Mineral Resources of the Elkhorn Wilderness Study Area, Broadwater and Jefferson Counties, Montana

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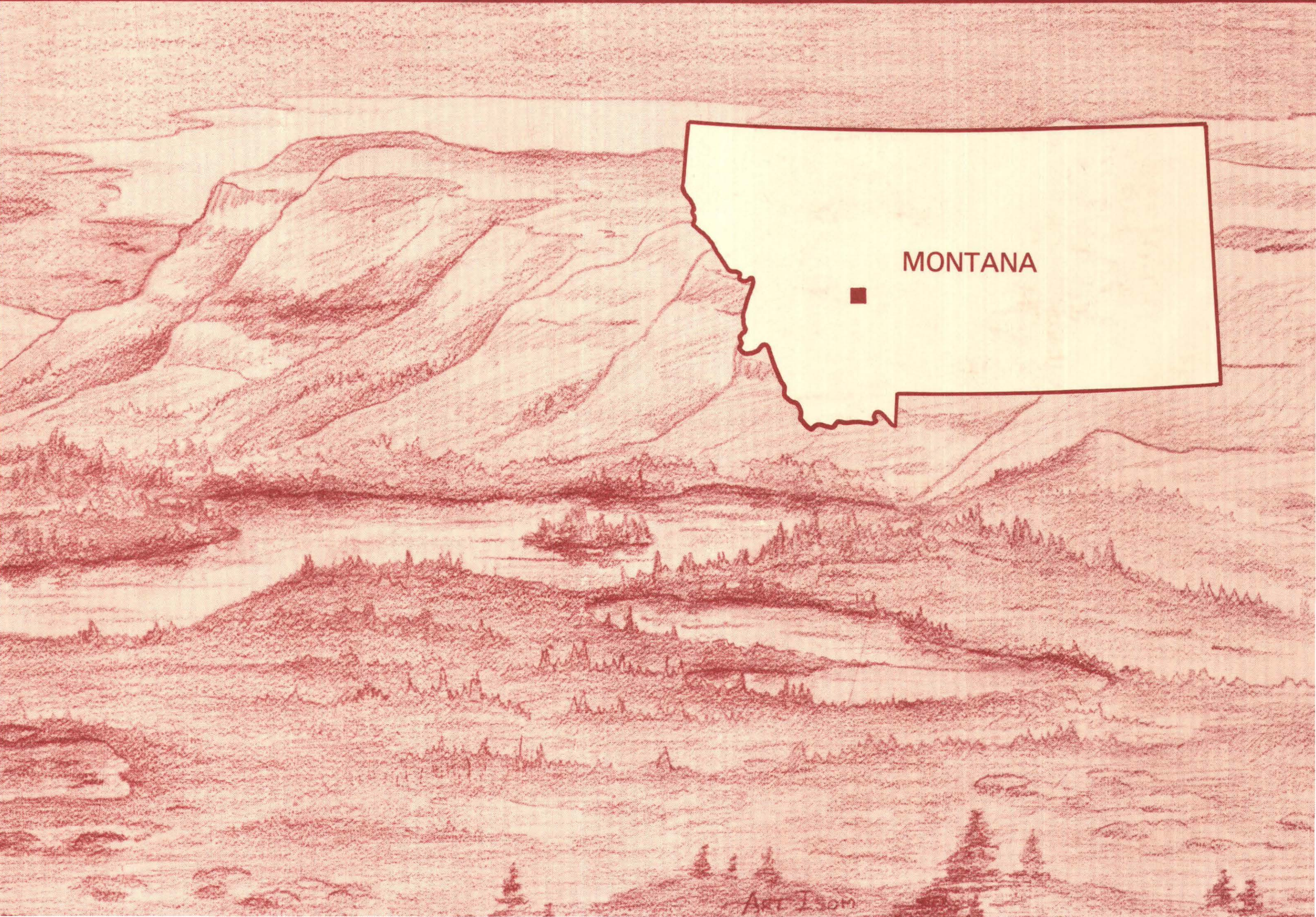

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By WILLIAM R. GREENWOOD, STEVE LUDINGTON, WILLIAM R. MILLER, and WILLIAM F. HANNA

With a section on URANIUM AND THORIUM POTENTIAL

By KAREN J. WENRICH, WILLIAM R. MILLER, VIVIAN J. SUITS, and JOHN B. MCHUGH

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STUDIES RELATED TO WILDERNESS

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STUDIES RELATED TO WILDERNESS

In accordance with the provisions of the Wilderness Act (Public Law 88–577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The Act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of national forest land in the Elkhorn Wilderness Study Area, Montana, that is being considered for wilderness designation (Public Law 94–557, October 19, 1976). The area studied is in the Helena and Deerlodge National Forests in Broadwater and Jefferson Counties.

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Mineral Resources of the Elkhorn Wilderness Study Area, Broadwater and Jefferson Counties, Montana

By William R. Greenwood, Steve Ludington, William R. Miller, *and* William F. Hanna
with a section on Uranium and thorium potential
By Karen J. Wenrich, William R. Miller, Vivian J. Suits, *and* John B. McHugh

SUMMARY

The Elkhorn Wilderness Study Area in west-central Montana has a moderate to high potential for resources of porphyry-type copper and molybdenum in the western part of the area, and a moderate to high potential for resources of gold, silver, lead, and zinc in replacement and vein deposits in the eastern part of the area. No evidence of potential oil, gas, and geothermal resources was identified in this study.

The study area includes about 87,000 acres (350 km^2) of national forest lands in the Elkhorn Mountains about 15 miles (24 km) southeast of Helena, Mont. The study area comprises about 82,000 acres (330 km^2) designated by Congress for wilderness study in 1976, plus about 5,000 acres (20 km^2) studied at the request of the U.S. Forest Service. Some mineralized areas next to the study area are also discussed in this report.

The study area includes parts of the Beaver Creek, Elkhorn, and Park mining districts, and all of the Tizer-Wilson mining district, none of which were producing ore at the time of the study (fig. 1). The study area also includes part of the Warm Springs mining district, within which only the White Pine mine, outside the study area, was producing ore during the study.

The mineral resource potential of the study area and adjacent areas was evaluated by the U.S. Geological Survey and the U.S. Bureau of Mines in 1976 and 1977. The evaluation consisted of a mineral resource assessment by the U.S. Geological Survey based on geologic, geochemical, and geophysical surveys and an economic appraisal by the U.S. Bureau of Mines based on studies of existing mines and prospects. The Bureau of Mines appraisal will be published separately.

The mineral resource assessment by the U.S. Geological Survey was based principally upon geologic studies including chemical analyses of rocks, a detailed geochemical survey of stream deposits, and a detailed aeromagnetic survey. In the geochemical survey, bulk stream sediments and panned stream sediments were analyzed for 30 elements by semiquantitative spectrographic methods and for gold, zinc, and arsenic by atomic absorption methods. Geologic studies and rock sampling were then conducted in drainage basins from which stream-sediment samples showed anomalously high metal content or in which evidence of hydrothermal alteration was known. The aeromagnetic survey served as a guide for collecting rock samples which were subsequently measured for remanent and induced magnetization for purposes of determining the range of physical properties of anomaly sources. Uranium and thorium resources were investigated by analyzing water and stream-sediment samples and by an airborne radiometric survey. Altogether, more than 1,400 samples were analyzed in the assessment.

The geologic and geochemical data indicate that the western part of the Elkhorn Mountains has a moderate to high potential for resources of porphyry-type copper and (or) molybdenum. Three deposits, Jackson Creek (fig. 2, loc. l), Golconda (loc. 2), and Turnley Ridge (loc. 3), which are adjacent to the study area, have been explored by drilling, Golconda showing the highest potential for development. On the basis of geologic studies, other areas that have high potential for molybdenum and (or) copper resources include breccia pipes and dikes cemented by tourmaline, quartz, and sulfide minerals. The breccia bodies may overlie buried porphyry-type copper and (or) molybdenum deposits. These breccias occur at the south margin of the study area (near the

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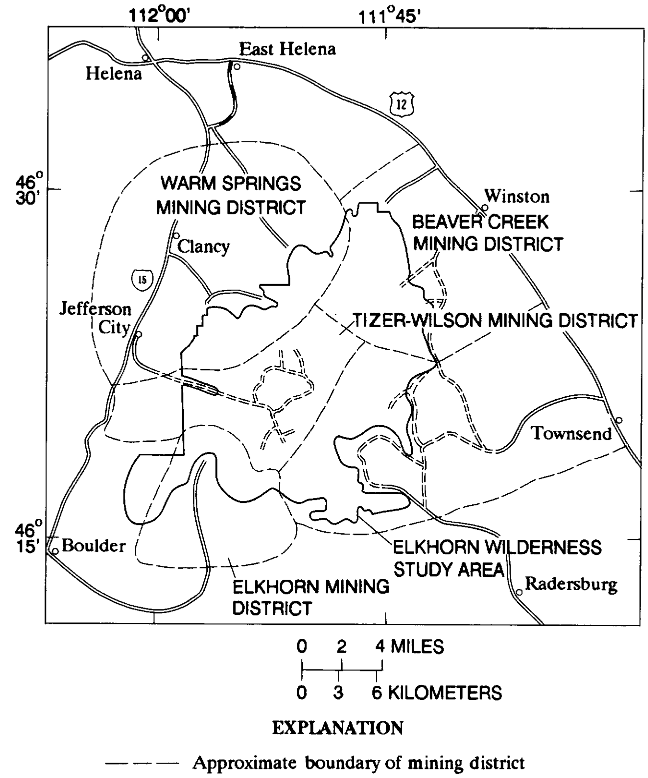


Figure 1. Mining districts in and near the Elkhorn Wilderness Study Area, Montana.

Skyline mine, fig. 2, loc. 4) and the north margin (near and south of the Chicago mine, (loc. 5). Geochemical data suggest a high potential for molybdenum and (or) copper resources at Nursery Creek (loc. 6), Hidden Lake (loc. 7), and South Fork Warm Springs Creek (loc. 8), localities which show high contents of molybdenum, tin, and (or) tungsten in both panned concentrates and rock samples; and at Dutchman Creek (loc. 9), which shows high contents of molybdenum, tin, and (or) tungsten in the panned concentrates alone.

The geochemical data also suggest a moderate potential for precious- and base-metal resources in a broad northeast-trending zone in the southeast part of the study area. Several areas of high potential for these metals are indicated within this zone (fig. 2, locs. 10, 11, 12, 13, and 14). Of these, localities 10 and 14 include major mines, the workings from which have contributed to the high metal contents in the panned concentrates. The high metal contents in samples from localities 11, 12, and 13 (Longfellow Creek, an unnamed tributary to Crow Creek, and Staubach Creek, respectively) do not appear related to any major mine.

Aeromagnetic anomaly and rock magnetic data suggest that relative negative anomalies, or lows, are in many places associated with subsurface zones of alteration and silicification in the Boulder batholith and in the Elkhorn Mountains Volcanics near the batholithic contact and that relative positive anomalies, or highs, are in many places associated with shallowly buried plutons in Elkhorn Mountains Volcanics farther from the contact. Both the lows and highs occur over many terranes which have been mined or prospected and, therefore, delineate subsurface regions which merit consideration for future exploration.

Anomalously high uranium was found in water samples at Badger Creek (fig. 2, loc. 15), Muskrat Creek (loc. 19), and Rawhide Creek (loc. 17). The entire drainage of Warm Springs Creek (loc. 8) had high concentrations of uranium in stream-sediment samples. Radon in water was anomalously high in samples from Dutchman Creek (loc. 9), Warm Springs Creek, and Muskrat Creek. Anomalously high thorium was found in stream-sediment pan-concentrate samples from the following creeks: Rawhide, Nursery (loc. 6), Weimer and Anderson (loc. 2), Dutchman, Warm Springs, North Fork Warm Springs (loc. 16), and McCarthy (loc. 18) Creeks.

MINERAL RESOURCE ASSESSMENT

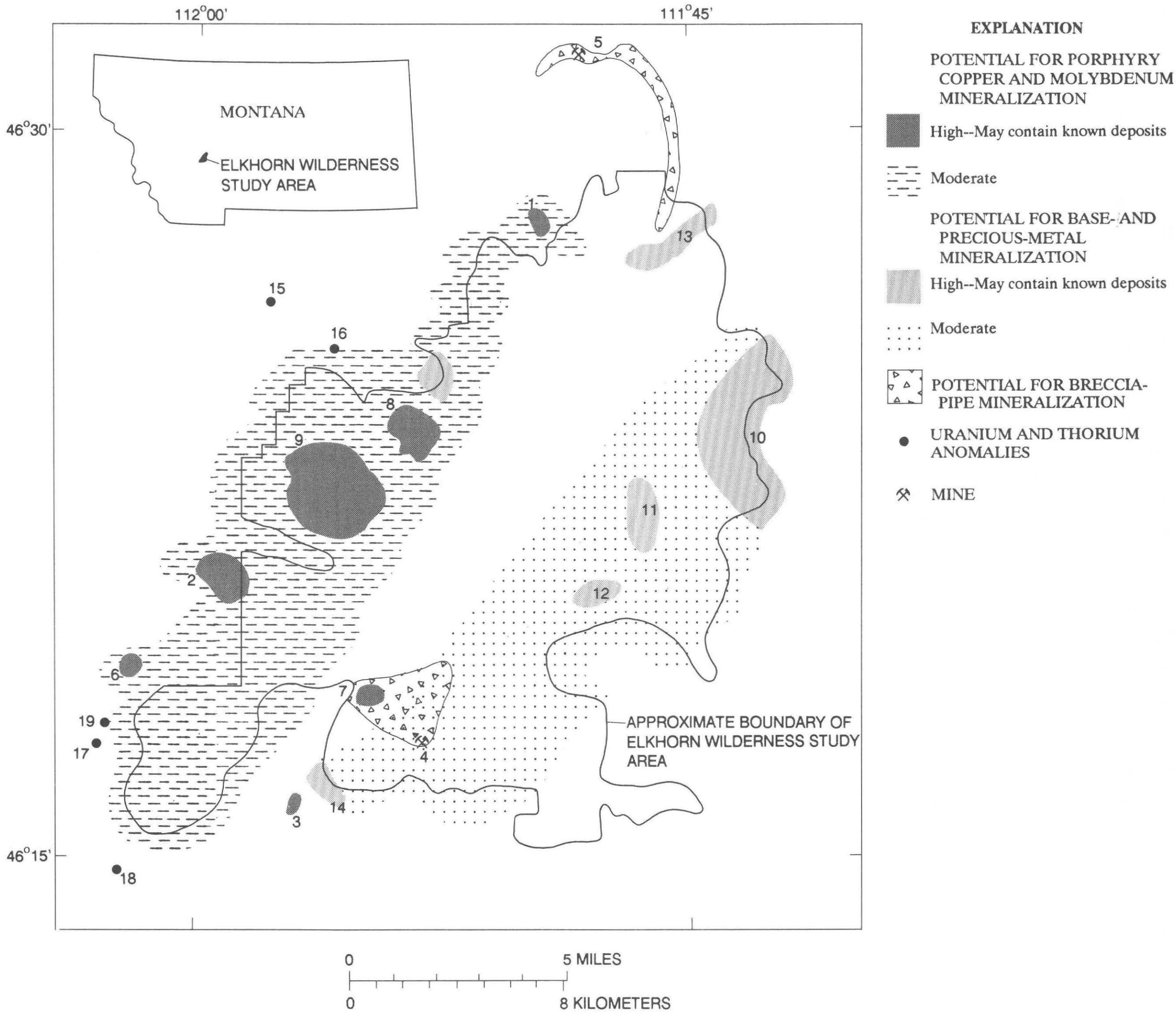
By William R. Greenwood, Steve Ludington, William R. Miller, and William F. Hanna

Introduction

The study area as described in this report includes the Elkhorn Wilderness Study Area designated by Congress in 1976, consisting of about 82,000 acres (330 km^2), and an additional area studied at the request of the U.S. Forest Service, consisting of about 5,000 acres (20 km^2). The study area is in parts of Broadwater and Jefferson Counties in western Montana, and includes parts of the Helena and Deerlodge National Forests. Some lands adjacent to the study area were also examined, as indicated in the report.

The study area is accessible from the east by several secondary roads leading from U.S. Highways 12 and 287. From the west it is reached by several secondary roads leading from U.S. Interstate Highway 15. Jeep trails provide access throughout Tizer Basin (an informal name for the basin at the head of Crow Creek—see pl. 3) and lower parts of the bordering slopes of the basin. From the south the study area is reached by secondary roads leading north from Montana State Highway 281 and a secondary road connecting the towns of Elkhorn and Radersburg. U.S. Forest Service trails provide access by foot or horseback to most of the study area from June through October. During the winter and spring much of the study area is inaccessible to land vehicles due to snow.

The study area includes the higher, central part of the Elkhorn Mountains, an isolated range in west-central Montana. Relief in the area is about 4,800 feet (1,500 m), ranging from an elevation of about 4,600 ft (1,400 m),



LOCALITIES

1. Jackson Creek	6. Nursery Creek	11. Longfellow Creek	16. North Fork Warm Springs Creek
2. Golconda	7. Hidden Lake	12. Unnamed tributary to Crow Creek	17. Rawhide Creek
3. Turnley Ridge	8. So. Fork Warm Springs Creek	13. Staubach Creek	18. McCarthy Creek
4. Skyline mine	9. Dutchman Creek	14. Elkhorn mining district	19. Muskrat Creek
5. Chicago mine	10. Park mining district	15. Badger Creek	

Figure 2. Mineral resource potential of the Elkhorn Wilderness Study Area, Montana.

where Warm Springs Creek leaves the study area, to 9,414 ft (2,869 m) at Crow Peak, the highest peak in the study area. Although the maximum local relief is in the northern part of the study area, the scenery is more spectacular in the southern part because of the glacial cirques on the flanks of Crow and Elkhorn Peaks.

The study area is in the Missouri River watershed and is drained on the east mainly by Crow Creek and Beaver Creek, on the northwest by Prickly Pear Creek, Dutchman Creek, Warm Springs Creek, and McClellan Creek, and on the southwest by Muskrat Creek, Elkhorn Creek, and Dry Creek.

The study area was glaciated during Pleistocene time and glacial features include cirques on the higher peaks. The upper parts of many valleys are U-shaped, and moraine and outwash deposits fill parts of Tizer Basin and most of the major drainages.

