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Mineral Resource Assessment of the Dillon 1° × 2° Quadrangle, Idaho and Montana

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Mineral Resource Assessment of the Dillon 1° × 2° Quadrangle, Idaho and Montana

By ROBERT C. PEARSON, CHARLES M. TRAUTWEIN,
EDWARD T. RUPPEL, WILLIAM F. HANNA,
LAWRENCE C. ROWAN, JEFFREY S. LOEN,
and BYRON R. BERGER

Background information to accompany a folio of
geological, geophysical, remote sensing, and
mineral resource maps—a part of the Conterminious
United States Mineral Assessment Program (CUSMAP)

U.S. GEOLOGICAL SURVEY CIRCULAR 1077

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Mineral Resource Assessment of the Dillon 1° × 2° Quadrangle, Idaho and Montana

By Robert C. Pearson, Charles M. Trautwein, Edward T. Ruppel, William F. Hanna, Lawrence C. Rowan, Jeffrey S. Loen, *and* Byron R. Berger

ABSTRACT

The Dillon 1°×2° quadrangle in southwestern Montana and east-central Idaho was investigated as part of the U.S. Geological Survey's Conterminous United States Mineral Assessment Program (CUSMAP) to determine its mineral resource potential. An interdisciplinary study was made of geology, geochemistry, geophysics (gravity and aeromagnetics), remote sensing, and mineral deposits. The results of those studies, as well as mineral resource assessment of numerous mineral-deposit types, are published separately as a folio of maps. This report summarizes the studies, provides background information on them, and presents a selected bibliography relevant to the geology and mineral resources of the quadrangle.

The quadrangle contains large resources of gold and substantial resources of talc and chlorite, all of which were being mined in the 1980's and early 1990's. Submarginal resources of molybdenum, copper, tungsten, and iron range from moderately large to large. Other commodities that may be present in significant amounts are chromite, lead, zinc, silver, barite, zeolite minerals, and various nonmetallic metamorphic minerals.

PURPOSE OF THE STUDY

The studies of geology and mineral resources that are summarized in this report were made largely under the Conterminous United States Mineral Assessment Program (CUSMAP), the chief purpose of which is to determine the mineral resource potential of selected quadrangles by means of a multidisciplinary approach. CUSMAP is intended to provide information on mineral resources to assist Federal, State, and local governments in formulating minerals policy and land-use policy and to provide information to the general public for use in mineral exploration and development. This report gives general information on the Dillon quadrangle and describes and summarizes a series of reports that present pertinent features of geology, geochemistry, geophysics, and mineral resources. These reports are mainly in the form of maps at a scale of 1:250,000. Mineral commodities considered to be beyond the scope of this project are coal, oil and gas, thorium, uranium, phosphate, and geothermal energy.

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LOCATION AND GEOGRAPHY

The studies described herein were made within the Dillon 1°×2° quadrangle in southwestern Montana and east-central Idaho, a region that encompasses about 6,820 mi^2 (fig. 1). The quadrangle is bounded by latitude 45° and 46° north and longitude 112° and 114° west. The Montana part of the quadrangle is drained largely by the Jefferson River and its tributaries, most notably the Big Hole, the Beaverhead, and the Ruby Rivers (fig. 2). Small areas along the northern edge of the quadrangle are drained by tributaries of the Clark Fork River, and the northwestern corner is drained by the Bitterroot River—both of these rivers are on the western side of the Continental Divide. The Idaho part of the quadrangle is in the Salmon River drainage, which is also west of the Divide.

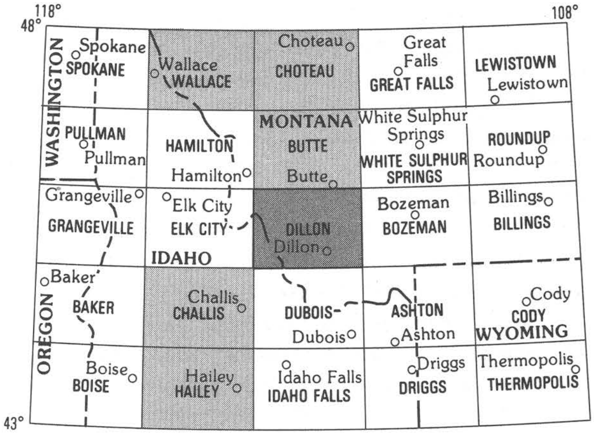

Figure 1. Index map showing location of Dillon 1°×2° quadrangle and nearby quadrangles. CUSMAP quadrangles patterned.

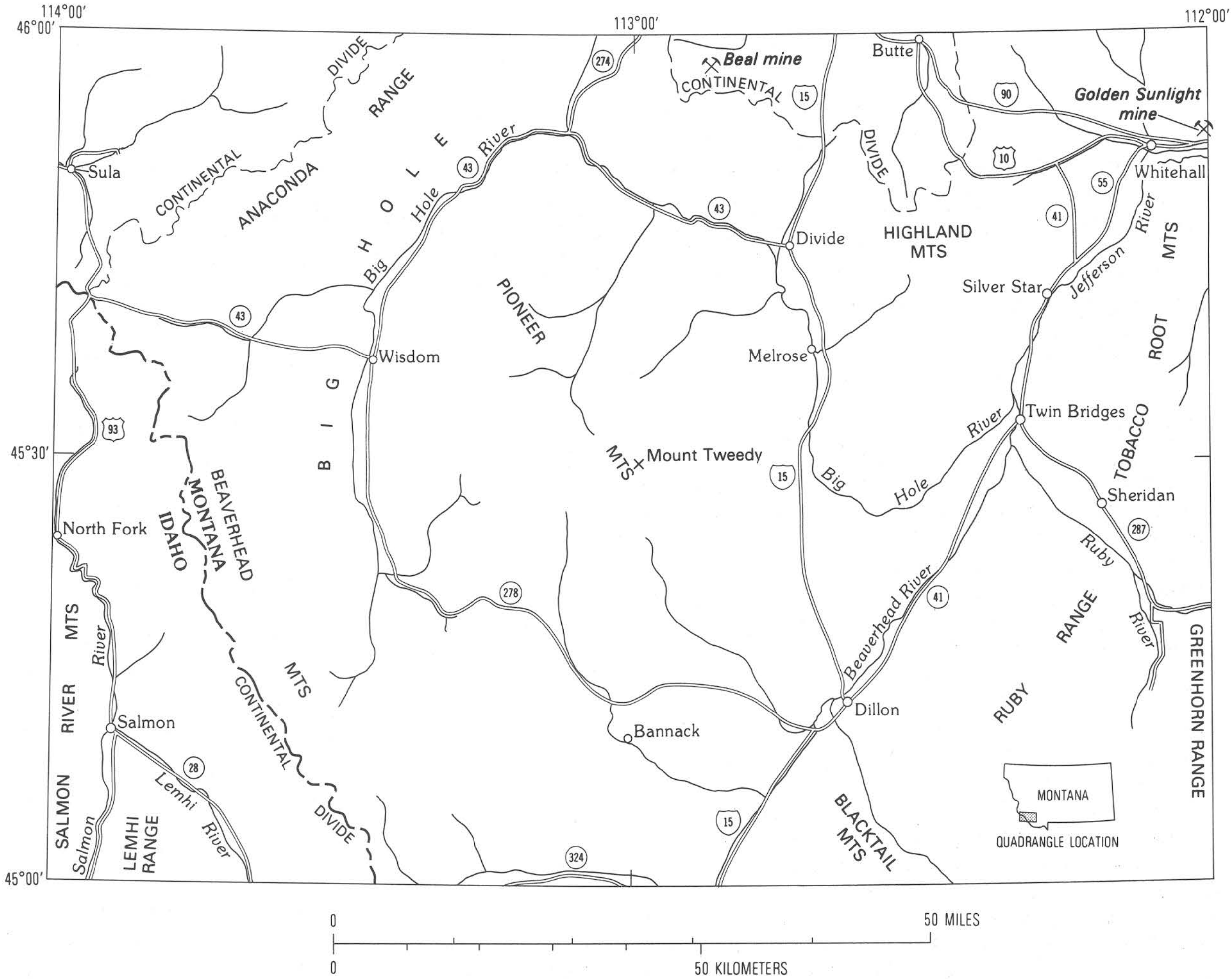

Figure 2. Index map of Dillon 1°×2° quadrangle showing geographic features.

The Montana part of the quadrangle contains many small mountain ranges—the Tobacco Root Mountains, Ruby Range, Blacktail Mountains, Highland Mountains, Pioneer Mountains, and Anaconda Range. The Continental Divide, on the crest of the Beaverhead Mountains in the western part of the quadrangle, forms the boundary between Idaho and Montana. In Idaho, parts of the Lemhi Range and Salmon River Mountains are present. The mountain ranges, especially in Montana, are separated by broad valleys that are used mostly as irrigated crop or pasture land.

The lowest altitude within the quadrangle is about 3,600 ft, where the Salmon River leaves the quadrangle at its western edge, and the highest point is 11,154 ft, on Mt. Tweedy in the Pioneer Mountains, very near the center of the quadrangle.

