced, but the district has also produced large amounts of gold, silver, zinc, lead, manganese, molybdenum, cadmium, bismuth, sulfuric acid, selenium, and tellurium.

Many areas in the Butte quadrangle, in addition to the Butte district, that have been large producers of metals and of other commodities. The most productive districts (and their principal products) are the Wickes (gold, silver, copper, lead, and zinc), Philipsburg (silver, manganese, zinc, lead, and copper), Marysville (gold, silver, and lead), Garrison (phosphate), Rimini (silver and lead), and Black Pine (silver). Other commodities produced in large quantities from the Butte quadrangle, in addition to those above, are tungsten, fluorite, barite, sapphires, limestone, and silica.

Mining and exploration is active at several locations within the quadrangle. Major deposits of copper and molybdenum are mined and milled at Butte; and, at the Montana Tunnels mine, about 17 mi south of Helena, a large ore body containing gold, silver, zinc, and lead is mined and milled. Phosphate ore is mined near Warm Springs, in the Garnet Range. Continuing exploration, especially for gold, has resulted in the discovery of gold deposits in several areas of the quadrangle.

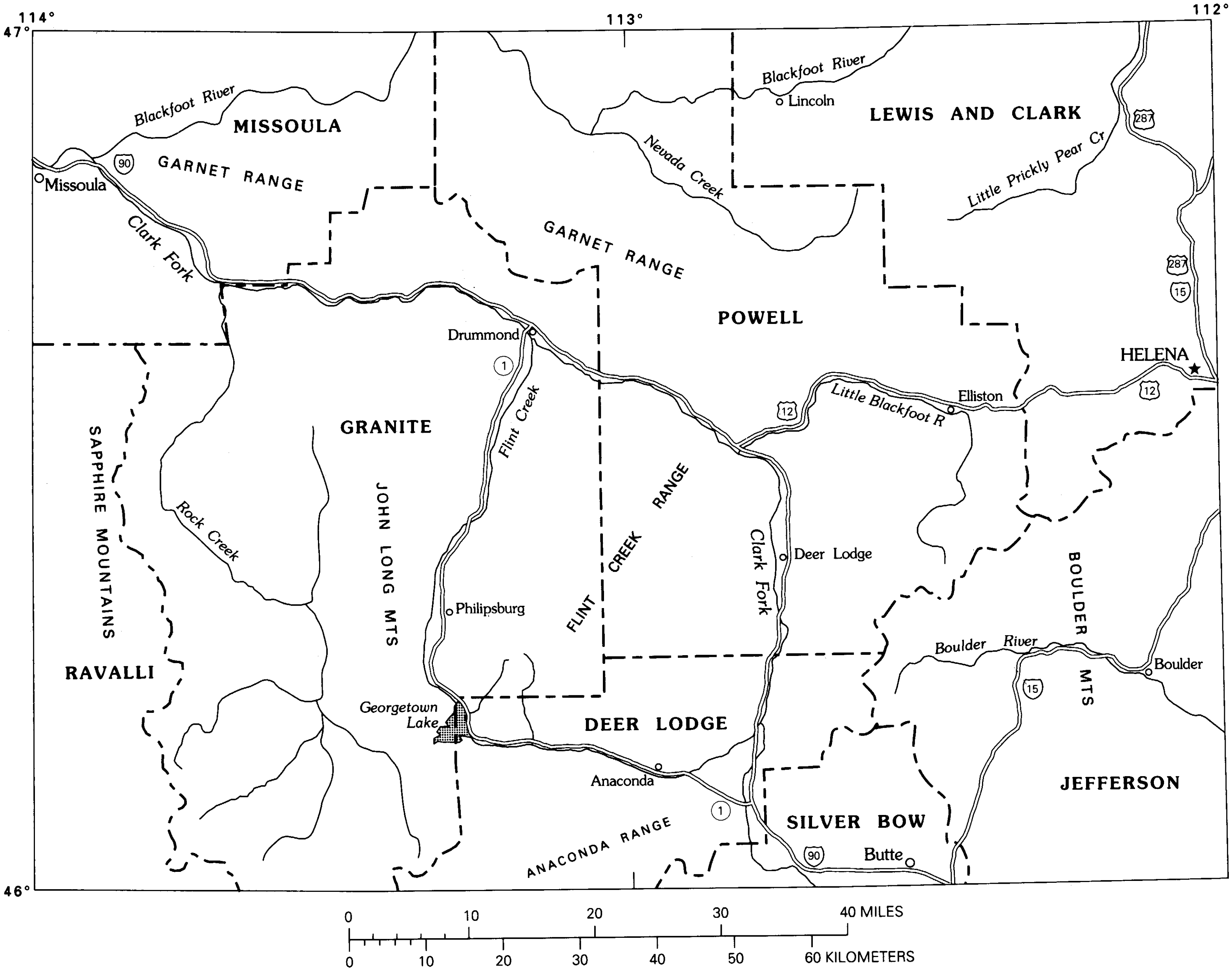

Figure 2. Index map of the Butte 1°×2° quadrangle .

Table 2. References to the geology and mineral deposits of the Butte 1°×2° quadrangle.