The highest ridges and peaks of the area have talus-covered slopes with a sparse cover of whitebark pine and alpine fir (vegetation data from U.S. Forest Service, 1976). Lower ridges and the upper slopes and basins generally are densely covered with lodgepole pine. Midslopes and valley bottoms have a mosaic of Douglas-fir and lodgepole-pine woodlands and mountain grassland parks. On the lower slopes to the east and south, these parklands pass into open grasslands and shrub lands.

The climate of the area is modified continental with large annual and daily temperature variations (U.S. Forest Service, 1976). Precipitation ranges from less than 12 inches (30 cm) per year in the valleys to over 30 in. (76 cm) per year at higher elevations. Average snowfall is over 100 in. (250 cm) per year in the high country and makes up a large part of the annual precipitation of that part of the area. The area generally has very little rain during July and August. The temperature ranges from a minimum of well below 0°F (-18°C) in winter to a maximum of nearly 90°F (32°C) in summer and is quite variable from day to day.

The study area is used principally as a livestock range and for recreational fishing and hunting. Logging in the area has yielded about 20 million board feet of timber and is a potential economic resource (U.S. Forest Service, 1976). Mineral exploration in the study area is being conducted by individual prospectors and by companies, and mine development work is being done on properties adjacent to the study area on Warm Springs Creek.

Previous Studies

The geology and mineral deposits of different parts of the study area have been discussed in many reports, which are listed in the references and cited elsewhere in this report. The geologic map of the study area (pl. 1) was compiled from the reports by Klepper and others (1957); Klepper, Ruppel, and others (1971); Becraft and others (1963); and Smedes (1966); details were added locally based on our mapping. The synopsis of geology presented here is drawn largely from these papers, supplemented by subsequent summaries and topical reports by these authors and their co-workers. The spirited exchange between Hamilton and Myers (1967, 1974a, b) and Klepper, Robinson, and Smedes (1971, 1974) presented much useful information and opinion on the shape and manner of emplacement of the Boulder batholith.

Present Investigation and Acknowledgments

Investigations in the study area by the U.S. Geological Survey were made during November 1976 by W. R. Greenwood and W. R. Miller, and during June, July, and August 1977 by these geologists and S. D. Ludington, assisted in 1977 by Judy Melia Allen, Enid Bittner, and David Thompson.

The fieldwork was conducted mainly by foot traverses through the area. Jeeps were used on several trails in Tizer Basin and to gain access to sample localities on the periphery of the study area.

The mineral survey included reconnaissance geologic mapping aimed primarily at checking and updating existing maps. Most of the field effort, however, was devoted to collecting samples for geochemical analysis and searching for evidence of mineralization. Bulk stream-sediment samples and panned concentrates of stream sediments were collected from all first order (unbranched) streams. Water samples were also collected from these streams and from springs and seeps. The common rock types were sampled, as were visibly altered or mineralized rocks. Altogether, more than 1,400 samples were collected and analyzed. The spectrographic analyses of these samples were made in a U.S. Geological Survey mobile laboratory by Jerry Motooka. Sample preparation and other chemical analyses were conducted in a mobile laboratory by John B. McHugh.

The mineral survey benefited greatly from assistance extended by local residents, U.S. Forest Service officials, claim owners, and others. In particular we would like to acknowledge help received from James W. Whipple, formerly U.S. Forest Service geologist of the Helena National Forest, and Richard I. Walker, U.S. Forest Service, team leader for the Elkhorn Wilderness Study Area project.

Resource Potential Definitions

The following definitions of mineral resource potential, recently published by Goudarzi (1984), were used by the U.S. Geological Survey in this study.

Geologic terranes considered unfavorable for the occurrence of mineral resources are generally classed as having *low* potential, recognizing that most of these areas still have a small likelihood of containing mineral resources. Areas with terrane considered favorable are subdivided into areas of *moderate* and *high* potential.

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

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

High mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral forming processes have been active in at least part of the area. Resources or deposits need not be identified for an area to be assigned high resource potential.

Geologic Setting

The Elkhorn Wilderness Study Area is underlain mostly by Elkhorn Mountains Volcanics and related intrusive rocks of Late Cretaceous age and by the Boulder batholith and satellitic stocks of Late Cretaceous age. A smaller part of the study area is underlain by strata of Paleozoic to Mesozoic age. Middle Proterozoic sedimentary rocks of the Belt Supergroup crop out extensively in the Elkhorn Mountains and presumably lie beneath the Paleozoic strata in parts of the study area. Mineral deposits occur in quartz veins, as replacement deposits, in breccia pipes, as disseminated deposits and stockworks in plutonic rocks, in skarns along intrusive contacts, and along faults that were active during Cretaceous plutonism. All these rocks were intruded by igneous dikes and stocks and locally are overlain by related volcanic rocks of middle Tertiary and late Tertiary age.

The mountain range containing the study area is a tectonically uplifted block, bounded on the east and north and probably south and west by major faults. This uplifted block has been eroded to its present form by glaciers and by running water.

The study area is located at the northeast apex of a trapezoidal structural block bounded on the north by the northwest-trending Proterozoic to Holocene Lewis and Clark lineament, on the east by north-trending Cretaceous thrust faults of the Townsend Valley and Paleocene thrust faults of the Montana disturbed belt, and on the south by the east-trending Precambrian and Cretaceous to Paleocene Willow Creek lineament. The western boundary of this block is not well defined but may be marked by north-trending Cretaceous thrust faults in the Deer Lodge valley west of the batholith. Cretaceous volcanics were deposited throughout this block; the Boulder batholith and related satellitic plutons underlying most of it comprise the east-most major Cretaceous batholithic unit of the Cordillera. The sedimentary and igneous history of the study area and the mineral deposits contained in it have been influenced or determined by the structural evolution of this block.

Sedimentary Rocks

Sedimentary rocks about 12,000 ft (4,000 m) thick and ranging in age from Middle Proterozoic to Cretaceous are exposed in or near the study area. These strata are overlain by a thick pile of Upper Cretaceous volcanic rocks. The Cretaceous and older rocks were strongly folded and faulted prior to and during the intrusion of the Boulder batholith and related Upper Cretaceous intrusive rocks.

The sedimentary rocks and volcanic units in the study area have been fully described by Klepper and others (1957); Klepper, Ruppel, and others (1971); Smedes (1966); and Becraft and others (1963); accordingly, they are summarized here and in the explanation of plate 1. Only the details that are significant to resource assessment are discussed in this review.

Middle Proterozoic Rocks

Hornstone mapped as Belt Supergroup (Middle Proterozoic age), or specifically as Spokane(?) Shale, is exposed in the faulted core of an anticline in the Elkhorn mining district, adjacent to the southwest border of the study area (Klepper and others, 1957). The hornstone could be the Empire Formation which overlies the Spokane. The hornstone does not appear to be favorable for the occurrence of mineral deposits; only a few mines have been developed in the Belt rocks of this district.

Paleozoic Rocks

Paleozoic rocks in the study area comprise carbonate rocks and shale and include subordinate amounts of quartzite, phosphatic quartzite, and chert. These rocks have been mapped in 14 formations (pl. 1) having a combined thickness of about 5,000 ft (1,600 m). They crop out in the cores of two anticlines at the south edge of the study area and in upfolded rocks several miles east and north of the study area.

Most of the mines of the Elkhorn mining district (Klepper and others, 1957) and some lead-zinc deposits in the Quartzite Ridge area southeast of the study area (Klepper, Ruppel, and others, 1971) have been developed in Paleozoic rocks. Many of these metal deposits formed as replacements of carbonate rocks near contacts with overlying relatively impermeable shale. Such carbonate-shale contacts are attractive exploration targets and are shown in the southwestern and southeastern parts of the study area as well as just east of the study area (pl. 1). The phosphatic quartzite and chert of the Phosphoria Formation (Permian) locally contain one or two thin beds of phosphate rock as much as 30 in. (0.8 m) thick. Some phosphate rocks of the Phosphoria Formation of the region have anomalous uranium contents (Maughan, 1976), and such rocks are a possible exploration target.

Mesozoic Rocks

The Mesozoic sedimentary rocks in the study area (pl. 1) consist predominantly of sandstone and shale with subordinate limestone, tuff, and tuffaceous sandstone. They have a combined thickness from about 2,000 ft (610 m) to as much as 3,840 ft (1,170 m). Marine and nonmarine sandstone and shale, partly calcareous or with limestone interbeds of the Swift, Morrison, and Kootenai Formations, are overlain by marine dark shale and sandstone of the Colorado Formation. North of Johnny Gulch in the southeastern part of the study area, these rocks grade upward through tuffaceous sandstone into tuff of the Slim Sam Formation that is conformably overlain by the Elkhorn Mountains Volcanics. South of Johnny Gulch, outside the study area, the Elkhorn Mountains Volcanics rest with angular unconformity on sandstone and shale of the Kootenai (Klepper, Ruppel, and others, 1971).

The Mesozoic sedimentary rocks contain several carbonaceous units, and the upper part of the Slim Sam Formation contains carbonized and silicified wood in many places. Carbonaceous sedimentary rocks such as these commonly contain high concentrations of metals. Several mines and prospects in the southeastern part of the study area have been developed in or near those carbonaceous units, especially where they are cut by intrusive rocks. Leaching of the carbonaceous rocks by magmatic fluids may have released metals that were then concentrated in some of the ore deposits of the study area. The carbonaceous units are also of economic interest as possible sites of concentrations of uranium leached from the interbedded and overlying tuffs.

The Mesozoic sedimentary rocks also contain lenticular beds of titaniferous magnetite that appear to be lithified beach placers. Near Radersburg, about 6 mi (10 km) southeast of the study area, such beds have been mined for use in cement.

Cenozoic Rocks

Cenozoic sedimentary rocks in and adjacent to the study area include thick Tertiary fluvial and lacustrine basin-fill deposits and generally thin, unconsolidated Tertiary and Quaternary deposits.

Tertiary fluvial and lacustrine deposits in the Townsend Valley east of the study area contain tuff interbeds (Klepper, Ruppel, and others, 1971). Tuff interbeds in similar deposits in western Utah contain beryllium, lithium, and uranium; a few mines have produced beryllium and uranium from those deposits (Lindsey, 1977).

Unconsolidated deposits of Tertiary and Quaternary age in the study area are grouped on plate 1 according to the means and amount of transportation from their source. Surficial deposits originally mapped as fan deposits, mantle, hillwash pediment gravel, and mass-waste deposits (such as landslides) are combined on plate 1 into one map unit, regardless of age. These deposits generally are coarse grained, were derived by mechanical erosion, and most have been transported only short distances. Glacial deposits are combined in one unit, and alluvial deposits of several ages are combined in one unit.

Igneous Rocks

Igneous rocks of the study area include Cretaceous volcanic and hypabyssal rocks, predominantly of trachyandesitic to rhyodacitic composition; the Cretaceous Boulder batholith and related dikes, plugs, and stocks, predominantly of quartz monzonitic composition; quartz latite stocks and dikes of Tertiary, probably Eocene, age; rhyolite domes and tuff and basalt flows of Tertiary, probably late, age.

Cretaceous volcanic and intrusive igneous rocks underlie most of the study area. Cretaceous volcanic and volcaniclastic rocks mapped as the Elkhorn Mountains Volcanics predominate in the east half of the study area and the Boulder batholith underlies the west half. The Elkhorn Mountains Volcanics are intruded by many sills and dikes of porphyritic igneous rock similar in composition and apparently related to the volcanics. These sills and dikes were intruded during and shortly following deposition of the volcanic rocks. The volcanic rocks and associated porphyritic intrusions are intruded by the Boulder batholith and by smaller, generally discordant plutonic bodies that are satellitic to the batholith. Eocene quartz latite dikes and related stocks were emplaced in the study area following uplift and erosion of the Elkhorn Mountains Volcanics and Boulder batholith. Late Tertiary rhyolite flows, volcanic sandstone, and tuff, and associated intrusive rhyolite domes and intrusive breccias and basalt flows occur on and near the west and east edges of the study area.

The nomenclature used in this report for igneous rocks follows that of Klepper, Ruppel, and others (1971).

Cretaceous Elkhorn Mountains Volcanics

The Elkhorn Mountains Volcanics of Late Cretaceous age are divided into a lower heterogeneous volcanic member, a middle welded-tuff member, and an upper volcaniclastic member (Klepper and others, 1957). The lower member ranges in thickness from 2,500 to 5,000 ft (760–1,520 m) and consists predominantly of complexly interbedded rhyodacitic and trachyandesitic tuff, tuff breccia, and breccia, with subordinate flows and thin welded-tuff units. Most of the finer grained tuff in the lower member is finely laminated and was deposited in shallow water with minor reworking (Klepper, Ruppel, and others, 1971). The middle member is as much as 7,500 ft (2,290 m) thick and consists of rhyolitic welded tuff interlayered with crystal and lithic tuff and with some less abundant volcanic breccia (Smedes, 1966, p. 26). The upper member is about 2,000 ft (610 m) thick in its thickest preserved section near High Peak in the northern part of the study area (Smedes, 1966, p. 26). This member consists of water-laid epiclastic mudstone to conglomerate, bedded tuff, and a few thin beds of volcanic breccia.

Cretaceous Intrusive Rocks Related to Elkhorn Mountains Volcanics

Several large laccolithic, lopolithic, and irregular bodies, consisting mainly of syenodiorite porphyry and granodiorite porphyry and many dikes, sills, plugs, and irregular bodies of trachyandesite porphyry and rhyodacite porphyry cut the Elkhorn Mountains Volcanics and older rocks. These intrusive rocks are compositionally similar to the volcanics and probably are products of the same magma or magmas (Klepper, Ruppel, and others, 1971, p. 20). Some of the larger intrusive bodies appear to have been emplaced as a series of sill-like sheets that coalesced to form laccolithic bodies, and locally the magma of these bodies breached the surface forming laharic or mud-flow deposits (Klepper, Ruppel, and others, 1971, p. 23). These larger intrusive bodies are concentrated along the axial zones of a major syncline in the center of the study area and along a major anticline in the eastern part of the study area, and they may have been emplaced during the early stages of folding (Smedes, 1966, p. 61; Klepper, Ruppel, and others, 1971, p. 33).

Cretaceous Boulder Batholith and Related Intrusive Rocks

The Upper Cretaceous rocks of the Boulder batholith are divided into Butte Quartz Monzonite; leucogranodiorite; and alaskite, aplite, and related rocks (pl. 1). The rocks of plutons satellitic to and apparently the same age as the Boulder batholith have been mapped as mafic rocks, granodiorite and related rocks, and quartz monzonite and granite.

Butte Quartz Monzonite makes up most of the Boulder batholith in the study area and consists of granodiorite and quartz monzonite of many textural varieties. These textural varieties previously were mapped separately, but they have gradational boundaries (Smedes, 1966), are chemically similar, and apparently are the same age (Tilling, 1973).

Leucogranodiorite is mapped near Jackson Creek at the northwest margin of the study area. This small, late intrusive body contains abundant disseminated pyrite and chalcopyrite.

Aplite, alaskite, and related rocks are concentrated in a northeast-trending zone that also contains most of the major metalliferous veins in the northwestern part of the study area.

Plutons satellitic to the Boulder batholith intrude the volcanic and sedimentary rocks in a north-trending zone that generally follows the axial zone of a major syncline east of the batholith. The satellitic mafic rocks range from gabbro to dark granodiorite and calcic syenite. The satellitic granodiorite and related rocks range from granodiorite to granite.

Eocene Quartz Latite Porphyry

Dikes and stocks of quartz latite porphyry cut into rocks of the Boulder batholith and older rocks in the northern part of the study area. The quartz latite intrusions are at the northeastern end of a swarm that extends southwest 12.5 mi (20 km) to the quartz latitic Lowland Creek Volcanics (Smedes, 1962). These volcanics and the associated dike swarm have been dated as early Eocene (Smedes and Thomas, 1965).

Tertiary Felsic Flows, Tuffs, and Intrusive Bodies

Scattered outcrops of a flow-laminated felsitic rock occur along Crow Creek. The chemical analysis and norm of the rock (Klepper, Ruppel, and others, 1971, p. 30), and spectroscopic analyses (Motooka and others, 1978; samples 77BG049G through 77BG054G), indicate it to be a quartz latite or rhyodacite. The rock is gray to black, and generally is dense to sparsely vesicular, but locally it is scoriaceous or lithophysal. It contains sparse phenocrysts of labradorite, pyroxene, and an opaque mineral, probably magnetite. The outcrops are remnants of flows (Klepper and others, 1957; Klepper, Ruppel, and others, 1971) and may, in part, be welded tuff that underwent secondary flowage.

Rhyolite with a K-Ar age of 36 m.y. (Chadwick, 1977) occurs just outside the northwestern boundary of the study area as funnel-shaped plugs, dikes, tuff, breccia, volcanic sandstone, and conspicuously laminated lava flows. This rhyolite has high contents of tin (10–15 ppm), niobium (30–100 ppm), and fluorine (0.2–0.5 percent). Phenocrysts of quartz, K-feldspar, and sodic plagioclase are present but sparse. Topaz is commonly found in miarolitic cavities.

At Lava Mountain, silver-bearing galena, sphalerite, fluorite, and quartz occur in braided veinlets cementing brecciated rhyolite, as fillings in lithophysal cavities, and as local small replacement masses (Smedes, 1966, p. 107–108). The extrusive rhyolite of this unit appears to occur as blocks that have partly foundered into the intrusive rhyolite during emplacement of the stocks (Smedes, 1966, p. 94).

Tertiary Basalt Flows

A few remnants of basalt flows crop out along and near Crow Creek from Sagebrush Gulch eastward in the southeastern corner of the study area. The basalt flows locally rest on sedimentary tuff considered to be of Oligocene age by Klepper, Ruppel, and others (1971, p. 29–30). The basalt probably is late Miocene or Pliocene in age but could be as old as Oligocene (Klepper, Ruppel, and others, 1971, p. 30).

Structural Geology

The rocks east of the Boulder batholith in the study area are deformed by many folds and faults of Cretaceous and Tertiary age. These structural features strongly influenced the location of mineral deposits.

The structural features are divided here into four groups listed by decreasing age: prevolcanic, synvolcanic, synbatholithic, and postbatholithic. Evidence for prevolcanic and synvolcanic structural features commonly is faint, because of later intrusion and deformation; however, these older structural features are important because they appear to have largely determined the trends and location of younger structures and related mineralization.

