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MAP I–1803–E
PAMPHLET

MAPS SHOWING MINERAL RESOURCE ASSESSMENT FOR VEIN AND REPLACEMENT DEPOSITS OF BASE AND PRECIOUS METALS, BARITE, AND FLUORSPAR, DILLON 1°×2° QUADRANGLE, IDAHO AND MONTANA

By

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CUSMAP

This report is one of a series of reports that present, chiefly with maps at a scale of 1:250,000 and 1:500,000, various aspects of the geology, geochemistry, geophysics, and mineral resources of the Dillon 1°×2° quadrangle, southwestern Montana and east-central Idaho (fig. 1). These studies 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 produce sound scientific data that may be of value to private industry and the general public in mineral exploration and development.

INTRODUCTION

This report is one of several that assess the mineral resources in the Dillon quadrangle. For the purpose of the assessment, the deposits that are known in the quadrangle, or suspected to be present from a knowledge of the geologic setting, have been grouped into 30 deposit types on the basis of the mineralogy or commodity in the ore and the structural or depositional setting of the deposit. The emphasis in these assessment reports is on metallic minerals, but some important nonmetallic minerals are also considered. Fossil fuels are beyond the scope of this investigation, phosphate and uranium have been investigated previously (Swanson, 1970; Wodzicki and Krason, 1981), and certain nonmetallic minerals, including bulk commodities such as sand and gravel, are in large supply and thus are not considered.

The mineral resource assessment discussed in this report concentrates on a single deposit type (of the total of 30 types) that we call "vein and replacement deposits of base and precious metals." Base and precious metals produced from such deposits are copper, lead, zinc, gold, and silver. Vein deposits of barite and fluorspar are also discussed, but because they seem to be of minor importance, they are treated briefly. Vein and replacement deposits of base and precious metals are classified as a single deposit type rather than as numerous possible subordinate types that might be distinguished on the basis of mineralogy, metal content, or other factors, because the characteristics of the ore, the ore bodies, and the structural setting are not sufficiently well known to yield a consistent detailed classification for the entire quadrangle. Furthermore, the criteria used here to explain the localization of deposits are too general to allow discrimination among subordinate types at a scale of 1:250,000 or smaller.

In assessing mineral resources, we have adopted a general philosophy similar to that of Harrison and others (1986). We attempt to identify parts of the quadrangle that are favorable for the occurrence of mineral resources, and we make an assignment of the relative resource potential of all parts of the quadrangle. We do not attempt to locate specific exploration targets nor to determine the quantity of reserves or resources present.

The assessment was made using geological, geochemical, geophysical, and mineral-occurrence data derived from the Dillon quadrangle and known attributes of vein and replacement deposits to find favorable terrane. Six criteria were developed from these data that bear on the localization of vein and replacement deposits, and the assessment is based on these six criteria only. These criteria probably incorporate the most important localizing

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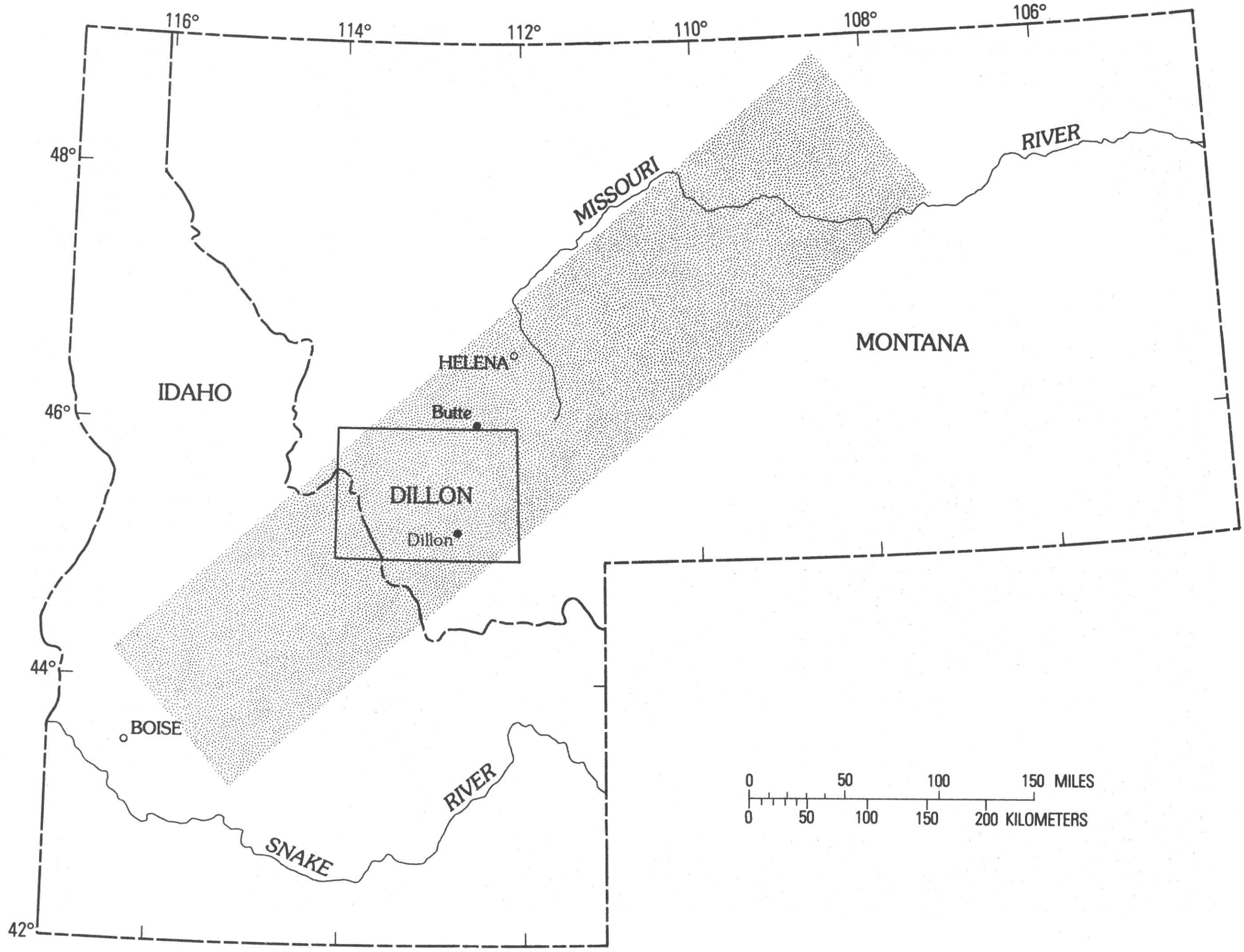

Figure 1. Index map showing location of Dillon 1°×2° quadrangle and Idaho-Montana porphyry belt (Rostad, 1978).

factors for such deposits in the quadrangle and maybe elsewhere in similar geologic environments. Many other criteria are probably also important, but data relevant to them are not available at all or not available quadrangle-wide, and hence they were not used. Each criterion permits delineation of terrane that is favorable for the deposit type from a consideration of that criterion alone. When all criteria are combined, the more favorable terrane is revealed in different degrees of "favorability," a term that may have been coined by Voelker and others (1979) in the context of mineral resource assessment. The term has since been used in this way by Pratt (1981), Harrison and others (1986), and Goudarzi (1984). Finally, the favorability of any terrane is translated into differing degrees of mineral resource potential.

The depth to which the assessment applies is also governed by the scale of the assessment and the amount of detail in the data. The data apply to rocks and geologic relations essentially at the Earth's surface, except for geophysical data, which in this case do not predict the depth to anomalies. Geologic features could probably be projected locally downdip or downplunge, but such a projection is not considered valid here because of the reconnaissance nature of the studies and uncertainties in the data.

Vein and replacement deposits in the quadrangle range widely in their geographic distribution, in their physical parameters, in their metal content, and in their geologic setting. Of the 521 mines and prospects in vein and replacement deposits that we have catalogued (Loen and Pearson, 1989), some have been moderately large producers of gold, silver, lead, or copper, although none is of a size comparable to many of the veins at Butte, 1 mi north of the quadrangle, or to the Granite or Bimetallic veins in

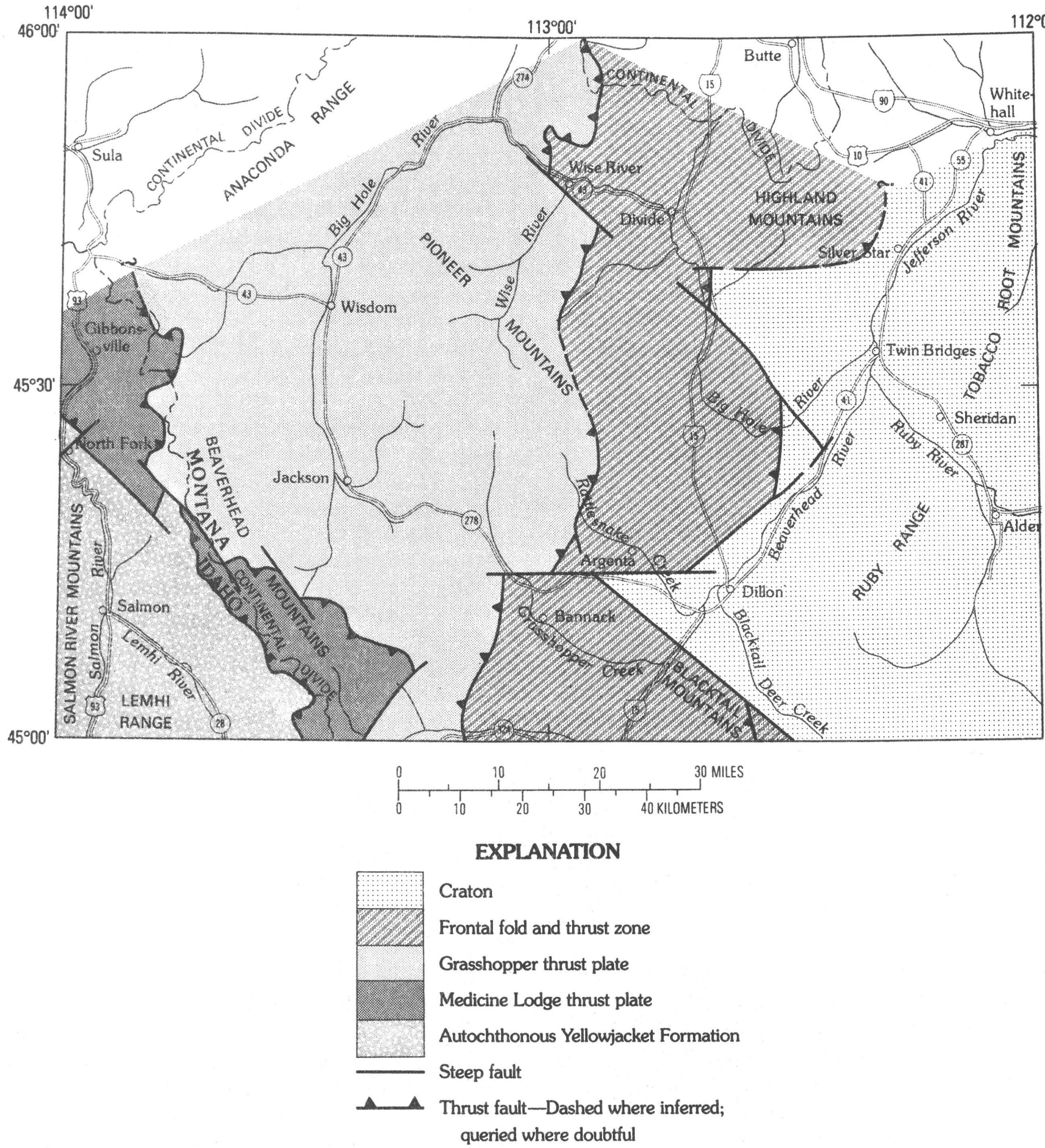

Figure 2. Tectonic province map of Dillon 1°×2° quadrangle, Idaho and Montana. Modified from Ruppel and Lopez (1984). Igneous rocks and surficial deposits not shown.

the Philipsburg district, 40 mi northwest of Butte. More than two-thirds of the 521 mines and prospects in the Dillon quadrangle for which we have data produced some ore, but a large percentage of these probably have less than 100 tons to their credit. Table 1 lists features of 15 of the largest mines and closely associated groups of mines; the table emphasizes the wide geographic distribution and variety of geologic settings typical of mines in the quadrangle, as well as the relatively large size of these selected mines.

Acknowledgments.—We are indebted to many colleagues whose work with mineral deposit models and techniques of data handling have facilitated our studies of the Dillon quadrangle. We especially acknowledge J.E. Harrison and W.P. Pratt, who have given advice and shared their experiences with other CUSMAP projects,

and J.E. Elliott, who has been a close collaborator while making a similar, concurrent study of the adjacent Butte quadrangle.

GEOLOGIC SETTING

The geology of the Dillon quadrangle involves rocks in two major tectonic provinces: the Montana thrust belt occupies approximately the western two-thirds of the quadrangle, and the North American craton occupies the eastern one-third (fig. 2). Rocks of both provinces are similar stratigraphically and temporally and include crystalline basement, mainly of Archean age; sedimentary strata of Proterozoic, Paleozoic, and Mesozoic age; igneous rocks, both intrusive and extrusive, mostly of late Mesozoic and early Cenozoic age; and basin-fill, glacial, and alluvial deposits of Cenozoic age.

The geologic base map on map J was generalized from Ruppel and others (1983) and because of the scale does not show all of the geologic features mentioned in this report. A computer plot of the generalized map (map A) illustrates the digitized geology as it was used in the mineral resource assessment.

The crystalline basement is widely exposed on the craton and is of Archean age except for Proterozoic mafic dikes (James and Hedge, 1980). In the thrust belt the basement is exposed only in the core of the Armstead anticline in the south-central part of the quadrangle, where it is probably Archean, and as two small fault blocks that, according to U/Pb and Rb/Sr age determinations, are Early Proterozoic (Arth and others, 1986; R.E. Zartman, written commun., 1984). Because all three of these exposed masses are within the thrust belt, they may be allochthonous.

Proterozoic rocks, primarily the Belt Supergroup and the Lemhi Group, are exposed mainly in the thrust belt. They are in fault contact with the crystalline basement, and hence their depositional bases are not exposed. Proterozoic intrusive rocks, in addition to the mafic dikes in the craton, are represented by a granite pluton along the west side of the quadrangle that has intruded the Yellowjacket Formation (Evans and Zartman, 1981).