References	Area of Study
Weed, 1897	Butte district
Emmons and Tower, 1897	Do.
Weed, 1912	Do.
Sales, 1913	Do.
Meyer and others, 1968	Do.
Barrell, 1907	Marysville district
Emmons, 1907	Philipsburg and Cable districts
Emmons and Calkins, 1913	Philipsburg 30-minute quadrangle
Calkins and Emmons, 1915	Do.
Goddard, 1940	Philipsburg district
Holser, 1950	Do.
Prinz, 1967	Do.
Knopf, 1913	Helena mining region
Pardee and Schrader, 1933	Do.
Billingsley and Grimes, 1918	Boulder batholith region
Pardee, 1918a	Garnet district
Kauffman, 1963	Do.
Pardee, 1918b	Dunkleberg district
Lyden, 1948	Gold placers in Montana
Pardee, 1951	Pioneer district

PREVIOUS STUDIES

The geology and mineral deposits of the Butte quadrangle have been studied and described in publications since the late 1800's. The principal references to these earlier studies are listed in table 2. The earliest studies were centered on major mining districts such as Butte, Marysville, Philipsburg, and Cable. Later studies, in the early 1900's, resulted in publications on the geology and mineral deposits of the Philipsburg quadrangle and the Butte, Garnet, and Dunkleberg districts, and ore deposits of the Helena mining region and the Boulder batholith. The Butte district, because of its importance as a major mining district, has been the focus of numerous studies and reports; many of these are summarized by Meyer and others (1968). Many districts, such as districts in the Helena mining region and the Garnet and Philipsburg districts, were studied in more detail during the period of about 1925–1960. Also during this period of time, studies specific to gold placers of the Pioneer and other districts in the quadrangle were conducted.

During the 1950's, a major effort by the U.S. Geological Survey to study the geology and mineral deposits of the Boulder batholith was started. The Boulder batholith occupies much of the southeastern part of the quadrangle plus parts of the adjacent White Sulfur Springs, Bozeman, and Dillon quadrangles (fig. 1). Maps and reports from these studies formed the basis of compilations of the geology and mineral deposits of the southeast part of the quadrangle for the CUSMAP studies. The U.S. Geological Survey work included areal geologic mapping and mineral deposit studies (Becraft and others, 1963; Ruppel, 1961, 1963; Becraft and Pinckney, 1961; Pinckney and Becraft, 1961; Smedes, 1968; Smedes and others, 1962; Knopf, 1963; Weeks, 1974), and related topical studies of the Boulder batholith (Hamilton and Myers, 1974; Klepper and others, 1971; Tilling, 1973; Tilling and others, 1968) and volcanic units such as the Lowland Creek Volcanics (Smedes, 1962).

Numerous published works and unpublished student theses for studies in the Butte quadrangle discuss a wide range of topics that include petrology (Allen, 1966; Hyndman and others, 1982), glacial geology (Beaty, 1961; Ruppel, 1962), geochronology (Chadwick, 1980; Hyndman and others, 1972), geophysics (Biehler and Bonini, 1969; Kleinkopf and Mudge, 1972), structure (Pardee, 1950; Poulter, 1956), and stratigraphy (Gwinn and Mutch, 1965).

PRESENT INVESTIGATIONS

Systematic studies of the Butte 1°×2° quadrangle by the U.S. Geological Survey under the CUSMAP program began in 1980. The studies included preparation of geologic maps, collection and analysis of geochemical samples, collection of geophysical data, collection of geochronologic data, and interpretation of Landsat multispectral scanner and side-looking airborne radar images. The CUSMAP geologic studies were preceded by regional geologic studies in the Butte quadrangle that started in 1975 as part of the Geologic Framework and Synthesis Program. The field and laboratory studies were also supported, in part, by the Wilderness Program. The studies of the mineral resource potential of designated Wilderness and Roadless study areas were conducted concurrently with the CUSMAP studies and resulted in the publication of several maps and reports (Elliott and Avery, 1984; Elliott and Close, 1984; Elliott and others, 1985; Elliott and others, 1984; Lidke and Close, 1984; Lidke and others, 1983; Lidke and others, 1988; Wallace and Bannister, 1984; Wallace and others, 1985; Wallace and others, 1983; Wallace and Mayerle, 1984; Wallace and others, in press). All field studies in the Butte quadrangle were essentially completed by 1983.

In addition to the principal maps of the Butte 1°×2° quadrangle shown in table 1 and associated reports on geology, geochemistry, geophysics, and mineral occurrences, studies of the quadrangle resulted in the production of numerous reports on economic geology (Elliott and others, 1988; Loen, 1986a, 1986b, 1987, 1989a, 1989b; Loen and others, 1988; Loen and Waters, 1986, 1988; Sillitoe and others, 1985), geographic information systems (GIS) technology (Dwyer and others, 1987; Elliott and others, 1989; Moll and others, 1989; Moll and others, 1988), structural geology (Lidke and Wallace, 1988; Lidke and others, 1987; Wallace, 1987b; Wallace and others, 1985; Wallace and others, 1990), and stratigraphy (Schmidt and others, 1983; Wallace and others, 1989; Wallace and others, 1984; Winston and Wallace, 1983).

Geochemical, geophysical, and remote sensing studies were conducted during the period 1980–82. Geochemical surveys, under the direction of J.C. Antweiler and W.L. Campbell, consisted of the collection and analysis of stream-sediment and panned-concentrate samples from drainages and of rock samples from mines, prospects, and natural exposures (Campbell, McDanal, and Hopkins, 1982a-i; McDanal and others, 1985). Mineralized and unmineralized rock samples were also collected and submitted for analysis by J.E. Elliott, C.A. Wallace, and others while they were conducting geologic studies and examining mines and prospects. Samples of native gold were collected and analyzed as part of the geochemical studies (Campbell, Nowlan, and Antweiler, 1982). A gravity survey was conducted during 1980–1982 (Hassemer, 1981, 1984a, 1984b, 1986) and an aeromagnetic survey for the entire quadrangle was completed during 1983 (U.S. Geological Survey, 1984). Audiomagnetotelluric surveys were done in 1981 at selected sites in the quadrangle (Hoover and others, 1982). Remote sensing studies included the analysis of a Landsat multispectral scanner (MSS) image (acquired in 1976) and a side-looking airborne radar (SLAR) image (recorded in 1979). Interpretations were made during 1980–82 and hydrothermally altered rocks detected on the Landsat image were examined during 1981–82.