Prevolcanic Structural Features

Prevolcanic folding or faulting is indicated by facies changes and erosional thinning across syndepositional anticlines (sec. 19, T. 9 N., R. 1 W.) in the Upper Cretaceous Slim Sam Formation about 3 mi (5 km) northeast of the batholith contact in the north edge of the study area (Smedes, 1966, p. 96). These folds plunge 20–30° SSW., have a wavelength of 0.3 mi (0.5 km), an amplitude of about 29.5 ft (9 m), and are asymmetric, being slightly overturned to the east. Erosional thinning of this formation is also shown south of Johnny Creek on the east side of the study area (Klepper, Ruppel, and others, 1971). To the southwest, the Slim Sam was completely eroded before deposition of the Elkhorn Mountains Volcanics near the town of Elkhorn (Klepper and others, 1957). These data suggest that prevolcanic structural adjustments that induced erosion of the Slim Sam Formation were most intense near the present batholith contact and that uplift was most pronounced in the southwestern part of the study area. This suggests that prevolcanic inflation of the present batholith area produced Slim Sam age erosion in the west-central part of the study area. Preliminary interpretations of stratigraphic and structural data in the Boulder batholith region (Greenwood and others, 1979) support this interpretation and indicate that uplift of as much as 3,200 ft (1,000 m) was widespread in the batholith area. Most of this uplift occurred after deposition of the Cretaceous Colorado Formation and prior to the deposition of the Elkhorn Mountains Volcanics. The syndepositional folds described in the Slim Sam Formation suggest that inflation was accompanied by east-west compression. These folds appear to be the result of regional thrusting which continued into early volcanic time as described in the following section.

Synvolcanic Structural Features

Synvolcanic structural features include the following: early inflation of the batholith area accompanied by east-directed, north- to northeast-trending thrusting and related high-angle reverse faulting in the study area; eruption of a volcano and formation of one or possibly two volcanic caldrons, apparently in a northeast-trending fault zone that was subsequently intruded by the batholith; and depression of the study area and most of the batholith area concomitant with volcanism.

Broad north- to northeast-trending structures in gently dipping, sedimentary rocks near the batholith contact in the west-central part of the study area pass into open-folded, moderately dipping, sedimentary rocks in the eastern part of the study area (pl. 1). To the east of the study area near the west side of the Townsend Valley, the folds are tight and cut by reverse faults in steeply dipping sedimentary rocks. The intensity of deformation increases away from the batholith contact, the regional folding and faulting, and thus is not directly related to batholith emplacement. The synvolcanic structural features appear to be the result of east-directed regional thrusting, the lead edge of which is partly exposed at the edge of the Townsend Valley and partly covered by valley-fill deposits.

Reverse faulting mapped by Klepper, Ruppel, and others (1971) near the edge of the Townsend Valley about 2 mi (3 km) east of the study area (pl. 1) displaces the lower and middle members of the Elkhorn Mountains Volcanics against older rocks. As much as 0.6 mi (1 km) stratigraphic offset was measured by Klepper, Ruppel, and others (1971, p. 31) along the Whitehead Ranch fault (secs. 4 to 27, T. 8 N., R. 1 W.) in this zone. They note that volcanic-related dikes both are cut by and intrude the Whitehead Ranch fault, which establishes the synvolcanic age of this fault zone. Reverse faults in this zone, named here the Indian Creek fault zone, parallel north-trending, locally tight folds with wavelengths of 1.8–3 mi (3–5 km) and amplitudes of over 0.6 mi (1 km) (Klepper, Ruppel, and others, 1971, p. 1). East-, northwest-, and northeast-trending faults were offset and are intruded by volcanic-related dikes, and thus were developed at the same time as the north-trending reverse faults and folds. The northwest- and northeast-trending faults show lateral offsets of as much as 2,300 ft (700 m) and appear to be complementary shears related to east-west compression (Klepper, Ruppel, and others, 1971, p. 32). These writers also indicate that the northeast-trending faults served as tear faults during thrust movement and they relate to the Lombard thrust, an east-directed, post-batholith thrust, the lead edge of which is located to the east of the Townsend Valley (Freeman and others, 1958, p. 525–526). A tear fault of similar trend was mapped by Smedes (1966, pl. 1) near the Helena Valley north of the study area (secs. 13, 14, T. 9 N., R. 2 W.). Smedes related this tear to a near-bedding plane thrust fault he mapped in sec. 14, T. 9 N., R. 2 W., north of the study area. The thrust and tear faults mapped by Smedes (1966) have the same symmetry as the reverse and tear faults of Klepper, Ruppel, and others (1971). Movement in these fault zones may have been recurrent with both synvolcanic Cretaceous thrusting and postvolcanic Paleocene thrusting.

We propose a synvolcanic origin for the fault zone mapped by Smedes (1966) between Mitchell Gulch and Corral Creek (sec. 22, T. 9 N., R. 2 W.) and named here the Mitchell Gulch fault zone. This structural feature was interpreted by Smedes (1966, p. 9) as a step fault with over 0.6 mi (1 km) up-to-the-west aggregate stratigraphic offset. He notes, however, that large south-plunging drag folds mapped in this zone indicate strong compression during faulting. Smedes (1966, p. 98) relates this fault zone to batholith emplacement. Although the location of these faults does suggest that they influenced the location of the eastern contact of the batholith, other evidence indicates an earlier origin for the zone. Because these faults offset the lower member of the Elkhorn Mountains Volcanics, are intruded by and do not offset rocks of the Boulder batholith, they are considered to be synvolcanic to early batholithic in age. Evidence for important synvolcanic up-to-the-west faulting in this zone is provided by the following: (1) boulders of Paleozoic limestone found during this study in conglomerate near the base of the lower member of the Elkhorn Mountains Volcanics on the ridge east of Corral Creek (sec. 23, T. 9 N., R. 2 W.), which indicate nearby exposed Paleozoic rocks during deposition; and (2) similar boulders and large blocks of Paleozoic limestone associated with thick (as much as 98 ft (30 m)) lenticular resedimented carbonate interbeds within lava flows at the base of the lower member of the volcanics on Elkhorn Peak (sec. 1, T. 6 N., R. 3 W.). These resedimented carbonate beds and blocks probably were deposited in water ponded against a fault scarp that exposed Paleozoic limestone to erosion and mass wasting. We suggest that this scarp was produced by up-to-the-west reverse faulting on an extension of the Mitchell Gulch fault zone. These stratigraphic data suggest an early synvolcanic age for the first major movement on this zone of reverse faulting. We suggest that this movement was related to regional thrusting. Aligned along the proposed trace of this zone are a partly preserved volcano at Radersburg Pass just south of the study area; a probable ash-flow caldron extending south from a ring fault and dike at the Chicago mine (sec. 26, T. 9 N., R. 2 W.), just north of the study area, to south of Crazy Peak (sec. 35, T. 8 N., R. 2 W.) in the center of the study area; and a possible ash-flow caldron extending south from Tizer Basin (sec. 28, T. 7 N, R. 2 W.) to near Crow Peak (sec. 7, T. 6 N., R. 2 W.) at the southern margin of the study area. These volcanic and structural features range in age from lower member to middle member and suggest a continued influence of the Mitchell Gulch fault zone during volcanism. Late volcanic influence of this zone is suggested by resurgence and emplacement of laccoliths during deposition of the predominantly volcaniclastic upper member in these proposed caldrons. Peperitic laccoliths contacts in the High Peak area (sec. 34, T. 8 N., R. 2 W.) indicate that the laccoliths intruded into unconsolidated wet upper member sediments during or shortly following deposition. Similar and probably coeval laccoliths were emplaced along the axis of the syncline west of the leading edge of the proposed thrust at Townsend Valley.

The largest synvolcanic structural feature is the major depression of the batholith area shown on the geologic map of Montana (Ross and others, 1955) and other small-scale geologic compilations of the area. These maps show predominantly Cretaceous layered rocks at and near the batholith contact and progressively older rocks in all directions away from the contact as observed by Hamilton and Myers (1967) and other workers. This depression appears to have begun to form after the early volcanic inflation of the batholith area described above and continued during batholith emplacement. The synvolcanic Upper Cretaceous Golden Spike Formation (Gwinn and Mutch, 1965) in the Garrison area about 25 mi (40 km) west of the batholith consists of north- and northwestward-derived prevolcanic rocks and subordinate volcanic rocks similar to the lower member of the Elkhorn Mountains Volcanics. Rocks comparable to the middle member are absent near Garrison as if a topographic barrier prevented westward flowage of these welded tuffs. This indicates that major depression of the batholith area began after inflation and by middle member time generally kept pace with volcanic deposition. At least 14,500 ft (4,400 m) of volcanic and volcaniclastic rocks were deposited in this depression.

Synbatholith structural features in the study area include the following: major down-to-the-west normal faulting that controlled the eastern contact of the batholith by the Mitchell Gulch fault zone; localization of most satellite plutons in a syncline west of the Indian Creek fault zone; formation of faults and shear zones at the near intrusive contacts, mostly by reactivation of faults or weakness directions of volcanic age. Synbatholithic faults associated with intrusives were the main controls for mineralization in the eastern part of the study area. The batholith intrudes and is not cut by reverse faults of the Mitchell Gulch fault zone and therefore is entirely post thrusting. Rocks of the batholith intrude and are cut by normal faults in several places. Apparently extension and subsidence and not compression predominated during batholith emplacement. Late during batholith crystallization, a major northeast-trending weakness zone formed into which many alaskite-aplite, leucogranodioite, and metalliferous quartz veins were emplaced in the western part of the study area. Right-lateral and dip-slip offsets are shown on northeast-trending faults in this zone; east-trending faults in this zone show left-lateral and dip-slip offsets; and the few northwest-trending faults show right-lateral and dip-slip offsets (Smedes, 1966; Becraft and others, 1963). In the general vicinity of Jefferson City (sec. 6, T. 7 N., R. 3 W.), the northeast-trending zone and its constituent fractures, faults, veins, and igneous bodies turn east and pass generally north of the study area. Most of these structures and bodies are confined to the batholith itself.

Postbatholithic Structural Features

The northeast-trending weakness zone in the batholith also was site of Eocene volcanism and related plutonism (Smedes, 1966, pl. 1; Becraft and others, 1963). Oligocene volcanism and plutonism occurred in but appear to cut across this weakness zone.

Range-front faults of late Tertiary to Holocene age are exposed along the northeast front of the Elkhorn Mountains (Klepper, Ruppel, and others, 1971, p. 32). The major faults of this system mostly are covered by fan gravel, but they probably bound the range on the north (Smedes, 1966), east (Klepper, Ruppel, and others, 1971), and southwest (Klepper and others, 1957). These faults are part of a broad system of basin and range faults that produced the north- and northwest-trending valleys south of the Lewis and Clark line, which extends through the Helena Valley (Reynolds, 1977) to the north. Extensional faulting that produced these valleys, which are filled with Cenozoic sediments, is apparently related to major right-lateral faulting in the northwest-trending Lewis and Clark line.

Geophysical Exploration

By William F. Hanna

Introduction

Geophysical assessment of mineral resource potential in the Elkhorn Wilderness Study Area has been confined almost exclusively to an interpretation of recently acquired aeromagnetic anomaly data. Older reconnaissance gravity anomaly data were also examined, especially in light of recently measured rock densities, but were found to lack sufficient resolution to be of significant value in the overall assessment (Greenwood and others, 1978). Aeromagnetic data were obtained in two surveys: a regional survey flown by the U.S. Geological Survey in 1953 and 1955, reported in Johnson and others (1965) and generalized in figure 3, and a detailed survey flown for the U.S. Geological Survey in April 1977, shown on plate 2. The trapezoid-shaped area (pl. 2) is bisected by part of the contact between two vast terranes of Upper Cretaceous igneous rock: the Boulder batholith and the Elkhorn Mountains Volcanics (fig. 4). The regional aeromagnetic data generalized in figure 3 had indicated a close association of high-amplitude highs with the Elkhorn Mountains Volcanics and plutons intrusive into the volcanics, most prominently expressed near the contact between the volcanics and the Boulder batholith. The regional survey also showed that weaker highs and lows are associated with much of the Boulder batholith, the lows in places delineating regions of pronounced mineralization and ore deposition (Hanna, 1969). The detailed survey made for this study (pl. 2) not only confirms the existence of these regional patterns but also discloses a number of low- and high-amplitude anomalies unseen in the original survey, permitting much improved correlations of individual anomalies with specific lithologic units. The purpose of the present investigation is to establish such correlations between the anomalies and their source rocks to help assess the mineral resource potential of the study area.

Rock Magnetic Data

An important aim of aeromagnetic anomaly interpretation is identification of the kinds of rocks responsible for causing the anomalies. Interpretation of anomaly source rocks is greatly aided where direct correlations of magnetic rock occurrences and measured anomalies are observed. For example, if there is a pronounced positive correlation of magnetic rock outcrops with anomalies, these rocks, or others allied in composition to them, may be inferred to extend into the subsurface, serving as the overall anomaly source. By measuring the magnetization of these exposed rocks, the subsurface volume and distribution required to produce the observed anomalies can be estimated. In the present study, total magnetizations of 51 outcrop samples were measured, the remanent component using a spinner magnetometer and the induced component using a magnetic susceptibility bridge.

The measured remanent and induced magnetizations of the 51 samples, all of which were plutonic or volcanic rocks (table 1; pl. 2), range over five orders of magnitude, consistent with data from nearby collecting sites in Elkhorn Mountains Volcanics, Boulder batholith, and Lowland Creek Volcanics (Hanna, 1965, 1967, 1969, 1973a, b, and 1977b). Of special interest are the magnitudes of remanent and induced magnetization, listed in table 1 under columns denoted "REM J" and "IND J," respectively. In the study area, rocks having magnitudes of either remanent or induced magnetization exceeding 100×10^{-5} emu/cm^3 are capable of generating high-amplitude anomalies, depending upon their distribution in the subsurface, and are thus candidates for active sources of anomalies. Table 1 shows that 13 samples have both remanent and induced magnetizations exceeding this value, 3 samples have remanent magnetizations alone exceeding the value, and 10 samples have induced magnetizations alone exeeding the value. Of the remainder, 22 samples have magnetizations sufficiently weak to be considered nonmagnetic, most having been altered, silicified, or otherwise mineralized, and are thus candidates for passive sources of negative anomalies where surrounded by normally polarized rocks. The directions of remanent magnetization, denoted by values under columns "REM D" and "REM I" for the 14 oriented samples collected, indicate normal, reversed, and perhaps anomalous paleofield directions. Interpretations of the paleomagnetic significance of these data are limited by uncertainties about the possible overprint of secondary magnetization components acquired after the period of volcanism and plutonism and the structural history of tilting of layered volcanic rocks possessing stable remanent magnetization.

Principal Features of Anomaly Map

In the following discussion, unnecessary usage of numerical values of magnetizations will be avoided by using the terms "strong" magnetizations for those from 100 to $1{,}000 \times 10^{-5}$ emu/cm^3 and "very strong" magnetizations for those exceeding $1{,}000 \times 10^{-5}$ emu/cm^3.

The aeromagnetic anomaly map (pl. 2) has two principal features: steep magnetic gradients that largely coincide with the outcrop of the broadly folded, thick pile of Elkhorn Mountains Volcanics, which in the study area is intruded by a number of small plutons, and gentle magnetic gradients of the magnetic plateau associated with most of the Boulder batholith. Gradients are steep near the volcanic rock pile because total magnetizations of the volcanic and associated intrusive (unit Ki, pl. 1) rocks are generally strong to very strong and also because much of the volcanic rock terrane occurs at high topographic elevations, not far below the flight elevation at which magnetic field measurements were obtained. The effect of topography is in many places further enhanced by strong isothermal remanent magnetizations introduced by lightning discharges which are more numerous on high ground than on low. Gradients are gentle over most of the Boulder batholith terrane because total magnetizations are generally weak to moderately strong and because lateral contrasts of rock types and corresponding magnetizations are relatively small, the batholith proper having a remarkably uniform composition.

A notable exception consists of the steep magnetic gradients which extend westward across the Boulder batholith–Elkhorn Mountains Volcanics contact in the southwestern part of the map area. These gradients appear to coincide with an increase in the Bouger gravity anomaly field (Greenwood and others, 1978) signifying relatively dense, highly magnetic rocks in the shallow subsurface of this part of the Boulder batholith. Such rocks might belong to a westward-dipping tract of Elkhorn Mountains Volcanics or to highly mafic plutonic rocks of the Boulder batholith intruded during an early phase of plutonism.

Interpretation of Anomalies

Many individual anomalies within the study area are clearly associated with mapped lithologic units; others are only vaguely, if at all, related to exposed rocks. Because the number of magnetic features of possible economic interest is so large, they are labeled on plate 2.