The Paleozoic and Mesozoic strata are widely distributed on the craton part of the quadrangle, where the basal unit (the Middle Cambrian Flathead Sandstone nearly everyplace) is in depositional contact with the crystalline basement, and in the eastern part of the thrust belt, where various units at the base are in depositional contact with Proterozoic strata. Progressive differences evident in sedimentary facies from the craton westward into the thrust belt, especially in some of the marine Paleozoic units, are partly the result of telescoping by the thrusts.

Phanerozoic igneous rocks in the quadrangle are of Late Cretaceous and Cenozoic age. The Phanerozoic plutons are mainly of intermediate composition but range from hornblende gabbro, through granodiorite and monzogranite, to two-mica granite, and they have calc-alkalic affinities. They intrude all older major groups of rocks and are especially abundant in the north half of the quadrangle. The southeastern part of the quadrangle has none of these plutons. Volcanic rocks associated with the Cretaceous plutons are present locally in the northeastern and central parts of the quadrangle. Volcanic rocks of Cenozoic age are present in isolated patches mainly in a north-trending belt through the middle of the quadrangle but also near the southwest corner, along the west edge, and very locally elsewhere.

The Cenozoic deposits that fill the basins to thicknesses of from hundreds to many thousands of feet consist of an appreciable pyroclastic component, especially in tuffaceous mudstone, locally derived fine to coarse fluvial detritus, and some lava.

The thrust belt has been treated as two major plates, the Medicine Lodge plate to the west and the Grasshopper plate to the east (fig. 2; Ruppel and Lopez, 1984). The eastern part of the thrust belt is called the "frontal fold and thrust zone" (Ruppel and Lopez, 1984), a gradational zone that has characteristics of both the thrust belt and the craton. West of the Medicine Lodge plate, in the southwestern part of the quadrangle, the bedrock is largely the Proterozoic Yellowjacket Formation, which is interpreted by Ruppel (1978) and Ruppel and Lopez (1984) to be autochthonous. Although rocks as young as Late Cretaceous are involved in thrusting, all Mesozoic plutons, so far as is known, are younger than thrusting.

High-angle faults are widespread in all parts of the quadrangle, and many of them belong to one or another of two major groups. A northwest-trending group is evident in the Archean terrane as well as in younger rocks; these have been active at various times from at least the Proterozoic to the late Cenozoic. A north- and northeast-trending group commonly is along and within Tertiary basins; these faults moved mainly in middle to late Cenozoic time, delineating the existing mountain ranges.

The Dillon quadrangle is intersected by a northeast-trending regional concentration of intrusive rocks and various types of mineral deposits referred to by Jerome and Cook (1967) as the "transverse porphyry belt," by Rostad (1978) as the "Idaho-Montana porphyry belt," and by Armstrong and others (1978) and Armstrong and Hollister (1978) as the "White Cloud–Cannivan porphyry molybdenum belt." An approximate outline of the belt is shown in figure 1. The belt occupies all but regions in the northwest and southeast corners of the quadrangle. By Rostad's (1978) definition, the belt extends about 450 mi from the vicinity of the Boise Basin in central Idaho to the

Little Rocky Mountains in north-central Montana. O'Neill and Lopez (1985) describe major structural features that are parallel with or are contained within parts of the porphyry belt.

CHARACTERISTICS AND RELATIONSHIPS OF VEIN AND REPLACEMENT DEPOSITS

Vein and replacement deposits of base and precious metals are the most numerous mineral deposits in the Dillon quadrangle, and collectively they have produced much of the ore mined. Exploitation of these deposits began soon after the discovery and initial mining of placer gold in 1862. Most of the mining districts that contain deposits of this type were discovered in the 1860's and 1870's, and the principal period of mining ended soon after 1900. Although exploration for, and mining of, vein and replacement deposits has continued in economically favorable periods, the cost of discovering, developing, and mining these rather small deposits has progressively increased through time with respect to the value of the ore bodies found. Summaries of mining history in various parts of the Dillon quadrangle are given in Winchell (1914), Tansley and others (1933), Sassman (1941), and Geach (1972), and details are given in many reports on individual mines and districts. A brief history of mining in the entire quadrangle and a lengthy list of references are given in Loen and Pearson (1989).

The deposits tend to be clustered in mining districts, most of which are in the central and northeastern parts of the quadrangle in the eastern Pioneer Mountains, the Highland Mountains, and the Tobacco Root Mountains. Veins are more widely dispersed in the southwestern part of the quadrangle, through the Beaverhead Mountains, Salmon River Mountains, and Lemhi Range, but in that large area only the Pope Shenon mine, 10 mi south of Salmon, and the A.D.&M. mine at Gibbonsville were major producers (table 1) (Loen and Pearson, 1989). The southeastern and northwestern parts of the quadrangle are notable for their paucity of vein and replacement deposits, but for different reasons because the geology of these two areas differs greatly. The almost complete absence of Cretaceous and lower Tertiary intrusive rocks in the southeastern part is probably sufficient explanation for the near absence of mines and prospects in that area, as will be discussed later in this report. The northwestern part, on the other hand, is mostly plutonic rock, and many of these plutons evidently crystallized at considerable depth in an environment where vein and most other hydrothermal deposits would not be expected to form. However, some plutons have epizonal characteristics suggesting that additional mineral deposits might be expected in those areas. Much of the plutonic rock in the northwestern part is biotite-muscovite granite, which, typically, is not a type noted for its association with base- and precious-metal deposits.

The vein and replacement deposits are present in all major groups of brittle rocks; however, certain rock types and rock units are clearly more favorable than others, especially if we consider the amount of ore derived from each of them and not just the number of deposits. Quaternary sedimentary deposits contain no vein or replacement deposits, and the Tertiary basin deposits contain none that has been mined. Many of the principal deposits are in carbonate rocks, either Paleozoic or Archean limestone or dolomite. Some of these are fissure veins, but the deposits having the largest production are principally replacement deposits. In many deposits, both veins and replacement bodies are present, and in some places veins were clearly feeders, providing access by ore-forming fluids to a site favorable for metasomatic replacement. Undoubtedly the chemical reactivity of the carbonate host played an important role in localizing the deposits, but physical properties such as permeability are probably equally important, for most of the important deposits are in recrystallized and thick-bedded units within the contact aureole of a pluton. Carbonate strata of Mesozoic age, mainly in the Kootenai Formation, contain very few deposits, perhaps because their outcrop area is small or because, fortuitously, they are unfavorably situated with respect to plutons, as discussed below. Other favorable host rocks are Archean gneiss, Proterozoic siliciclastic sedimentary rocks, and Cretaceous and Tertiary intrusive rocks. Units least favorable are Paleozoic and Mesozoic siliciclastic rocks, in part because of their incompetence during deformation.

The Proterozoic siliciclastic rocks are actually low-grade metamorphic rocks such as quartzite and argillite and hence are more brittle and more favorable as hosts than similar lithologies that are younger and not recrystallized. Evidence from the Hecla and Quartz Hill districts suggests that certain Paleozoic pelitic units folded without fracturing while adjacent, more massive carbonate units formed open fractures. Even some of the quartzitic units, such as the Proterozoic Missoula Group and the Pennsylvanian Quadrant Quartzite, which would be expected to act brittly, tend to form wide breccia zones along faults rather than planar breaks. Except for quartz cement, these breccia zones do not seem to be mineralized, perhaps because they did not sufficiently confine fluid movement during hydrothermal mineralization.

Vein and replacement deposits are closely associated with a variety of intrusive rocks, and some types of plutonic rock have a closer association with vein and replacement deposits than do others. Many mines are

Table 1. *Some of the principal vein and replacement deposits in the Dillon 1°X2° quadrangle, Idaho and Montana*

[M, million; >, greater than]

No. on map	Name of deposit	Mining district	Location of deposit		Principal (and secondary) commodities	Estimated production[1]	Comments
			Lat N.	Long W.			
1	A.D.&M.	Gibbonsville	45°33'30"	113°55'07"	Au	83,500 oz Au	Narrow east-trending quartz veins that cut Yellowjacket Formation; contain pyrite and chalcopyrite; large diorite dike and small equant pluton of granodiorite are about 1 mi to west.
2	Pope Shenon	Eureka	45°04'31"	113°51'20"	Cu (Ag)	2.6 M lbs Cu; 22,000 oz Ag.	East-trending ore shoot 7-20 ft thick and as much as 200 ft long in major northeast-trending silicified fault zone in Yellowjacket Formation. Post-ore dike probably related to Eocene Challis Volcanics. Primary ore mineral mainly chalcopyrite.
3	Hand (Mauldin).	Argenta	45°17'12"	112°51'53"	Pb, Ag (Zn, Cu, Au).	Several million dollars.	Production from 20 or more veins and replacement deposits in Mississippian limestone at and near monzogranite stock. Ore mostly oxidized; plumbojarosite, cerrusite, and anglesite predominant.
4	Ermont	Argenta	45°15'58"	112°54'51"	Au (Ag, Cu.	41,000 oz Au; 7,000 oz Ag; 4,800 lbs Cu.	Auriferous quartz and iron oxides disseminated in Jefferson Dolomite at contact with fine-grained hornblende granodiorite (andesite) sills and in a silicified fracture zone trending northwest and cutting granodiorite. Most ore oxidized but pyrite present at 500-ft level.
5	Golden Leaf	Bannack	45°09'20"	112°59'45"	Au (Ag, Cu, Pb).	30,000 oz Au; 96,000 oz Ag.	Irregular replacement and skarn deposits in Mississippian limestone near granodiorite stock. Ore mostly oxidized; sulfides are pyrite and minor chalcopyrite and galena.
6	New Departure.	Blue Wing	45°11'52"	112°55'15'	Ag, Pb	$1.5-3 million	Largely replacement deposits in rrystralized Mississippian limestone near sill-like body of fine-grained granodiorite that separates Mississippian limestone klippe from underlying Late Cretaceous volcanic rocks. Both oxide and sulfide ore mined; sphalerite, galena, and argentiferous tetrahedrite are main sulfide minerals.

Table 1. *Some of the principal vein and replacement deposits in the Dillon 1°X2° quadrangle, Idaho and Montana*--Continued

No. on map	Name of deposit	Mining district	Location of deposit		Principal (and secondary) commodities	Estimated production[1]	Comments
			Lat N.	Long W.			
7	Polaris	Polaris	45°22'01"	113°05'06"	Ag (Cu, Pb)	500,000 oz Ag	Vein and replacement deposits in recrystallized Paleozoic dolomite within several feet of N. 60° E. fault, which separates dolomite from Proterozoic quartzite. Ore mostly oxidized, although tetrahedrite, galena, and sphalerite reported. Recrystallization is caused by Pioneer batholith, 0.5 mi to east.
8	Lion Mountain Group	Hecla	45°36'16"	112°55'52"	Ag, Pb (Cu, Au).	[2]11.5 M oz Ag; 88 M lbs Pb; 5 M lbs Cu; 12,000 oz Au.	Several gently pitching manto-like replacement deposits in Cambrian and Devonian dolomite, localized generally along bedding by fractures and minor fold crests. Various granite to quartz diorite plutons of Pioneer batholith are 0.5-1 mi away. Ore mostly oxidized, although tetrahedrite, galena, and sphalerite are known.
9	Lone Pine	Quartz Hill-Vipond	45°42'56"	112°53'48"	Ag (Cu)	2 M oz Ag	Replacement deposits and feeder veins in Cambrian dolomite. Ore guided by fractures and fold crests. No outcropping pluton within 2 mi.
10	Butte Highlands	Highland	45°47'50"	112°30'56"	Au	>63,000 oz	Replacement deposits along east-trending fault in hinge of steeply plunging fold in brecciated, partially silicated Cambrian Meagher Limestone. Sills of granite and diorite in workings; stocks and batholith within 1 mi.
11	Watseca	Rochester	45°37'12"	112°30'19"	Au	>50,000 oz	Four northeast-trending quartz veins in Archean gneiss and schist. Most ore is oxidized; sulfides include pyrite, chalcopyrite, arsenopyrite, sphalerite, and galena. Quartz monzonite and diorite stocks 2 mi east of mine.
12	Green Campbell	Silver Star	45°41'45"	112°19'55"	Au	>20,000 oz	West-trending, 20° to 40° S.-dipping vein cutting Archean gneiss and schist, about 1,500 ft south of granodiorite of Rader Creek (Boulder batholith). Ore mostly oxidized.

Table 1. *Some of the principal vein and replacement deposits in the Dillon 1°X2° quadrangle, Idaho and Montana*--Continued

No. on map	Name of deposit	Mining district	Location of deposit		Principal (and secondary) commodities	Estimated production[1]	Comments
			Lat N.	Long W.			
13	Mammoth	South Boulder	45°40'42"	112°00'47"	Au, Ag (Cu)	100,000 oz Au; 200,000 oz Ag; >1 M lbs Cu.	West-trending, 60° S.-dipping quartz vein cutting Archean gneiss, in regional fault zone, shoots localized by intersecting fractures. Contains auriferous pyrite and minor chalcopyrite.
14	Mayflower	Renova	45°47'38"	112°00'05"	Au	>100,000 oz Au.	Vein and (or) replacement bodies in Cambrian Meagher Limestone on north side of fault in contact with Cretaceous volcanics. Tellurium was noted in the ore; most ore is oxidized.
15	Golden Sunlight	Whitehall	45°54'22"	112°00'51"	Au	>100,000 oz Au (through 1959).	Quartz veins in north-trending zone cutting argillite and calcareous argillite of the Proterozoic Greyson Formation and latite of probably Late Cretaceous age. Veins are associated with a breccia pipe that hosts part of a large disseminated gold deposit. Gold is mostly free and associated with pyrite.

[1]From Loen and Pearson (1989)) and other sources mentioned therein.

[2]Includes production from several other mines; Lion Mountain Group probably accounts for 80-90 percent of totals listed.

closely grouped around plutons in such districts as Bannack, Blue Wing, and Argenta, and probably in Sheridan, Tidal Wave, Renova, Whitehall (Cardwell), Highland, and Hecla, but the relationship is not clear for Virginia City, Quartz Hill, Gibbonsville, and the part of the Eureka district in the Lemhi Range. Geophysical data that suggest buried plutons reinforce the spatial association in areas such as the Beaverhead Mountains where outcrops of intrusive rocks are sparse. The size of a plutonic rock body also seems to be a controlling factor: the outcropping plutons at Bannack, Blue Wing, Argenta, Sheridan, Renova, and Whitehall are less than 0.5 mi in diameter, whereas individual plutons of batholithic size, such as Butte Quartz Monzonite and Uphill Creek Granodiorite, are not surrounded by mining districts that contain numerous vein and replacement deposits. In general, the vein and replacement deposits are associated with plutons of intermediate composition, chiefly those that contain varietal biotite and hornblende. Although the ages of the plutons in the quadrangle are not all known, there is a definite tendency for the most mafic rocks to be the oldest and for a progression toward more felsic composition with decreasing age (Snee, 1982). In particular, two-mica granite, mainly in the Anaconda Range and Pioneer Mountains, is mostly early Tertiary and therefore includes some of the youngest plutons; few vein and replacement deposits are associated with two-mica granite.