After acquisition, all geological, geochemical, geophysical, and remote sensing data were compiled, interpreted, and entered to a computer system. The final data sets included maps, tables, gridded data, and previously digitized information. All data were processed within a geographic information system (GIS) at the EROS Data Center, Sioux Falls, South Dakota, to produce a series of mineral-resource assessment maps (described in detail later in this report). The GIS has effective and efficient techniques for analyzing large, diverse data sets (Dwyer and others, 1987; Elliott and others, 1989; Moll and others, 1988; Moll and others, 1989). Computer processing was done during 1986 and 1987.

DESCRIPTIONS OF MAPS AND RESULTS OF THE BUTTE CUSMAP PROJECT

GEOLOGIC MAPS (OF–86–292, MF–1925)

A preliminary geologic map, at a scale of 1:250,000, with an explanation of map units, was released as an Open-File report, 86–292 (Wallace and others, 1986). A final colored geologic map with cross-sections and descriptions of geologic units is in preparation. A generalized geologic map, also at a scale of 1:250,000, was published as MF–1925 (Wallace, 1987a).

The geologic maps are products of the compilation of previous mapping (approximately one-third of the quadrangle) and the acquisition of new data (approximately two-thirds of the quadrangle). In addition to the CUSMAP Program, mapping was also supported by the Geologic Framework and Synthesis and by the Wilderness Programs.

The geologic maps were the most important components of the data used for mineral resource assessment.

These maps are the primary sources of data for the distribution of host rocks favorable to the occurrence of mineral deposits, the distribution of igneous rocks that may be sources of metals, thermal energy, or hydrothermal solutions, and the locations of structures, such as faults and folds, that may have acted as conduits for hydrothermal or other fluids. The geologic maps were used also in the development of a geophysical derivative map that shows the distribution of magnetic plutonic rocks and for interpretation of linear features that were mapped on Landsat and SLR images.

The primary source of geologic data was the generalized geologic map (MF–1925). All geologic map units plus structures were digitized from this map for the mineral-resource assessment of the quadrangle. For some deposit types, additional, more detailed geologic data was needed. These additional details were digitized from the preliminary geologic map (OF–86–292) and combined with the digital data from the generalized geologic map. The Butte quadrangle contains igneous, metamorphic, and sedimentary rocks and surficial deposits that range in age from Middle Proterozoic to Quaternary. Proterozoic, Paleozoic, and Mesozoic sedimentary rocks are abundant and widespread, as are Cretaceous and Tertiary plutonic rocks; the latter occur in the cores of most mountain ranges with associated metamorphic rocks. Volcanic and volcaniclastic rocks of Cretaceous and Tertiary age are found mostly in mountain ranges in the eastern and northern parts of the quadrangle. Intermontane basins are filled with Tertiary and Quaternary sedimentary rocks and deposits.

The oldest rocks exposed in the quadrangle are Belt Supergroup rocks that were deposited during Middle Proterozoic time when part of the Belt basin occupied the area of the Butte quadrangle; clastic and carbonate rocks of the Belt Supergroup have a total thickness of at least 52,000 ft in the quadrangle. Mafic dikes and sills were intruded into the Belt rocks, probably during Late Proterozoic time. During Paleozoic time, near-shore and shallow-water carbonate and carbonate-bearing clastic sediments were deposited and have a total thickness of about 7,800 ft; Paleozoic strata occur mainly in the north, central, and northeastern parts of the quadrangle. About 22,000 ft of clastic and carbonate Mesozoic sedimentary rocks were deposited in a foreland basin in the central part of the quadrangle, and about 7,800 ft of equivalent strata were deposited in the northeastern part of the quadrangle.

In Late Cretaceous time, magmatism resulted in the formation of numerous stocks and several batholiths that were emplaced at mesozonal and epizonal depths and of hypabyssal and volcanic rocks that were intruded at shallow depths or extruded on the surface. Principal plutons include the Boulder, Idaho, Sapphire, and Philipsburg batholiths, which are composed chiefly of monzogranite and granodiorite; smaller stocks of diorite, granodiorite, and monzogranite are abundant throughout the quadrangle. Hydrothermal activity during and following the waning stages of magmatism formed many mineral deposits. Volcanic and volcaniclastic rocks of the Elkhorn Mountains Volcanics, of Late Cretaceous age, occur as roof pendants in and along the margins of the Boulder batholith and probably represent early extrusive phases of the Boulder batholith.

Volcanism and erosion, as well as sedimentation in intermontane valleys, took place during Tertiary time. Extensive early and middle Tertiary volcanism formed the Lowland Creek Volcanics in the southeastern part of the quadrangle, major volcanic fields in the Garnet Range and east of Lincoln, and minor volcanic fields northeast of Deer Lodge in the northwestern part of the Boulder Mountains and in the southern Sapphire Mountains. Lacustrine and fluvial deposits accumulated in intermontane valleys during mid- to late-Tertiary time. Concurrent volcanism contributed volcanic debris to the intermontane basins. During late Tertiary time, extensive pediments formed, some of which contain valuable placer deposits of gold.