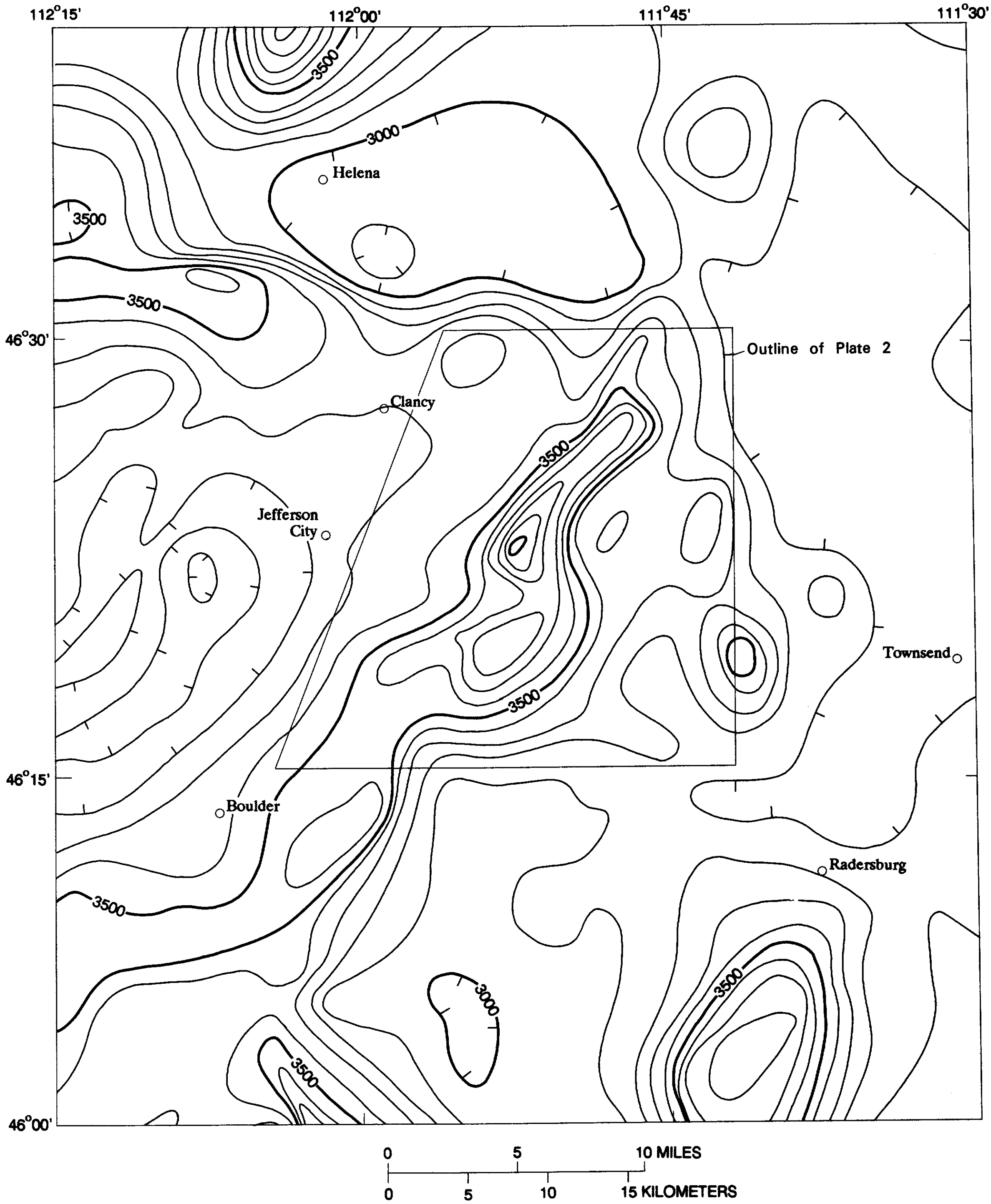


Figure 3. Aeromagnetic map of the Elkhorn Wilderness Study Area and vicinity, Montana (modified from Johnson and others, 1965). Contours show total intensity magnetic field of the Earth in gammas relative to an arbitrary datum. Hachured to indicate closed areas of lower magnetic intensity; dashed where data are incomplete. Specifications of regional survey: flight spacing, 2 miles (3.2 km); flight elevation, 10,500 feet (3,200 m) above sea level; compilation scale, 1:250,000; contour interval, 100 gammas. Flown by U.S. Geological Survey, 1953 and 1955. Trapezoid-shaped outline shows area of detailed aeromagnetic survey discussed in text and shown on plate 2.

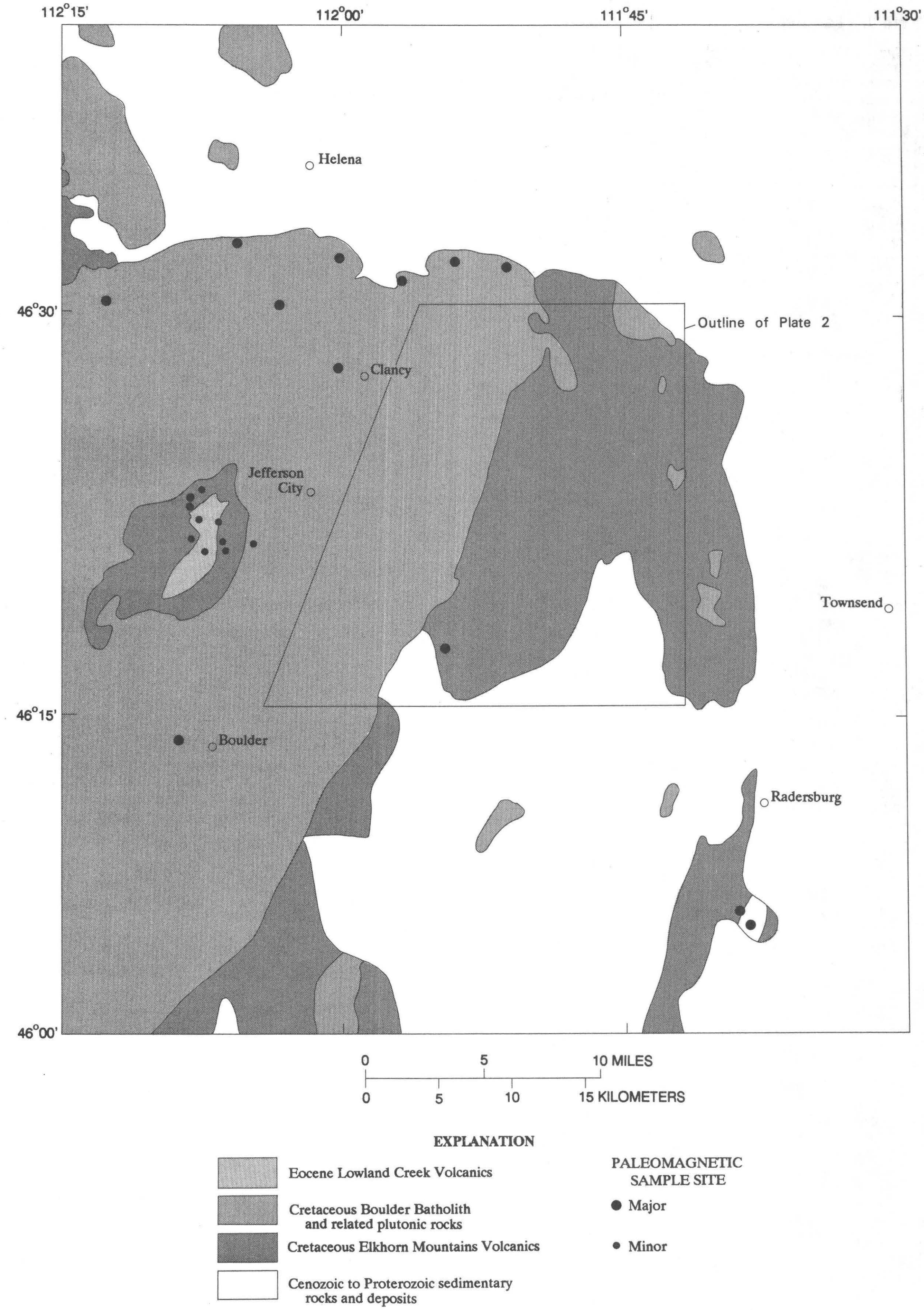


Figure 4. Generalized geologic map of the Elkhorn Wilderness Study Area and vicinity, Montana. Major terranes of igneous rocks highlighted (modified from Smedes and others, 1968).

Table 1. Magnetization and density data for selected rocks from the Elkhorn Wilderness Study Area and vicinity, Montana

[Sample localities shown on plate 2. Leaders (---), no data. Field no. indicates sample designation. Abbreviations: REM D, declination of remanent magnetization, degrees east of north; REM I, inclination of remanent magnetization, degrees below horizontal, REM J, magnitude of remanent magnetization, x 10^{-5} emu/cm^3; K, intrinsic magnetic susceptibility based on sample-shape demagnetization factor of $4\pi/3$, 10^{-5} emu/cm^3; IND J, magnitude of induced magnetization, x 10^{-5} emu/cm^3; Q, Koenigsberger ratio of magnitudes of remanent magnetization to induced magnetization; ρ, dry bulk density, g/cm^3; J–type of likely anomaly source, type of magnetization which is sufficiently strong (at least 10^{-3} emu/cm^3) to serve as a source for high-amplitude anomalies: R—remanent magnetizations, I—induced magnetization, C—combined remanent and induced magnetization, if similar in direction and sense, NON—relatively nonmagnetic; asterisks denote very strong magnetizations (greater than 10^{-2} emu/cm^3)]

Sample locality No.	Field No.	REM D	REM 1	REM 3	K	IND 3	Q	ρ	Rock type	J-type of likely anomaly source
1	77LA081	---	---	794	28.9	16.7	47.5	2.35	Flow-banded rhyolite, Strawberry Butte.	R
2	GE049P	---	---	147	256	148	0.993	2.65	Biotite quartz monozonite.	R, I
3	GE036P	---	---	3.01	38.1	22.0	0.137	2.54	Weathered quartz monzonite; limonite boxworks.	NON
4	GE035P	---	---	15.2	66.5	38.4	0.396	2.56	Granite dike.	NON
5	GE033P	---	---	79.6	242	140	0.568	2.61	Biotite quartz monzonite.	I
6	GE042P	---	---	15.2	25.1	14.5	1.05	2.36	Weathered porphyritic quartz monzonite.	NON
7	GE039P	---	---	0.415	1.90	1.90	0.381	2.51	Weathered biotite quartz monzonite.	NON
8	GE045P	---	---	34.8	207	119	0.292	2.61	Biotite quartz monzonite.	I
9	GE046P	---	---	16.6	280	162	0.102	2.66	Porphyritic biotite granodiorite.	I
10	77LA079	---	---	5.01	287	166	0.00302	2.64	Altered porphyritic granodiorite.	I
11	BG126	275.5	21.0	259	271	156	1.66	2.66	Biotite granodiorite.	R, I
12	BG130	347.4	10.7	153	256	148	1.03	2.61	Biotite granodiorite.	R, I
13	77LA073	---	---	19.6	280	162	0.121	2.66	Altered granodiorite.	I
14	77LA077	---	---	27.3	176	102	0.268	2.61	Altered porphyritic quartz monzonite.	I
15	BG274	---	---	68.0	89.8	51.8	1.31	2.77	Andesitic sandstone, Elkhorn Peak.	C
16	BG097	---	---	1600	559	322	4.97	2.76	Breccia.	R*, I
17	GE013P	---	---	13.3	58.7	33.9	0.392	2.68	Altered pyrite-rich aplite.	NON
18	GE010P	---	---	0.377	1.30	0.750	0.503	2.50	Altered tourmaline-rich plutonic rock.	NON
19	GE011P	---	---	0.199	1.80	1.04	0.191	2.49	Altered aplite.	NON
20	GE012P	---	---	0.459	7.50	4.33	0.106	2.64	Altered plutonic rock.	NON
21	GE009P	---	---	451	269	155	291	273	Diorite.	R, I
22	GE033P	---	---	44.0	292	168	0.262	2.69	Biotite quartz diorite.	I
23	GE032P	---	---	15.0	72.7	41.9	0.358	2.84	Hornblende-rich basalt.	NON
24	GE024P	---	---	20.1	23.9	13.8	1.46	2.62	Weathered porphyritic volcanic intrusive (?) rock.	NON
25	BG155	---	---	81.3	325	188	0.432	2.69	Quartz-dioritic granodiorite.	I
26	GE031P	---	---	57.4	319	184	0.312	2.78	Lithic fragmented tuff.	I
27	GE029P	---	---	10.1	49.7	28.7	0.352	2.63	Altered sandy volcaniclastic rock.	NON
23	GE025P	---	---	2.10	7.50	4.33	0.458	2.68	Pyrite-rich welded tuff; Ballard mines.	NON
29	GE027P	---	---	4.66	6.10	3.52	1.32	2.67	Altered silicified pyrite-rich welded tuff.	NON
30	GE018P	---	---	0.369	5.50	3.17	0.116	2.75	Silicified pyrite-rich andesite.	NON
31	GE017P	---	---	0.0689	2.90	1.67	0.0412	2.67	Silicified pyrite-rich volcanic(?) rock.	NON
32	GE016P	---	---	0.320	0.900	0.519	0.616	2.38	Altered pyrite-rich andesite; Cataloma mine.	NON
33	GE005P	---	---	0.298	1.80	1.04	0.286	2.72	Argillitic.	NON
34	GE003P	---	---	0.180	6.40	3.69	0.0488	2.73	Andesitic dike.	NON
35	GE001P	---	---	27.4	4.20	2.42	11.3	2.77	Andesite.	NON
36	GE002P	---	---	89.2	154	88.8	1.00	2.71	Porphyritic-lithic fragmental volcanic (andesite).	C
37	77LA073	346.2	–23.8	0.318	7.09	4.09	0.0778	2.92	Gabbro.	NON
38	77LA075	18.5	49.6	37.4	324	187	0.200	2.68	Porphyritic quartz monzonite.	NON
39	77LA070	302.3	–40.4	0.233	4.06	2.34	9.96	2.84	Hornfels.	NON
40	BG112	91.1	27.4	490	478	276	1.78	2.72	Slim Sam stock; granodiorite.	R, I

Table 1. Magnetization and density data for selected rocks from the Elkhorn Wilderness Study Area and vicinity, Montana—Continued

Sample locality No.	Field No.	REM D	REM 1	REM 3	K	IND 3	Q	ρ	Rock type	J-type of likely anomaly source
41	BG113	332.1	72.0	49.9	35.8	20.6	2.42	2.70	South Fork stock; granodiorite.	NON
42	77LA069	109.2	-47.3	174	24.0	13.8	12.6	2.77	Diabasic flow.	R
43	BG123	---	---	874	425	245	3.57	2.83	Porphyritic andesitic flow or crystal tuff.	R, I
44	BG120	---	---	334	675	389	0.859	2.84	Porphyritic augite-rich diorite.	R, I
45	BG125	9.3	-5.9	5700	363	209	27.3	2.84	Hornblendic plagioclase porphyry.	R*, I
46	BG118	330.5	56.1	115	513	296	0.388	2.66	Vosburg stock; quartz monzonite porphyry.	R, I
47	BG119	274.3	5.0	113	60.8	35.1	3.22	2.72	Hornfelsic welded tuff.	R
48	BG209	---	---	1000	469	271	3.69	2.89	Amygdaloidal augite basalt.	R*, I
49	BG117	24.8	-57.9	1790	1150	664	2.70	2.79	Diabasic intrusive.	R*, I
50	BG115	240.1	39.7	961	401	231	4.16	2.81	Orphan Boy intrusive; diorite-gabbro.	R, I
51	BG114	344.1	46.6	21.4	453	261	0.0820	2.66	Antelope Creek Stock; granodiorite.	I
A	E1–E5	---	---	460	8.30	4.78	96.2	2.85	Andesitic tuff; 5 samples measured in 1962.	R
B	E6–E11	---	---	86	3.10	1.78	48.2	2.84	Andesitic flow; 5 samples measured in 1962.	NON
C	E16–E20	---	---	80	2.40	1.38	57.9	2.72	Andesitic tuff; 5 samples measured in 1962.	NON
D	E21–E25	---	---	50	2.90	1.67	29.9	2.71	Andesitic flow; 5 samples measured in 1962.	NON

Major anomalies or groups of anomalies are numbered and parts of anomalies or individual anomalies in the groups are given letter symbols, starting first with high-amplitude anomalies near the contact between the Boulder batholith and Elkhorn Mountains Volcanics and progressing to terranes of volcanic rocks to the southeast and batholithic rocks to the northwest.

Anomalies 1, 2, and 3

This northeast-trending group of magnetic highs, among those having the highest amplitude in the study area, is associated principally with topographically high exposures of intrusive rocks (Ki, pl. 1) associated with the Elkhorn Mountains Volcanics. Although magnetization data for these rocks are not available, magnetizations of similar intrusive rocks (table 1, locs. 44, 45, and 49) southeast and northeast of the topographic ridge are among the strongest in the area. Adding to the effects of the intrusive rocks are strong magnetizations of neighboring volcanic rocks which are also exposed at high elevations. For example, near the crest of anomaly 1, outcrops of amygdaloidal augite basalt (loc. 48) have very strong remanent and strong induced magnetizations; on the southwest flank of anomaly 3, exposures of volcanic breccia (loc. 16) have magnetizations even stronger than the basalt. Although part of the magnetizations of these highly elevated rocks may be attributable to strong isothermal remanent magnetization induced by lightning discharges at the surface, the observed strong induced magnetizations indicate that these rocks are highly magnetic in the subsurface.

On the northwest flank of anomaly 1, the negative indentation 1A is associated with plutonic rocks exposed in the upper reaches of Jackson Creek, probably a manifestation of relatively nonmagnetic altered subsurface rocks. Northeast of the anomaly, the elongate negative feature 1B appears to be the result of both a polarization low associated with anomaly 1 and a residual low nested between two high-amplitude positive anomalies. This negative feature widens over part of the upper drainage of Staubach Creek, indicating that magnetizations of subsurface rocks are weakest there. On the southeast flank of anomaly 1, the negative indentation 1C appears to be caused by a small area of relatively nonmagnetic rocks that are not indicated by topography. In contrast, the positive indentation 1D and negative indentation 1E are clearly associated with topographic relief developed on volcanic rocks. Other features which are influenced by topography are saddles 1F and 2A, negative feature 2B, positive noses 3A and 3B, and negative indentation 3C. Features correlating at least partly with topographic expression and partly with extrusive and intrusive rocks of the Elkhorn Mountains Volcanics are positive indentation 3D and negative indentation 3E.

Anomaly 4

This broad high-amplitude magnetic high, which tapers southwestward to the vicinity of Elkhorn Peak, occurs over a topographically high region of extrusive and intrusive rocks largely covered by Quaternary sediments. Of the five samples collected from an area beneath the broader part of the anomaly (locs. 25, 26, 27, 28, and 29), altered or mineralized welded tuffs and volcaniclastic rocks are essentially nonmagnetic whereas granodiorite and lithic tuff are strongly magnetic, containing mainly induced magnetization. Near the tapered part of the anomaly, marked by the positive closure of contour lines near Elkhorn Peak (feature 4A), andesitic sandstone (loc. 15) has a combined remanent and induced magnetization, which if coincident with each other, are sufficiently strong to explain the anomaly. Although numerous lithologic units appear to serve collectively to produce the overall anomaly, buried intrusive rocks similar to those correlated with anomalies 1, 2, and 3, may also help to produce the anomaly. Near Elkhorn Peak, which has an elevation approximately the same as that of the aeromagnetic flights, a significant effect may be caused by local occurrences of magnetite-rich metamorphic rocks. Indeed, two bodies of such rock on the south and west slopes of Elkhorn Peak have been mined, its iron content giving it particular value as a smelter flux (Knopf, 1913a; Klepper and others, 1957).

To the north of the broad part of the anomaly, features 4B, 4C, and 4D form closures over a region of low magnetic gradients. Of the 11 intrusive and extrusive rocks collected from this area (locs. 17, 18, 19, 20, 21, 22, 23, 24, 30, 31, and 32), all but two are nonmagnetic. Much of the magnetization assumed to have been present was probably diminished througn ieaching and other chemical alteration. The two exceptions are relatively magnetic diorite and biotite quartz diorite (locs. 21 and 22, respectively) which crop out beneath gradients on flanks of the local closures. The entire region covered by features 4B, 4C, and 4D is probably underlain by relatively nonmagnetic rock, much of which probably has been chemically altered.