The northern boundary of the quadrangle passes through Butte, Montana, the largest city in the immediate area. Salmon, Idaho, and Dillon, Montana, are other small cities, and ten or so other communities are scattered through the quadrangle. The largest of these other towns are Whitehall, Twin Bridges, Sheridan, and Wisdom, all in Montana.

Much of the mountainous terrain is National Forest. Together, the Beaverhead, Deer Lodge, Bitterroot, and Salmon National Forests occupy more than 50 percent of the area of the quadrangle. Lands administered by U.S. Bureau of Land Management or owned by the two States comprise additional sizable tracts, leaving about one-quarter of the land of the quadrangle under private ownership.

The principal industry in the area is agriculture. Cattle ranching and growing of forage and small-grain crops predominate. Tourism is a significant industry that has grown steadily just as logging has steadily declined. The mining industry increased appreciably in importance during the 1980's as a result of an increase in gold mining.

Mining of talc in the Ruby and Greenhorn Ranges was the principal mineral industry activity in the Dillon quadrangle in the 1970's and early 1980's, but as the price of gold rose, more emphasis was placed on its exploration and development. In 1990, the largest mining operation in the quadrangle, as well as the largest gold mine in the State of Montana, was the Golden Sunlight mine near Whitehall (fig. 2). The Beal mine, in the north-central part of the quadrangle (fig. 2), is also a large-tonnage gold mine that began operations in 1988. In addition, several smaller mining operations have produced ore in recent years, and exploration continues, chiefly for precious metals and talc.

PREVIOUS STUDIES

Geologic studies in the Dillon quadrangle began in the early part of the twentieth century. Umpleby (1913) prepared a geologic map of the Idaho part of the quadrangle and reported on its mining districts. Winchell (1914) made a cursory but extremely valuable investigation of all mining districts in the eastern half of the quadrangle and adjacent areas and commented on their geologic setting. Those early studies were followed by more detailed studies of individual mining districts: Shenon (1931) in the Bannack, Blue Wing, and Argenta districts; Karlstrom (1948) in the Hecla district; Sahinen (1939, 1950) in the Rochester, Silver Star, and several other districts in the Highland Mountains; Johns (1961) in the southern Tidal Wave district; Burger (1967) in the Sheridan district; and Alexander (1955) and Lindquist (1966) in the Whitehall district. Important compilations of information on mines and geology are those by Geach (1972), Roby and others (1960), and Tansley and others (1933). A very significant report on the history of mining in Beaverhead County, Montana, is by Sassman (1941).

A selected bibliography, which is applicable to the geology and mineral deposits of the quadrangle, is at the end of this report, and a more extensive bibliography is given in Loen and Pearson (1989).

PRESENT INVESTIGATIONS

Geologic mapping in connection with the Dillon CUSMAP project began in 1977 in the southwestern part of the quadrangle by E.T. Ruppel and D.A. Lopez. New geologic mapping and field checking continued intermittently through 1988. In 1978, a series of mineral resource assessments of Wilderness Study Areas was begun by the U.S. Geological Survey (O'Neill, 1983a, 1983b; O'Neill and others, 1983; Berger and others, 1983; Elliott and others, 1985; Pearson and Zen, 1985; Pearson and others, 1987; Pearson and others, 1988; Smedes and others, 1980; and Tysdal and others, 1987a, 1987b). These studies, which continued through much of the 1980's, provided information important to the objectives of the CUSMAP project. The wilderness studies produced critical new geologic mapping, stream-sediment and rock geochemical data, and aeromagnetic and ground gravity measurements. Examination and sampling of mining districts and individual mineral deposits and prospects began in 1981 by R.C. Pearson and B.R. Berger. A literature search and a compilation of information on mines and prospects was made by J.S. Loen and R.C. Pearson; data were compiled through 1984. Aeromagnetic coverage of the quadrangle was completed in 1981 (U.S. Geological Survey, 1975, 1979, 1981a, 1981b), and gravity measurements were completed in 1986 (Hassemer and others, 1986; Kaufmann and others, 1983). Results of analysis of remote-sensing data to locate hydrothermally altered rocks and linear features in rocks (Segal and Rowan, 1989; Purdy and Rowan, 1990) were field checked to a limited extent by D.B. Segal and L.C. Rowan. Digitizing and computer analysis of the data and maps were done at the U.S. Geological Survey's EROS Data Center, Sioux Falls, South Dakota, under the direction of C.M. Trautwein.

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Of the many persons who contributed significantly to this project, the authors of several of the principal reports—in addition to those of the present report—should be mentioned expressly: J.H. Hassemer, H.L. James, S.K. Jenson, H.E. Kaufmann, D.A. Lopez, S.H. Moll, J.M. O'Neill, T. L. Purdy, B.D. Ruppel, and D.B. Segal. Others who have contributed directly to the completion of the project are N.R. Desmarais, J.L. Dwyer, D.L. Hanneman, W.C. Pecora, L.W. Snee, and E-an Zen.

PRODUCTS AND RESULTS OF THE DILLON CUSMAP PROJECT

The principal reports resulting from the Dillon CUSMAP project are listed in table 1 and discussed below, together with a summary of their contents.

Geology

(Open-File Report 83–168; Map I–1803–H)

The geologic map of the Dillon quadrangle includes earlier mapping that was field checked and compiled from many sources and much new mapping in the central and western parts of the quadrangle. A preliminary version of the map, U.S. Geological Survey Open-File Report 83–168 (Ruppel and others, 1983), was used in interpreting and depicting the remote sensing and geophysical data and as a source of data for mineral resource assessment. A

Table 1. Maps of the Dillon quadrangle CUSMAP folio

[See Selected Bibliography for complete references. OF, U.S. Geological Survey Open-File Report; I, U.S. Geological Survey Miscellaneous Investigations Series Map]

Map No.	Subject	Authors
OF-83-168	Preliminary geologic map	Ruppel, O'Neill, and Lopez
I-1803-A	Limonite and hydrothermal alteration	Segal and Rowan
I-1803-B	Analysis of linear features	Purdy and Rowan
I-1803-C	Mines and prospects	Loen and Pearson
I-1803-D	Mineral assessment of Precambrian deposits	Pearson and others
I-1803-E	Mineral assessment of vein and replacement deposits	Pearson and others
I-1803-F	Mineral assessment of placer deposits	Pearson and others
I-1803-G	Mineral assessment of skarn and porphyry deposits	Pearson and others
I-1803-H	Final geologic map	Ruppel, O'Neill, and Lopez
I-1803-I	Aeromagnetics and Bouguer gravity	Hanna and others

generalized version of the map has been used as a geologic base for other maps in the Dillon quadrangle folio. The Open-File map is superseded by U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–H (Ruppel and others, in press), which is the final geologic map, printed in color.

The rocks of the Dillon region differ in each of the tectonic provinces shown on figure 3. Those in the eastern, foreland part of the quadrangle include a sequence about 11,500 ft thick of marine and nonmarine sedimentary rocks of Paleozoic and Mesozoic age that were deposited on the Archean and Early Proterozoic crystalline metamorphic rocks of the North American craton (fig. 4). Sedimentary rocks in the frontal fold and thrust zone and in the Grasshopper thrust plate (fig. 3) are similar to those on the craton, except that the Grasshopper plate includes a sequence of Middle Proterozoic sandstone and quartzite more than 23,000 ft thick. The Medicine Lodge thrust plate, in the western part of the quadrangle (fig. 3), is made up of sedimentary rocks of Middle Proterozoic age, mainly quartzite and siltite that differ radically and abruptly from those on the Grasshopper plate. The Medicine Lodge plate is above the Middle Proterozoic Yellowjacket Formation, which is inferred to be autochthonous.

The thrust faulting that defines the different tectonic provinces probably began, perhaps some distance west of the quadrangle, about 90–100 Ma (mid Cretaceous) and was completed by about 65 Ma (latest Cretaceous to early Paleocene). Most of the thrusting had ended when the first of the widespread complex bodies of granitic rocks, many of batholithic dimensions, were intruded at about 80 Ma. Thrusting, probably minor, also took place at about 77 Ma and at about 65–70 Ma. The earliest thrust faulting was accompanied by foreland deformation that formed a synclinal moat in front of the thrust belt and, farther east, a broad, anticlinal foreland uplift (Blacktail-Snowcrest uplift). The moat was partly filled with clastic sediments derived both from the advancing thrust plates and from erosion that exposed Archean rocks in the core of the foreland uplift. Volcanic rocks, also of Late Cretaceous age, were erupted in the northeastern and south-central parts of the quadrangle.

In Eocene and Oligocene time, broad blankets of tuffaceous sediments were deposited in shallow basins, and volcanic rocks were erupted from many local centers. The present deep basins of the region started to form in the late Oligocene, and tuffaceous sedimentary deposits continued to accumulate in them throughout Miocene and Pliocene time. These basins and their flanking mountain blocks are bounded by steeply dipping faults, many of Archean ancestry, that have moved recurrently throughout the Cenozoic and continue today to control the rhombic pattern of faults in the region.