Quaternary time was dominated by extensive alpine glaciation in many of the mountain ranges in the quadrangle. Icecaps occupied the topographic crests of the Flint Creek and Anaconda Ranges and the Boulder Mountains, and valley and cirque glaciers were prevalent in these and other ranges. Four glacial events have been identified in the Flint Creek Range, and multiple glacial events must have occurred in the other ranges as well. Extensive glacial lakes repeatedly filled valleys in the northeastern and western parts of the quadrangle during the last glacial event. Postglacial time was one of erosion and deposition of alluvium in modern stream channels.

The principal structural elements in the Butte quadrangle are the Sapphire thrust plate (Ruppel and others, 1981), the southwestern end of the Montana disturbed belt (Mudge, 1972), and strike-slip faults of the Lewis and Clark line (Wallace and others, 1990). The complexly faulted and folded Sapphire thrust plate occupies much of the western and central parts of the quadrangle, and the Montana disturbed belt is located in the northeastern part where it abuts faults of the Lewis and Clark line. The Lewis and Clark line consists of a broad zone of east-southeasterly to southeasterly trending faults that extends across the west-central and northeastern parts of the quadrangle. Some steeply dipping faults of the Lewis and Clark line may have originated during deposition of the Proterozoic Belt rocks. However, most faulting and folding resulted from regional compression during late Mesozoic time. The most intense deformation occurred during Late Cretaceous time when the laterally extensive Sapphire thrust plate, which includes thrust sheets, zones of imbricate thrusts, and tight and overturned folds, was formed. The prevalent movement of thrust sheets was from west to east. Most of the pre-Tertiary sedimentary rocks in the quadrangle have been moved to their present positions by thrust and strike-slip faults. Most Late Cretaceous magmatism postdates thrust and strike-slip faults; stocks and batholiths emplaced into the faulted terrane made the terrane more resistant to continued deformation. Normal faulting during early Tertiary time and subsequent erosion controlled the development of some of the present mountain ranges and drainage systems. Some normal faulting along the east side of Deer Lodge Valley and north of Elliston continued into middle Tertiary time. Slip on Quaternary faults may be related to continued activity along some normal faults and along some strike-slip faults of the Lewis and Clark line.

GEOCHEMICAL MAPS AND DATA (OF–82–0617–A TO I, USGS–GD–85–006)

Geochemical data are available as a series of open-file reports (OF–82–0617–A to I; Campbell, McDanal, and Hopkins, 1982a-i) and on magnetic tape (USGS–GD–85–006; McDanal and others, 1985). In these reports and magnetic tape, the data including sample location, sample type, and analytical results are in tabular format. A series of colored geochemical maps (with explanatory text) that show areas with anomalously high concentrations of many elements in the quadrangle are in preparation (Lee and others, in preparation).

A total of 3,410 stream-sediment, 2,639 heavy-mineral panned-concentrate, 2,407 rock, and 217 soil samples were collected during a sampling survey by the USGS (McDanal and others, 1985). The stream-sediment and panned-concentrate analytical data were used in the mineral-resource assessment of the quadrangle. These samples, unlike the rock and soil samples, were distributed throughout the quadrangle and were judged to provide the best data for mineral-resource assessment.

Anomalously high concentrations of ore metals and other elements (pathfinder elements) are commonly found in streams that drain areas containing mineral deposits (Levinson, 1974). Many geochemical anomalies were detected in the geochemical survey of the Butte quadrangle, both in areas containing mines and prospects and in areas with no mines or prospects. The presence of geochemical anomalies in drainages is a diagnostic criterion for many types of mineral deposits, and the results of the geochemical survey formed an important part of the mineral-resource assessment procedure.

Using the analytical results of the drainage survey and techniques available with the GIS, a series of geochemical anomaly maps were prepared. These maps are interpolated "surfaces" in which areas of high values correspond with areas of geochemical anomalies. These geochemical anomalies were used in the recognition criteria for different types of deposits and the application of these geochemical criteria were essential to the mineral-resource assessment of the quadrangle.

Sampling methods—Stream-sediment samples, which consisted predominantly of silt-size material from alluvium, were collected from most first-order (unbranched) drainages and from all second-order and larger streams. At each sample locality, a composite sample of fine-grained material that weighed about 300 to 500 gm was collected and placed in a metal-free paper envelope. Each sample was air dried and sieved using an 80-mesh (0.17 mm) stainless steel screen, and the minus-80-mesh fraction of the sample was saved for analysis.

Panned-concentrate samples were usually collected near the stream-sediment samples but from coarser grained material (usually containing gravel-size particles). This coarse detritus represents a high-energy depositional environment in the stream channel where a natural concentration of heavy minerals is most likely to occur. Concentrates were prepared by panning, usually at the sample locality and placed in a plastic bag. Each sample, which ranged approximately in weight from 15 to 30 gm, was air dried and saved for analysis.

Analytical methods—All samples were analyzed for 31 elements using a semiquantitative, direct-current arc, emission spectrographic (SES) method (Grimes and Marranzino, 1968). Many samples were analyzed for gold, arsenic, copper, lead, zinc, silver, bismuth, cadmium, and antimony by atomic-absorption (AA) methods described by Thompson and others (1968), Ward and others (1969), and Viets (1978), and some samples were analyzed for tungsten by colorimetric (CM) methods (Welsch, 1983). The precision of the SES method is given by Motooka and Grimes (1976). For the resource assessment of the Butte quadrangle, only SES and AA analyses were used since the CM analyses had not been performed on the majority of samples. Analytical results were entered into the Rock Analysis Storage System (RASS), which is a computerized data base maintained by the USGS in Denver, Colorado (Van Trump and Miesch, 1976). RASS contains both descriptive geologic data and analytical data.