East of feature 4D, a steep north-trending magnetic gradient is indented by a negative feature 4E. This region between and near the margins of the lows has been extensively mined (Callahan, Pataloma, Big Tizer Wildcat, and Golden Age mines). Other minor variations of the commonly steep magnetic gradient, such as 4F, 4G, 4H, and 4I, appear to be appreciably influenced by topography developed on the extrusive and intrusive rocks. Of greater interest, the negative closure 4J is centered near the site of the Little Tizer Wildcat mine, suggesting altered subsurface rocks. Farther south, the negative closure 4K and the dipole feature 4L, though not associated with previous mining, may also mark local terranes of altered subsurface rock. Another association of a negative magnetic feature with mineralized rock occurs near the Elkhorn Skyline mine marked by the indentation 4M; the dipole feature 4N may reflect another zone of altered volcanic rocks not exposed at the surface. The local high-amplitude negative closure 4O, centered near the upper drainages of Black Canyon and Rabbit Gulch, reflects strong polarization associated with topographically high volcanic rocks near Elkhorn Peak, but the anomaly itself is developed over plutonic rocks of the Boulder batholith, which is relatively nonmagnetic in this region. North of anomaly 4O, the prominent positive bulge 4P is influenced by high topographic relief over rocks of the Boulder batholith.

Anomaly 5

This prominent magnetic low, developed as a northwest- to west-trending trough near Elkhorn, is associated with an intensively mineralized zone which includes sites of the Heggen, Moreau, East Butte, Hard-cash, and Carmody mines as well as molybdenum-rich rock of Turnley Ridge (the unnamed ridge in the Elkhorn mining district about 1 mi (1.6 km) south of the study area). Although the previously mined area is almost entirely restricted to the northern flank of this anomaly (a notable exception is the Boulaway mine site located on the anomaly axis), its westward extension to feature 5A may reflect an almost continuous subsurface zone of alteration across the contact between the Boulder batholith and Elkhorn Mountains Volcanics. The westernmost extremity of the anomaly, feature 5A, also reflects a polarization effect developed north of the high-amplitude positive feature 5B, the high presumably associated with relatively magnetic plutonic rocks of the Boulder batholith. Northeast of the magnetic trough, the southeast-trending positive nose of dipole anomaly 5C and the positive bulge 5D are associated with mafic plutonic rocks which intrude Precambrian and Paleozoic sedimentary rocks. The negative indentation 5E due north of Elkhorn is associated with intense mineralization marked by sites of the Louise, Golden Moss, C and D, and Union mines.

Although magnetizations of rock samples were not determined in mineralized areas near Elkhorn, previously obtained data from Elkhorn Mountains Volcanics northeast of feature 5E and south of feature 4N (locs. A, B, C, and D) provide representative values which are normal for this part of the volcanic rock section (Hanna, 1965, 1967). Data from 20 samples indicate the presence of weak to strong remanent magnetizations but only weak induced magnetizations (table 1).

Anomaly 6

Near the northeastern corner of the map area, in approximate alignment with anomalies 1, 2, and 3, a broad high-amplitude magnetic high occurs over a major exposed tract of the Antelope Creek stock, in a topographically low area drained by Antelope Creek. Although most of the anomaly is associated with granodiorite of the stock, which has an induced magnetization (loc. 51), part of the anomaly is generated by diabasic intrusive rocks (loc. 49) and such mafic rocks as diorite-gabbro of the Orphan Boy intrusive (loc. 50), both of which have strong remanent and induced magnetizations.

Northwest of the anomaly, the high-amplitude magnetic low 6A, only partially included in the detailed survey, appears to be associated with Elkhorn Mountains Volcanics containing mineralized breccia deposits.

Anomaly 7

At the eastern margin of the map area, a very high amplitude positive anomaly is associated with plutonic rocks of the Vosburg stock and surrounding volcanic rocks. Although the eastern half of the anomaly is largely attributable to quartz monzonite porphyry (loc. 46) of the stock, which has strong remanent and induced magnetization, it is also partially generated by a mixture of other rocks, including metamorphosed welded tuff (loc. 47) having strong remanent magnetization and hornblendic plagioclase porphyry (loc. 45) having very strong remanent and strong induced magnetization. The regular form of the anomaly suggests that plutonic rocks of the stock extend in the subsurface west of the mapped contact; however, it appears that rocks of the Elkhorn Mountains Volcanics also contribute to the western half of the anomaly. For example, porphyritic andesite (loc. 43) and porphyritic augite-rich diorite (loc. 44) both have strong remanent and induced magnetizations, and could contribute significantly to the feature.

North of the anomaly, the prominent magnetic trough 7A is developed over a tract of volcanic and plutonic rocks covering part of the upper drainage of Beaver Creek; either the quartz monzonite of the Moose Creek stock is relatively nonmagnetic, or the body is thin and extends to only shallow depth, in sharp contrast to similar plutonic rocks of the Antelope Creek and Vosburg stocks. Regardless of how much of the anomaly is a polarization effect linked with anomaly 7 and how much is a residual low developed between anomalies 6 and 7, the underlying tract of subsurface rocks is deficient in magnetite.

On the northern flank of anomaly 7, the positive indentations 7B and 7D conform somewhat to topography but may in part represent subsurface lobes of plutonic rock extending from the core of the Vosburg stock. Negative indentations 7C and 7E are residual lows over relatively nonmagnetic rocks adjacent to the positive features. Positive feature 7F at the southwest margin of anomaly 7 is associated with an exposed quartz monzonitic body allied to the Vosburg stock; positive feature 7H to the southeast is probably associated with a similar, though completely buried, small body of quartz monzonite. Negative indentation 7G south of the anomaly occurs over the trace of a major fault; the feature may in part be caused by gouge and chemical alteration of rocks within the fault zone.

Anomalies 8, 9, and 10

This trio of anomalies west of anomaly 7 probably represents the three expected polarization effects associated with the concave part of a bow-shaped outcrop pattern of Elkhorn Mountains Volcanics, convex to the north (fig. 3), having on the average a normal total magnetization. The low of anomaly 8 is associated mainly with the eastern part of the pattern; the low of anomaly 10, with the western part. The residual positive anomaly 9 results from the combined decrease in amplitude of both negative anomalies with increasing lateral distance from the sides or limbs of the pattern. Thus, these polarization effects cannot be correlated with local occurrences of mapped units; they are caused by the bulk effect of the volcanic rock pile. The local positive-negative interruption 10A of the western gradient of anomaly 10 is not part of the polarization effect; this feature appears to be a local east-west dipole anomaly of unknown source.

Anomaly 11

This very broad low-amplitude magnetic low is associated mostly with relatively nonmagnetic Mesozoic sedimentary rocks (for example, nonmagnetic shale of loc. 33) forming part of the core of the major anticline in that area. The negative lobes 11A, 11B, and 11C along the northern flank of the anomaly coincide in large part with drainages of Crow Creek, Longfellow Creek, and Eureka Creek; intervening positive lobes appear to be related to exposures of intrusive rocks (unit Ki, pl. 1) of the Elkhorn Mountains Volcanics.

Anomaly 12

East of anomaly 11, at the eastern edge of the study area, a partially defined high amplitude magnetic high appears to be associated with mapped exposures of mafic plutonic rocks and intrusive rocks (Ki, pl. 1) of the volcanic rock pile. One sample of diabasic lava flow (loc. 42) has expectedly strong remanent magnetization, sufficient to serve as an anomaly source. To the north, negative feature 12A appears to be a polarization and residual low developed over rocks of the lower member of the Elkhorn Mountains Volcanics. To the south, negative indentation 12B is associated with a block of highly siliceous welded tuff of the middle member of the Elkhorn Mountains Volcanics; positive indentation 12C is associated with andesitic rocks of the lower member.

Anomalies 13 and 14

Southwest of anomaly 12, the saddle-shaped high 13 is developed over quartz monzonite of the South Fork stock, the saddle interrupting an otherwise continuous magnetic trough at anomalies 11 and 14 that are associated with relatively nonmagnetic sedimentary rocks in the core of the major anticline. It is of considerable interest that, unlike most stocks which intrude the volcanic and sedimentary rocks within the study area, the South Fork stock has a very low amplitude magnetic signature. Granodiorite (loc. 41) from the stock has a weak remanent magnetization and a very weak induced magnetization. This indicates that the stock probably has a subsurface extent similar to those of other stocks in the study area; however, for an unknown reason, the rock is deficient in magnetite.

Anomaly 15

South and west of anomalies 13 and 14, anomaly 15 is a high-amplitude magnetic high, partially within the surveyed area that occurs over the Slim Sam stock and neighboring Paleozoic sedimentary rocks. Granodiorite from the Slim Sam stock (loc. 40) exhibits strong remanent and induced magnetization, in sharp contrast with granodiorite from the South Fork stock, only 1 mi (1.6 km) to the northeast. The anomaly suggests that granodiorite of the Slim Sam stock extends in the subsurface as much as 1 mi (1.6 km) northwest of the mapped contact beneath a thin veneer of sedimentary rocks. The anomaly abruptly terminates in a magnetically featureless region 15A, marked by the Bonanza mine. The dipole feature 15B to the west, developed in a polarity sense reversed to others in the study area, has an unknown source.

Anomaly 16

Northwest of anomaly 15, a broad positive nose is associated with quartz monzonite of a small exposure of plutonic rock, which probably has a total magnetization more similar to that of the Slim Sam stock than the nearby South Fork stock. The regular form of the anomaly suggests that the intrusive body may be nearly as large as the Slim Sam or South Fork stocks at depth, of possible significance to a geochemical anomaly observed in stream-sediment samples from Jenkins Gulch. Hornfels (loc. 39) which occurs at the intrusive rock contact, as well as andesite, gabbro, and quartz monzonite exposed farther to the north (locs. 34, 35, 36, 37, and 38), are relatively nonmagnetic except for a fragmental volcanic rock (loc. 36) which may have a combined remanent and induced magnetization sufficiently strong to serve as an anomaly source. The negative indentations 16A and 16B represent polarization and residual lows adjacent to the positive anomaly.

Anomaly 17

At the northwest corner of the study area, in the Boulder batholith, a broad low-amplitude magnetic high is developed over Strawberry Butte, Shingle Butte, and lower terrain extending eastward to McClellan Creek. The closure at Strawberry Butte and the prominent nose at Shingle Butte reflect topographically high exposures of rhyolite flows, which also create the broad positive nose 17A on Burnt Mountain, south of Strawberry Butte. Remanent magnetization of the rhyolite (loc. 1) is stronger than all but six of the volcanic and plutonic rocks sampled in the study area, a remarkable property considering its highly silicic composition.

Southeast of Strawberry Butte, the positive nose 17B appears to be associated with topographically high exposures of porphyritic quartz monzonite. South of this feature, the negative closure 17C bears no relation to mapped geology and therefore may represent a low-amplitude residual anomaly. Biotite quartz monzonite (loc. 2) from a region northeast of Burnt Mountain has strong remanent and induced magnetization assumed to be typical of much of the unaltered Boulder batholith and presumably accounts for feature 17A.

Anomaly 18

East of anomaly 17 and northwest of anomaly 1, a broad high-amplitude magnetic low extends over the contact between the Boulder batholith and Elkhorn Mountains Volcanics and is probably associated with a large tract of altered subsurface rocks covering much of the drainage of Jackson Creek. The elongate positive nose 18A to the north may be caused by a combination of unaltered plutonic rocks of the Boulder batholith and intrusive rocks (map unit Ki) of the Elkhorn Mountains

Volcanics which crop out along the northwest gradient of the anomaly, 1 mi (1.6 km) southeast of Little Butte.

Anomaly 19

Southwest of anomaly 18, a northwest-trending low-amplitude magnetic trench forming closure at 19 and 19A is developed over the Middle Fork Warm Springs Creek drainage. Surprisingly, the rhyolitic rocks of Lava Mountain produce no conspicuous anomaly, such as those associated with rhyolites of Strawberry Butte, Shingle Butte, and Burnt Mountain to the north. The rhyolites may be very thin at Lava Mountain or they may have been altered. Also surprising is that a number of plutonic rocks collected along Warm Springs Creek and Middle Fork Warm Springs Creek (locs. 5, 8, and 9) have strong induced magnetizations, ordinarily sufficiently strong to produce a magnetic high; others (locs. 3, 4, 5, and 7) which are highly silicic or intensively altered, are essentially nonmagnetic, as expected. Weathered porphyritic granodiorite (loc. 10) from an area beneath the weak gradient separating 19C and 19D also possesses strong induced magnetization and is assumed to contribute to the anomaly source of the positive nose, which is also strongly influenced by topography. Despite the presence of some strongly magnetic plutonic rocks in the area underlying the magnetic trench, most rocks in the subsurface are probably relatively nonmagnetic, perhaps as a result of extensive alteration. The broad positive noses 19B and 19E reflect a constriction of the relatively nonmagnetic zone; thus the region most magnetite-deficient widens to include part of the drainage of South Fork Warm Springs Creek at the southern margin of anomaly 19 and to include the confluence of the North, Middle, and South Forks at anomaly 19A. The region circumscribed by anomaly 19 includes the sites of numerous inactive mines, and it contains a geochemical anomaly based on stream-sediment samples.

Anomaly 20

Southwest of anomaly 19, a broad magnetic low associated with biotite granodiorite of the Boulder batholith is flanked by the most gentle magnetic gradients observed on the aeromagnetic anomaly map. Samples of the granodiorite from two isolated outcrops (locs. 11 and 12) have strong remanent and induced magnetizations, indicating that even in areas of insignificant magnetic relief, the magnetization of the batholith proper is significant. The observed magnetizations, about 10^{-3} emu/cm^3, offer some measure of magnetization for "normal" batholithic rock. Inferred magnetizations of sources of anomalies elsewhere in the batholith can be referenced to this figure.

Anomaly 21

East of anomaly 20, conspicuous positive noses 21 and 21A, separated by the negative indentation 21B, are significantly influenced by topography developed on granodiorite of the Boulder batholith, presumed to have strong magnetizations similar to the unaltered rock from locality 2 to the north.

Anomaly 22

Southwest of anomaly 20, a prominent magnetic trough extending from features 22 to 22A is developed over the drainages of Prickly Pear and Golconda Creeks. Although the negative nose and closure of 22A appears to result from effects of high topography to the north and south, most of the elongate feature marks a zone of relatively nonmagnetic subsurface rocks that are perhaps hydrothermally altered. The highest amplitude portion of the negative anomaly overlaps a geochemical anomaly based on stream-sediment samples and covers a region of interest for possible porphyry copper deposits.

Anomaly 23

Southeast of anomaly 22, the east-west-trending magnetic ridge 23, as well as positive noses 23A and 23B, is associated with highly elevated plutonic rocks conforming closely to topographic configuration. Indentation 23C, which follows the steep upper drainage of Muskrat Creek, is a negative expression of this same topographic relief.

Anomaly 24

Southwest of anomaly 23, the high-amplitude broad positive nose 24 extending southwestward to the positive closure 24A is developed over altered plutonic rocks not conformable with topography. Altered porphyritic quartz monzonite from an outcrop underlying anomaly 24 (loc. 14) and altered granodiorite from an outcrop underlying feature 24A (loc. 13) have induced magnetizations sufficiently strong to serve as anomaly sources. Negative indentations 24B, 24C, 24D, 24E, and 24F are all developed over relatively nonmagnetic rocks, a number of them associated with mineralization and alteration. Feature 24D, aligned with the principal drainage of Muskrat Creek, overlaps a geochemical anomaly based on stream-sediment samples. Features 24E and 24F, following part of the drainage of Rawhide

Creek, may also reflect zones of subsurface mineralization.

Relationship of Anomalies to Mineralized Ground

This study of aeromagnetic anomalies shows that the data can reflect mineralized terrane in two ways; first, known mineralized ground associated with extensive altered areas show distinctive negative anomalies, and second, some intrusive rocks associated with mineralized areas show positive anomalies. In rare instances, anomalies may directly reflect magnetite-rich deposits, such as the skarn in replacement bodies near Elkhorn Peak; however, the resolution of the aeromagnetic anomaly data is insufficient to delineate other known magnetite-rich deposits such as stream placers and sedimentary lenses known to occur within and adjacent to the study area.

Examples of negative anomalies which are associated with mineralized ground marked by mines and excavations in and near the western part of the study area include the following anomalies: north of 23A, at 19, surrounding 5E, southeast of 5, north of 4A, at 4M, at 4J, and northwest of 4E. Examples of positive anomalies associated with mineralized ground in and near the eastern part of the study area include those east of anomaly 6, surrounding 7, north and south of 7H, north of 12, and west of 15. Near the center of the study area, magnetic gradients forming the flanks of anomalies are associated with mines southeast of 3D and north of 4A. Thus, within the Boulder batholith and Elkhorn Mountains Volcanics near the batholith contact, magnetic lows tend to correlate directly with mineralized ground; within the Elkhorn Mountains Volcanics and intruded plutons far from the contact, magnetic highs tend to be associated with mineralized ground.

Magnetic Anomalies and Strong Geochemical Anomalies

Most of the regions within the study area that have strong geochemical anomalies based on pan concentrate samples (pl. 4) are associated with the magnetic gradients forming the flanks of aeromagnetic anomalies rather than with the central parts of the anomalies. Regions of anomalous gold, silver, arsenic, lead, and copper, characteristic of hydrothermal vein-type mineralization determined by geochemical studies in the eastern part of the study area, are associated with gradients forming the saddle on the magnetic ridge connecting 4 and 4A; the high-low-high triplet of 7, 12A, and 12; the high-low-high triplet of 1, 1B, and 6; the southeastern margin of anomaly 9; and the eastern margin of anomaly 4F. Regions of anomalous molybdenum, tungsten, niobium, thorium, lanthanum, and yttrium, characteristic of molybdenite mineralization in the Boulder batholith determined by geochemical studies, are associated with the northern flank of the magnetic trough connecting 19 and 19A; the northwestern flank of anomaly 3; the western flanks of anomalies 21 and 21B; the northern flank of anomaly 2; the southwestern flank of anomaly 4A; and the northwestern margin of anomaly 24D.

Geochemical anomalies indicate possible mineralization on or close to the surface and magnetic anomalies indicate possible mineralization at depth. In the study area, surficial mineralization is strongest where there are lateral contrasts of magnetization. Some of these contrasts may indicate subsurface hydrothermal alteration. Because many of the geochemical anomalies cover regions having gradients connected with one or more positive anomalies over relatively high terrain, much surficial mineralization may be located on the upper flanks of these combined topographic and magnetic highs.