Thus, the present basins and ranges are products of faulting and mountain building that have been almost continuous through much of the Cenozoic. The ranges have been steepened and their height accentuated through sculpturing by repeated alpine glaciation, and mountain valleys commonly are choked with moraines. Glacial outwash gravels are widespread in the Big Hole, a Tertiary basin in the western and north-central parts of the quadrangle (fig. 2). In other parts of the region, glaciers contributed gravels to broad alluvial fans and to the alluvial fill that continues to accumulate along most stream valleys.

Aeromagnetic and Gravity Studies

(Map I–1803–I)

Aeromagnetic and gravity maps were prepared from data gathered in several separate surveys that range widely in scale, age, and quality. These interpretations are being released as map I–1803–I (Hanna and others, in press).

The interpretation of aeromagnetic and gravity data was enhanced by laboratory measurement of rock density and magnetization on 291 samples.

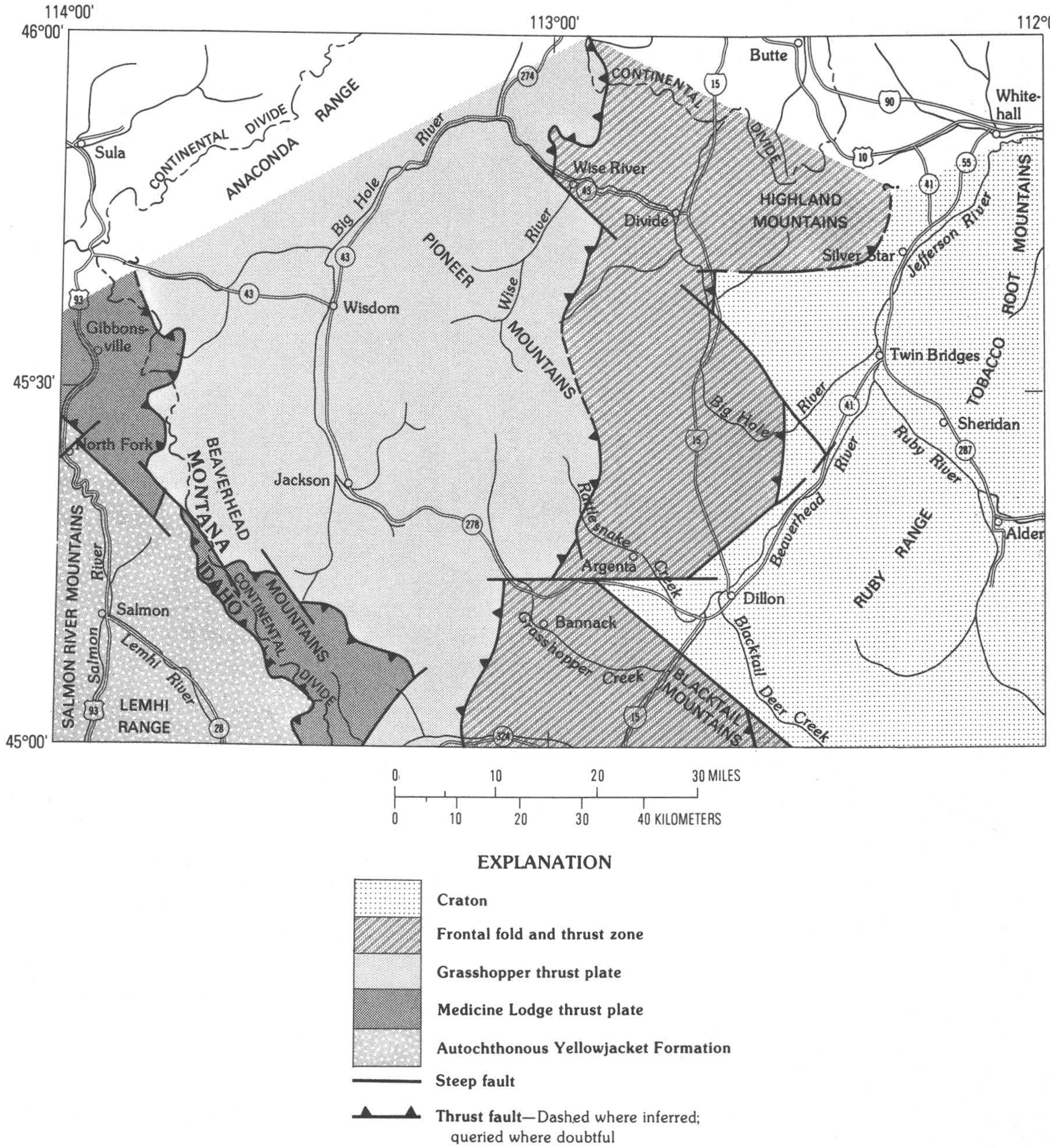
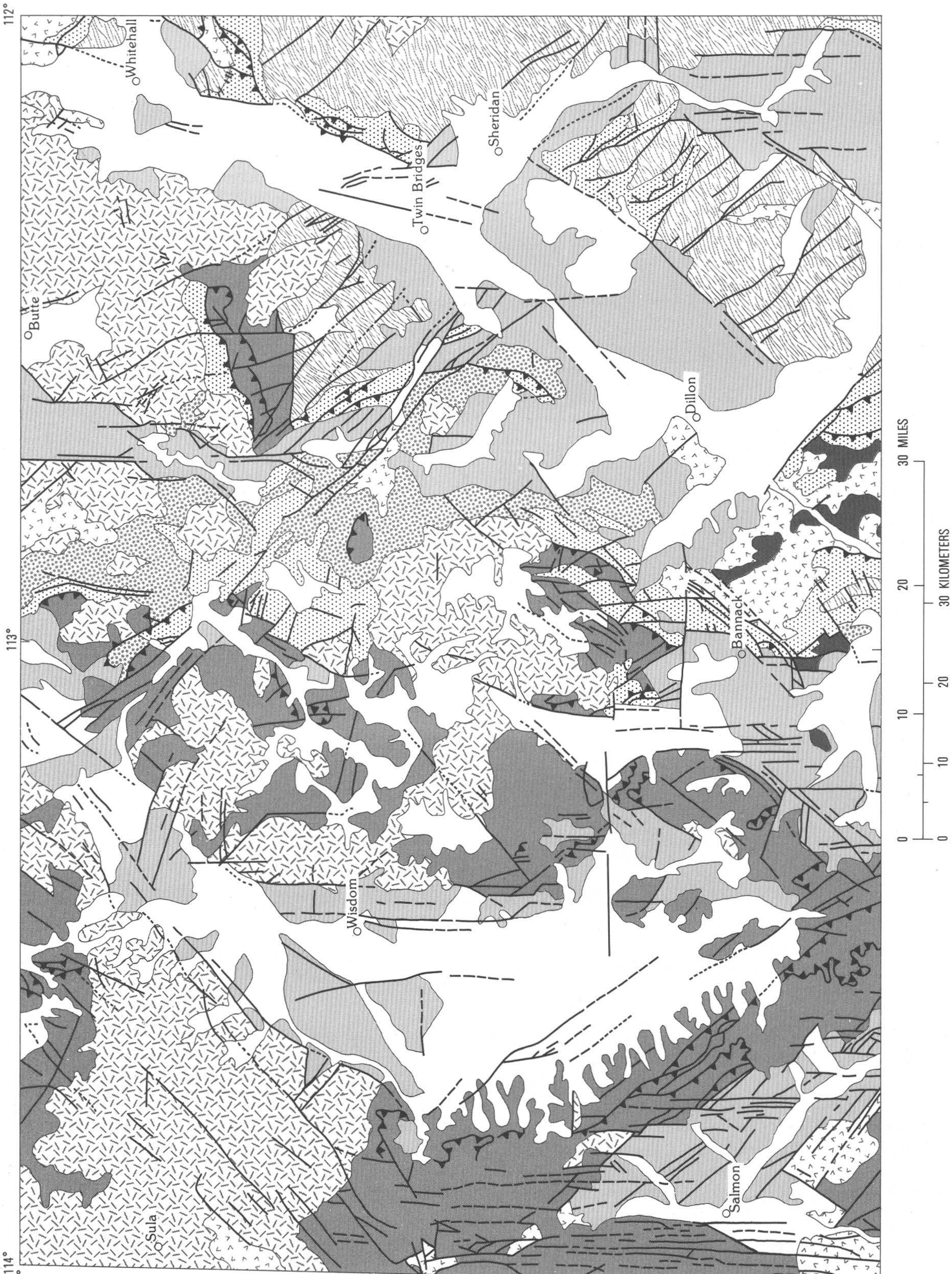


Figure 3. Tectonic province map of Dillon 1°×2° quadrangle, Idaho and Montana; modified from Ruppel and Lopez (1984). Igneous rocks and surficial deposits not shown.

The aeromagnetic maps were derived from data collected in five surveys flown at different times, flight heights, flight-line spacings, and other specifications (Johnson and others, 1965; U.S. Geological Survey, 1975, 1979, 1981a, 1981b). The individual surveys were combined photographically to produce a single map that contained all of the detail of the original surveys. The data of the original surveys were also merged mathematically to produce another map with uniform parameters. Both maps, as well as other derivative maps, were used to interpret the distribution and magnetization of various rock bodies and structures that, in turn, were used in the interpretation of mineral resource potential.