GRAVITY AND MAGNETIC ANOMALY MAP (I–2050–I)

New gravity and magnetic surveys were completed for the Butte quadrangle during the CUSMAP project. The results of these surveys are in figures and plates accompanied by an explanatory text in U.S. Geological Survey Map I–2050–I (Hanna and others, in press). The gravity survey consisted of 2,325 observations within and directly adjacent to the quadrangle (Hassemer, 1981; 1984a; 1984b; 1986), of which 1,900 are new, 262 were made previously by the USGS, and 163 were obtained from nonproprietary data files of the Department of Defense. All gravity data were obtained using high-precision Lacoste and Romberg geodetic gravimeters. The aeromagnetic survey represents total-field measurements along 70 flight lines in an east-west direction, spaced 1 mi apart at an average elevation of 9,000 ft above mean sea level. Gravity and magnetic data were supplemented by measuring the densities and magnetization of 823 rock samples from the quadrangle representing a range of rock types that varied in density and magnetization.

High and low gravity anomalies were interpreted from a compiled Bouguer gravity anomaly map. In general, large-amplitude gravity lows correlate with thick, low-density sediment in intermontane basins and with relatively thick occurrences of felsic to intermediate intrusive rocks. Small-amplitude gravity highs correlate with relatively thick occurrences of Proterozoic and (or) Phanerozoic sedimentary rocks, which have higher densities than intrusive rocks or basin-fill deposits. Basin-fill deposits probably reach maximum thicknesses of about 3.5 km and intrusive rocks of the Boulder batholith are present to a depth of at least 5 to about 10 km. Other plutons extend from about 0.5 to 3 km in depth.

The compiled aeromagnetic map shows two contrasting regions in the quadrangle; (1) the southeastern part of the quadrangle contains a cluster of highs and lows that correspond with the region occupied by the Boulder batholith, the Elkhorn Mountains Volcanics, and the Lowland Creek Volcanics, and (2) the remainder of the quadrangle is characterized by many isolated highs that correlate with locations of plutonic igneous rocks of Cretaceous and Tertiary age. Magnetic lows of diverse amplitudes and wavelengths coincide with locations of plutonic or volcanic rocks that are inferred to be hydrothermally altered.

Using filter techniques, the gravity and magnetic data were combined to form an interpretative map that shows the distribution of surface and subsurface magnetic plutonic igneous rocks. This derivative map aided in the identification of areas of mineral resource potential in the mineral-resource assessment of several mineral deposit types in the quadrangle and is included in several of the mineral resource assessment maps (Elliott, Wallace, and others, 1992a, 1992b, in press).

LIMONITE AND HYDROTHERMAL ALTERATION MAP (I–2050–A)

The distribution of limonitic rocks in the quadrangle, some of which are hydrothermally altered, was mapped using a Landsat Multispectral Scanner (MSS) image (no. 2553–27331, recorded on July 28, 1976). Limonite, a combination of ferric iron oxide minerals, can be identified on MSS digital images because of its diagnostic spectral reflectance in the wavelength region of 0.4–1.1 micrometers (Rowan and others, 1974; Segal, 1983).

Rowan and Segal (1989) processed the MSS image data, which covered nearly all of the Butte 1°×2° quadrangle, to display the characteristic limonite spectr al reflectance and to distinguish limonite from dry vegetation, which has similar spectral reflectance. A color-ratio composite, instead of single-channel composite images, was used to subdue albedo and topographic illumination effects. Areas identified as having anomalously high limonite were transferred from the color-ratio composite image to topographic maps, and these areas were evaluated in the field to distinguish between limonite that resulted from weathering of hydrothermally altered rocks and limonite that resulted from weathering of unaltered iron-bearing rocks. The discrimination of limonitic rocks from Landsat imagery is limited by vegetative cover. Much of the quadrangle is heavily forested and vegetative cover greater than approximately 30 to 40 percent obscures the spectral response of limonitic rocks. Shadows on images caused by rugged topography also hampers mapping of limonitic rocks.

The limonite and hydrothermal alteration map (I–2050–A; Rowan and Segal, 1989) shows areas of limonitic rocks that were evaluated in the field and assigned to three categories: (1) hydrothermally altered, (2) unaltered, and (3) undetermined origin. The presence of hydrothermally altered rocks is a recognition criterion for several types of mineral deposits. The limonite and hydrothermal alteration map was used in the mineral-resource assessment procedure because of the observed association of hydrothermal alteration and mineral deposits. Hydrothermally altered limonitic rocks include zones adjacent to metalliferous veins, replacement bodies, and breccia and areas of pervasive silicic or argillic alteration. Limonite-stained but unaltered rocks were formed by diagenetic processes or secondary weathering of iron-bearing minerals in unaltered rocks. Areas classified as "undetermined origin" include some areas of poor exposure where the origin of limonite could not be specified and some that were not field checked.

The results of this study show that areas of limonitic rocks are commonly small and usually related to faults, breccia zones, contact aureoles of plutons, and areas of hydrothermal veins. Most areas of limonitic rocks are adjacent to known mineralized areas, such as the Butte district, but several hydrothermally altered limonitic areas have few or no mines or prospects. These areas may warrant further evaluation. Areas of limonitic rocks classified as "unaltered" include limonitic Proterozoic clastic and carbonate rocks of the Belt Supergroup, Paleozoic carbonate rocks, Cretaceous and Tertiary volcanic and volcaniclastic rocks, Cretaceous and Tertiary plutonic rocks, and Quaternary glacial deposits.