Aeromagnetic Anomalies Possibly Related to Mineralized Rock

More than 50 aeromagnetic anomalies (fig. 5) within and near the study area may be related to mineralized rock. Magnetic lows, even if only low-amplitude negative indentations of magnetic gradients, serve as reliable guides to subsurface alteration and associated mineralization in the terrane of Boulder batholith and on both sides of the Boulder batholith–Elkhorn Mountains Volcanics contact. One example of such a low in the Boulder batholith is anomaly 22; examples near the contact are negative closures 4J and 4K. Magnetic highs associated with small plutonic rock bodies in the terrane of Elkhorn Mountains Volcanics serve as guides to possible subsurface mineralization within or at the margins of these bodies. Examples of such features are positive noses 7F and 7H and the northwestern part of high-amplitude magnetic high 15.

The association of aeromagnetic anomalies with known mineralized ground and with other areas believed to be mineralized indicates that further exploration might well disclose additional deposits.

Geochemical Exploration

By William R. Miller, Steve Ludington, and William R. Greenwood

Geochemical studies were made in the Elkhorn Wilderness Study Area, Montana, during November 1976 and the summer of 1977 to help evaluate the

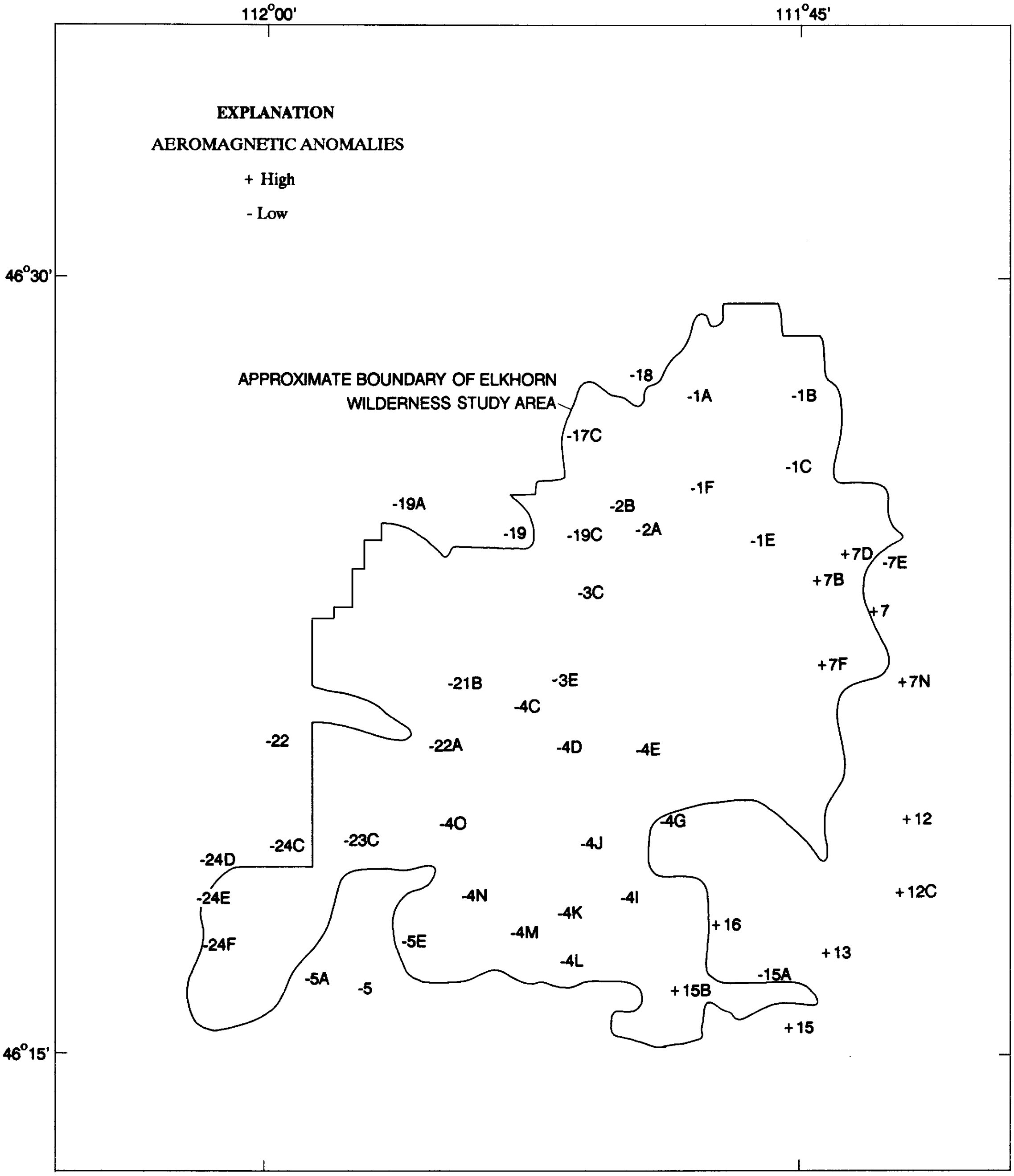


Figure 5. Aeromagnetic highs and lows in and near the Elkhorn Wilderness Study Area, Montana. Anomalies keyed to plate 2.

mineral resource potential of the area. A geochemical orientation survey was conducted during November 1976 to determine the optimal sampling medium and spacing. The results indicated that the nonmagnetic heavy-mineral fraction of panned concentrates from stream-sediment samples was the most useful sample medium for delineating areas of anomalous metal concentrations. In addition, the sampling of small, unbranched (first-order) streams provided the most efficient sampling density.

During the fieldwork in 1977, rock, soil, and stream-sediment samples were collected in addition to panned concentrates. All samples were analyzed by semi-quantitative emission spectrometry for 30 elements and by atomic absorption for gold, zinc, and arsenic on selected samples. Sample localities are shown on plate 3. The results of the analyses of all samples have been published by Motooka and others (1978).

Approximately 187 panned concentrates were collected, predominantly from small, unbranched streams above the confluence with major drainages. The samples were collected in active channels in the streams and panned at the sites. Duplicate samples of each sample type were collected at about 10 percent of the sample localities. Sample density averaged approximately one sample per 0.5 mi^2 (1.5 km^2). The material sampled usually ranged from silt to sand and represents material that was introduced to the stream bed from bedrock and colluvium within the drainage basin. In this area, the use of nonmagnetic heavy-mineral concentrate samples is particularly useful for detecting molybdenum, tin, and tungsten.

After panning, the sample was dried and sieved through a minus-18-mesh sieve. Magnetite and other highly magnetic minerals were removed using a hand magnet. The sample was then separated into two fractions using bromoform (specific gravity, 2.86). The light-mineral fraction was discarded, and the heavy-mineral fraction was passed through a Frantz Isodynamic Magnetic Separator with the current set at 0.2 amperes and the forward and side tilt settings at 15°. The magnetic fraction was discarded, and the nonmagnetic fraction was further separated at 0.6 amperes into a nonmagnetic and magnetic fraction. Each fraction was examined with a microscope and the mineralogy determined. The non-magnetic fraction generally contained minerals such as zircon, monazite, apatite, sphene, and ore minerals such as sulfides and oxides. Scheelite was identified from several samples using an ultraviolet light. Both fractions were then pulverized to pass a minus-150-mesh sieve and analyzed for 30 elements by semiquantitative spectroscopic methods (Grimes and Marranzino, 1968). Based on the analysis of the duplicate samples, reproducibility is usually within one reporting interval.

Because of higher total content and regional variation of trace-element concentration, the data on the nonmagnetic fraction were used for the geochemical interpretation.

Histograms for elements of possible economic interest are shown on plate 4, one set representing streams draining the Boulder batholith, and another set representing all other streams. The histograms illustrate the geochemical differences between the two major rock terranes, and it is evident that rock type influences the background and threshold of some elements. Nevertheless, the differences are not large, and no distinction was made in the treatment of data from the two terranes.

Statistical analysis of the geochemical data using the STATPAC (Van Trump and Miesch, 1977) statistical evaluation library indicates that groups of interrelated elements are present. The correlation coefficients (table 2) form the basis for delineating two groups, called here Group 1 and Group 2. The two groups of interrelated elements are considered separately because they seem to be related to different types, and perhaps different periods, of mineralization. A normalized sum was computed for each group, because an element with large values, like arsenic, could dominate a simple summation. Sums were normalized by dividing the analytical value for an element by the threshold value of that element. Thus,

Table 2. Correlation coefficients of two groups of elements in geochemical samples from the Elkhorn Wilderness Study Area and vicinity, Montana

[Circles indicate non-significant correlation at the 5 percent confidence level]

Group I

Correlation coefficients

Number of paired samples	Ag	Au	As	Pb	Cu
Ag		.90	.58	.52	.70
Au	4		.74	.75	.73
As	22	3		.52	.53
Pb	32	5	42		.52
Cu	35	4	36	93	

Group II

Correlation coefficients

Number of paired samples	La	Mo	Nb	W	Y	Th
La		.49	.68	.09	.84	.29
Mo	128		.48	.64	.56	.45
Nb	143	121		.19	.76	.06
W	74	72	69		.27	.54
Y	167	134	144	77		.65
Th	62	61	62	38	61	

$$\text{Normalized sum} = \frac{\textit{Element 1}}{\text{Threshold of element 1}} + \frac{\textit{Element 2}}{\text{Threshold of element 2}} + \ldots + \frac{\textit{Element n}}{\text{Threshold of element n.}}$$

The threshold values were selected subjectively and are shown on plate 4. The normalized sums for each of the two groups were calculated for each sample and the results plotted as histograms on plate 4.

Group 1 consists of gold, silver, arsenic, lead, and copper. The normalized sum appears to represent hydrothermal-vein-type mineralization. This factor delineates the Park mining district in and near the eastern part of the study area (pl. 4, A–1). A slight anomaly is outlined near Lava Mountain (A–2), an area also containing several known mines. In area A–3, a sulfide-bearing vein was observed within a cirque. Other anomalies such as areas A–4 and A–5 probably represent small veins, in many cases associated with intrusives.

Group 2 consists of lanthanum, molybdenum, niobium, tungsten, yttrium, and thorium. Because of its association with elements such as tin, and the greater contrast of molybdenum relative to copper, the normalized sum probably represents disseminated molybdenum mineralization. The largest anomalies appear within the Boulder batholith (pl. 4, B–1). This area appears to have a good potential for porphyry-type deposits of molybdenum. Another anomaly occurs just east of the study area (pl. 4, B–2) near the Vosburg mine. Small amounts of molybdenite have been reported from the mine (Klepper, Ruppel, and others, 1971).

A third type of mineralization appears to be present within the study area and is represented by boron. Boron is anomalous along the contact of the volcanic rocks with rocks of the Boulder batholith (pl. 4). In this area, tourmaline and sometimes pyrite are present, but there is a scarcity of economic minerals.

GEOLOGICAL AND GEOCHEMICAL EVALUATION

By Steve Ludington and William R. Greenwood

Introduction

Several geologic and geochemical features within the Elkhorn Wilderness Study Area suggest the presence of mineral resources. To assist in evaluating these features, we first describe the geology of nearby ore deposits, and then describe the results of our geologic and geochemical investigations of individual areas. Together, these data provide the basis for our evaluation.

Mineral Deposits In and Near the Study Area

Data from major metal mines in and near the study area are summarized here to provide a background for later discussion of geologic, geochemical, and geophysical evidence of mineral resources.

The total recorded value of metals produced from these mines is about $109 million (Klepper and others, 1957; Klepper, Ruppel, and others, 1971; Smedes, 1966; Becraft and others, 1963). The mines within the study area are small, none having produced as much as $300,000, but several large historic producers are within a few miles of the study area boundary. The location of these larger mines is shown on figure 6.

East Flank Zone

Mines along the east flank of the Elkhorn Mountains have produced about $17 million worth of ore since 1866, primarily gold and silver with subordinate base metals. The zone lies mostly outside the study area. All data in this section of the report are abstracted from Klepper, Ruppel, and others (1971).

Gold and silver occur principally in pyritic veins within or close to several granitoid stocks that intrude the axial zone of a major north-trending syncline.

The veins include the following types:

(1) Early quartz-rich veins north of Indian Creek associated with porphyritic felsic stocks. They have shallow dips and consist of pyrite, gold, a little molybdenite and chalcopyrite, and locally, sparse arsenopyrite, galena, and sphalerite.

(2) Late quartz-rich veins north of Indian Creek associated with porphyritic felsic stocks. They dip steeply and consist of pyrite, gold, and various combinations of galena, sphalerite, arsenopyrite, chalcopyrite, and tetrahedrite.

(3) Quartz-poor veins south of Indian Creek associated with nonporphyritic stocks of intermediate composition. They contain auriferous pyrite, sparse marcasite, very sparse chalcopyrite, and traces of pyrrhotite, galena, sphalerite, and chalcocite. These veins also dip steeply.

In the Quartzite Ridge mining district, silver-lead-zinc replacement deposits form pipes and lenses along east-trending faults in carbonate rocks. The deposits are in thin dolomite beds between quartzite beds of the Quadrant Formation, and a few also occur in the Mission Canyon Limestone. The ore is oxidized and consists of cerussite, pyromorphite, limonite, quartz, calcite, galena, and manganese oxides; locally it also contains smithsonite, wulfenite, sphalerite, pyrite hemimorphite, barite, cerargyrite, or fluorite.

A small amount of gold occurs locally in calc-silicate skarns adjacent to a few stocks. Gold also occurs in placers south and west of Radersburg, along Indian Creek, and along Weasel and Beaver Creeks.

Titaniferous magnetite has been mined near Radersburg from some lenticular beds in the middle of the Slim Sam Formation that probably are lithified beach concentrations. These deposits have been mined for use in making a special type of cement.

Elkhorn-Tizer Basin Zone

Mines in the Elkhorn mining district and to the north in the vicinity of Tizer Basin, here called the Elkhorn-Tizer Basin zone, have produced metal with a value of about $16 million since 1875. Of this total, silver and gold accounted for about 75 percent and 12 percent, respectively. Data on mines in the Elkhorn-Tizer Basin zone cited in this portion of the report are from Klepper and others (1957) except as indicated. Much of this zone is in or immediately adjacent to the study area.

Mines in the Elkhorn mining district, most of which lie just south of the study area, accounted for about 98 percent of the metal produced in the zone, and exploited

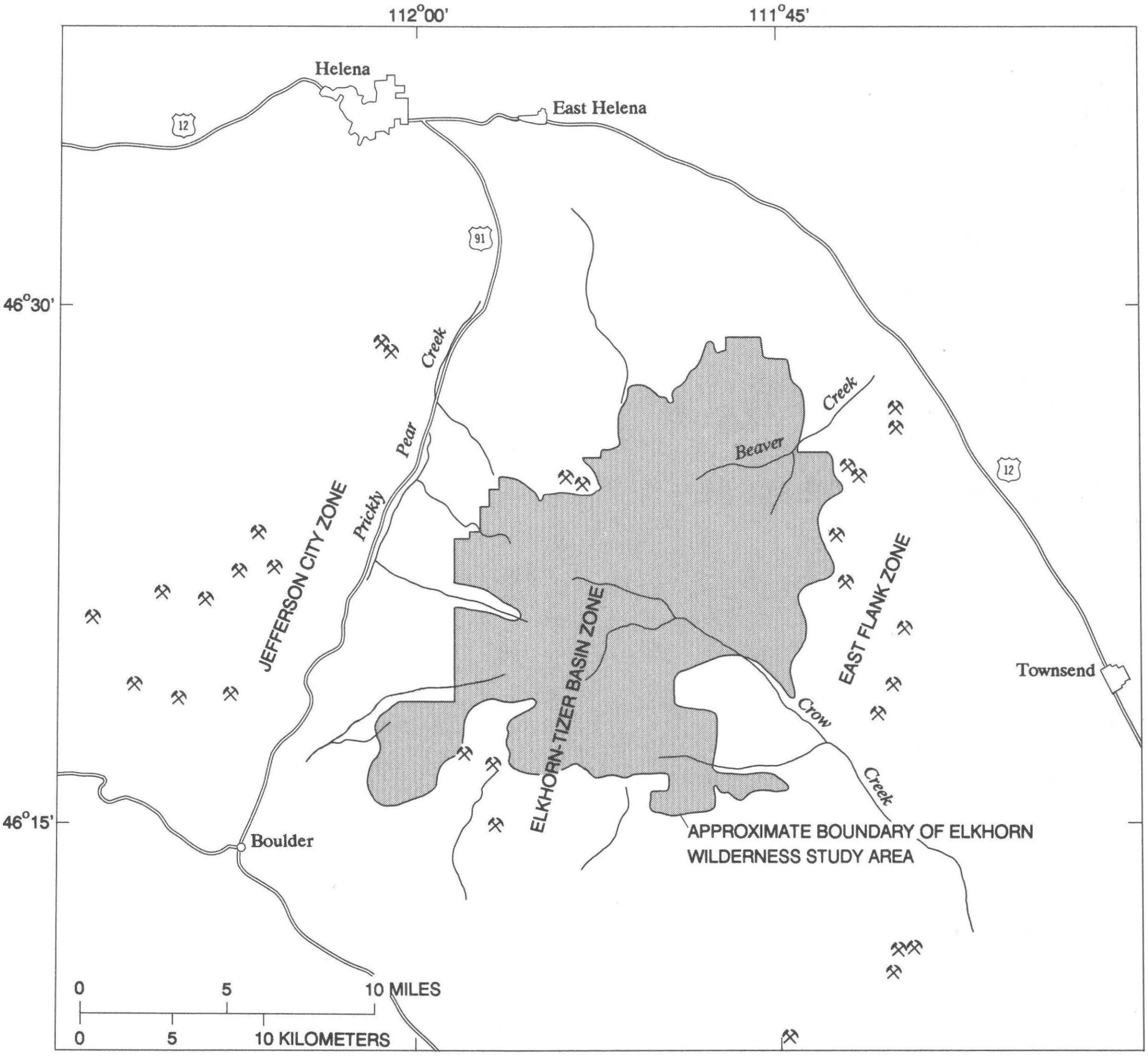


Figure 6. Location of major mines (with production of $300,000 or more) near the Elkhorn Wilderness Study Area, Montana.

replacement deposits in Paleozoic carbonate rocks. The deposits consist of argentiferous galena associated with a small amount of auriferous pyrite and sphalerite. Chalcopyrite, tetrahedrite, bournonite, and argentite in a quartz gangue also occur in some deposits. Much of the ore occurs as tabular siliceous bodies in the uppermost bed or beds of the Pilgrim Dolomite and as pods and irregular bodies of non-siliceous ore in lower beds of the Pilgrim. Ore also occurs in the Mission Canyon Limestone, Lodgepole Limestone, and Meagher Limestone. Most of these deposits formed along the crest or flanks of minor anticlines and beneath a hanging wall of silicified shale or argillite, though some deposits occur along steeply dipping shears that cut across bedding in the carbonate rocks.