The controls for the vein and replacement deposits are undoubtedly structural in part, although the specific control of some replacement deposits is not known. Some significant mines are in fractured rock associated with major faults of regional significance. Among these are the Mammoth mine along the Mammoth fault, the Bismark mine along the Bismark fault, the Pope Shenon mine along what appears to be a major shear zone (although its exposed length is only a few miles), numerous mines in the Elkhorn district along the Comet fault, and numerous mines in the Beaverhead Mountains in and near the Beaverhead Divide fault zone. Most of the mines, however, are in and near faults and fractures that seemingly have had little movement and have little regional geologic importance. Although some of the faults that bound or are within Tertiary basins are probably younger than mineralization, many faults are known to have been active at more than one time. It is impossible, in most instances, to determine if any individual fault existed or did not exist during periods of mineralization. Fold crests have also been shown to be effective controls of ore deposition, especially minor anticlines in incompetent pelitic units above massive carbonate units, such as in some of the mines in the Argenta (Geach, 1972, p. 66), Hecla (Karlstrom, 1948), and Quartz Hill (Taylor, 1942) districts. A less certain structural control is suggested by linear features observed on aerial photos and Landsat imagery in the Quartz Hill and Hecla districts.

Veins range from thin films of hydrothermal minerals along joints to tabular bodies many feet thick, consisting predominantly of quartz. Some veins are massive, others are layered and show changes during growth in the mineral species, crystal size, and mineral composition, and still others are sheared and brecciated, reflecting alternating periods of mineral deposition and structural adjustment. Although most veins probably represent open-space filling, some may have involved metasomatic replacement as well, especially wide silicified shear zones (such as at the Pope Shenon and Dike mines near Salmon, Idaho) that contain variably silicified and otherwise hydrothermally altered remnants of wall rock. Mined veins commonly range from a few inches thick, if sufficiently rich, to several feet thick. Metals are very rarely evenly distributed throughout the veins but rather are concentrated in shoots that can range widely in size or attitude but tend to pitch steeply. Minable shoots are as much as several hundred feet long and of an equal or greater vertical dimension but more commonly are a few tens of feet long.

Replacement ore bodies are almost entirely in carbonate rocks. Those that have been mined generally range from pods that contain about one short ton of ore to bodies several hundred feet long and more than 100 sq ft in cross-sectional area that contain about 50,000 short tons of ore. Some replacement bodies are closely associated with veins that were the pathway for the ore-forming solutions, whereas others have no evident connection with veins. Commonly, the replacement deposits are along the bedding or extend outward irregularly from fissures. The largest replacement ore bodies in the quadrangle that have been mined are two in the Lone Pine mine (Quartz Hill district), the Cleopatra deposit in the Lion Mountain group (Hecla district), and the Butte Highlands deposit (Highland district).

Primary sulfide ore in vein and replacement deposits contains pyrite, either alone or in various combinations with galena, sphalerite, chalcopyrite, and tetrahedrite-tennantite. The gangue is commonly quartz. Many deposits mined for gold (with or without some silver) contained auriferous pyrite as the sole sulfide mineral, but the other common sulfide minerals were generally present in at least minor amounts. In addition to its association with pyrite, elemental gold is also present as inclusions in chalcopyrite or sphalerite in some mines. Deposits mined chiefly for silver contained significant amounts of galena and (or) argentiferous tetrahedrite as the primary sulfide mineral(s), and these deposits commonly produced lead as a coproduct or lead, copper, and (or) zinc as byproducts. Numerous other sulfide and sulfosalt minerals have been identified, but they have not been important sources of metals. Wolframite is common in the veins of the Elkhorn district and locally common elsewhere but, despite exploration specifically directed for it, has not been found in commercial quantities. Tellurium was reported in ores from the Mayflower mine (Winchell, 1914), and several telluride minerals were identified in ore from the Golden Sunlight mine (Porter and Ripley, 1985); both of these mines are in the northeast corner of the quadrangle. Shenon (1931) reported tetradymite in Bannack ores.

Most ore mined from vein and replacement deposits was oxidized to a siliceous, limonitic, porous, generally friable aggregate that generally was richer, especially in gold, silver, and lead, than the primary ore from which it was derived. But not only was the secondary ore richer, its soft, friable nature made mining and milling easier and cheaper. The large production from the Hecla district and from the Butte Highlands mine in the Highland district resulted partly from the fact that much of the ore could be excavated by pick and shovel without costly drilling and blasting; the economic advantages also permitted mining and milling larger tonnages of lower-grade ore than would have been possible with harder ore. A large number of secondary minerals are in the oxidized ore, as listed by Winchell (1914) and Shenon (1931). The most important economically have probably been cerussite, plumbojarosite, cerargyrite, smithsonite, anglesite, and hemimorphite. Manganese and iron oxides and hydroxides are generally conspicuous, and jasperoid, some of which may be secondary, is common locally.

Gangue minerals in the ore include quartz, calcite, barite, and siderite. Although quartz is the principal gangue mineral, calcite, locally a pink manganoan variety, is common, and calcite is the only gangue mineral in some deposits in carbonate host rocks. Where slightly weathered, the manganese-bearing calcite is coated with black manganese oxides, and where completely dissolved away its former presence is evident from the loose powdery aggregate of manganese oxides. Siderite and barite are widespread but not abundant.

BARITE AND FLUORSPAR

In addition to base- and precious-metal deposits, barite and fluorspar veins are known in the quadrangle, but they have not been greatly exploited and do not appear to contain significant resources. Although barite is common as gangue in quartz veins in many districts, only three veins are known in which barite is the predominant mineral: the Lucky Jim Beam claim group in the southwestern Pioneer Mountains, the Golden Fleece claim group in the Blacktail Mountains, and an occurrence near the mouth of Soap Gulch, in the Melrose district on the southwest flank of the Highland Mountains (Loen and Pearson, 1989). The occurrence on the Golden Fleece claims was described by Tysdal and others (1987); they concluded that it contains a subeconomic resource of barite of about 9,000 short tons.

The only significant fluorspar occurrence known is along a fault between Cambrian dolomite and the Moose Creek pluton and associated with basin-bounding Neogene faults near Divide, Mont.; this occurrence was described by Smedes and others (1980), who concluded that fluorspar had been mined there in the past and that the deposit contains resources of 800–1,000 short tons of submarginal grade (20–30 percent CaF_2).

RESOURCE ASSESSMENT PROCEDURE

The procedure used here in the assessment of the Dillon quadrangle for base- and precious-metal resources in vein and replacement deposits follows one outlined in Shawe (1981) and is a modification of those used by Pratt (1981), Pratt and others (1984), and Harrison and others (1986). Very generally, the procedure calls for construction of a mineral deposit model for each deposit type based on currently accepted concepts, background knowledge, and available data. Then the model is applied to the area in question to determine the degree of fit and hence the favorability of the area for the occurrence of deposits of that type. In its simplest form, the model is a list of characteristics and relationships (referred to here as "favorability criteria") that are known or suspected to be associated with the deposit type. In the past several years, deposit models have been constructed for numerous deposit types. Models of vein deposits were made and applied to resource assessment by Harrison and others (1986). The criteria used are those that can be treated at a scale of 1:250,000. Generally with this approach the criteria are determined subjectively from regional or even worldwide experience and knowledge, and they are given subjectively weighted scores depending on their perceived relative importance. In the Dillon quadrangle, however, vein and replacement deposits are sufficiently numerous, well known, and geologically and geographically widely distributed to permit the criteria to be evaluated, in part at least, empirically. The basic geologic controls for the formation of vein and replacement deposits in the quadrangle are considered to be (1) structural features (mainly fractures), (2) kind of host rock, and (3) a spatial association with Phanerozoic plutons. Stream-sediment geochemical anomalies and remotely sensed limonite are interpreted to be manifestations of hydrothermal alteration and mineralization. The specific relationships of mines and prospects to these criteria were determined by spatial data analysis in a computer-based geographic information system (GIS). The empirical relations thus determined were then used in the development of the final model.

The steps involved in the procedure are summarized as follows; they are listed in approximately the sequence they were performed, although some steps overlapped:

1. Compile existing data (geology, geochemistry, aeromagnetics, gravity, remote sensing, and mineral resources) and, where feasible, gather additional data where information is inadequate for resource assessment.
2. Determine which mineral deposit types are likely to be present in the area on the basis of our understanding of the geologic environment and mining history, and define the type as closely as possible in light of current concepts and knowledge.
3. Prepare a tentative list of favorability criteria, which constitutes a preliminary deposit model.
4. Digitize the geologic map, compile other data sets in digital form, and enter the digital data into a multilayered, computer-based GIS.
5. Using the GIS, compare the areal distribution of mines and prospects with the appropriate parts of the database to determine the relative importance of each criterion in the model. This step assists in weighting scores assigned to the criteria.
6. Sum the weighted scores assigned to all favorability criteria and plot these sums on a map. Areas where the sums are highest are interpreted to be the most favorable for the occurrence of vein and replacement deposits.
7. Discuss and subjectively evaluate the areas determined to have high and very high potential.

Inasmuch as the model was derived in large part empirically by a comparison with features of the districts, mines, and ores themselves, it should be expected that the districts would appear as areas of moderate and high potential in the resulting plots of favorability of occurrence.

DATABASE

Seven main data sets were employed in the resource assessment. These were compiled from pre-existing data, reports, and other compilations and from new data gathered during the field phase of the Dillon project. Pre-existing data include geologic mapping, stream-sediment geochemistry, various gravity and aeromagnetic surveys, Landsat Multispectral Scanner (MSS) and side-looking radar (SLAR) images, and compilations of historical information on mines and prospects. The new data include geologic mapping, investigation of mines and prospects, some rock and stream-sediment geochemistry, and partial coverage by gravity and aeromagnetic surveys. Much of the information was obtained since 1977 in connection with mineral resource assessments of National Forest Wildernesses and wilderness study areas made by the U.S. Geological Survey and U.S. Bureau of Mines, specifically the Anaconda-Pintlar Wilderness (Elliott and others, 1985), the Middle Mountain–Tobacco Root area (O'Neill, 1983a, 1983b; O'Neill and others, 1983), the West Pioneer Mountains area (Berger and others, 1983), and the eastern Pioneer Mountains area (Pearson and others, 1988; Pearson and Zen, 1985).

GEOLOGY

A preliminary geologic map of the entire quadrangle (Ruppel and others, 1983) was compiled, field checked, and modified from numerous older sources supplemented by reconnaissance mapping suitable for publication at 1:250,000, mainly from 1978 to 1983. The preliminary map was generalized. Geologic factors thought to be important for the mineral resource assessment were emphasized. The generalized map is shown as a base for map J, and a computer plot of the same map is shown as map A.

GEOCHEMISTRY

The regional geochemical component of the Dillon quadrangle mineral resource assessment consists of analytical data from stream-sediment samples. Stream sediment was sampled under the National Uranium Resource Evaluation (NURE) program of the U.S. Department of Energy (Broxton, 1979). The minus-100-mesh fraction of 1,600 samples was used for analysis. The NURE analytical results were supplemented with new analyses for arsenic, antimony, zinc, molybdenum, calcium, magnesium, and zirconium by laboratories of the U.S. Geological Survey.

In order to determine which suite of elements in the regional stream-sediment database best reflects the presence of vein and replacement deposits, approximately 2,500 mineralized rock samples were collected from three general classes of deposit types in the quadrangle and analyzed: vein and replacement deposits, porphyry copper and molybdenum deposits, and tungsten and base- and precious-metal skarn deposits (Leatham-Goldfarb and others, 1986). Discriminant-function analysis was used to test the validity of the generalized classification scheme and to indicate the most useful suites of elements for discriminating each of the three deposit types. Seven elements (silver, copper, lead, zinc, antimony, arsenic, and cadmium) best discriminate vein and replacement deposits from the other two classes and herein constitute the geochemical "vein model."