Gravity measurements were made at about 2,500 stations in the quadrangle. About 2,050 of these were made by Harold E. Kaufmann, Scott B. Sorensen, and Kelley J. O'Neill (Kaufmann and others, 1983). Additional measure-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Dillon
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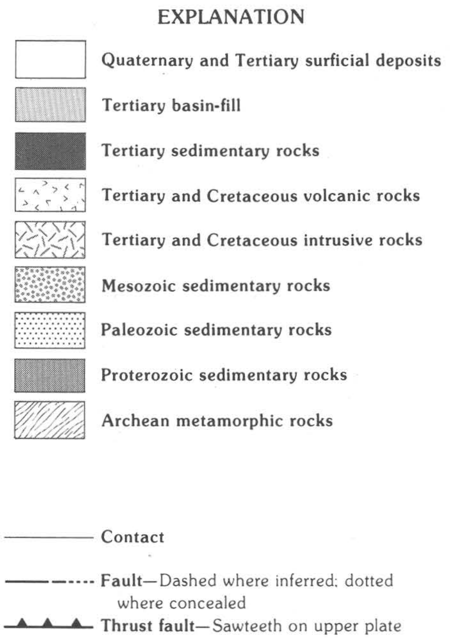

Figure 4 (above and facing page). Generalized geologic map of the Dillon 1°×2° quadrangle, Idaho and Montana (adapted from Ruppel and others, 1983, by Purdy and Rowan, 1990).

ments were made by Jerry H. Hassemer (Hassemer and others, 1986) and Byron D. Ruppel (unpub. data).

Remote Sensing

Measurements of reflected and emitted electromagnetic radiation from the surface of the earth were recorded by means of satellite and airplane. These measurements are referred to as remote-sensing data. Interpretation of these data is presented in maps I–1803–A and I–1803–B.

Limonite and Hydrothermally Altered Rocks

(Map I–1803–A)

Map I–1803–A portrays the areal distribution of iron hydroxides (commonly called limonite) that stain the surface of certain rocks. Limonite in some environments is significant in mineral resource investigations because it is a common product of weathering of minerals, typically iron sulfides, that are associated with metallic mineral deposits. The sulfides break down to form limonite, whose existence can be recognized by combining measurements of certain spectral wavelength bands obtained from satellite imagery. Limonite can form in ways other than weathering of iron-bearing sulfides associated with mineral deposits, and therefore, many limonite anomalies were examined on the ground to attempt to determine those which might have mineral-deposit significance. Coniferous forests and other types of vegetation, which are extensive in the Dillon quadrangle, conceal the limonite to a variable degree.

The presence of limonite, based on its characteristic spectral reflectance, can be approximated by determining ratios of spectral bands using Landsat multispectral scanner (MSS) images. Bands used are 4, 5, 6, and 7, which correspond, respectively, to wavelengths of 0.5–0.6 μm, 0.6–0.7 μm, 0.7–0.8 μm, and 0.8–1.1μm. The ratios of bands 4:5 and 6:7 and the compound ratio (4:5):(6:7) were found to be useful in identifying limonite in the Dillon quadrangle. In part, map I–1803–A distinguishes between anomalies that are thought to be caused by mineralization from those of other origins.

Lineaments and Linear Features

(Map I–1803–B)

Map I–1803–B reports the results of analysis of linear features observed on digitally processed MSS images; both color-infrared composite images and black-and-white images of MSS bands 5 and 7 are analyzed. In addition, linear features were mapped on synthetic-aperture radar images. Digitizing and statistical analysis of this data revealed clusters of linear features and certain azimuthal maxima. The clusters, some of which are aligned, are defined here as lineaments.

The linear features and lineaments derived from them are regarded as having structural significance and, as such, many of them represent faults, joints, and other geologic features.

A statistical analysis of the association of limonite anomalies, certain linear features, and lineaments with areas of mineralization in the Dillon quadrangle indicates a positive correlation.

Geochemistry

Several geochemical studies within the Dillon quadrangle were used in the mineral resource assessment (Berger, Breit, and others, 1979; Berger, Van der Voort, and others, 1979; Broxton, 1979; Elliott and others, 1985; Leatham-Goldfarb and others, 1986; O'Neill, 1983b; O'Neill and others, 1983; Pearson and others, 1987, 1988). Geochemical data on mineralized rock samples were interpreted by statistical techniques in order to relate suites of elements to various mineral-deposit types. Using the suites of elements thus determined, the database of Broxton (1979)—edited and augmented by additional geochemical analyses by the U.S. Geological Survey—was utilized in the mineral resource assessment. The samples of Broxton (1979) were stream-sediment samples that broadly covered the entire quadrangle.

Mines and Prospects

(Map I–1803–C)

The Dillon quadrangle occupies a part of the northern Rocky Mountains long known for its abundance and variety of mineral deposits. The locations of mines and prospects, their classification into mineral-deposit types, and various aspects of their geology are presented in map I–1803–C (Loen and Pearson, 1989). Mineral production of mining districts is also given, although the amount of this production is poorly known and, hence, largely estimated. The information in map I–1803–C was compiled from several earlier compilations, chiefly the U.S. Geological Survey's Mineral Resource Data System (MRDS) and also from numerous other compilations (Bentley and Mowatt, 1967; Geach, 1972; Roby and others, 1960; Sassman, 1941; Strowd and others, 1981; Tansley and others, 1933; Umpleby, 1913; and Winchell, 1914). A large number of other sources that provide detailed information about individual mines and prospects were used (see Loen and Pearson, 1989, for a list of these sources). A table that accompanies map I–1803–C gives information on 821 mines, prospects, claims, and claim groups.

More than 500 of the localities are classified as vein and replacement deposits of base and precious metals. These deposits include virtually all deposits that were mined and prospected, other than placer deposits, during the early days of mining (1862 until about 1900). These were, and continue to be, valuable mainly for gold or silver and lead; the ores from some have appreciable copper or zinc as well. The remaining mines and prospects have been classified into a variety of deposit types. Placer deposits of gold are abundant. Skarn tungsten deposits have been significant in the past. Porphyry, stockwork, or disseminated deposits and prospects of molybdenum and copper are numerous, but they have not yet been exploited, owing to subeconomic grades. Belt copper-silver (named for the Middle Proterozoic Belt Supergroup) and Sullivan-type massive sulfide deposits (named for the Sullivan mine in British Columbia) are known but, likewise, have not been mined, except where iron-rich gossan that had formed by weathering of the sulfides was used as smelter flux. Among the nonmetallic minerals, talc is of major significance; chlorite has been mined in recent years from one deposit; and deposits and prospects are known for barite, graphite, manganese, garnet, chromite, and several metamorphic minerals.

The mines and prospects tend to be clustered in mining districts. As they are recognized in this study, all or parts of 44 districts are in the quadrangle, and some mines and prospects are scattered outside recognized mining districts.

Mineral Resource Assessment

The mineral resource assessment of the Dillon quadrangle attempted to locate those parts of the quadrangle that are potentially favorable for various types of mineral deposits and to determine, if possible, the amount of mineral commodities that they contain in mineable concentrations. Mineral deposits that are known to exist (or that are suspected to exist from a knowledge of the geologic setting) have been grouped into 30 deposit types based on mineralogy, mineral commodity, or structural or depositional setting (table 2). These 30 deposit types may be combined in various ways. A separate assessment was undertaken for several of the deposit types listed in table 2. The deposit types have been divided into four groups whose similarities make them amenable to being treated together. Metallic minerals were emphasized, but some important nonmetallic minerals were also considered. Fossil fuels are beyond the scope of this

Table 2. Mineral-deposit types in the Dillon 1°×2° quadrangle

[*, deposit types assessed in CUSMAP folio reports]

Deposits associated with Archean crystalline rocks
*Bedded iron-formation
*Talc
*Chlorite
*Exhalative gold
*Chromite
*Nickel
*Graphite
Manganese
Metamorphic minerals (corundum, sillimanite, asbestos)
Deposits associated with Middle Proterozoic sedimentary rocks
*Exhalative Sullivan-type massive sulfide (base metals)
*Belt copper-silver
*Exhalative Blackbird-type cobalt-copper-gold
Hydrothermal and other epigenetic deposits
*Skarn (W, Cu, Ag, Au, Fe)
*Stockwork, porphyry, or disseminated (Mo, Cu, Au)
*Vein and replacement deposits (base and precious metals)
*Vein barite
*Vein fluorspar
Vein thorium
Vein manganese
Vein uranium
Syngenetic, diagenetic, and other deposits in sedimentary rocks
Manganese
Phosphate
Oil shale
Clay (bentonite and other clay)
Coal
Uranium
*Placer gold and silver
Zeolites
Building stone
Sand and gravel

investigation, and other minerals, such as phosphate, uranium, and thorium, have been investigated previously. Certain nonmetallic commodities, such as sand and gravel, are in very large supply, and the deposits of other commodities, such as clay, bentonite, and zeolites, are not sufficiently well known to permit an assessment.