Several pipelike breccia deposits in the district have been explored. The deposits consist of clasts of volcanic, sedimentary, and igneous rocks cemented or replaced by quartz, black tourmaline, galena, pyrite, sphalerite, and sparse arsenopyrite. Gold, silver, lead, and zinc have been produced from two of these deposits.

About $220,000 worth of metal production has been reported from gold-bearing veins that occur at several places where volcanic rocks are exposed in and near Tizer Basin. The veins consist of vuggy quartz, sparse pyrite, galena, sphalerite, chalcopyrite, rare flecks of native gold, and possibly tetrahedrite. Gold-bearing veins in the basin strike east-northeast to northeast and dip moderately to steeply southeast. A pipelike breccia deposit cemented by pyrite and tourmaline adjacent to the basin has not been mined.

Small non-mechanized placer operations have been conducted at several places along Wilson and Crow

Creeks. Small amounts of placer gold also are reported in Little Tizer Creek, just below Tizer Lake.

Jefferson City Zone

The Jefferson City zone comprises mines developed in a large swarm of metalliferous quartz veins and chalcedony veins that trends northeast through the Jefferson City quadrangle and then east through the northern Elkhorn Mountains. The zone lies mostly outside of the study area. The data cited here come from Becraft and others (1963) and Smedes (1966).

Most of the mines in the Jefferson City zone were developed on base- and precious-metal-bearing quartz veins that follow steeply dipping, east-trending shears. Recorded metal production from these quartz veins is about $67 million, chiefly silver and to a lesser extent lead. The veins are quartz-rich, contain abundant pyrite, and locally contain galena, sphalerite, arsenopyrite, and chalcopyrite. Wall rocks along the veins show intense argillic and sericitic alteration. These veins are primarily older than the Lowland Creek Volcanics (Eocene) in the Jefferson City quadrangle; however, pyrite-bearing quartz veins are associated with volcano-tectonic breccia in the Lowland Creek Volcanics west of Alta Mountain.

Reeflike outcrops of chalcedony and microcrystalline quartz veins follow and may cut the east-trending metalliferous quartz veins. The reeflike outcrops consist of many thin layers and stringers of chalcedony in silicified and argillically altered rocks. The veins locally contain pyrite and barite and sparse amounts of galena, sphalerite, arsenopyrite, ruby silver, argentite, molybdenite, chalcopyrite, and cinnabar. Small uranium deposits occur in some chalcedony veins and consist of primary uraninite and the secondary uranium minerals meta-autunite, metatorbernite, phosphuranylite, uranocircite, vaglite, and rutherfordine (Wright and others, 1957). In the northern Elkhorn Mountains, chalcedony cements brecciated silver-bearing quartz veins and locally chalcedony veins cut Eocene quartz latite dikes (Smedes, 1966, p. 106).

Uranium ore was mined at the W. Wilson mine sporadically from 1951 to 1956 (Smedes, 1966).

Brecciated Lowland Creek Volcanics in the Wickes mining district, about 5 mi (8 km) west of the study area, contain anomalous amounts of lead and zinc over an area larger than 2,400 ft by 1,200 ft (730 m by 365 m). Samples from exploratory workings in these rocks contain disseminated pyrite in the breccia clasts and coarsely crystalline quartz, microcrystalline quartz, sphalerite, galena, and possibly ruby silver in the matrix. A pipelike body of mineralized breccia on the north side of the Boulder River has been explored at the Obelisk mine. The breccia consists of abundant large clasts of quartz monzonite and subordinate clasts of alaskite and carbonate veins in a sand-size matrix. This material is cemented by calcite and locally by sphalerite, galena, quartz, and sparse pyrite and chalcopyrite, forming steeply plunging pipe-like ore bodies as much as 30 ft by 40 ft (9 m by 12 m) across. Siderite and elsewhere rhodochrosite occur in a few veinlets and vugs in and near the breccia.

Small silver-lead-zinc deposits consisting of veinlet stockworks, lithophysal fillings, disseminations, and local replacements occur in rhyolitic tuff, breccia, and rhyolite at Lava Mountain. The ore consists of galena, sphalerite, fluorite, topaz, and quartz.

Placer gold deposits in the Jefferson City zone are widespread. Extensive placer operations have been conducted along Prickly Pear and Clancy Creeks and to a lesser extent along the upper part of Mitchell Gulch.

Porphyry Deposits

At present, no porphyry-copper deposits or stockwork molybdenum deposits are being mined in the study area. Any such deposits would be of great interest because of their large potential value. Three possible porphyry deposits within or adjacent to the study area are described here. The probability is high that other such deposits may exist at depth in the western part of the study area, where the bedrock is Butte Quartz Monzonite, host to a large porphyry copper deposit at Butte, Mont.

Golconda Area

The Golconda area (fig. 7) is a porphyry copper-molybdenum deposit located astride the western study area boundary south of Prickly Pear Creek. It is significant not only for the value of any ore it may contain but also because it shows that the northern part of the Boulder batholith is favorable for the occurrence of this important type of ore deposit. In addition it can serve as a model to which other porphyry deposits may be compared.

The deposit was discovered by geologists of the Exxon Corporation in the early 1970's. The corporation pursued a program of detailed geologic mapping and geochemical sampling, and in the summer of 1977 four diamond drill holes (fig. 8) of unknown depth were completed or in progress.

The major rock type in the Golconda area is Butte Quartz Monzonite that has a wide range of composition (fig. 8) and grain size. Plagioclase in the rock forms sparse phenocrysts. Biotite is the principal mafic mineral, and hornblende is present locally; together they constitute 2 to 15 percent of the rocks; the mean is 8

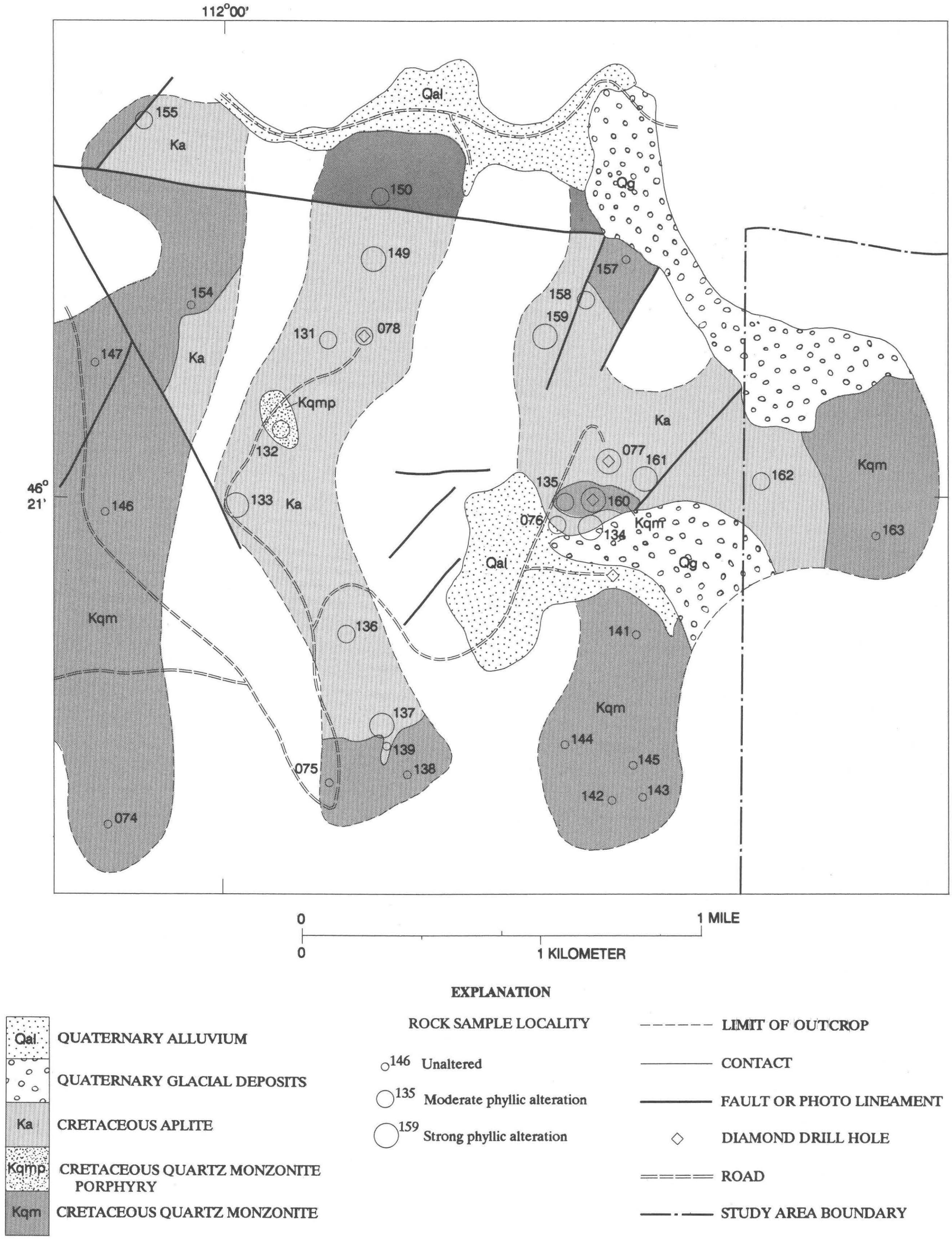


Figure 7. Golconda area, Elkhorn Mountains, Mont., showing diamond drill holes, rock sample localities, and geology. All sample numbers prefixed by 77SL. Blank areas not mapped in detail.

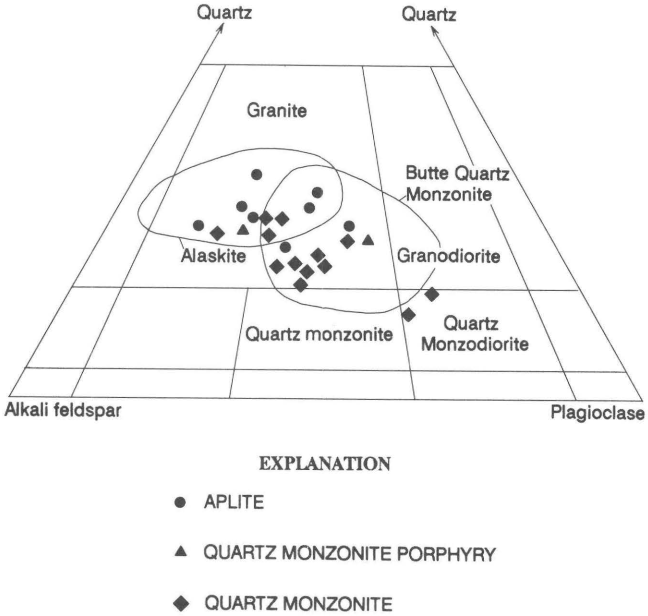


Figure 8. Ternary diagram showing modal compositions of intrusive rocks from the Golconda area, Elkhorn Mountains, Mont. Between 100 and 500 points were counted for each slab; quartz and feldspar recalculated to total 100 percent. Color index for aplites ranges from 0 to 7 (average 3). Color index for quartz monzonite and quartz monzonite porphyry ranges from 2 to 15 (average 8). Solid lines denote fields of alaskite and Butte Quartz Monzonite as reported by Becraft and others (1963). Modal classification is that of Streckeisen (1973).

percent. The quartz monzonite porphyry shown on the geologic map (fig. 7) is similar but contains more abundant plagioclase phenocrysts.

Equigranular aplite, the other major rock type in the area, is host to most of the copper-molybdenum mineralization and hydrothermal alteration. The color index of the aplite ranges from 0 to 7 and averages 3.

Post-mineral faulting is indicated by the abrupt termination of intensely hydrothermally altered aplite on the west and north along prominent topographic lineaments. Physical evidence for faulting along these lineaments was not observed.

Intersecting quartz-sulfide veinlets and associated hydrothermal alteration are confined largely to the aplite. At the surface, intense leaching and oxidation of the rock have taken place, and no fresh sulfides other than pyrite were observed in any surface specimens. Iron and manganese oxides are, however, abundant in the veinlets. Samples of these rocks commonly contain anomalously high copper and molybdenum contents, the distribution of which is shown on figure 9.

Hydrothermal alteration patterns shown in figure 7 were determined by petrographic and X-ray diffraction studies. Strong phyllic alteration is here defined as nearly complete (90 percent) replacement of both potassium feldspar and plagioclase by a very fine grained aggregate of quartz and sericite, absence of biotite or possible sericite and iron oxide pseudomorphs after biotite, and many (1–5 percent) disseminations and veinlets of pyrite and (or) iron oxide pseudomorphs after pyrite.

Weak and moderate phyllic alteration is similar to strong phyllic alteration, but more fresh feldspar remains, and the former presence of biotite is commonly indicated by chlorite. Rock on the fringes of the altered area contains quartz-sulfide veinlets with 0.5- to 2-in. (1–5 mm) selvages of strong phyllic alteration, suggesting that the strong phyllic zone is the result of coalescence of alteration envelopes around more closely spaced veinlets. The most strongly altered rocks generally have the highest copper and molybdenum values. Many of the rocks indicated as unaltered on figure 7 show partial replacement of biotite by chlorite, contain sparse disseminated pyrite, and probably constitute a propylitic alteration zone. Comparison of semiquantitative spectrographic analyses of altered and unaltered rocks shows that hydrothermal alteration of feldspars to quartz and sericite liberated significant amounts of calcium, but left barium and strontium largely fixed in the rock.

The observed characteristics of the exposed portion of the Golconda prospect agree well with those ascribed to the upper part of a model porphyry copper system (Lowell and Guilbert, 1970; Gustafson and Hunt, 1975) with the significant exception that molybdenum-to-copper ratios at the Golconda prospect appear to be quite high. This may be partly because the surface samples are generally highly oxidized; copper is much more highly mobile than molybdenum in acid oxidizing waters, and so may have been significantly leached from the surface exposures. If this is true, the subsurface copper grade may be several times higher than surface sampling suggests, and a secondary enrichment blanket may be present at depth. However, even if copper has been removed, the absolute values of molybdenum seem high—three samples contain 500 ppm molybdenum. If such molybdenum contents were widespread, they would contribute materially to the value of the deposit and characterize it as a molybdenum-rich porphyry copper system.

Jackson Creek Area

Rocks of the Jackson Creek area, which lies just outside the study area, contain anomalous amounts of copper, molybdenum, and bismuth. However, Jackson Creek does not appear to resemble a typical porphyry copper system. More detailed studies would be needed to determine the nature and origin of this deposit. Our studies indicate the area has a low potential for the occurrence of metallic mineral resources.

It is not known when exploration in the area first began, but the copper occurrence was known as early as

EXPLANATION

Qal	QUATERNARY ALLUVIUM
	QUATERNARY GLACIAL DEPOSITS
Ka	CRETACEOUS APLITE
Kqmp	CRETACEOUS QUARTZ MONZONITE PORPHYRY
Kqm	CRETACEOUS QUARTZ MONZONITE

ROCK SAMPLE LOCALITY, SHOWING MOLYBDENUM AND COPPER CONTENT IN PARTS PER MILLION

○ <5 ppm Mo; <100 ppm Cu

5-30 ppm Mo;100-300 ppm Cu

50-200 ppm Mo; 500-1000 ppm Cu

>300 ppm Mo; >1000 ppm Cu

LIMIT OF OUTCROP

CONTACT

FAULT OR PHOTO LINEAMENT

◇ DIAMOND DRILL HOLE

ROAD

STUDY AREA BOUNDARY

Figure 9. Copper and molybdenum content of rock samples collected in the Golconda area, Elkhorn Mountains, Mont. Area shown is same as on figure 7 (sample localities and geology). Left half of symbol refers to molybdenum content; right half to copper content.

1911 (Stone, 1911, p. 86). It was tested in the mid 1960's by Rio Amex Inc. by means of four shallow (< 600 ft (200 m)) drill holes. That drilling was not followed by further exploration.

The area occupies the central part of the Jackson Creek lobe of the Boulder batholith (Smedes, 1966), a wedge of intrusive rock separated from the main part of the batholith by a screen of strongly sheared and contact-metamorphosed Elkhorn Mountains Volcanics (fig. 10). Modal analysis of stained slabs of rock indicates the presence of quartz monzonite, monzonite, granodiorite, syenodiorite, diorite, and quartz diorite in the mineralized area. Outcrops are too few to determine whether the wide scatter of rock types represents an inhomogeneous pluton or a series of intrusions made up of many rock types. Accordingly, rock types are not differentiated in this discussion.

The modal and chemical analyses reveal that the Jackson Creek lobe contains distinctly less potassium and more sodium than most of the Boulder batholith. The spectroscopic analyses indicate that the rocks are enriched in barium and strontium relative to the batholith. They possibly belong to the sodic magma series of Tilling (1973).

Phyllic alteration in the Jackson Creek area is weak and irregularly distributed. Most specimens exhibit some sericite but none show strong phyllic alteration and most have fresh biotite.

The copper and molybdenum content of the samples is shown on figure 11. Samples 77SL034, 77SL035, and 77SL036 contain 700, 1,000, and 1,500 ppm copper, respectively, but no other samples contain as much as 100 ppm. The copper in samples 77SL034 and 77SL035 occurs in large (0.1 to 1.0 mm), isolated, anhedral blebs of chalcopyrite, which show no evidence of association with sporadic quartz veinlets that cut the rock. In 77SL056, the copper occurs in an azure blue mineral.

There is a scattering of anomalous molybdenum values, the highest of which is 50 ppm. In addition to copper and molybdenum, one sample (77SL057) contains 1,000 ppm bismuth. The bismuth-bearing mineral is unknown, but it may be in the 5 to 10 percent disseminated pyrite in the rock.

The Jackson Creek copper occurrence does not resemble any reported porphyry copper system. It may represent a poorly developed example of the sort of magmatic copper occurrence described by Knopf (1913b) from the Golden Curry mine (pl. 3) in the Elkhorn district. The likelihood that the area contains a copper deposit is low.

Turnley Ridge Prospect

The Turnley Ridge prospect is in the Elkhorn mining district about 1 mi (1.6 km) south of the study area. It was recognized in 1969 by the Siskon Mining Corporation of Reno, Nev. U.S. Borax completed two diamond drill holes to depths of 970 ft (297 m) and 690 ft (210 m) on the property in 1973 and 1974. The results were not encouraging, and the property was relinquished. All information presented here on the Turnley Ridge prospect is taken from Senter (1975).