LINEAR FEATURES ASSOCIATED WITH METAL-BEARING MINES AND PROSPECTS MAP (I–2050–B)

Linear features were mapped from MSS and SLAR images and compared to the distributions of metal-bearing mines and prospects. After analysis and interpretation of the data, a map was prepared at a scale of 1:250,000 that shows linear features or intersections of linear features and their association with metal-bearing mines and prospects (Rowan and others, 1991).

Linear features are distinct linear to slightly curvilinear elements mappable on MSS and SLAR images. They commonly represent linear segments of streams or ridges, terminations of topographic features, or tonal differences in bedrock, surficial deposits, or vegetation. For the Butte quadrangle, most of the linear features probably reflect underlying structures, such as fractures, faults, dikes, and alignments of fold axes. Linear features associated with layering due to bedding or volcanic flows and cultural features were excluded from the map. Linear features were mapped on images that are approximately 1:300,000 scale. These images are contrast-enhanced, Landsat MSS band 5 (0.6–0.7 micrometers) and band 7 (0.8– 1.1 micrometers) images and a 1:250,000 MSS color-infrared composite image. Additional linear features were mapped on a 1:250,000-scale SLAR image mosaic. After mapping, all linear features were digitized to facilitate analysis.

Linear features have three principal properties: areal density, azimuthal trend, and length. Each of these properties was analyzed individually and in combinations for the entire quadrangle. This initial analysis of the linear features indicated complex patterns with variations of length, density, and trends in different parts of the Butte quadrangle. The complexity of the linear features is a reflection of the geologic and structural complexity of the quadrangle. The quadrangle was subdivided into six geologic domains based on patterns of linear features and their relation to areas of similar structural history and lithology. A comparison of the spatial association of linear features with known mines and prospects resulted in the subdivision of the 6 domains into 16 subdomains. Within each subdomain, the distribution of mineralized sites was compared with linear trends of six azimuthal ranges. This comparison showed that some linear features and intersections of linear features show close spatial associations with known mines and prospects and that others do not. Those showing a close spatial association with mineralized sites were used in the mineral-resource assessment of the quadrangle. These favorable linear features and intersections of linear features helped to outline areas of mineral resource potential for several mineral deposit types.

MINES AND PROSPECTS MAP (I–2050–C)

Mineral-deposit data for 1,128 mines, prospects, and mineral occurrences have been compiled for the Butte quadrangle. Mines and prospects are shown on a colored map at a scale of 1:250,000 and on several other maps at larger scales and described in accompanying text and tables (Elliott, Loen, and others, 1992). The sites are tabulated according to mining district and geographic area. The mines and prospects are found throughout the quadrangle, but most sites are concentrated in principal mining districts; 78 percent are clustered in 47 established mining districts, and the remaining 22 percent are more widely scattered over the remainder of the quadrangle.

The data for mines and prospects were compiled from all published and unpublished data; the principal source of data was the U.S. Geological Survey (USGS) Mineral-Resource Data System (MRDS). All the MRDS records for the Butte quadrangle were checked for accuracy against original sources and revised if necessary. Additions to the MRDS files included data from more recent published reports than those cited in MRDS, unpublished records of the U.S. Forest Service, and data collected during the Butte CUSMAP project and Wilderness projects conducted by the USGS and U.S. Bureau of Mines. The MRDS records are available to the public through USGS Mineral Information Offices in Washington, D.C.; Spokane, Washington; Reno, Nevada; and Tucson, Arizona. During field work in the Butte quadrangle between 1980–83, approximately 150 mineralized sites were visited to verify the MRDS and other data and to collect additional information on geology, geochemistry, alteration, and mineralization.

For the purpose of mineral-resource assessment, mineral occurrences are classified into 13 deposit types. The most common deposit type is vein and replacement deposits of base and precious metals. 772 (69.5 percent) of the mines and prospects are classified as this type. Next in frequency of occurrence is placer deposits (nearly all gold but some tungsten and sapphire) with 135 (12.2 percent) mines and prospects. The other deposit types are porphyry and stockwork copper-molybdenum-tungsten, skarn tungsten-gold-copper, stockwork and disseminated gold-silver, strata-bound copper-silver, vein and replacement manganese, vein and replacement tungsten, strata-bound phosphate, vein barite, vein and replacement fluorite, miscellaneous nonmetallic deposits, and miscellaneous metallic deposits.

The mineral-deposit data were vital for the development of descriptive mineral-deposit models and the application of these models. This is particularly true for types of mineral deposits well-represented in the Butte quadrangle. For other types, not well-represented in the quadrangle, mineral-deposit data from other regions of Montana or other parts of the Western U.S. were used.

For many deposit types, the mineral-deposit data were the basis for the development of recognition criteria, and for ranking of criteria, such as host rocks, plutonic rocks, and geochemical anomalies.

MINERAL-RESOURCE ASSESSMENT MAPS (I–2050–D, E, F, G, AND H)

The mineral-resource assessment maps display mineral-resource potential for vein and replacement deposits of gold, silver, copper, lead, zinc, manganese, and tungsten (Elliott, Wallace and others, 1992a, I–2050–D), skarn deposits of gold, silver, copper, tungsten, and iron (Elliott, Wallace, and others, 1992; I–2050–E), porphyry and stockwork deposits of copper, molybdenum, and tungsten (Elliott and others, in press; I–2050–F), stockwork and disseminated deposits of gold and silver (Elliott and others, in press; I–2050–F), Tertiary and Quaternary gold placers (Elliott and others, in preparation; I–2050–G), and miscellaneous deposit types including strata-bound copper-silver and phosphate and vein and replacement barite and fluorspar (Elliott and others, in preparation; I–2050–H). Each map is accompanied by a pamphlet that explains the methods used in the mineral-resource assessment and descriptions of the mineral deposit models used in the assessment. Most of these models were developed specifically for this study and designed to utilize the types of data available for the Butte 1°×2° quadrangle.