An assessment of the quadrangle for uranium was made under the National Uranium Resource Exploration Program (NURE) (Wodzicki and Krason, 1981). This study was largely a compilation of existing data and included only minimal field studies. The results of this investigation indicate that the Dillon quadrangle probably does not contain substantial resources of uranium. No uranium has been mined, and the few places that exhibit abnormally high radioactivity do not have geologic characteristics that indicate a high potential. The geologic environments with the highest potential for uranium are the Tertiary basins that contain abundant pyroclastic debris that may have provided a source of uranium. The basins also have permeable aquifers that could serve as host rocks.

Thorium resources are present in the Lemhi Pass thorium district, which is mostly south of the Dillon quadrangle. The deposits in the Lemhi Pass district are in veins that cut Proterozoic sedimentary rocks. Moderately large resources are present in these deposits (Staatz, 1979). The few veins that extend from the main part of the district into the Dillon quadrangle probably contain only very small resources of thorium.

Phosphate resources were studied by Popoff and Service (1965) and Swanson (1970). Phosphate rock was mined for many years from deposits in the central part of the quadrangle near Melrose. Large resources remain, but they are considered to be subeconomic at the present time. The Permian Phosphoria Formation, which contains the phosphate resources, also contains subeconomic resources of oil shale, fluorine, uranium, vanadium, and other minor metals either within the phosphate rock or in associated strata (Swanson, 1970).

Mineral resources in the quadrangle were assessed using a procedure that relied on the development of deposit models for each deposit type. The models used here are basically a description of the deposits' physical characteristics and of their spatial relationships to local and regional geological, geochemical, and geophysical features. Once a model was constructed for each deposit type, the quadrangle was examined throughout to determine the distribution of all pertinent characteristics or attributes, and, from that, the favorability for deposits of each type was estimated.

A computer-based geographic information system (GIS) was used to develop each deposit model, to assist in the mineral resource assessment, and to prepare the mineral resource assessment maps. The GIS provides a means of comparing and interrelating the various kinds of data that can be referenced geographically. The data sets described above (geology, geochemistry, gravity, aeromagnetics, linear features, hydrothermal alteration, and mines and prospects) were digitized and entered into the GIS, where they could be compared quantitatively throughout the quadrangle. By this technique, the effects of any two or more data sets at any geographic point can be considered simultaneously. Details of the technique—what it consists of and how it was used—are presented in the discussion that accompanies maps I–1803–E, I–1803–F, and I–1803–G. This is the first comprehensive application of GIS technology to assess mineral resources of large areas.

For some deposit types, the important characteristics (favorability criteria) that are relevant to the formation or localization of a deposit are both few and simple or are not available at the scale of this study (1:250,000). The assessment for those types was made almost entirely subjectively. In some cases, the only available pertinent criteria were the kind and age of host rock. Talc deposits in Archean dolomite units are an example. Other deposit types were treated by the more sophisticated GIS procedure, in which all favorability criteria were examined for the entire quadrangle.

Assessment of Deposits of Precambrian Age

(MAP I–1803–D)

Map I–1803–D deals with mineral deposits that formed in the Precambrian and that are hosted by Precambrian rocks. The Precambrian rocks can be divided into crystalline rocks of Archean and Early Proterozoic age and unmetamorphosed to weakly metamorphosed sedimentary rocks of Middle Proterozoic age. Each of these groups of rocks is favorable for a separate group of mineral deposits.

Archean metamorphic rocks in the southeastern part of the Dillon quadrangle are hosts for deposits and prospects of talc, iron, chlorite, chromium, and other mineral commodities. Archean dolomite marble units host economically significant talc deposits in the Ruby Range and adjacent areas in the southeastern part of the quadrangle. Bedded iron-formation is also present in that part of the quadrangle. Although these deposits contain substantial amounts of iron of adequate grade for mining, the aggregate tonnage available cannot justify construction of ore processing facilities in the foreseeable future. Deposits of high-grade magnesian chlorite, formed by replacement of granitic gneiss, have been mined, beginning in 1977 and continuing throughout the 1980's, at one mine near Silver Star (Berg, 1979). Small bodies of chromitite have been prospected; trace amounts of nickel minerals are present; and vein-type graphite deposits have been mined. These and numerous concentrations of metamorphic minerals that may have some future economic importance are present in the crystalline rocks.

Mineral deposits in the Middle Proterozoic Belt Supergroup, Lemhi Group, and Yellowjacket Formation include types of deposits that are known widely in the same rock groups outside the Dillon quadrangle. Stratabound copper-silver deposits are present in the Belt Supergroup and have been explored but not mined. Base-metal sulfide deposits of the exhalative Sullivan type are known in the Highland Mountains and have been explored extensively but, likewise, have not been mined. Minor amounts of cobalt in the Yellowjacket Formation at one small mine in the Salmon, Idaho, area suggest a low probability of cobalt deposits in the Dillon quadrangle, although the main Idaho cobalt belt is west of the quadrangle.

Assessment of Vein and Replacement Deposits of Base and Precious Metals

(MAP I–1803–E)

The vein and replacement deposits of base and precious metals in the quadrangle are discussed in map I–1803–E. Of the several hundred deposits, mines, and prospects of this deposit type, only a few (about 15) have been moderately large producers (about $1 million to $20 million worth of metals at the time of production). Of these, most are gold mines, but in addition, silver and lead have been the main commodities from mines in the Argenta, Blue Wing, and Hecla districts, and copper has been predominant at the Pope Shenon and Harmony mines near Salmon, Idaho (Ross, 1925).

This deposit type combines many sorts of deposits that might have been classified differently and assessed separately. Other investigators perhaps would have done so. A lack of diagnostic criteria to make such separate assessments meaningful, however, prompted us to be "lumpers" rather than "splitters."

The Golden Sunlight deposit, near the northeast corner of the quadrangle, for example, in earlier decades produced substantial gold from high-grade veins, but it has recently been developed into a large bulk-tonnage mine. The Golden Sunlight deposit is considered to be a vein and replacement deposit for the purpose of this study, although it could, perhaps, be more properly classified as a breccia-pipe or disseminated type. Similarly, the Beal deposit, which was the lode source of one of the largest placer deposits in the quadrangle (German Gulch), is a disseminated deposit, similar in some respects to the Golden Sunlight, and it too might have been classified differently.

Vein barite and replacement and vein fluorspar also are similar to the vein and replacement deposits, and they are included in the discussion in map I–1803–E, although they are not base or precious metals.

Assessment of Placer Gold and Silver Deposits

(MAP I–1803–F)

Placer gold and silver deposits in the Dillon quadrangle are assessed in map I–1803–F. Placer deposits have been the main source of gold, and they are numerous in the quadrangle. Placer mining in the quadrangle began in 1862, and it continues in the 1990's. Most of the placering has taken place along small to medium-sized streams, either in Holocene alluvium on the present flood plains or in bench placers that are locally more than 100 ft above present stream levels. In addition, some eluvial deposits have been mined from slopes directly below lode deposits.

Other sedimentary deposits that are considered in map I–1803–F are the Tertiary deposits in basins. During the late Tertiary, uplift of mountainous parts of the quadrangle was rapid. The resulting rapid erosion caused debris to be moved from the uplands out into the developing basins. Wherever gold-bearing lodes were eroded during this period, gold might have been transported to a site in the basin (most probably a site along the edge of the basin and not far from the lodes) and concentrated into placer deposits. Placer mining of such deposits has taken place only to a limited degree, but the possible existence of such deposits is inferred, and an attempt is made to delineate areas where such deposits may occur.

Assessment of Porphyry Deposits of Copper, Molybdenum, and Gold and Skarn Deposits of Tungsten, Copper, Silver, and Gold

(MAP I–1803–G)

Porphyry deposits of copper, molybdenum, and gold and skarn deposits of tungsten, copper, silver, and gold are assessed in map I–1803–G. The largest tungsten mines in Montana are in the Dillon quadrangle. These mines have produced very little since the 1950's, but exploration during the 1970's and 1980's has indicated that large tungsten resources remain.

Porphyry deposits were sought extensively by mining companies in the 1960's and 1970's. One deposit was delineated by drilling, and others were drilled sufficiently to determine that they have high economic potential. The porphyry deposits are mostly in the Pioneer Mountains and occur in the Highland Mountains, Tobacco Root Mountains, Salmon River Mountains, and Anaconda Range as well. None of the porphyry deposits have been mined. Copper is the principal metal sought in two of the prospects: the Bobcat Gulch prospect near North Fork, Idaho, and the Grasshopper prospect east of Bannack. The Grasshopper prospect was initially explored for copper and molybdenum, but in 1989, exploration was conducted in the same location for gold. Molybdenum is the principal metal in the Cannivan Gulch deposit, which has been developed by drilling to an extent that size and grade are known. All known porphyry deposits are within or adjacent to granitic plutons of Late Cretaceous or earliest Tertiary age.