GEOPHYSICS

Magnetic and gravity anomaly data acquired and compiled throughout the quadrangle are regional in scale and

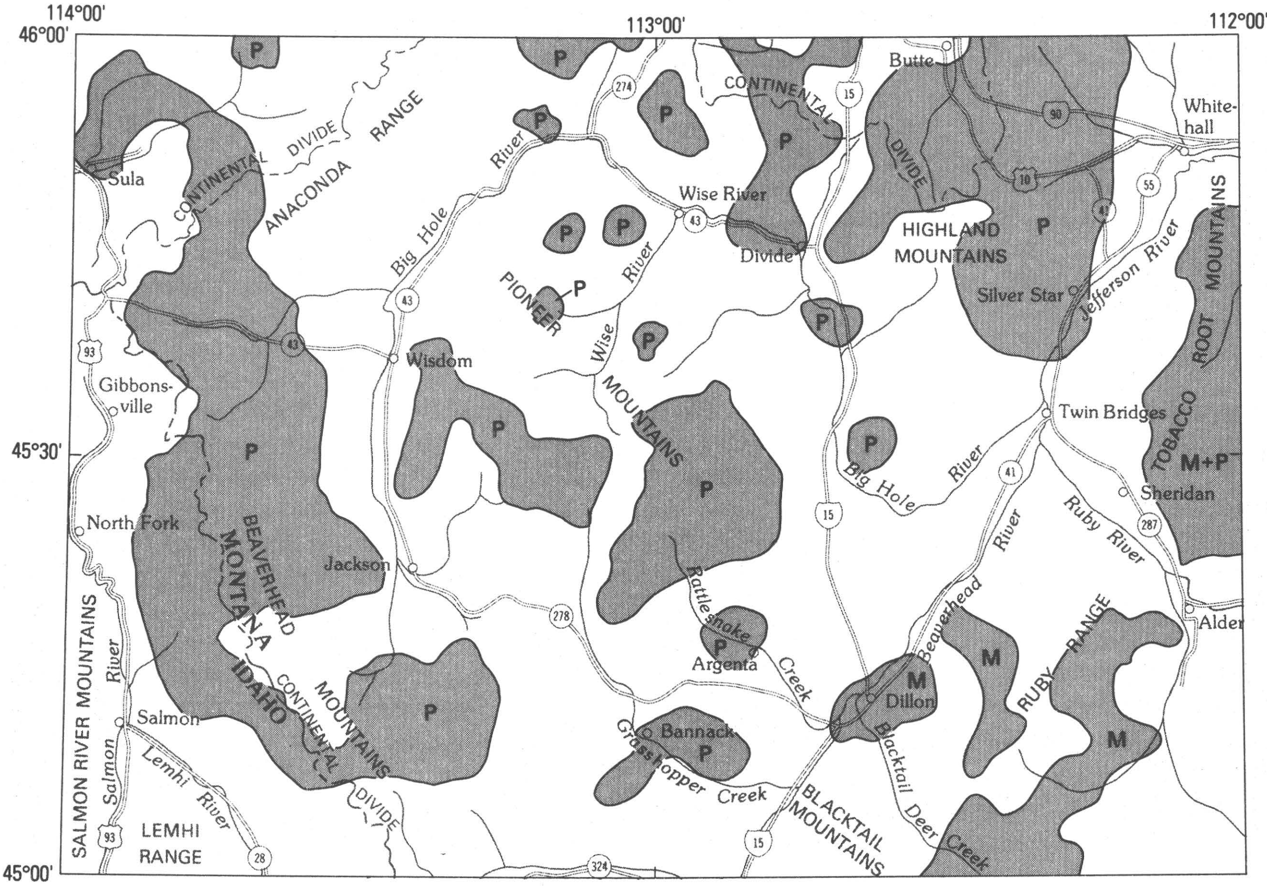

Figure 3. Distribution of plutons (P) and metamorphic rocks (M) as interpreted from geophysical aeromagnetic and gravity data, Dillon 1°×2° quadrangle, Idaho and Montana.

were used to broadly delineate major occurrences of magnetic plutonic rocks (fig. 3). In this study, filtered magnetic anomaly maps of gridded data were used to infer boundaries of these magnetic rocks, derived in the following sequence of steps:

1. Data from six local surveys and one regional survey, all having diverse flight specifications, were merged by analytical continuation and smoothing techniques into a single gridded data set. The data and interpretations were extended 15 minutes of latitude and longitude beyond the quadrangle boundaries to reduce edge effects.

2. A pseudogravity gradient map was computed. This map illustrates the amplitude of the horizontal gradient of the aeromagnetic data. Elongate crests of the pseudogravity anomalies were contoured.

3. A reduced-to-pole map was computed. On this map, effects of the inclination of the Earth's magnetic field are removed.

4. Zero-contour lines of a bandpass-filtered second-vertical-derivative map computed from the reduced-to-pole map were plotted.

5. Regions of areal overlap of closed axial traces of crests (step 2) and closed zero-contour lines (step 4) were taken as the location of significant bodies of subsurface magnetic rocks.

These techniques are known to be effective in delineating steep-sided bodies and are thought to be useful in delineating bodies with sloping sides.

The boundary lines of these subsurface bodies can be drawn objectively, but whether anomaly sources are Precambrian metamorphic rocks or Phanerozoic mafic to intermediate igneous rocks is commonly unknown. Gravity anomaly values may help to distinguish the two rock types because gravity anomalies tend to be higher over the more dense metamorphic rocks. However, where high-density metamorphic rocks are overlain by lower density sedimentary rocks, the superposition of the metamorphic-rock gravity high and the sedimentary-rock gravity low may result in an ambiguous anomaly of moderate size.

In the Dillon quadrangle, the combined gravity and magnetic anomaly data suggest that regions in the southeast corner of the quadrangle, covering much of the Ruby Range, Beaverhead River valley, Tobacco Root Mountains, and an area extending southward from the Tobacco Root Mountains, are underlain in large part by the Archean metamorphic rock complex. However, in and near the Tobacco Root Mountains, magnetic sources composed of intermediate Cretaceous plutonic rocks intrude mafic to ultramafic Precambrian metamorphic rocks, and these cannot be distinguished. The distinction between subsurface anomaly sources here could be improved by using higher resolution geophysical techniques or by drilling.

REMOTE-SENSING DATA

Three remote-sensing data sets were used in the analysis of the Dillon quadrangle: interpreted lineaments, northeast-trending (N. 35°–58° E.) linear features, and hydrothermally altered rocks (Segal and Rowan, 1989; Purdy and Rowan, 1990). The lineaments and northeast-trending linear features were derived from three Landsat MSS images and a proprietary SLAR image mosaic. The spatial resolutions of the MSS and SLAR data are 79 m and 10 m, respectively. The SLAR data were used to supplement the MSS data because of higher resolution and different illumination direction (west), which highlighted features that were not highlighted in the MSS images. The distribution of hydrothermally altered rocks was determined through field evaluation of MSS images that had been digitally processed to enhance the diagnostic reflectance characteristics of limonite, which is inferred to be associated with hydrothermal alteration. Approximately 75 percent of the bedrock area of the quadrangle is forested, a factor that restricts recognition of limonite to an unknown degree.

MINES AND PROSPECTS

Many mines throughout the quadrangle were examined. The geologic setting, character of mineralization, and deposit type were determined where possible, and samples were collected for analysis. These newly acquired data were compiled together with information from the U.S. Geological Survey's Mineral Resource Data System (MRDS) (previously known as the Computerized Resource Information Bank (CRIB)). Because much of the MRDS file was derived from old reports that did not reflect modern geologic concepts or terminology, the contents of the file were checked against original sources and updated where possible. The MRDS format was then recast by Loen and Pearson (1989) into a simplified tabular format that contained information expected to be of use in the resource assessment. Of the total of 829 mines, prospects, and significant mineral occurrences in the quadrangle, 521 are classified as of the vein and replacement type.

THE GEOGRAPHIC INFORMATION SYSTEM

A computer-based geographic information system (GIS) was used to develop the deposit model, assist in the mineral resource assessment, and prepare the mineral resource assessment map. A GIS provides a means of comparing and inter-relating various kinds of data that can be referenced geographically. An analogy may be made with a stack of transparent maps of the same area that are superimposed and registered, each map showing a particular kind of data. For example, one map might show surface geology (geologic map) and another map might show location of mines and prospects. If one wished to compare visually the distribution of mines and prospects of a certain mineral deposit type with the distribution of a certain geologic map unit, each of these subsets of data would have to be made readily identifiable, and only a qualitative estimate of the relationship could generally be made. However, when the data are digitized and entered into a GIS, the relationships between any two (or more) data sets can be compared quantitatively throughout the map area by the use of arithmetic and other statistical operations. Thus, the effects of two or more data sets at any point can be considered simultaneously. For some comparisons of two or three simple data sets, the GIS may be superfluous, but where the number of data sets increases and the kinds of data become more complex, the manual or visual approach can treat the analysis objectively and uniformly only with the expenditure of large amounts of time, if at all. The manual approach to CUSMAP mineral assessment was used by Pratt (1981) and by Harrison and others (1986), but the potential advantages of the GIS technique were demonstrated by Pratt and others (1984). Some technical aspects of the GIS are described in the following paragraphs.

The GIS used in this study consists of (1) three main subsystems, (2) interfaces that operate between subsystems, and (3) capabilities for a variety of manipulative, mathematical, and plotting functions. The three subsystems are known as a relational database management subsystem (RDBMS), a vector subsystem, and a raster subsystem. These are needed because the diverse data, as described in a previous section, are in tabular, gridded, and map form, each of which requires different treatment. The interfaces provide the necessary ability to edit, reformat, and transfer data from one subsystem to another. Other capabilities provide for data entry, data manipulation, surface generation, contouring, statistical analysis, and the generation of tabular, statistical, and cartographic products.

Data were provided for computer processing in a variety of formats, each having its own requirements for entry into the GIS. Initially, all data were entered into the RDBMS, the vector subsystem, or into both. After some manipulation, the data were entered into the raster subsystem, in which most of the model development and resource assessment procedures were performed.

The RDBMS deals with tabular data and provides powerful techniques for editing, combining, and subsetting tables. Although used primarily for attribute and analytical data, spatial data may also be entered and manipulated in an RDBMS. RIM (Relational Information Manager) and INFO were the RDBMS packages used.

The vector subsystem treats data as either points, lines, or polygons (areas bounded by lines) and maintains information on the topologic relationships among them. This subsystem is suitable for very detailed work, for those data that have multiple attributes, and for those discrete data types whose treatment requires separation into points, lines, or polygons. The vector subsystem used in this investigation is ARC/INFO.

The raster subsystem, which treats all data as a matrix of small grid cells, is much faster than the vector subsystem for many functions. It is useful for treatment of continuous surfaces. Its resolution, once the grid-cell size has been selected, is fixed for any given surface. The raster subsystem used is IDIMS (Interactive Digital Image Manipulation System).

All spatial data sets must be coregistered in both coordinate units and map projection. The base map used for data compilation is the Dillon 1°×2° quadrangle (1955 edition, revised 1977) that uses the Transverse Mercator projection. Hence all data sets were transformed to this projection. Important parameters include a central meridian of 113° and a scale factor of 0.9996. Other parameters were a latitude of origin of 45° and no false easting or northing. The 1927 North American Datum, based on the Clarke 1866 ellipsoid (Snyder, 1982, p. 15–16), was used throughout. To minimize the potential error in coregistering maps, all projection changes were performed using the General Cartographic Transformation Package (GCTP), which is incorporated in the vector subsystem and the RDBMS but not in the raster subsystem.

The types of data used included maps, text, tables, gridded data, and previously digitized information:

Maps.—Hand-drafted maps included (1) a generalized geologic map showing 25 rock units and 7 types of structures (used to generate map A), (2) a map showing boundaries of mining districts and other areas that contain mines and prospects (used to generate map B), (3) an interpretive geophysical map showing extent of principal magnetic rock bodies (used to generate fig. 3), (4) maps showing some geochemical sample and mineral-occurrence localities (not published in this report), and (5) maps showing lineaments and limonitic rocks interpreted from remote-sensing data (used to generate map H). Geologic structures were treated as lines, the sample and mineral-occurrence localities as points, and other data (rock units and geophysical anomalies) as polygons. These data were digitized by tracing the lines defining the respective features from the original map or from a photographically enlarged copy of the original map. Each type of feature was assigned a unique numeric code (class value) that could be used to access, edit, manipulate, and display specific variables, associations, and relationships within the database. The geologic map units, geologic structures, and geophysical interpretive map required several iterations of digitizing and editing, chiefly to add detailed information requisite to the deposit model but not present on the generalized geologic map and to account for reinterpretation of the geophysical data. After editing, these maps were converted into raster format for entry into IDIMS.

Tables and text.—Two data sets (stream-sediment geochemistry and mines and prospects) were nominally tabular but were treated differently prior to conversion to raster format.

The stream-sediment geochemical data were received on magnetic tape in U.S. Geological Survey Statpac tabular format. Output from the program is as 80-character records with one or more header records describing the contents and size of ensuing records (Kork and Miesch, 1984). A program was written that reads the header and then generates a relation (a table maintained by the RDBMS). The header information is used to generate the schema (the name, order, and size of attributes in each record of the relation). Next, another program loads the data into the relation, decoding Statpac qualifying flags and modifying the data accordingly as it runs. After reprojecting sample-site coordinates from geographic to Transverse Mercator coordinates, the data are subjected to a minimum-curvature surface-generation function to produce a raster map (Briggs, 1974; Webring, 1981.)

Data on mines and prospects were received on magnetic tape as a text file containing tables with pertinent data embedded in the text. The text required extensive editing to extract and reformat the tables prior to entry into the RDBMS. After further manipulation in the RDBMS, site coordinates were extracted and processed to create a point map in the vector subsystem. This map was then reprojected from geographic to Transverse Mercator coordinates and rejoined with the attribute information. These data were then queried and plotted according to required combinations of attribute values. A vector-to-raster conversion step was necessary to create raster images from these point maps.

Gridded data.—Data sets available in gridded formats on magnetic tape but not used directly in the resource assessment are Landsat Multispectral Scanner (MSS), residual aeromagnetic anomalies, Bouguer gravity anomalies, and a digital elevation model (DEM). The DEM data were put into the raster subsystem and processed to create a topographic shaded-relief image that could be used for display and interpretation.

Previously digitized data.—Linear features derived from remote sensing data were received in digital form. These data consisted of geographic coordinates of the start and end of line segments and the length and azimuth of each segment. The data were reformatted to generate a geographic-coordinate file and an attribute file that were put into the vector subsystem. After reprojecting into Transverse Mercator projection, selected linear features were converted to a raster file.

Developing and applying the deposit model was accomplished primarily in the raster-based subsystem (IDIMS) of the GIS. All resident data sets within the GIS were reformatted as grid-cell arrays containing 559 rows and 789 columns. Each coregistered grid cell represents a ground area of 200 m × 200 m. Cell size was selected on the basis of national map accuracy standards, which state ". . . for maps on publication scales of 1:20,000 or smaller, . . . not more than 10 percent of the points tested shall be in error by more than 1/50 inch" (Thompson, 1979, p. 104). At 1:250,000, 1/50 in. equals 126 m. The minimum resolvable line (two points) and polygon (three points) adds to the overall locational error, and co-locating points during the overlay proces multiplies the errors. Thus a cell size of 200 m × 200 m reflects a compromise between accurate feature location and reasonable detail. Furthermore, computer-processing time can become inordinately long if the cell size chosen is too small.

THE DEPOSIT MODEL

From the preceding description of vein and replacement deposits and kinds of data available, the following list of six attributes and relationships, referred to collectively as the "deposit model" and individually as "favorability criteria," were determined to be the most generally applicable in the Dillon quadrangle:

1. **Favorability of host rock**—Some geologic units are much more favorable than others.
2. **Proximity to plutons**—Deposits tend to be near plutons.
3. **Stream-sediment geochemistry**—Seven elements (silver, copper, lead, zinc, antimony, arsenic, cadmium) in stream-sediment samples discriminate vein and replacement deposits from other types of deposits.
4. **Proximity to faults**—Veins are in fractured rocks and tend to be along and near faults.
5. **Limonite anomalies**—Limonite determined by remote sensing is interpreted to be indictive of hydrothermal alteration.
6. **Lineaments and northeast-trending linear features**—These remote-sensing features are interpreted to be the result of faults and other zones of fractured rock.