The methods employed for mineral-resource assessment of the Butte quadrangle required the use of descriptive mineral deposit models and the application of these models using the computer-based spatial data processing technology of GIS. The general procedure is:

1. Compilation of geologic, geochemical, geophysical, and other data pertinent to the occurrence of mineral deposits.
2. Determination of the types of mineral deposits known to exist and the types that possibly exist in the quadrangle.
3. For each deposit type, apply available descriptive models or develop models and recognition criteria as required.
4. Evaluate the areal distribution and relative importance of recognition criteria.
5. Assess the mineral-resource potential based on the presence and relative importance of recognition criteria.

For the Butte quadrangle, most of the data needed for resource assessment were acquired through new studies consisting of geologic mapping, geochemical and geophysical surveys, remote sensing and geochronologic studies, and examination of mines and prospects. These data, combined with data from previous published and unpublished sources, were compiled on maps at a scale of 1:250,000 or in tables and entered into a computer-based GIS.

A GIS, consisting of computer hardware and software components, was used to develop procedures for mineral-resource assessment, interpret compiled and processed data, and prepare the map-based products of resource assessment. Nearly all of the original data were either in map or tabular form. Maps, which include a generalized geologic map, mining district map, geophysical anomaly map, limonite map, and linear features map, were digitized and entered into a vector graphics subsystem of the GIS. Geochemical data and mine and prospect data were entered as tabular data in the GIS.

Descriptive mineral deposit models were developed based on the types of mineral deposits that are present or could exist in the Butte quadrangle. Each mineral deposit model consists of a description and a list of recognition criteria. For deposit types that are well represented in the Butte quadrangle, the recognition criteria are based mainly on observed characteristics of deposits in the quadrangle and in adjacent regions of southwestern Montana. For some deposit types that are not present or not well represented in the quadrangle, descriptions and (or) models for deposits in other parts of the Northwestern and Western U.S. were used. The kinds and quantity of data available for the Butte quadrangle limited the number and types of recognition criteria for each mineral deposit model. The recognition criteria are also limited to data that apply to the entire, and not just selected parts, of the quadrangle.

For each mineral-deposit model, GIS submodels were developed that correspond to recognition criteria of the deposit model. Within each GIS submodel, a scoring or weighting range was generated that expresses the degree of favorability for factors such as host rock, associated igneous rock, geochemical anomalies, and other factors. The scores are based mostly on observed or measured association of mines and prospects with certain classes of host rock, igneous rocks, geochemical anomalies, and so on. Each submodel has several levels with scores in the range of 0 to 5. The final mineral-resource assessment maps are derived by combining the GIS submodels into summary GIS models and then assigning levels (low, moderate, high, very high) of mineral-resource potential to the final maps.

The mineral-resource assessment maps show areas of low, moderate, high, and, in some cases, very high potential for undiscovered resources of each mineral deposit type. Many areas of the quadrangle are favorable for the occurrence of undiscovered resources and have moderate, high, or very high potential for the occurrence of one or more deposit types. Many of these areas are in established mining districts that contain many mines and prospects; but some favorable areas contain few or no mines and prospects, and these areas are possible targets for future exploration and for more detailed geologic, geophysical, and geochemical studies.

Mineral resource assessment map for vein and replacement deposits of gold, silver, copper, lead, zinc, manganese and tungsten (I–2050–D)–The mineral-resource assessment map shows four levels of potential—low, moderate, high, and very high—for the occurrence of undiscovered resources in polymetallic vein and replacement deposits in the Butte quadrangle. The areas of moderate (24.1 percent of the quadrangle), high (5.1 percent), and very high (1.0 percent) potential are all favorable for the occurrence of vein and replacement deposits. Approximately 30 percent (sum of moderate, high, and very high areas) of the Butte quadrangle is favorable for the occurrence of these deposits, and about 84 percent of the mines and prospects of this deposit type are within these areas. As expected, most of the areas of very high potential coincide with known mining districts, which have many highly productive vein and replacement deposits. Of particular interest for mineral exploration are areas of high or very high potential which have few or no mines and prospects. Nine such areas are identified and described in the mineral-resource assessment map.

Mineral resource assessment map for skarn deposits of gold, silver, copper, tungsten, and iron (I–2050–E)–The mineral-resource assessment map shows four levels of potential for the occurrence of undiscovered resources in skarn deposits in the Butte quadrangle. The areas of moderate (11.4 percent of the quadrangle), high (2.3 percent), and very high (0.4 percent) potential are all favorable for the occurrence of skarn deposits. Approximately 14 percent (sum of moderate, high, and very high areas) of the Butte quadrangle is favorable for the occurrence of skarn deposits and approximately 67 percent of the mines and prospects of this deposit type are located in the favorable areas. All the areas of very high potential for skarn deposits are in mining districts and are at or near the contacts of stocks with sedimentary rocks. Most of the areas of high potential are also restricted to mining districts, although many of these areas do not have productive skarn deposits. Eight areas of high or very high potential and with skarn mines or prospects are identified and described in the mineral-resource assessment map. Seven other areas of high potential and significant size (approximately 1 mi^2 or larger) are not associated with known skarn occurrences, but these areas are also very favorable for exploration for undiscovered deposits; these areas are also identified and described in the map.