CONCLUSIONS

The Dillon quadrangle is part of a mineral-rich region where mining has been continuous since 1862. A wide variety of mineral commodities is present. Mining has always been sporadic, waxing and waning with fluctuations in prices of commodities and costs of production; some deposits have become exhausted and new deposits have been discovered. It will probably continue to be a mining region indefinitely. Many deposits are known that have not been mined because their small size or low grade render them uneconomic. As of 1991, gold production is at an all-time high. The Golden Sunlight mine is producing more than 90,000 ounces of gold per year, and the Beal mine is producing at a rate of more than 35,000 ounces per year. It seems likely that additional deposits of a wide variety of mineral commodities will continue to be discovered.

SELECTED BIBLIOGRAPHY

[Includes references cited in this report and other selected references to geology and mineral deposits in the Dillon quadrangle. *, principal reports of the Dillon CUSMAP folio]

Alden, W.C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geological Survey Professional Paper 231, 200 p.

Alexander, R.G., Jr., 1955, Geology of the Whitehall area, Montana: Yellowstone-Bighorn Research Association Contribution 195, 106 p.

Anderson, A.L., 1956, Geology and mineral resources of the Salmon quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 60, 15 p.

______1957, Geology and mineral resources of the Baker quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 112, 71 p.

______1959, Geology and mineral resources of the North Fork quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 118, 92 p.

Armstrong, F.C., and Full, R.P., 1950, Geologic maps of Crystal graphite mine, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 50–26.

Armstrong, R.L., and Hollister, V.F., 1978, K-Ar dates for mineralization in the White Cloud–Cannivan porphyry belt of Idaho and Montana—A reply: Economic Geology, v. 73, p. 1,368.

Armstrong, R.L., Hollister, V.F., and Harakel, J.E., 1978, K-Ar dates for mineralization in the White Cloud–Cannivan porphyry molybdenum belt of Idaho and Montana: Economic Geology, v. 73, p. 94–108.

Bayley, R.W., and James, H.L., 1973, Precambrian iron formations of the U.S.: Economic Geology, v. 68, no. 7, p. 934–959.

Bentley, C.B., and Mowatt, G.D., 1967, Reported occurrences of selected minerals in Montana: U.S. Geological Survey Mineral Investigations Resource Map MR–50, scale 1:500,000.

Berg, R.B., 1979, Talc and chlorite deposits in Montana: Montana Bureau of Mines and Geology Memoir 45, 66 p.

______1987, Potential for talc deposits within the BLM Wilderness Study Area of the northern part of the Ruby Range, Madison County, Montana: U.S. Geological Survey Open-File Report 87–1, scale 1:24,000.

______1988, Barite in Montana: Montana Bureau of Mines and Geology Memoir 61, 100 p.

Berger, B.R., Breit, G.N., Siems, D.F., Welsch, E.P., and Speckman, W.S., 1979, A geochemical survey of mineral deposits and stream deposits in the Eastern Pioneer Wilderness Study Area, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 79–1079, 128 p.

Berger, B.R., Snee L.W., Hanna, W.F., and Benham, J.R., 1983, Mineral resource potential of the West Pioneer Wilderness Study Area, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1585–A, scale 1:50,000.

Berger, B.R., Van der Voort, J.L., Siems, D.F., and Welsch, E.P., 1979, Geochemical exploration studies in the Dillon, Montana-Idaho 1°×2° quadrangle: Geochemical reconnaissance of mining districts in the southern Pioneer Mountains and vicinity, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 79–1426, 45 p.

Breit, G.N., 1980, Geochemical exploration study of the Polaris mining district and vicinity, Beaverhead County, Montana: Golden, Colorado School of Mines, M.S. thesis, 265 p.

Broxton, D.E., 1979, Uranium hydrogeochemical and stream-sediment reconnaissance of the Dillon NTMS quadrangle, Montana/Idaho, including concentrations of forty-three additional elements: U.S. Department of Energy Open-File Report GJBX–38(79), 228 p.

Bunning, B.B., and Burnet, F.W., 1981, Copper-molybdenum mineralization in the Bobcat Gulch porphyry system, Lemhi County, Idaho: Reprint of paper presented at the 87th Annual Northwest Mining Association Convention, Spokane, Washington, December 5, 1981.

Burger, H.R., III, 1967, Bedrock geology of the Sheridan district, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 41, 22 p.

Chadwick, K.E.W., 1941, Some chromite deposits—Madison County, Montana: Butte, Montana School of Mines, B.S. thesis.

Desmarais, N.J., 1981, Metamorphosed ultramafic rocks in the Ruby Range, Montana: Precambrian Research, v. 16, p. 67–101.

______1983, Geochronology and structure of the Chief Joseph plutonic-metamorphic complex, Idaho-Montana: Seattle, University of Washington, Ph.D. thesis, 150 p.

Elliott, J.E., Wallace, C.A., O'Neill, J.M., Hanna, W.F., Rowan, L.C., Segal, D.B., Zimbelman, D.R., Pearson, R.C., Close, T.J., Federspiel, F.E., Causey, J.D., Willett, S.L., Morris, R.W., and Huffsmith, J.R., 1985, Mineral resource potential map of the Anaconda-Pintler Wilderness and contiguous roadless area, Granite, Deer Lodge, Beaverhead, and Ravalli Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1622–A, scale 1:50,000.

Evans, K.V., and Zartman, R.E., 1988, Early Paleozoic alkalic plutonism in east-central Idaho: Geological Society of America Bulletin, v. 100, p. 1,981–1,987.

______1990, U-Th-Pb and Rb-Sr geochronology of Middle Proterozoic granite and augen gneiss, Salmon River Mountains, east-central Idaho: Geological Society of America Bulletin, v. 102, p. 63–73.

Fields, R.W., Rasmussen, D.L., Tabrum, A.R., and Nichols, Ralph, 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho: A summary, *in* Flores, R.M. and Kaplan, S.S., eds, Cenozoic paleogeography of west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists Symposium 3, p. 9–36.

Filipek, L.H., and Berger, B.R., 1981, Effects of bedrock geology and geomorphology on the partitioning of Fe, Mn, Cu, and Zn in stream sediments and soils [abs.]: Geological Society of America Abstracts with Programs, v. 13, no. 7, p. 450.

Ford, R.B., 1954, Occurrence and origin of the graphite deposits near Dillon, Montana: Economic Geology, v. 49, p. 31–43.

Fraser, G.D., and Waldrop, H.A., 1972, Geologic map of the Wise River quadrangle, Silver Bow and Beaverhead Counties, Montana: U.S. Geological Survey Quadrangle Map GQ–988, scale 1:24,000.

Garihan, J.M., 1973, Geology and talc deposits of the central Ruby Range, Madison County, Montana: University Park, Pennsylvania State University, Ph.D. thesis, 209 p.

Geach, R.D., 1972, Mines and mineral deposits (except fuels), Beaverhead County, Montana: Montana Bureau of Mines and Geology Bulletin 85, 193 p.

Giletti, B.J., 1966, Isotopic ages from southwestern Montana: Journal of Geophysical Research, v. 71, p. 4,029–4,036.

Hammitt, R.W., and Schmidt, E.A., 1982, Geology and mineralization of the Cannivan Gulch deposit, Beaverhead County, Montana: Guidebook of the Seventh Annual Tobacco Root Geological Society Field Conference, p. 15–20.

*Hanna, W.F., Kaufmann, H.E., Hassemer, J.H., Ruppel, B.D., Pearson, R.C., and Ruppel, E.T., in press, Interpretation of gravity and magnetic anomalies, Dillon 1°×2° CUSMAP quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Investigations Map I–1803–I, scale 1:250,000, 1:500,000.

Hassemer, J.H., Kaufmann, H.E., and Hanna, W.F., 1986, Description of magnetic tape containing the principal facts for the gravity stations in and adjacent to the Dillon 1°×2° quadrangle, Montana and Idaho: National Technical Information Service PB 86–197407/AS, 6 p.

Heinrich, E.W., 1949, Pegmatite mineral deposits in Montana: Montana Bureau of Mines and Geology Memoir 28, 56 p.

Heinrich, E.W., and Rabbitt, J.C., 1960, Pre-Beltian geology of the Cherry Creek and Ruby Mountains areas, southwestern Montana: Montana Bureau of Mines and Geology Memoir 38, 40 p.

Hum, C.K.W., 1943, Geology and occurrence of graphite at the Crystal graphite mine near Dillon, Montana: Butte, Montana College of Mineral Science and Technology, B.S. thesis.

James, H.L., 1981, Bedded Precambrian iron deposits of the Tobacco Root Mountains, southwestern Montana: U.S. Geological Survey Professional Paper 1187, 16 p.

______1990, Precambrian geology and bedded iron deposits of the southwestern Ruby Range, Montana: U.S. Geological Survey Professional Paper 1495, 39 p.

James, H.L., and Hedge, C.E., 1980, Age of basement rocks of southwestern Montana: Geological Society of America Bulletin, v. 91, pt. 1, p. 11–15.

James, H.L., and Wier, K.L., 1972a, Geologic map of the Carter Creek iron deposit, sec. 3, 9, and 10, T. 8 S., R. 7 W., Madison and Beaverhead Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–359, scale 1:3,600.