In addition to these six criteria, local or unique relationships, particularly regarding structural control, are crucial to understanding the localization of individual deposits but for the most part are beyond the scope of this report. Some comments on structural details are included in the discussions of individual areas having high or very high mineral resource potential. The rationale for the development of each criterion listed above is discussed in the following section. Figure 4 summarizes the favorability criteria and the numerical scores assigned to each in the following discussion of the criteria.

FAVORABILITY OF HOST ROCK

To determine the relative favorability of host rocks, the distributions of known vein and replacement deposits were compared with the various bedrock units on the geologic map. Using a raster-based algorithm within the GIS, we computed the number of grid cells that contained one or more mines and prospects for each map unit. Next, this number was divided by the total number of cells that contain mines and prospects to obtain a ratio for each map unit. However, as this ratio does not take into account the different outcrop area of the various map units, a ratio of the area of each unit to the total area of the quadrangle was calculated. Then, the mines-and-prospects ratio was divided by the map unit area ratio to obtain a number that represents, in effect, the number of mines per unit area of each map unit.

These calculations reveal, as expected, that brittle rocks and carbonate rocks contain the most deposits (per unit area), and unconsolidated surficial and basin-fill deposits contain essentially none. The brittle rocks are chiefly Archean gneiss, Proterozoic sedimentary rocks (slightly metamorphosed), and Cretaceous and Tertiary plutonic rocks. Carbonate rocks in the quadrangle are mostly in the two map units of Paleozoic sedimentary rocks and in Archean marble. Replacement deposits are essentially confined to carbonate rocks.

In addition to the calculated ratios, a determination of the relative importance or productivity of mines within each map unit is another factor taken into account subjectively in determining favorability of host rocks. Table 1 shows that the more productive deposits are commonly in carbonate rocks even though more mines and prospects are in Archean and plutonic rocks, and for this reason carbonate rocks are considered to be the most favorable host. Although large numbers of deposits are in plutonic rocks, most are occurrences or prospects that have produced little or no ore, and hence these units are regarded as less favorable and rated lower. Table 2 gives the results of the

Favorability criteria	Favorability scores					Maximum possible score
	5	4	3	2	1	
Favorability of host rock	Upper and lower Paleozoic sedimentary rocks; Archean marble and calc-silicate gneiss	Chamberlain Shale, Greyson Shale, Newland Limestone, Prichard Formation, Archean gneiss and schist	LaHood, Yellowjacket, and Swauger Formations, and Lemhi Group	Cretaceous (73–79 Ma) hornblende-biotite granodiorite, quartz diorite, tonalite, and latite porphyry	All other map units except Quaternary deposits, and Tertiary basin-fill deposits	5
Proximity to plutons	Area 0–4 km from exposed plutons and within geophysical anomalies	Area 0–4 km from exposed plutons and 0–4 km from geophysical anomalies	Area 0–4 km from exposed plutons and more than 4 km from geophysical anomalies	Within geophysical anomalies	Area 0–4 km from geophysical anomalies but not within 0–4 km zone around exposed plutons	5
Stream-sediment geochemistry			Log normalized geochemical value 1.4228–4.1848	Log normalized geochemical value 0.7533–1.4227	Log normalized geochemical value 0.3348–0.7532	3
Proximity to faults				Area 0–1 km from mapped faults		2
Limonitic alteration				Area of anomaly and 1-km zone around anomaly		2
Lineaments and northeast-trending linear features					Area of lineament and 0–1 km around N. 35°–58° E. linear features	1

Total maximum score 18

Figure 4. Diagram summarizing the elements that constitute the favorability criteria and scores assigned to each criterion, Dillon 1°×2° quadrangle, Idaho and Montana.

Table 2. *Empirical relation between mines and prospects and host rocks, Dillon 1°X2° quadrangle, Idaho and Montana*

Host rock (map unit symbols from maps J and K)	Pct. mines in area of host rock	Pct. quadrangle accounted for by host rock	Pct. mines/ pct. area	Favorability score
PMs, D€s, Ac.	25.2	7.1	3.557	5
Yc, Au	24.2	8.6	2.816	4
Yl, Yy, Ylh, Yqm.	18.1	7.6	2.386	3
Kghb	13.4	11.7	1.143	2
Other bed-rock.	19.1	30.0	0.637	1
Qa, Tt	0	35.0	0.000	0

calculations and the partly subjective determinations of favorability ranking of map units, which are grouped and each group given a score of from 1 to 5. Surficial deposits are given a score of 0, except when they were thin enough to ignore, such as the narrow strips of alluvium and glacial deposits along stream valleys.

Map C is a computer-generated map showing the favorability of all map units in the quadrangle as determined by this scheme.

Proximity to plutons

The spatial relationship of mines and prospects developed in vein and replacement deposits to exposed plutons is shown in figure 5. This histogram illustrates that about 60 percent of all mines and prospects and 13 of 15 of the most productive mines (table 1) are 0–4 km from plutons. The number of mines and prospects decreases with distance beyond 4 km. Although about 17 percent of the mines and prospects are within plutons, few of them have produced ore and none of them is in the group of the 15 most productive deposits.

This relationship was recognized qualitatively, and as shown in figure 5 and table 3, was made quantitative by calculations performed within the GIS. A raster-based algorithm permits generation of a map showing proximity to a specified grid-cell class. In this algorithm, each cell in a data set is relabeled on the basis of its distance (in number of grid cells) from other grid cells of a specified class. The same technique was used as that described in a previous paragraph for evaluation of favorability of host rocks. Each of the eight different kinds of intrusive rocks was analyzed separately with respect to the distribution of vein and replacement deposits, but the data for all kinds were then combined and treated as a single data set. The density of mines within 4 km of plutons of all classes was determined to be greater than average per unit area (a ratio of percent mines/percent area greater than 1 in table 3).

Having determined a close spatial association between mines and prospects and exposed plutons, an analogy was made with plutons that are inferred from geophysical data, some of which are in the subsurface and some of which are exposed at the surface. It is assumed that a comparable relationship exists with the subsurface plutons. That is, a comparable 4-km-wide zone around the sides of subsur-

Table 3. *Empirical relation based on proximity of mines and prospects to plutons, Dillon 1°X2° quadrangle, Idaho and Montana*

[Distance from subsurface plutons is lateral distance away from geophysical anomalies (fig. 3). Data within anomalies are inferred to reflect a position above subsurface plutons]

Distance (km) from plutons	Pct. mines	Pct. area	Pct. mines/ pct. area	Favorability score
Exposed plutons				
0.0-1.0	24.3	13.7	1.77	3
1.1-2.0	17.3	11.2	1.54	3
2.1-3.0	13.3	9.4	1.41	3
3.1-4.0	10.9	9.2	1.19	3
4.1-5.0	7.0	7.4	0.94	0
5.1-6.0	5.6	6.2	.90	0
Subsurface plutons inferred from geophysical data				
Within anomalies.	29.6	25.8	1.15	2
0.0-1.0	7.2	6.8	1.05	1
1.1-2.0	7.2	6.8	1.05	1
2.1-3.0	5.6	6.6	.85	1
3.1-4.0	3.8	6.6	.58	1
4.1-5.0	3.8	5.3	.71	0
5.1-6.0	3.2	4.4	.73	0

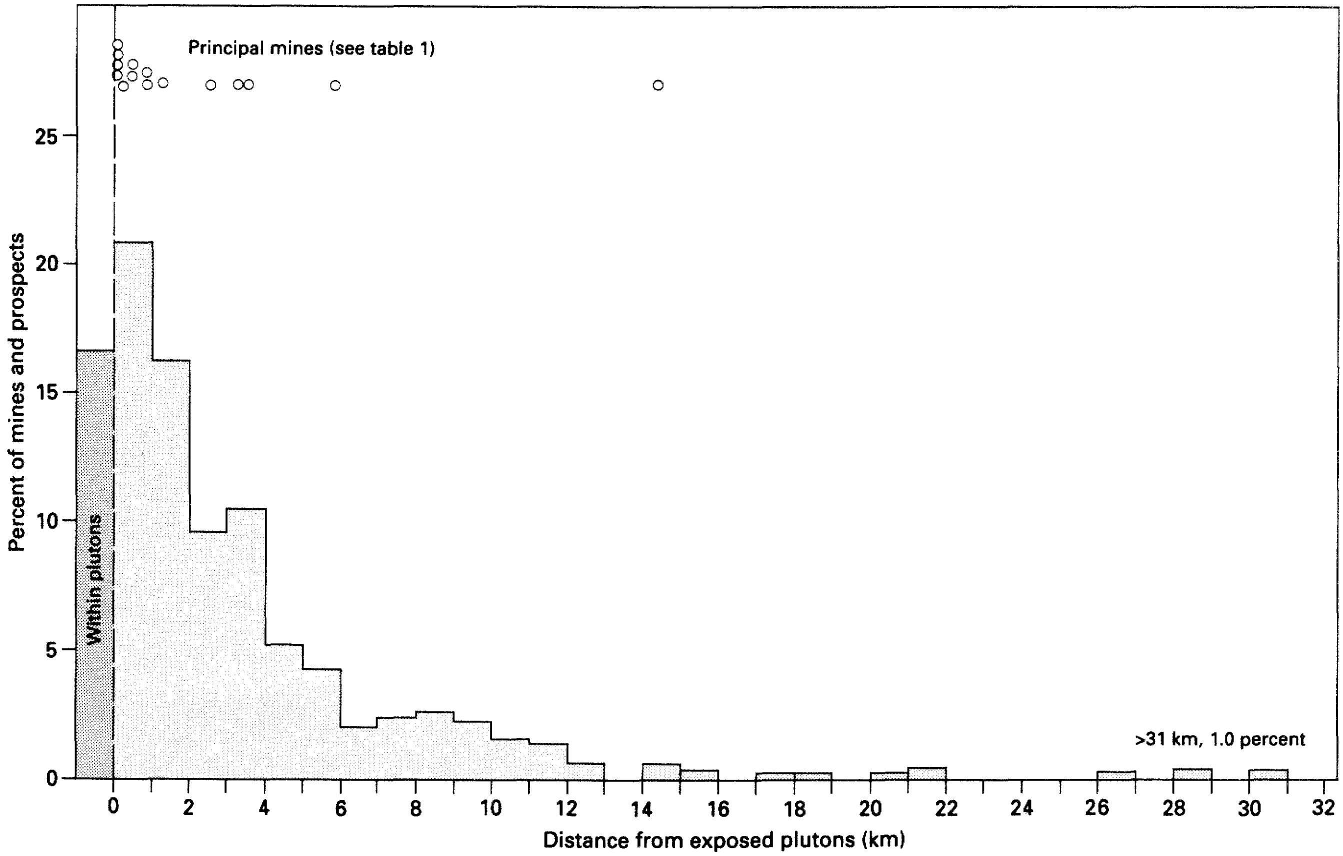

Figure 5. Histogram showing spatial relation of mines and prospects in vein and replacement deposits to exposed plutons, Dillon 1°×2° quadrangle, Idaho and Montana.

face plutons is assumed to be favorable, and a similar 4-km-wide zone (or less because of erosion) is present above subsurface plutons. Hence, subsurface plutons were combined with exposed plutons in the analysis, although the depth to these subsurface plutons has not been determined. Some subsurface plutons are in basins and may underlie basin-fill deposits. When the same GIS procedure is applied to subsurface plutons as was applied to exposed plutons for comparing the distribution of mines and prospects with plutons, the correspondence is not as good (table 3). The mines and prospects are not as closely clustered around "geophysical plutons," nor are they expected to be because the mines and prospects are essentially at the surface, whereas the subsurface plutons may be much deeper than 4 km.

Composition of plutonic rocks also seems to be a factor in localizing vein and replacement deposits. In the Dillon quadrangle these deposits seem to be more abundant near more highly magnetic plutons, which are mainly hornblende-biotite granodiorite and monzogranite. The more highly magnetic plutons also include gabbroic and dioritic rocks that probably have few vein and replacement deposits genetically associated with them; however, these mafic plutons are so small and sparse that they do not affect the results significantly. The deposits are uncommon in association with relatively nonmagnetic plutons such as two-mica granite and granodiorite.

Thus, when considering plutons, we rate the 4-km-wide zone around exposed magnetic plutons as the map area that is the most favorable (fig. 6). The 4-km zone above subsurface plutons, identified as the area within the geophysical anomalies attributed to plutons (fig. 3), is rated lower than the zone around exposed plutons because of the uncertainty as to their depth and even some uncertainty as to their existence. The 4-km shell around the sides of subsurface plutons, identified as the 4-km-wide zone around the geophysical anomalies, is rated still lower because of the same uncertainties, and the favorable ground thus defined is at still greater depth. Where a geophysical anomaly overlaps an exposed pluton, partly or entirely, no interpretation is made as to whether the anomaly is caused by the exposed pluton or a subsurface pluton; it may be caused by either or both.