Mineral resource assessment map for porphyry and stockwork deposits of copper, molybdenum, and tungsten and stockwork and disseminated deposits of gold and silver (I–2050–F)–The mineral-resource assessment map includes separate maps for porphyry copper-molybdenum-tungsten and disseminated gold-silver deposits that each show three levels of mineral resource potential (low, moderate, and high). For porphyry copper-molybdenum-tungsten deposits, the areas of moderate potential cover 23.9 percent and the areas of high potential cover 5.1 percent of the quadrangle. Therefore, 29 percent of the area of the quadrangle is favorable for the undiscovered deposits of porphyry copper-molybdenum-tungsten. For disseminated gold-silver deposits, the areas of moderate potential cover 32.7 percent and the areas of high potential cover 2.3 percent of the quadrangle. Therefore, 35 percent of the area of the quadrangle is favorable for undiscovered deposits of disseminated gold-silver.

For porphyry copper-molybdenum-tungsten deposits, the favorable areas (moderate plus high potential) are located within and adjacent to mining districts and are related to granodiorite and monzogranite stocks and batholiths. The largest favorable areas are located in the eastern part of the quadrangle and are associated with the Late Cretaceous Boulder batholith. Other favorable areas are found in the northeastern, central, northwestern, and southwestern parts of the quadrangle.

For disseminated gold-silver deposits, the largest favorable areas are in the eastern and southeastern parts of the quadrangle, mainly in well-known districts and in areas that were extensively hydrothermally altered and mineralized. These areas have plutonic rocks of the Boulder batholith and Late Cretaceous and Eocene volcanic rocks. Smaller, widely scattered, areas of favorable potential are located in the northeastern, northwestern, central, and south-central parts of the quadrangle.

Mineral resource assessment map for Tertiary and Quaternary placer gold deposits (I–2050–G)–The mineral-resource assessment map includes separate maps for Tertiary and Quaternary placer gold deposits. The map for Tertiary placers shows three levels of potential: low, moderate, and high. The map for Quaternary placers shows four levels of potential: low, moderate, high, and very high.

Areas of favorable potential for Tertiary placer gold deposits are located along the margins of large basins with thick sections of Tertiary rocks. Factors that control the location of favorable areas include favorable lithologies in Tertiary rocks, proximity to source areas with gold-bearing lode deposits, and proximity to range-front normal faults. The largest favorable areas are located in the northwestern, north-central, central, and west-central parts of the quadrangle.

For Quaternary placer gold deposits, the mineral-resource map displays many portions of streams and valleys that are favorable (moderate, high, or very high potential). The most favorable areas are along the margins of intermontane basins and wide valleys in mountainous areas. Many placers have been mined in the quadrangle and future discoveries will probably be of buried placers that have little or no surface expression. Many of the placers in mountainous areas are narrow valley-type placers of small size and high grades of gold. Larger volume, lower grade placers could exist in wide valleys and on the margins of intermontane basins. The most promising areas in the quadrangle for Quaternary placer gold deposits are in northwestern, central, and northeastern parts of the quadrangle.

Mineral resource assessment map for miscellaneous deposit types of phosphate, copper, silver, barium, and fluorine (I–2050–H)–The mineral-resource assessment map for miscellaneous deposit types displays areas of low and moderate potential for strata-bound copper-silver deposits in Belt rocks, areas of high potential for strata-bound phosphate deposits, areas of low, moderate, and high potential for fluorine deposits, and areas of low and moderate potential for barium (as barite) deposits.

Strata-bound copper and silver minerals are present at several localities in Middle Proterozoic Belt Supergroup rocks. Most of these occurrences are in either the Spokane or Mount Shields Formations. Areas of moderate potential for strata-bound copper-silver deposits are located in the northeastern and western parts of the quadrangle where the Spokane and Mount Shields Formations are present and where samples from the geochemical survey show anomalies in copper, silver, barium, and lead.

Strata-bound phosphate deposits are found only in the Lower Permian Phosphoria Formation. The areas of high potential for these deposits coincide with exposures of Phosphoria Formation on the geologic map and downdip extensions of this formation. These areas are scattered through the central and east-central parts of the quadrangle.

Fluorine is present in the Butte quadrangle in two distinct deposit types. In stratabound phosphate deposits, fluorine is found as carbonate-fluorapatite, the ore mineral of phosphate. Phosphate ore contains 1 part fluorine for every 10 parts P_2O_5, and fluorine is a viable byproduct of phosphate mining and processing. Therefore, the areas of high potential for strata-bound phosphate deposits mentioned above are of high potential for fluorine also. Fluorine is common also as fluorite in hydrothermal vein and replacement deposits. In the Butte quadrangle, fluorite is a major component of some hydrothermal deposits associated with monzogranite and granodiorite stocks and a common minor component in base- and precious-metal deposits. Areas of moderate and high potential for vein and replacement deposits of fluorite are present in the southwestern, central, southeastern, and northeastern parts of the quadrangle.

Vein deposits of barite are scattered throughout the western part of the quadrangle in Middle Proterozoic Belt rocks. Barite is also a common constituent in some base- and precious-metal vein deposits in the central and eastern parts of the quadrangle. Areas of moderate potential for barite vein deposits include the areas of Belt rocks in the Sapphire thrust plate in the western and central parts of the quadrangle and a few small areas in the east-central part of the quadrangle.

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Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that maybe cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales, they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. The series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; the principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

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