______1972b, Geologic map of the Kelly iron deposit, sec. 25, T. 6 S., R. 5 W., Madison County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–349, scale 1:2,400.

James, H.L., Wier, K.L., and Shaw, K.W., 1969, Map showing lithology of Precambrian rocks in the Christensen Ranch and adjacent quadrangles, Madison and Beaverhead Counties, Montana: U.S. Geological Survey Open-File Report 69–132, scale 1:20,000.

Jerome, S.E., and Cook, D.R., 1967, Relation of some metal mining districts in the western United States to regional tectonic environments and igneous activity: Nevada Bureau of Mines Bulletin 69, 35 p.

Johnson, R.W., Jr., Henderson, J.R., and Tyson, N.S., 1965, Aeromagnetic map of the Boulder batholith area, southwestern Montana: U.S. Geological Survey Geophysical Investigations Map GP–528, scale 1:250,000.

Johns, W.M., 1961, Geology and ore deposits of the southern Tidal Wave mining district, Madison County, Montana: Montana Bureau of Mines and Geology Bulletin 24, 53 p.

Jones, V.E., 1931, Chromite deposits of Sheridan, Montana: Economic Geology, v. 26, no. 6, p. 625–629.

Karasevich, R.P., 1981, Structural history of the pre-Beltian metamorphic rocks of the northern Ruby Range, southwestern Montana [abs.]: Geological Society of America, Abstracts with Programs, v. 13, no. 4, p. 200.

______1981, Geologic map of the northern Ruby Range, Madison County, Montana: Montana Bureau of Mines and Geology Map GM 25.

Karlstrom, T.N.V., 1948, Geology and ore deposits of the Hecla mining district, Beaverhead County, Montana: Montana Bureau of Mines and Geology Memoir 25, 87 p.

Kaufmann, H.E., Sorensen, S.B., and O'Neill, K.J., 1983, Principal facts and complete Bouguer gravity anomaly map for the Dillon 1°×2° quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF–1354–E, scale 1:250,000.

Kirkemo, Harold, Anderson, C.A., and Creasey, S.C., 1965, Investigations of molybdenum deposits in the conterminous United States: U.S. Geological Survey Bulletin 1183–E, 90 p.

Koschmann, A.H., and Bergendahl, M.H., 1968, Principal gold districts in the United States: U.S. Geological Survey Professional Paper 610, 283 p.

Kuenzi, W.D. and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana: Geological Society of America Bulletin, v. 82, no. 12, p. 3,373–3,394.

Lambe, R.N., 1981, Crystallization and petrogenesis of the southern portion of the Boulder batholith, Montana: Berkeley, University of California, Ph.D. thesis, 171 p.

Leatham-Goldfarb, S., Siems, D.F., Welsch, E.P., and Berger, B.R., 1986, Analytical results and sample locality map of skarn, porphyry, and vein samples from the Dillon, Butte, and Dubois 1°×2° quadrangles, Idaho-Montana: U.S. Geological Survey Open-File Report 86–37, 83 p.

Levandowski, D.W., 1956, Geology and mineral deposits of the Sheridan-Alder area, Madison County, Montana: Ann Arbor, University of Michigan, Ph.D. thesis, 318 p.

Lindquist, A.E., 1966, Structure and mineralization of the Whitehall mining district, Jefferson County, Montana: Butte, Montana College of Mineral Science and Technology, M.S. thesis.

*Loen, J.S., and Pearson, R.C., 1989, Map showing location of mines and prospects in the Dillon 1°×2° quadrangle, Idaho and Montana: U. S. Geological Survey Miscellaneous Investigations Series Map I–1803–C, scale 1:250,000.

Lopez, D.A., 1981, Stratigraphy of the Yellowjacket Formation of east-central Idaho: Golden, Colorado School of Mines, Ph.D. thesis, 252 p.

Lorain, S.H., 1937, Gold lode mining in the Tobacco Root Mountains, Madison County, Montana: U.S. Bureau of Mines Information Circular 6972, 72 p.
Lorain, S.H., and Metzger, O.H., 1939, Reconnaissance of placer-mining districts in Lemhi County, Idaho: U.S. Bureau of Mines Information Circular 7082, 81 p.
Lowell, W.R., 1965, Geologic map of the Bannack-Grayling area, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–433, scale 1:31,680.
Lyden, C.A., 1948, The gold placers of Montana: Montana Bureau of Mines and Geology Memoir 26, 152 p.
McMannis, W.J., 1963, LaHood Formation—a coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, no. 4, p. 407–436.
Meyer, J.W., 1980, Alteration and mineralization of the Grasshopper prospect, Beaverhead County, Montana: Tucson, University of Arizona, M.S. thesis, 90 p.
Moore, G.T., 1956, The geology of the Mount Fleecer area, Montana: Bloomington, Indiana University, Ph.D. thesis, 88 p.
Myers, W.B., 1952, Geology and mineral deposits of the northwest quarter Willis quadrangle and adjacent Browns Lake area, Beaverhead County, Montana: U.S. Geological Survey Open-File Report, 46 p.
Newcomb, R.C., 1941, Gray quartz breccia ore body of the Highland mine, Butte, Montana: Economic Geology, v. 36, p. 185–198.
Noel, J.A., 1956, The geology of the east end of the Anaconda Range and adjacent areas, Montana: Bloomington, Indiana University, Ph.D. thesis, 74 p.
Okuma, A.F., 1971, Structure of the southwestern Ruby Range near Dillon, Montana: University Park, Pennsylvania State University, Ph.D. thesis, 122 p.
Olson, R.H., 1976, The geology of Montana talc deposits, *in* Eleventh Industrial Minerals Forum Proceedings: Montana Bureau of Mines and Geology Special Publication 74, p. 99–143.
O'Neill, J.M., 1983a, Geologic map of the Middle Mountain–Tobacco Root Roadless Area, Madison County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1590–A, scale 1:50,000.
______1983b, Geochemical map of the Middle Mountain–Tobacco Root Roadless Area, Madison County, Montana: U. S. Geological Survey Miscellaneous Field Studies Map MF–1590–B, scale 1:50,000.
O'Neill, J.M., Cather, Eric, and Cinne, J.M., 1983, Mineral resource potential map of the Middle Mountain–Tobacco Root Roadless Area, Madison County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF–1590–C, scale 1:50,000.
O'Neill, J.M., and Lopez, D.A., 1985, Character and regional significance of Great Falls tectonic zone, east-central Idaho and west-central Montana: American Association of Petroleum Geologists Bulletin, v. 69, no. 3, p. 437–447.
Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359–406.
Pattee, E.C., 1960, Tungsten resources of Montana—deposits of the Mount Torry batholith, Beaverhead County: U.S. Bureau of Mines Report of Investigations 5552, 41 p.
Pearson, R.C., and Berger, B.R., 1980, Geology and geochemistry of some hydrothermally altered rocks, Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 80–706, 24 p.
Pearson, R.C., Berger, B.R., Kaufmann, H.E., Hanna, W.F., and Zen, E-an, 1988, Mineral resources of the eastern Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1766, 34 p.
*Pearson, R.C., Hanna, W.F., James, H.L., Loen, J.S., Moll, S.H., Ruppel, E.T., and Trautwein, C.M., 1990, Map showing mineral resource assessment for silver, cobalt, and base metals in Proterozoic sedimentary rocks and for iron, chromium, nickel, talc, chlorite, gold, and graphite in Archean crystalline rocks, Dillon 1°×2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–D, scale 1:250,000.
Pearson, R.C., Hassemer, J.H., Hanna, W.F., Hoover, D.B., Pierce, H.A., and Schmauch, S.W., 1987, Mineral resources of the Farlin Creek Wilderness Study Area, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1724–C, 13 p.
*Pearson, R.C., Loen, J.S., Trautwein, C.M., Ruppel, E.T., and Moll, S.H., 1991, Mineral resource assessment of placer gold and silver, Dillon 1°×2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–F, scale 1:250,000.
*Pearson, R.C., Trautwein, C.M., Berger, B.R., Hanna, W.F., Jenson, S.K., Loen, J.S., Moll, S.H., Purdy, T.L., Rowan, L.C., Ruppel, E.T., and Segal, D.B., in press, Mineral resource assessment of vein and replacement deposits of base and precious metals, barite, and fluorspar, Dillon 1°×2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–E, scale 1:250,000, 1:500,000.
*Pearson, R.C., Trautwein, C.M., Moll, S.H., Berger, B.R., Hanna, W.F., Loen, J.S., Rowan, L.C., Ruppel, E.T., and Segal, D.B., in press, Mineral resource assessment of copper and molybdenum in porphyry and stockwork deposits and tungsten, iron, gold, copper, and silver in skarn deposits, Dillon 1°×2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–G, scale 1:250,000, 1:500,000.
Pearson, R.C., and Zen, E-an, 1985, Geologic map of the eastern Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1806–A, scale 1:50,000.
Pecora, W.C., 1987, Geologic map of the central part of the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 87–79.
Perry, E.S., 1948, Talc, graphite, vermiculite and asbestos in Montana: Montana Bureau of Mines and Geology Memoir 27, 44 p.
Popoff, C.G., and Service, A.L., 1965, An evaluation of the western phosphate industry and its resources; Part 2, Montana: U.S. Bureau of Mines Report of Investigations 6611, 146 p.
Porter, E.W, and Ripley, E.M., 1985, Petrologic and stable-isotope study of the gold-bearing breccia pipe at the Golden Sunlight deposit, Montana: Economic Geology, v. 80, no. 6, p. 1,689–1,706.
*Purdy, T.L. and Rowan, L.C., 1990, Analysis of linear features in the Dillon, Idaho-Montana, 1°×2° quadrangle for mineral appraisal: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–B, scale 1:250,000.
Rasmussen, D.L., 1973, Extension of the middle Tertiary unconformity into western Montana: Northwest Geology, v. 2, p. 27–35.
Reid, R.R., 1957, Bedrock geology of the north end of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 36, 26 p.
Roby, R.N., Ackerman, W.C., Fulkerson, F.B., and Crowley, F.A., 1960, Mines and mineral deposits, except fuels, Jefferson

County, Montana: Montana Bureau of Mines and Geology Bulletin 16, 120 p.