As shown in fig. 6, the zone around all outcropping plutons is given a score of 3; the area within geophysical anomalies (corresponding to either the magnetic character of an exposed pluton or the favorable 4-km zone above a subsurface pluton) is given a score of 2; and the 4-km zone

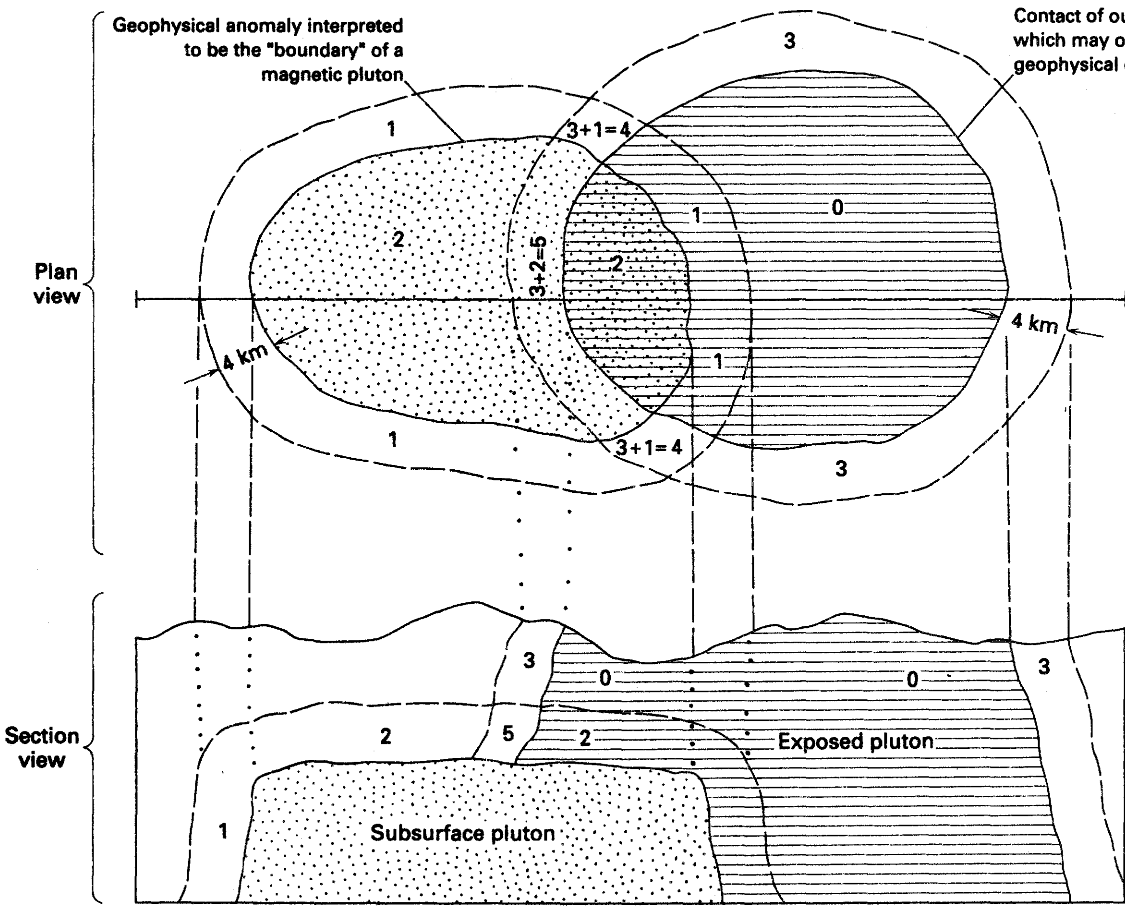

Figure 6. Sketch showing scheme for rating spatial association with plutons. Numbers 0–5 are scores assigned to various relationships. Plan and section illustrate only one of many possible physical relationships between exposed and inferred plutons and geophysical anomalies. The sketch is a general case that accounts for all possible combinations of scores.

around geophysical anomalies is given a score of 1. These scores are added together where the zones and areas overlap, resulting in a range in scores of from 1 to 5 for this criterion. Many other sketches similar to figure 6 would be required to show all possible geometric configurations of outcropping plutons, subsurface plutons, and geophysical anomalies. Figure 6 illustrates only the simplest and most general configuration that accounts for all possible combinations of scores. Combining geophysical anomalies, which locate both subsurface and exposed magnetic plutons, with exposed plutons, which may be either strongly magnetic or weakly magnetic, does two things: it not only shows the favorable 4-km zone around all plutons (subsurface and exposed) but also ranks higher those plutons that have the more favorable composition, that is, those that are more magnetic and produce a geophysical anomaly. This rationale justifies, we believe, the adding together of the two types of data. Furthermore, it is helpful that it does so in a manner that can be accomplished readily within the GIS.

Maps D and E show the distribution of these relationships in the quadrangle.

Stream-sediment geochemistry

The geochemical model, consisting of seven elements (Ag, As, Cd, Cu, Pb, Sb, Zn), was processed within the GIS to develop a map that gives numerical scores for favorability based on geochemistry. First, analytical data for each element were subjected to a minimum-curvature gridding algorithm in the GIS to create a 559×789 grid-cell array of interpolated geochemical values. The resultant array of values for each element was then logarithmically transformed, divided by the geometric mean (which defines the anomalous threshold value) of the raw analytical values for that element, and normalized. The normalizing consisted of assigning background values (those less than the mean) to 0 and linearly rescaling the anomalous values to the range 0–1. At this point in the processing, a raster map of the normalized values existed

Table 4. *Empirical relation between mines and prospects and geochemical anomalies, Dillon 1°X2° quadrangle, Idaho and Montana*

[Log-normalized and summed values for seven elements (Ag, As, Cd, Cu, Pb, Sb, Zn) are described in pamphlet and called "composite anomaly interval" in table below]

Composite anomaly interval	Pct. mines	Pct. area	Density	Favorability score
1.4228-4.1848	20.543	3.279	6.265	3
0.7533-1.4227	16.279	8.680	1.875	2
0.3348-0.7532	25.000	17.671	1.415	1
0.0-0.3347	38.188	70.370	0.543	0

for each of the seven elements. Finally, the seven normalized data sets were superimposed and summed within the GIS to produce a single composite geochemical anomaly map in which each grid cell had a value in the range 0–4.1848 out of a possible range 0–7.

To develop a numerical-score map for geochemistry from the composite anomaly map, intervals within the numerical range were ranked on the basis of how well they correlated with the areal distribution of known vein and replacement mines and prospects. The mines are more densely concentrated at the high end of the numerical range. The density is the ratio of the percent of mines to the percent of area of the quadrangle occupied by those mines. A density of 1 or less would indicate that mines are not concentrated in that interval. A score of 3 was given to the composite anomaly interval of 1.4228–4.1848, in which the density of mines exceeds 6. A score of 2 was given to the interval 0.7533–1.4227, in which the density is 1.875. A score of 1 was given to the interval 0.3348–0.7532, in which the density is 1.415. The interval 0–0.3347 has a density less than 1 and was given a score of 0. Table 4 shows the relationship between the distribution of mines and the calculated intervals and scores. Map F is the geochemical anomaly map that shows areas scored 1, 2, and 3 by this procedure.

It was recognized in using these graphical procedures that stream-sediment samples tend to reflect all or part of the bedrock chemistries for that part of the drainage basin topographically above the sample site. For the purposes of this 1:250,000 resource assessment, we feel that the algorithm applied in the contouring procedure does not itself produce spurious prospective areas nor misleading information. At the time of this study, we had neither a digitized drainage network map for the quadrangle nor an algorithm to produce one from the digital topography.

We determined that the geochemical model reflects mineralized areas instead of host-rock by detailed studies of the relationship of geomorphic features, soil chemistry, and bedrock geochemistry by Breit (1980) and Filipek and Berger (1981) and by inspecting single-element plots and successive plots of single- through seven-element assemblages. No regional trends were discerned in the data related to any specific sedimentary rock geochemistry, such as black shale laden with heavy metal. For example, the Permian Phosphoria Formation was found through bedrock sampling in the central and eastern parts of the quadrangle to commonly contain in excess of 5,000 ppm zinc. However, the stream-sediment samples having the highest detected zinc concentrations were not from sites downstream from Phosphoria outcrops nor from any other specific sedimentary rock formation. Rather, the patterns of higher zinc values reflect more the distribution of intrusive igneous rocks and known mineral deposit occurrences than they do the distribution of zinc-rich lithologies.

Proximity to faults

Spatial relationships between known vein and replacement deposits and mapped faults were analyzed within the GIS through the generation of proximity maps for each class of fault represented in the raster version of the generalized geologic map (map A), as described in a preceding section. By this technique, the areas within 1 km of high-angle and thrust faults were found to have a statistically significant association with the distribution of mines and prospects and were subjectively given a score of 2.

Map G shows the area of the quadrangle within 1 km of faults.

Limonitic alteration

Areas of limonite-stained rocks recognized by remote sensing and field checked (Segal and Rowan, 1989) are interpreted to be evidence of hydrothermal alteration and mineralization, and hence favorable for the occurrence of vein and replacement deposits. Because the map areas of limonitic rocks are very small at 1:250,000 scale, their effect has been enlarged by 1 km outward, so that most of the resulting limonite anomalies are approximately circular and generally between 2 and 3 km in diameter. The enlargement of the effect of the limonitic rocks is believed justified because vegetation commonly restricts the extent of visible limonite and also because the hydrothermal alteration was likely more extensive than the recognized limonite.

In the raster mode of the GIS, a proximity analysis with respect to the limonite anomalies was generated. The distribution of mines and prospects of vein and replacement deposits was compared to the limonite anomalies, and the relationship was determined to be statistically significant. Calculations made by means of the GIS show that the ratio of the percentage of mines within 1 km of limonite anomalies to the percentage of area of the quadrangle accounted for by these altered areas is 6.99. The limonite anomalies thus determined are subjectively given a favorability score of 2.

The limonite anomalies are shown on map H.

Lineaments and northeast-trending (N. 35°–58° E.) linear features

Linear features recognized on various kinds of remotely sensed images by Purdy and Rowan (in 1990) are interpreted to represent structural features such as faults and joints that could localize vein and replacement deposits. Clusters of linear features are combined into larger features (areas that are generally elongate) called lineaments.

Interpreted lineaments and observed northeast-trending linear features were used to develop a lineament submodel by means of the GIS by comparing their spatial distribution with the distribution of vein and replacement deposits. Where northeast-trending linear features overlap the interpreted lineaments, the lineaments have been deleted because they are redundant. The ratio of the percentage of mines and prospects within lineaments to the percentage of the quadrangle occupied by all the lineaments regardless of orientation is 1.33, indicating a slightly greater concentration of mines within lineaments.

Northeast-trending linear features are generally more abundant in and around intrusive rocks and less abundant in volcanic, sedimentary, and metamorphic rocks farther from plutons. Because of the association of vein and replacement deposits with plutons, these linear features, therefore, are inferred to mark favorable sites for vein and replacement deposits. The ratio of the percentage of mines within 1 km of northeast-trending linear features to the proportion of the quadrangle occupied by these features is 1.15; because this ratio is larger than 1, it is considered significant.

Areas within lineaments and within 1 km of northeast-trending linear features are each given a favorability score of 1.

The distribution of lineaments and northeast-trending linear features are shown on map H.

SUMMARY RESOURCE ASSESSMENT MAP (MAP J)

The combined effects of all criteria for all parts of the quadrangle as illustrated on maps C–H were summed by means of the GIS. Each 200 m×200 m grid cell then had a combined favorability score of 0–17 of a possible score of 18 (no grid cell had a score equal to the maximum possible for all criteria (5+5+3+2+2+1)). A plot of these totals results in a map (map I) that is very complex and that consists of thousands of areas, each of which has a total score that differs slightly or greatly from its neighbors. Many of these separate areas are very small, some of them consisting of only one grid cell, and the plot is almost impossible to read or interpret. Furthermore, the distinction between areas having scores that differ by 1 or 2, such as between 15 and 16, is not considered significant. While map I may be useful to some, it is included in this report chiefly to illustrate the result of the GIS summation process. To provide a more meaningful illustration of mineral resource potential, map I was subjectively generalized into groups of scores classified as indicating low (0–7), moderate (8–10), high (11–13), and very high (14–17) mineral resource potential. This summary plot is shown as map J. At least three criteria must be present in an area for it to be designated as having high potential; at least four criteria must be present for it to have very high potential. Actually, most areas rated high and very high have contributions from four to six criteria.

In addition to the minimum number of criteria required to attain a particular level of potential, the various criteria are associated in different combinations. In any area some criteria may be present and others may be absent. Map K provides information on these associations or combinations of criteria for those parts of the quadrangle that are shown on map J as having moderate, high, or very high potential. Not all possible combinations of criteria are shown on map K, nor are a range of scores of the individual criteria considered. One use of map K could be to provide a means of determining those areas of moderate to very high potential where any particular criterion is absent. This map also illustrates one of many possible results of manipulating the data in the GIS. Different users might wish to combine the criteria differently than we have or give any of them different scores.

FAVORABILITY OF MINING DISTRICTS AND OTHER MINERALIZED AREAS

TOBACCO ROOT MOUNTAINS (AREA A, MAP J)

Much of the area of the Tobacco Root Mountains within the Dillon quadrangle has a rating of moderate, high, or very high potential for vein and replacement deposits. The highest favorability scores are for an area more than 3 mi long and 1 mi wide near Mount Jackson and Old Baldy Mountain. This area rated as having very high potential is part of the southern Tidal Wave mining district, which contains many formerly producing mines valuable chiefly for gold (Johns, 1961). All favorability criteria contribute to the rating of very high potential.

The most favorable host rock in the Tobacco Root Mountains, as it is in other parts of the quadrangle, is the Middle Cambrian Meagher Limestone (Ruppel, 1985).

Several small plutons, presumably satellitic to the Tobacco Root batholith, intruded very favorable Paleozoic sedimentary rocks and Archean crystalline rocks, both of which have been broken by numerous faults of generally small to moderate displacement. Some of the faults, particularly in the southwestern part of the range along and near the margin of the Tertiary basin occupied by the Jefferson River valley, have been active since mineralization, making the relationships among the criteria difficult to interpret, especially if these faults have had strike-slip movement as postulated by E.T. Ruppel. Interpretation of the geophysical data is also difficult because the gravity and magnetic data do not generally distinguish between Archean crystalline rocks and most of the smaller Cretaceous plutons that intruded the Archean rocks. Therefore, no buried plutons are inferred where Archean rocks are at or near the surface, although such plutons may exist.

The lack of data to indicate buried plutons may account for the fact that the area of the Mammoth mine, in the South Boulder mining district, one of the largest producers in the Tobacco Root Mountains (80,000–90,000 oz of gold and twice that amount of silver credited to it; Tansley and others, 1933), has only a high, rather than a very high, rating. The nearest outcropping pluton, the Tobacco Root batholith itself, is a little more than 1 mi to the southeast.

Areas of high potential in the northern Tobacco Root Mountains are in the Renova mining district. There, a group of small, generally elongate plutons of intermediate composition intrude the Proterozoic LaHood Formation, and a large sill and numerous smaller sills intrude the Paleozoic strata, commonly at or near the top of the Flathead Sandstone. Most of the productive veins in this part of the Renova district extend from Gold Creek northeastward along minor faults within the LaHood Formation. However, one of the largest deposits in the Tobacco Root Mountains was at the Mayflower mine, farther to the east along the quadrangle boundary. It produced more than 100,000 oz of gold. Although the Mayflower deposit was a replacement body in the highly favorable Meagher Limestone and along a major fault that separates the Paleozoic sedimentary rocks from Cretaceous volcanic rocks, it is not known to be closely associated with any pluton.

BULL MOUNTAIN AREA AND WHITEHALL DISTRICT (AREA B, MAP J)

The mineral resource potential of the southern Bull Mountain area, which is part of the Whitehall mining district, is mostly moderate or high. The favorability scores for this area reflect the problems inherent in treating data at a scale as small as 1:250,000: exposed intrusive bodies are very small and most faults are short and show little displacement. All exposed intrusive rocks are deuterically or hydrothermally altered, which, together with their small outcrop area, explains why geophysical techniques did not detect them or other plutons that may be present but buried.

The south end of Bull Mountain contains numerous small silver mines in the vicinity of Saint Paul Gulch on the west flank of the mountain and the Golden Sunlight gold mine on the east flank of the mountain. The silver veins mostly trend within 20° north or south of east and cut brittle argillite of the Proterozoic Greyson(?) Shale. The Golden Sunlight produced about 100,000 oz of gold prior to 1959. Higher gold prices in the 1970's resulted in development of a large (26 million tons), low-grade (0.05 oz gold per ton), open-pit mine, also called the "Golden Sunlight," that began production in December 1982, near the site of the old Golden Sunlight vein deposits (Porter and Ripley, 1985). The Golden Sunlight veins are in a north-trending vein zone on the east side of the mountain, near a basin-margin fault of similar trend. Numerous small latite porphyry bodies in and near the Golden Sunlight mine are hydrothermally altered and mineralized and are the host for about 25 percent of the disseminated ore. About half of the ore body is in a breccia pipe that consists partly of fragmented argillite and partly of fragmented latite porphyry. A K-Ar age of 79 Ma (Richard Marvin, written commun., 1982) for biotite from post-ore lamprophyre indicates that mineralization preceded intrusion of the principal plutons of the Boulder batholith and was probably about the same age as nearby Elkhorn Mountains Volcanics. The south end of Bull Mountain exhibits mineral and metal zoning from an auriferous quartz-pyrite zone on the southeast, through a lead zone, and into a manganese zone on the northwest; carbonate gangue is common in the lead and manganese zones (Lindquist, 1966). The mineralized breccia pipe seems, from a consideration of the zoning, to be the center of mineralizing activity. Individual vein deposits probably are present in blind structures and in unexplored parts of known structures in areas outside the disseminated deposit.

The northern part of Bull Mountain within the Dillon quadrangle could have a higher potential for vein and replacement deposits than shown on map J because the possible effects of an exposed pluton just north of the quadrangle boundary have not been considered in this analysis.

HIGHLAND MOUNTAINS (AREA C, MAP J)

A broad, irregular, and discontinuous belt of high and very high potential that trends northeast across the Highland Mountains includes several mineralized areas such as the Moose Creek and Highland districts and particularly the highly productive Butte Highlands mine (table 1). This belt also seems to continue southwest across the Big Hole River valley north of Melrose, Mont., onto the low eastern flank of the Pioneer Mountains. As thus delimited, the belt is about 30 mi long.

The most favorable host rocks in the belt are Paleozoic sedimentary rocks situated along the edge of, and as screens between, plutons of the Boulder batholith, chiefly the Butte Quartz Monzonite and granodiorite of the Rader Creek pluton. In the most productive of the deposits in these districts, the Meagher Limestone is host to replacement ore bodies. The belt also includes areas of high potential in Proterozoic sedimentary rocks that locally contain important vein deposits such as the Clipper-Columbia group in the Upper Camp Creek (Wickiup) district (Sahinen, 1950). Northeast-trending linear features are especially prominent in the Highland Mountains. The Berlin mine, west of the Big Hole River valley, is one of the few mines hosted in a Mesozoic sedimentary rock, the Cretaceous Kootenai Formation.

Gold ore extracted from the Butte Highlands mine was nearly all oxidized to a loose, porous siliceous aggregate as a result of destruction of pyrite and pyrrhotite that formed a considerable part of the primary ore. Much of the oxidized ore was mined without drilling or blasting. The mine was operating when closed in 1942 by Federal Order L–208 (Sahinen, 1950) and hence unmined ore (at 1987 prices for gold) may remain, despite the fact that most of this remaining ore probably is sulfide ore that presented beneficiation problems when the mine operated (Thor Kiilsgaard, oral commun., 1986).

SILVER STAR DISTRICT (AREA D, MAP J)

A very high potential is indicated where Paleozoic carbonate rocks are adjacent to granodiorite of Rader Creek and other intrusive bodies too small to show at the scale of the analysis. Several mines in this area, of which the Broadway and Hudson were among the most productive, are associated with calcium-magnesium-iron skarn and are classified by Sahinen (1939) as skarn deposits rather than as vein and replacement deposits being considered in this report. However, most of the ore mined from these deposits was gold-bearing jasperoid, and the gold content of the silicate skarn itself was generally low. Since jasperoid probably formed at a lower temperature than the coarse-grained silicate skarn, the gold mineralization probably was also later than the skarn and hence is considered to be of the vein and replacement type.

Most of the more typical vein deposits in the Silver Star district are in west- to west-northwest-trending structures in a block of Archean gneiss about 2 mi wide situated between the Hell Canyon pluton and the granodiorite of Rader Creek. More detailed studies perhaps would show that this entire block has high potential for additional vein deposits. Areas of high potential adjacent to or less than 1 mi from the Hell Canyon pluton extend from the Silver Star district south around the east side of the pluton and are also on the southwest side of the pluton between it and the Rochester district. These areas are not known to be mineralized, except very locally.

ROCHESTER DISTRICT (AREA E, MAP J)

The potential of most of the Rochester district is rated as high or very high. The most productive part of the district, including its largest mine, the Watseca, contains two areas of very high potential. In addition, two other areas of very high potential are present south of the most productive part of the district.

The veins are in Archean gneiss mainly along a conjugate set of shear faults probably related in their origin to strike-slip movement on regional northwest-trending faults. Detailed investigation of the fault pattern may provide clues to unrecognized mineralized structures, particularly in covered areas. Neogene movement on the regional northwest-trending faults (J.M. O'Neill, oral commun., 1985) should be borne in mind in structural studies. Small plutons, one of which is strongly altered and which was explored as a molybdenum prospect, are in the southeastern part of the district, but subsurface plutons that could have a bearing on localizing vein deposits have not been inferred from geophysical data to exist in this Archean crystalline terrane.

If mineralization in the Rochester district was genetically related to the small altered plutons in the eastern part of the district, the areas rated as having very high potential associated with these plutons would seem to warrant additional study, particularly south of these plutons.

QUARTZ HILL (VIPOND) DISTRICT (AREA F, MAP J)

The large area rated as having high or very high potential that encompasses the central and northern part of the Quartz Hill district also includes areas north of the productive part of the district and extends north of the Big Hole River. Few mines or prospects are in this northern area.

Most of the area of highest potential is in carbonate rocks of Paleozoic age that have been recrystallized to varying degrees by the Mount Fleecer and Lime Kiln Gulch stocks. The two largest ore bodies in the district, each of which produced about 1 million oz of silver, were in the Lone Pine mine. Both are replacement deposits in folded Cambrian dolomite. The folds are interpreted as exerting a control on ore deposition (Taylor, 1942), and other small folds that might be found in the district are favorable. The detailed fracture pattern of the district could also provide structural control. Some of the most favorable ground is covered by thin thrust sheets of Proterozoic quartzite and by Tertiary(?) gravel deposits, including abundant slope wash from the quartzite and the gravel on slopes below the outcrop (Zen, 1988). The possibility of undiscovered vein or replacement prospects in the Mississippian Mission Canyon Limestone east of the Lime Kiln Gulch stock is suggested by its being extensively silicified but evidently little prospected.

HECLA DISTRICT (AREA G, MAP J)

The largest area in the quadrangle rated as having very high potential includes the Hecla district and extends north to include the area around the Cannivan Gulch stock (Hammitt and Schmidt, 1982) and the two stocks to the west of the Cannivan Gulch stock. This large area is chiefly in Paleozoic carbonate rocks that have been recrystallized to varying degrees by the contact effects of several nearby plutons.

The Hecla district is the largest producer of base and precious metals from vein and replacement deposits in the Dillon quadrangle (nearly $20 million worth), chiefly from replacement deposits in Cambrian and Devonian dolomite (Karlstrom, 1948; Zen, 1988). Lion Mountain, the part of the district with the most production, is within the area of very high potential. The eastern part of the district, particularly the part between the Cleve-Avon and the Trapper mines, is largely covered by glacial deposits and hence is not well exposed or much explored. The favorable Paleozoic carbonate rocks are inferred to be continuous around the east side of the structural dome centered on the district and to be present beneath the till.

The northern part of the area of very high potential contains a few of the smaller mines in the southern part of the Quartz Hill (Vipond) district; the area also contains the Cannivan Gulch stockwork molybdenum deposit (Hammitt and Schmidt, 1982). Although numerous localities have been prospected in the area around the molybdenum deposit, such as on the top and high on the north face (Gold Coin mine) of Sheep Mountain (Geach, 1972), no significant ore deposits have been discovered. Nevertheless, favorable geology and evidence for abundant and pervasive mineralization surrounding the molybdenum deposit and related to its formation gives this area very high potential for vein and replacement deposits.

ELKHORN DISTRICT (AREA H, MAP J)

The area of the principal mines in the Elkhorn district has very high potential, and the surrounding area, particularly to the north, has high potential.

The veins in the Elkhorn district are mostly in subsidiary fractures in the hanging wall of the west-dipping Comet fault. Although the veins are abundant and persistent, ore shoots are small and discontinuous. Galena, sphalerite, and tennantite are the main ore minerals, but huebnerite found in some veins evidently was too low in grade to mine. Bedrock in the district is entirely Cretaceous intrusive rock. In addition to the batholith of Uphill Creek Granodiorite, dikes and small irregular bodies of fine-grained to aphanitic porphyritic rocks of intermediate composition intrude the Uphill Creek; the small intrusive bodies are commonly altered and mineralized. The Jacobson Meadows area in the northern part of the area of high potential contains a quartz-vein stockwork that has minor molybdenite, and underground workings in the main part of the district reveal numerous molybdenite-bearing quartz veins beneath the silver and base-metal veins, indicating a metal and mineral zoning. The area along the Comet fault is marked by a pronounced aeromagnetic low that is attributed to absence of magnetite as a result of destruction by hydrothermal solutions.

Area H has a high potential for deposits similar to the small ones already found and mined, but additional ones are likely to be small also.

POLARIS AND BALDY MOUNTAIN DISTRICTS (AREA I, MAP J)

Four small areas rated as having very high potential are within a larger area of high potential in the south-central Pioneer Mountains; these areas include the Polaris and Baldy Mountain mining districts. Also, a few small areas of high potential are about 5 mi northeast of the Polaris district. One of the four areas of very high potential corresponds to the Polaris district; the other three areas are in the Baldy Mountain district but do not coincide exactly with areas having productive mines.

Cambrian and Devonian carbonate rocks are the main hosts for vein and replacement deposits in these districts, but Mississippian carbonate strata are probably present also (Geach, 1972; Pearson and others, 1988; Zimbelman, 1984) and could probably serve as host for ores. Both districts are within 4 km of plutons of the Pioneer batholith. In addition, the districts are anomalous geochemically and contain lineaments, limonite anomalies, and numerous faults.

The Polaris district is essentially a one-mine district. The Polaris mine (table 1) is the only mine in either district to have produced more than a small amount of ore. The mine is in a small block of Paleozoic rocks intruded on the east by Uphill Creek Granodiorite of the Pioneer batholith and in fault contact on the west with Proterozoic Mount Shields(?) Formation. The fault seems to be mostly steep, but at the north end of the block, rock relations indicate that the Mount Shields(?) Formation has been thrust over the Paleozoic rocks. At the south end, Paleozoic rocks have been thrust over Proterozoic rocks and also contain intercalated slices of the Proterozoic rocks, suggesting that the Paleozoic strata are merely a thin imbricate slice. The Polaris mine is in dolomite, possibly Jefferson Dolomite, along a N. 60° E. fault; the adjacent Proterozoic quartzite contains no ore. The silver ore in the Polaris mine is in subsidiary fractures along and subparallel to the N. 60° E. fault.

The Baldy Mountain district contains several small vein deposits in Paleozoic carbonate rocks that have been fractured and folded and intruded by gabbro and granodiorite of the Pioneer batholith. Production from the Baldy Mountain district has apparently been small. Only a little over $27,000 is recorded from 1902 to 1965 (Geach, 1972), although production may have been considerably greater prior to 1902. Most of the prospects and mines have been described by Geach (1972), and some are mentioned by Winchell (1914). The mineral resource potential of the district was assessed in qualitative terms by Pearson and others (1988). In the western part of the district, between Driscoll Creek and Steel Creek, the Jefferson Dolomite, locally overlain by a thrust plate of Proterozoic quartzite, is bleached and locally brecciated and mineralized, commonly by replacement of the dolomite by fine-grained quartz that is localized, in part, along high-angle faults. Much of the quartz forms a boxwork, presumably as a result of the complete weathering away of dolomite or, perhaps, sulfide minerals. Samples of the quartz are geochemically anomalous in gold, silver, arsenic, antimony, molybdenum, tungsten, barium, and beryllium (Zimbelman, 1984).

The areas of high potential east of the Polaris district are underlain by Paleozoic sedimentary rocks adjacent to the Pioneer batholith. No mineralization is known in this area, but the Paleozoic rocks are nearly all covered by glacial deposits.

ARGENTA DISTRICT (AREA J, MAP J)

The main part of the Argenta mining district, north of the village of Argenta, has very high potential; smaller areas of very high potential are at the Ermont mine, southwest of Argenta, and at the Shafer claim group, along French Creek on the northwest side of the district.

The Argenta district is one of the most productive in the Dillon quadrangle, and the Hand (Mauldin) mine (table 1) is one of the largest mines. Geach (1972) described more than three dozen mines in the district; most of them, including the Hand, are vein and replacement deposits in Mississippian carbonate rocks in a strongly fractured block on the east flank of a large north-trending anticline between the Argenta stock and smaller stocks to the north. Several other mines, such as the Shafer group, are in the imbricated zone on the west flank of the anticline, mainly associated with bedding-plane faults involving the Devonian Jefferson Dolomite and Three Forks Formation. Still other mines are in veins in the Proterozoic Garnet Range Formation in the core of the anticline. The areas of very high potential reflect mainly the outcrop of Paleozoic strata on opposite flanks of the anticline and exposed plutons.

The granodiorite stock exposed at Argenta is covered on its south side by middle to upper Tertiary and Quaternary deposits. The close proximity of ore deposits to the exposed north side of the stock implies that the covered south side, which has been explored very little, is deserving of further study and exploration. Although the thickness of the surficial deposits is not well known, these deposits have undoubtedly deterred exploration in the past.