Ross, C.P., 1925, The copper deposits near Salmon, Idaho: U.S. Geological Survey Bulletin 774, 44 p.

Rostad, O.H., 1978, K-Ar dates for mineralization in the White Cloud–Cannivan porphyry molybdenum belt of Idaho and Montana—a discussion: Economic Geology, v. 73, p. 1,366–1,368.

Ruppel E.T., 1967, Late Cenozoic drainage reversal, east-central Idaho, and its relation to possible undiscovered placer deposits: Economic Geology, v. 62, p. 648–663.

______1978, Medicine Lodge thrust system, east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1031, 23 p.

______1985, The association of Middle Cambrian rocks and gold deposits in southwest Montana: U.S. Geological Survey Open-File Report 85–207, 26 p.

Ruppel, E.T., and Lopez, D.A., 1984, The thrust belt in southwest Montana and east-central Idaho: U.S. Geological Survey Professional Paper 1278, 41 p.

*Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1983, Geologic map of the Dillon 1°×2° quadrangle, Montana and Idaho: U. S. Geological Survey Open-File Report 83–168, scale 1:250,000.

*______in press, Geologic map of the Dillon 1°×2°quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–H, scale 1:250,000.

Sahinen, U.M., 1939, Geology and ore deposits of the Rochester and adjoining mining districts, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 19, 53 p.

______1950, Geology and ore deposits of the Highland Mountains, southwestern Montana: Montana Bureau of Mines and Geology Memoir 32, 63 p.

Sassman, Oren, 1941, Metal mining in historic Beaverhead: Missoula, University of Montana, M.A. thesis, 310 p.

Schmidt, E.A., and Worthington, J.E., 1979, Geology and mineralization of the Cannivan Gulch molybdenum deposit, Beaverhead County, Montana [abs.]: Geological Association of Canada, Program with Abstracts, v. 2, p. 46.

*Segal, D,B., and Rowan, L.C., 1989, Map showing exposures of limonitic rocks and hydrothermally altered rocks in the Dillon, Montana-Idaho, 1°×2° quadrangle: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–A, scale 1:250,000.

Shenon, P.J., 1931, Geology and ore deposits of Bannack and Argenta, Montana: Montana Bureau of Mines and Geology Bulletin 6, 77 p.

Sinkler, Helen, 1942, Geology and ore deposits of the Dillon nickel prospect, southwestern Montana: Economic Geology, v. 37, no. 2, p. 136–152.

Smedes, H.W., Hanna, W.F., and Hamilton, Michael, 1980, Mineral resources of the Humbug Spires Instant Study Area, Silver Bow County, Montana: U.S. Geological Survey Open-File Report 80–836, 25 p.

Smedes, H.W., Klepper, M.R., and Tilling, R.I., 1968, Boulder batholith—a description of geology and road log: Geological Society of America (Rocky Mountain Section, Bozeman, Montana), Field trip 3, 21 p.

Smith, J.L., 1970, Petrology, mineralogy, and chemistry of the Tobacco Root batholith, Madison County, Montana: Bloomington, Indiana University, Ph.D. thesis, 198 p.

Snee, L.W., 1978, Petrography, K-Ar ages, and field relations of the igneous rocks of part of the Pioneer batholith, southwestern Montana: Columbus, Ohio State University, M.S. thesis, 110 p.

______1982, Emplacement and cooling of the Pioneer batholith, southwestern Montana: Columbus, Ohio State University, Ph.D. thesis, 320 p.

Staatz, M.H., 1979, Geology and mineral resources of the Lemhi Pass thorium district, Idaho and Montana: U.S. Geological Survey Professional Paper 1049–A, 90 p.

Stroud, W.B., Mitchell, V.E., Hestedde, G.S., and Bennett, E.H., 1981, Mines and prospects of the Dillon quadrangle, Idaho: Idaho Bureau of Mines and Geology Mines and Prospects Map Series, 9 p., scale 1:250,000.

Swanson, R.W., 1970, Mineral resources in Permian rocks in southwest Montana: U.S. Geological Survey Professional Paper 313–E, p. 661–777.

Tansley, Wilfred, Schafer, P.A., and Hart, L.H., 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 9, 57 p.

Taylor, A.V., 1942, Quartz Hill district near Divide, Montana, *in* Newhouse, W. H., ed., Ore deposits as related to structural features: Princeton University Press, p. 215–216.

Thorson, J.P., 1984, Suggested revisions of the lower Belt Supergroup stratigraphy of the Highland Mountains, southwestern Montana: Montana Bureau of Mines and Geology Special Publication 90, p. 10–12.

Tilling, R.I., 1973, The Boulder batholith, Montana—a product of two contemporaneous but chemically distinct magma series: Geological Society of America Bulletin, v. 84, p. 3,879–3,900.

Tysdal, R.G., 1976, Geologic map of the northern part of the Ruby Range, Madison County, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–951, scale 1:24,000.

______1988, Geologic map of the northeast flank of the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–2041, scale, 1:24,000.

Tysdal, R.G., Lee, G.K., Hassemer, J.H., Hanna, W.F., and Benham, J.R., 1987a, Mineral resources of the Blacktail Mountains Wilderness Study Area, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1724–B, 21 p.

Tysdal, R.G., Lee, G.K., Hassemer, J.H., Hanna, W.F., and Schmauch, S.W., 1987b, Mineral resources of the Ruby Mountains Wilderness Study Area, Madison County, Montana: U.S. Geological Survey Bulletin 1724–A, 22 p.

Umpleby, J.B., 1913, Geology and ore deposits of Lemhi County, Idaho: U.S. Geological Survey Bulletin 528, 182 p.

U.S. Geological Survey, 1975, Aeromagnetic map of southwestern Montana and east-central Idaho: U.S. Geological Survey Open-File Report 75–655, scale 1:250,000.

______1979, Aeromagnetic map of the Pioneer-Beaverhead area, Montana: U.S. Geological Survey Open-File Report 79–758, scale 1:250,000.

______1981a, Aeromagnetic map of the Tobacco Roots area, Montana: U.S. Geological Survey Open-File Report 81–777, scale 1:50,000.

______1981b, Aeromagnetic map of the Sapphire/Anaconda Mountains area, Montana: U.S. Geological Survey Open-File Report 81–1160, scale 1:62,500.

Vitaliano, C.J., and Cordua, W.S., 1979, Geologic map of the southern Tobacco Root Mountains, Madison County Montana: Geological Society of America Map and Chart Series MC–31, scale 1:62,500.

Wardlaw, B.R., and Pecora, W.C., 1985, New Mississippian-Pennsylvanian stratigraphic units in southwest Montana and adjacent Idaho, *in* Sando, W.J., ed, Mississippian and Pennsylvanian stratigraphy in southwest Montana and adjacent Idaho: U.S. Geological Survey Bulletin 1656, p. B1–B9.

Weis, P.L., 1973, Graphite, *in* United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 277–283.

Willis, G.F., 1978, Geology of the Birch Creek molybdenum prospect, Beaverhead County, Montana: Missoula, University of Montana, M.S. thesis, 74 p.

Winchell, A.N., 1914, Mining districts of the Dillon quadrangle, Montana, and adjacent areas: U.S. Geological Survey Bulletin 575, 191 p.

Wodzicki, Antoni, and Krason, Jan, 1981, National uranium resource evaluation, Dillon quadrangle, Montana and Idaho: U.S. Department of Energy GJQ–007(81), 81 p.

Wooden, J.L., Vitaliano, C.J., Koehler, S.W., and Ragland, P.C., 1978, The late Precambrian mafic dikes of the southern Tobacco Root Mountains, Montana: Geochemistry, Rb-Sr geochronology, and relationship to Belt tectonics: Canadian Journal of Earth Sciences, v. 15, p. 467–479.

Zen, E-an, 1988, Geology of the Vipond Park quadrangle, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1625, 49 p.

Zimbelman, D.R., 1984, Geology of the Polaris 1 SE quadrangle, Beaverhead County, Montana: Boulder, University of Colorado, M.S. thesis, 154 p.

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