Gold has been an important product of mines at Ermont and mines in the western belt of high potential, but it has not been an important product of the central part of the Argenta district. Some gold placer mining has been done along French Creek and its tributary, Watson Gulch. As no placer mining is evident on French Creek above the mouth of Watson Gulch, a lode source of at least some of this gold must be at the head of Watson Gulch, where small mine workings and prospect pits are within and adjacent to hydrothermally altered, aphanitic to fine-grained intrusive latite porphyry (Myers, 1952).

BIRCH CREEK DISTRICT (AREA K, MAP J)

The area of very high potential that coincides with the Birch Creek district is part of a large area of high potential that is continuous between the Birch Creek and Argenta districts.

The Birch Creek district contains numerous skarn prospects in Paleozoic carbonate rocks adjacent to the Pioneer batholith. Most of these prospects were dug in search of tungsten, although chalcopyrite and molybdenite are also widely dispersed in the skarn. The Indian Queen mine was a substantial producer of copper and silver from skarn (Geach, 1972). No typical vein and replacement deposits are known in the district.

BANNACK AND BLUE WING DISTRICTS (AREA L, MAP J)

Paleozoic limestone that extends from a few miles south of Bannack northward through the Blue Wing district has high or very high potential. This belt includes all the mines in these districts and other contiguous favorable terrane. These districts include the New Departure mine and Golden Leaf group of mines, which are described in table 1, and the Kent mine, the first silver mine in Montana (Shenon, 1931). The New Departure mine is in a small area of very high potential east of the main belt, which is in a klippe chiefly of Mississippian limestone. A small area of high potential east of Bannack coincides with a dacite porphyry plug that is pervasively altered and mineralized with copper, molybdenum, and gold but contains no known veins. The limestone units that contain these mines are parts of a thrust sheet that overlies Upper Cretaceous conglomerate and volcanic rocks; only one small mine, the Missouri prospect, is known in the rocks below the thrust. The mines are all near small intrusive bodies of fine-grained granodiorite that have bleached and recrystallized the limestone (Lowell, 1965); only three, the Del Monte, Iron Mask, and Kent, have produced ore from veins in the granodiorite. The granodiorite body near the New Departure mine shows evidence of being at least partly a sheet intruded along the thrust, but the geophysical expression (fig. 3) suggests a bigger, largely buried stock that also includes the apophyses exposed at Bannack. More detailed geophysical studies may detect other places where the intrusive rock is shallow, within or beneath the thrust sheet.

CALVERT HILL DISTRICT (AREA M, MAP J)

A small area of high and very high potential in the Calvert Hill district coincides with outcrop of Paleozoic and Mesozoic sedimentary rocks and is near plutons. Locally, the sedimentary rocks, probably Pennsylvanian Amsden Formation, were converted to silicate skarn that was mined for tungsten at the Calvert deposit (Geach, 1972). A small mine about 0.75 mi west of the Calvert, the White Cap, is a vein deposit in carbonate rock; it has produced a few tons of silver ore (Geach, 1972). The area probably has potential for additional discoveries of vein and replacement deposits as well as skarn deposits.

WISDOM DISTRICT (AREA N, MAP J)

Areas of high potential in the Wisdom district are in the general vicinity of a few small vein deposits (Berger and others, 1983), and the district also contains small placer gold deposits. The host rock is entirely a pluton of the Pioneer batholith.

Another area of high potential in the west Pioneer Mountains and southeast of the Wisdom district is not associated with any known mineralized rock. This area is underlain by plutonic rock and Missoula Group rocks that are broken by major northeast-trending faults.

ANACONDA RANGE (AREA O, MAP J)

A small area shown as having high potential in the Anaconda Range at the north edge of the quadrangle includes parts of areas 2 and 8 that are discussed by Elliott and others (1985). In that report, area 2, the Warren Peak area (which is partly in the adjacent Butte quadrangle), is considered to have a moderate to high mineral resource potential for mesothermal veins, porphyry, and stockwork deposits because of (1) known deposits, including three having identified resources; (2) anomalous tin in rock samples; (3) favorable geology, including a granodiorite stock intruded into siliceous and calcareous sediments; (4) a positive magnetic anomaly; and (5) presence of hydrothermally altered rocks. Area 8 is considered to have low mineral resource potential by Elliott and others (1985). It contains prospects, sporadic geochemical anomalies, limonitic staining, favorable host rock in contact zones near intrusive bodies, fracturing, and magnetic anomalies. The areas of moderate to high potential given by Elliott and others (1985) do not exactly correspond with the areas of moderate and high potential shown on map J of this report, at least partly because of the difference in mapping scales, in data, and in resource assessment procedures used.

This area is in a highly faulted region in which imbricate sheets of Paleozoic sedimentary rocks are separated from Proterozoic sedimentary rocks by thrust faults, and both sequences are intruded by numerous small to moderate-size plutons. Paleozoic carbonate rocks in the Anaconda Range have not been found to be mineralized to the degree that they are in the eastern half of the Dillon quadrangle, perhaps because the plutonic rocks are different. Further investigation within a few miles of plutons or where carbonate rock is recrystallized could be fruitful.

GIBBONSVILLE DISTRICT (AREA P, MAP J)

The low to moderate potential rating in the Gibbonsville district is attributable to the paucity of exposed intrusive rock, the low-level geochemical anomaly, and the absence of remote sensing anomalies; faults present in part of the district contribute to the favorability score. A large buried pluton several miles to the east is inferred on the basis of geophysics.

The district is underlain by Proterozoic Yellowjacket Formation that is in fault contact with Proterozoic Lemhi Group rocks in the area surrounding the district. Eocene Challis Volcanics occupy a few square miles to the southwest of the district. A large north-trending mafic dike and a small, poorly exposed pluton of intermediate composition on the west side of the district are the only nearby intrusive rocks.

The A.D.& M. mine, the largest producer in the district, mined several narrow, east-trending veins that cut Yellowjacket Formation.

NORTH FORK (AREA Q, MAP J)

Several sizable areas of high potential are in the vicinity of the village of North Fork, Idaho. This region is sparsely mineralized except for the pervasively mineralized intrusive center in Bobcat Gulch (Bunning and Burnet, 1981), a few miles south of North Fork in the northern Salmon River Mountains. Few vein or replacement deposits are known in these areas of high potential. Farther south in the Salmon River Mountains, vein deposits in Proterozoic Yellowjacket Formation and Proterozoic granite are mostly small and widely scattered.

The bedrock in the Bobcat Gulch area is mainly Yellowjacket Formation that has been broken by numerous north-trending faults. The mineralized intrusive bodies are Eocene and presumably related to Challis Volcanics. They contain pyrite, chalcopyrite, and molybdenite in a quartz-vein stockwork. The intrusive rocks form small stocks and dikes that range from quartz diorite to rhyolite; the largest stock is 0.7 × 1.5 mi and is mostly granodiorite. Small bodies of extrusive rhyolite are near the largest stock and are present also just west of the Dillon quadrangle.

The area east and northeast of North Fork is underlain by Yellowjacket Formation, Lemhi Group, and Challis Volcanics that contain very few known vein deposits. The area is also underlain by a subsurface pluton inferred from geophysical data.

The North Fork area has many characteristics favorable for the occurrence of vein deposits; the north-trending faults might be logical places to explore. Even though the geologic map indicates some movement on these faults after intrusion and presumably after mineralization, these faults may date from an earlier time.

NORTHERN BEAVERHEAD MOUNTAINS (NORTH OF FREEMAN PEAK; AREA R, MAP J)

A small area of very high mineral resource potential within a large area of high potential is mainly west and northwest of the Carmen stock. In addition to proximity to the Carmen stock, the high potential results from a high geochemical anomaly, hydrothermal alteration, favorable host rock, and a buried pluton inferred from geophysical data. The geochemical anomaly is in East Fork Tower Creek. The only vein deposit in the area is the Silver Star property (Anderson, 1959), which has produced a small quantity of gold and base-metal ore.

Further investigation of the geochemical anomaly, in particular, seems warranted.

SOUTHERN BEAVERHEAD MOUNTAINS (SOUTH OF FREEMAN PEAK; AREA S, MAP J)

Several areas of high potential in the southern Beaverhead Mountains occupy parts of the Kirtley Creek, Eldorado, Pratt Creek, and Sandy Creek districts, which contain numerous small vein deposits that have been mined principally for gold (Loen and Pearson, 1989). The high favorability rating results from contributions by all favorability criteria, including a geophysical anomaly and a small exposed pluton. The area is traversed by the Beaverhead Divide fault zone. Several stream channels draining southwest, including Kirtley and Bohannon Creeks, have been mined for placer gold that may have been derived from the vein deposits in the Beaverhead Mountains.

Many fewer vein deposits are on the Montana side of the Beaverhead Mountains, and most of those are near the crest of the range.

A large subsurface pluton inferred from geophysical evidence to underlie much of the Beaverhead Mountains suggests that deeper levels (that is, closer to the pluton) may be more favorable than the exposed level. The large magnetic high west of Jackson, Mont., is largely in an area covered by glacial deposits. If this high reflects a pluton, it could be the subcrop beneath the glacial deposits at shallow depth.

LEMHI RANGE (AREA T, MAP J)

The northern tip of the Lemhi Range has a mineral potential score no higher than low. The criteria that contribute to the model evidently do not explain the localization of the Pope Shenon mine (table 1) or the Melody and Harmony mines to the south (Ross, 1925; Loen and Pearson, 1989). The nearby mass of Challis Volcanics, possibly including caldera filling, suggests a possible heat and (or) fluid source for the formation of the ore at these three deposits, except that the ore bodies, which are locally sheared, are cut by unsheared dikes of Challis(?) Volcanics. Another possibility for the origin of the Pope Shenon is that it is genetically related to Proterozoic granite similar to that exposed in the Salmon River Mountains a few miles to the northwest.

FAVORABILITY OF SOME UNMINERALIZED AREAS

Map J denotes several areas of high and very high potential that are not in mining districts or known to be significantly mineralized. Some of these areas not discussed previously in connection with mineralized areas are discussed briefly below.

NORTHWESTERN HIGHLAND MOUNTAINS (AREA AA, MAP J)

Large areas of high potential south and southwest of the Butte district seem to have been mineralized very little. There are no productive mines in these areas. Bedrock is entirely plutonic rock of the Boulder batholith. The favorability score is augmented by broad geochemical anomalies that may be caused by smelter contamination. If so, and if the geochemical data are ignored, these areas may have no more than moderate potential.

DICKIE PEAK (AREA BB, MAP J)

Three small areas of very high potential in an elongate north-trending belt of high potential are in the vicinity of Dickie Peak in the north-central part of the quadrangle. Although the areas show little evidence of mineralization and little or no mining has been done in these areas, the region has many characteristics favorable for vein and replacement deposits. Paleozoic sedimentary rocks are in a thrust-faulted zone and are recrystallized in part by nearby plutons. The Granulated Mountain and Hungry Hill stocks intruded rocks of both the upper and lower plates of the Johnson thrust and an intervening imbricated Paleozoic section (Moore, 1956; Noel, 1956; Fraser and Waldrop, 1972).

Placer mining in French Gulch and California Creek produced perhaps about $5 million in gold, some of it very coarse (Lyden, 1948). The quantity and coarseness of the gold indicate a nearby lode source, possibly veins in or adjacent to the northern part of the Granulated Mountain stock, although no veins have been reported to be there. The even more productive German Gulch placers in the Siberia district a few miles to the northeast are further evidence of gold mineralization in this area and also indicate that hornfelsed Cretaceous sedimentary rocks in the lower plate of the Johnson thrust are favorable hosts for gold deposits, such as the one present at the Beal deposit, which is the principal, and perhaps the only, lode source of the German Gulch placer deposits.

MAY CREEK–RUBY CREEK (AREA CC, MAP J)

Three areas of high potential within a larger area of moderate potential are aligned along a northwest trend for about 8 mi adjacent to the Joseph pluton southeast of Lost Trail Pass (map J). Although the country rock (Lemhi Group) intruded by the pluton in these areas of high potential contains no lode mines or significant prospects, the rock in places is cut by numerous barren-looking quartz veins, and several of the streams draining north into May Creek, southwest into Nez Perce Creek and Dahlonega Creek, and south into Ruby Creek have been mined for placer gold. These factors suggest that the veins, as unpromising as they appear, may actually have been the source of the placer gold. The veins at Gibbonsville are now much lower topographically and hence could not be the source for the gold in the modern streams.

Most of these veins that were observed are a few inches thick or less and ramify through the country rock without regard to through-going fractures. Such small veins are unlikely prospects for minable lode deposits, but larger structures could be present.

SUMMARY

The procedure described in this report resulted in outlining numerous areas in the Dillon quadrangle that have characteristics suggesting a range of favorability for the occurrence of vein and replacement deposits of base and precious metals (map J). These areas are described qualitatively as having low, moderate, high, or very high mineral resource potential based on six favorability factors, or criteria. The four qualitative categories were determined by subjectively grouping the sum of numerical scores given to each criterion; the total scores ranged from 0 to 17 out of a possible score of 18. Nearly all the mining districts in the quadrangle emerge from the procedure with a rating of high or very high potential, and conversely nearly all of the areas determined to have high or very high potential include mining districts. This conformity between high-potential areas and the location of known mines is expectable from the empirical approach used in the model development. Some other areas judged to have high or very high potential but not known to be appreciably mineralized are discussed in terms of the geologic features that combine to give them a high rating.

Although some of the better explored districts may be mined out and the high rating they have been given may indicate only what once was, intensive exploration by many mining companies continues in many districts. This optimism on the part of prospectors and explorationists results from past success in exploration and demonstrates, we believe, the validity of the high-potential ratings assigned here to old districts.

The boundaries between each of the four categories of mineral resource potential (low, moderate, high, and very high) should not be considered to be tightly constrained: some of the favorability criteria are themselves subjective, and the rating classes within the criteria are not precisely defined.

The quantity of base- and precious-metal resources in vein and replacement deposits cannot be determined with information available. After 125 years of prospecting and exploration, it is probable that most conventional deposits exposed at the surface have been found, but it is just as likely that deposits concealed by surficial geologic units and blind deposits below the bedrock surface remain to be discovered. Blind deposits and deposits whose surface exposure appeared to be of minor significance have been among the most productive in the quadrangle and include the Mayflower, Butte Highlands, and New Departure. Additional deposits of this magnitude, as well as many small ones, surely are still present. Even one fairly large vein or replacement deposit could contain as much metal as has been mined from all lode deposits in the entire quadrangle in the last 125 years. The requisite geologic environment is certainly present.

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