The prospect is located near the center of the Turnley Ridge stock, a quartz monzonite porphyry.

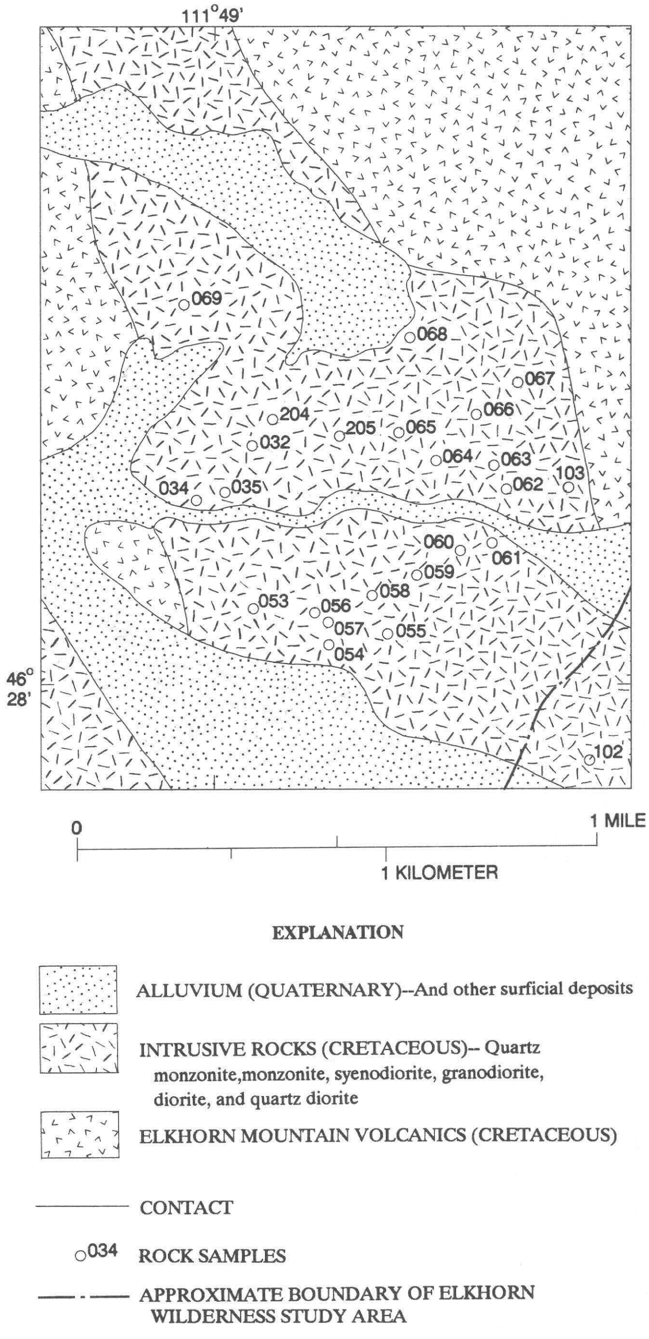


Figure 10. Geology and rock sample localities in the Jackson Creek area, Elkhorn Mountains, Mont. Sample numbers prefixed by 77SL.

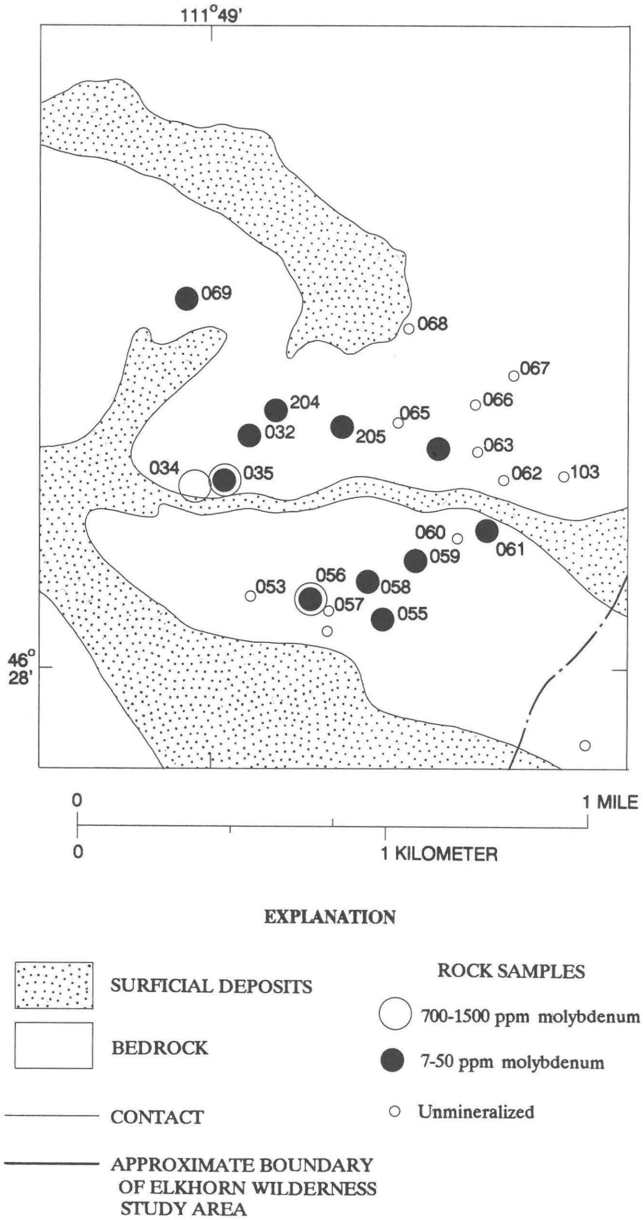


Figure 11. Copper and molybdenum content of rock samples from the Jackson Creek area, Elkhorn Mountains, Mont.

Modal analyses of four specimens showed the following averages: quartz, 35 percent; plagioclase, 28 percent; orthoclase, 30 percent; biotite, 2 percent; sericite, 2 percent; other mafics, 2 percent; and accessory epidote, sphene, apatite, and zircon, 1 percent. The stock is believed to be an outlier of the Butte Quartz Monzonite.

The distribution and characteristics of the hydrothermal alteration in the Turnley Ridge stock are shown on figure 12. Molybdenum and minor amounts of copper occur in quartz veins in the potassic and phyllic zones, most abundantly near the interface between the two zones. The best 10-ft (3-m) intercept in either drill hole was 0.079 percent Mo, with intercepts of 60 to 320 ft (20–100 m) averaging 50 to 200 ppm Mo. The fact that the orthoclase and quartz-rich central portion of the system crops out at the surface argues against the presence of better mineralization at depth, as does the observation by Senter (1975, p. 72) that "only rarely in hand specimen or in thin sections are the quartz veinlets displaced and crosscut by other quartz veinlets." Apparently the Turnley Ridge deposit represents a single phase, relatively weak porphyry system. The grade of the rock sampled does not represent ore, but the presence of this deposit provides additional encouragement for prospecting for porphyry systems in this part of the Boulder batholith.

Breccia Pipe Deposits

Breccia pipe deposits have produced very little of the mineral wealth of the study area, but they merit description because they may indicate mineral deposits at depth.

The two major breccia pipes—the Skyline and Blackjack mines—are shown on plate 3. They were mapped and sampled in detail during the present study.

Skyline Mine

The Skyline mine is in the cirque at the head of Queen Gulch, 1 mi (1.6 km) southeast of Crow Peak in the southern part of the study area. It was developed in a steeply plunging breccia pipe that has a roughly triangular horizontal section, with sides about 150 ft (46 m) long at the surface. The pipe cuts gently dipping andesite and pyroclastic quartz latite near the intersection of several normal faults, some of which may be pre-breccia and related to cauldron subsidence. Brecciated andesite and quartz latite in the pipe are cemented by vuggy quartz and tourmaline, and locally they have been partially to totally replaced by pyrite, galena, sphalerite, and sparse chalcopyrite, arsenopyrite, and marcasite. All sulfides have been leached at the surface leaving a porous iron-stained gossan. Numerous samples of the breccia pipe contain trace amounts (5–100 ppm) of molybdenum, tin, and tungsten. The deposit has been explored through two short adits, one of which leads to a 170-ft (51-m) winze and some short subdrifts, and by four diamond-drill holes. The most recent exploration (in 1953) was partially supported by the Defense Minerals Exploration Administration. The results of that exploration indicated that the volume and grade of the ore discovered did not justify further exploration at that time (McWilliams and Weeks, 1954).

Blackjack Mine

At the Blackjack mine, about 2 mi (3 km) north of the Skyline mine in the southern part of the study area, four shallow prospect shafts are in a steeply plunging

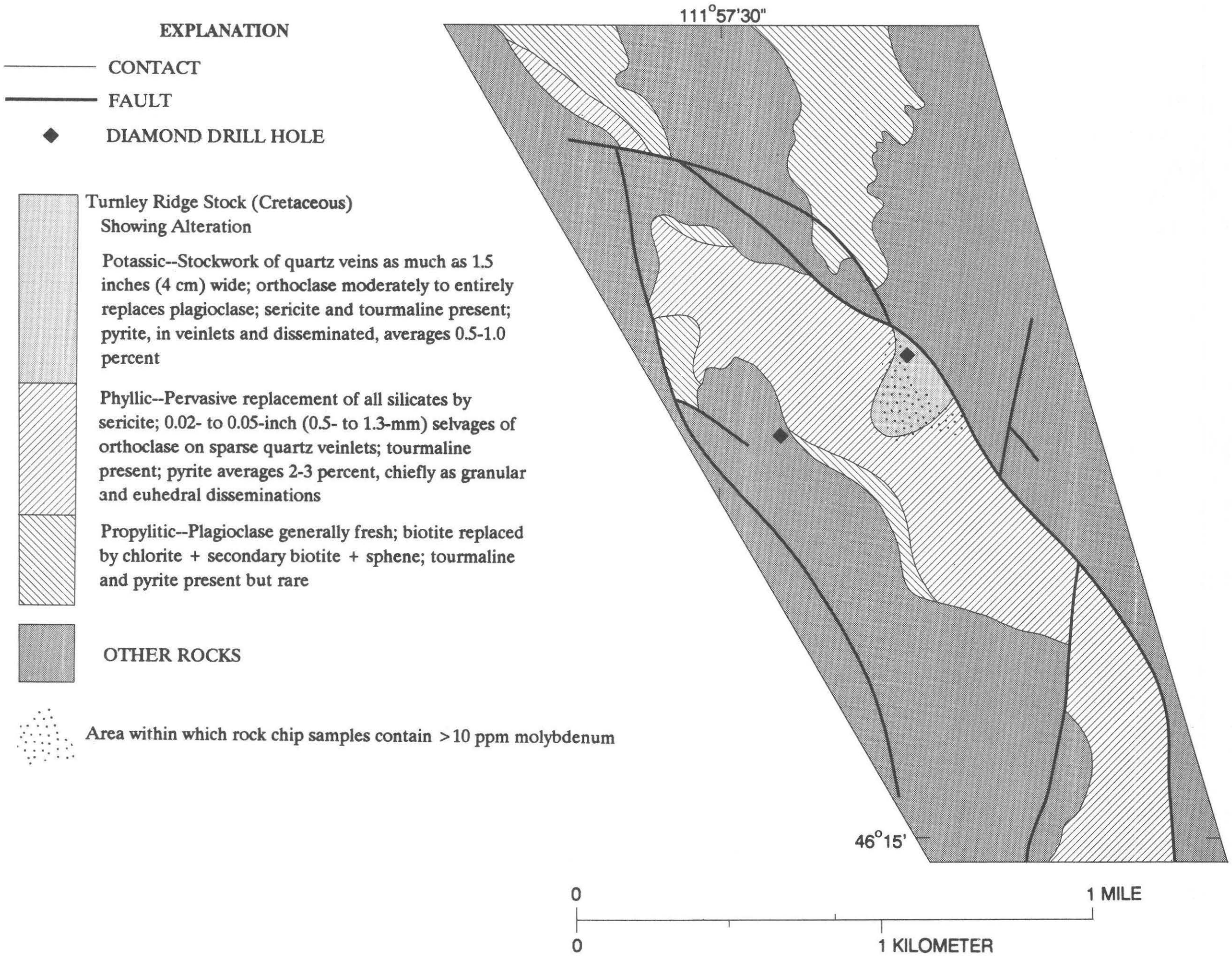


Figure 12. Altered and mineralized zones in the Turnley Ridge stock, Elkhorn Mountains, Mont.

breccia pipe which cuts andesite. The pipe, elliptical in plan view, is elongated west-northwesterly and is about 125 ft (38 m) long and about 60 ft (18 m) wide. The pipe is adjacent to a major fault (covered and not shown on pl. 1) that separates the andesite from cauldron-fill-type welded tuffs to the east. Brecciated andesite in the pipe is cemented by black tourmaline and quartz and lesser amounts of epidote and pyrite. Two exploration pits about 240 ft and 300 ft (73 m and 90 m) south of the pipe are on north- and north-northwest-trending fractures that are partly filled and replaced by veins of quartz and tourmaline and small amounts of pyrite. Most of the pyrite in surface outcrops has been oxidized to hematite and limonite.

Andesite, breccia, and vein samples show expectably high boron contents in and near the breccia pipe and in some veins. Molybdenum ranges from less than 5 ppm to 15 ppm, with a median of 5 ppm, in and near the breccia but is less than 5 ppm in the andesite. Copper and manganese are less abundant in the breccia than in andesite. Tin and tungsten were not detected in any samples.

The breccia pipe at the Blackjack mine is smaller than the breccia pipe at the Skyline mine but is cemented by the same high-temperature minerals. Both breccias have anomalous molybdenum contents although the Blackjack breccia lacks the anomalous tin and tungsten contents found in the Skyline breccia. Both pipes may be the result of venting of a volatile-rich intrusive that might contain significant amounts of metals. The lack of precious- and base-metal minerals and the lack of tin and tungsten anomalies suggest that the breccia at Blackjack is less deeply eroded than the breccia at Skyline.

Chicago and Last Hope Mines

The Chicago and Last Hope mines, about 2 mi (3 km) north of the study area (pl. 3), are described by Smedes (1966, p. 106) as being developed on veins that follow the contact between the lower and middle members of the Elkhorn Mountains Volcanics. However, detailed mapping indicates that near the Chicago mine these members are juxtaposed by a steep, down-to-the-south fault, which in most places is intruded by a ring dike of hornblende porphyry, which may mark the structural rim of a caldera. The Chicago and Last Hope mines and many unmapped prospect pits and shafts are developed at and near the contact of the hornblende porphyry dike with rocks of the middle member. The veins consist of quartz, carbonate minerals, pyrite, arsenopyrite, and small amounts of sphalerite and chalcopyrite. Gangue minerals are diopside, hedenbergite, garnet, tourmaline, epidote, and magnetite. The mines were worked for gold but also produced small amounts of silver, lead, copper, and zinc. The upper parts of the veins are oxidized and yielded high-grade gold ore. The mineralogy and structural setting at the Chicago and Last Hope mines is similar to that of the Skyline mine, suggesting that the Chicago and Last Hope veins may overlie one or more metal and volatile-rich intrusive bodies.

Significance of Geochemical Anomalies

This section attempts to place the geochemical anomalies discussed in an earlier section into a geologic perspective and to integrate the geochemical data with geologic observations.

Group 1—Precious- and Base-Metal Anomalies (Au-Ag-As-Pb-Cu)

Panned concentrate samples from eleven drainages are highly anomalous in the elements of this group. Seven of these drainages contain inactive precious-metal mines, as listed in table 3, and the anomalous amounts of metal in the samples were derived, at least in part, from these mines.

The other four drainages (Longfellow Creek, sample no. 77SL009; unnamed tributary of Crow Creek, sample no. 77LA008; Staubach Creek, sample no. 77SL023; cirque east of Elkhorn Peak, sample no. 77WM104) contain no known deposits and no veins were found, but the anomalous metal content or the samples suggests the presence of concealed or inconspicuous veins that contain precious and base metals.

All these drainages, except Staubach Creek, are found along or to the southeast of a line connecting the East Pacific mine and the town of Elkhorn. Thus, nearly all of the southeast part of the study area has a moderate potential (as defined in the Introduction) for precious- and base-metal deposits. The pattern is enhanced when zinc is considered along with other group 1 elements, even though zinc does not show a high overall correlation with these elements. The underlying nature of this pattern is not well understood. The Kleinschmidt, Champion, Marietta, Bullion King, Little Annie, Park, Eagle Basin, and St. Louis mines are all along or near the northeasterly trending Weasel Creek fault zone of Klepper, Ruppel, and others (1971), as are a series of related quartz monzonite porphyry stocks, but this structure forms an acute angle with the aforementioned line, as does the contact of the Boulder batholith with the Elkhorn Mountains Volcanics. Perhaps this northeasterly trending alignment of geochemical anomalies, ore deposits, and stocks is associated with an inhomogeneity in the Precambrian basement which is not otherwise reflected in younger rocks and structures.

Table 3. Samples with anomalous amounts of precious and base metals (group 1: Au-Ag-As-Pb-Cu) in drainages with known mines, Elkhorn Wilderness Study Area and vicinity, Montana

Sample no.	Drainage	Mines
77EB014	West fork Weasel Creek...	East Pacific.
77SL017	Weasel Creek	Stray Horse.
77DT008	East fork Badger Creek ...	Vosburg.
77SL020	West fork Badger Creek...	Champion.
77EB012	Indian Creek............	Marietta, Bullion King, Park.
77SL019	Tributary of Indian Creek .	Little Annie.
77SL002	West Fork Indian Creek...	St. Louis.

The group of precious- and base-metal deposits in and near the Vosburg stock on the east-central boundary of the study area is of particular interest because Klepper, Ruppel, and others (1971) reported that molybdenite occurs in some of the veins of the area. In addition, anomalous amounts of tungsten and molybdenum were found in some panned concentrate samples from drainages surrounding the Vosburg area. Accordingly, the area was mapped and sampled in detail during the present investigation.

Six of twelve vein samples from the area contained detectable (>5 ppm) molybdenum, and one sample contained 150 ppm tungsten. No molybdenum or tungsten-bearing minerals were recognized in hand specimen. Neither of these metals was detected in any samples of the stock. The observed occurrence of molybdenum and tungsten as accessory elements in the veins probably accounts for the geochemical anomalies; therefore the Vosburg is not likely to contain porphyry-type mineralization.

Six streams that drain radially from the ridge near the head of Staubach Creek at the northern end of the study area provided panned-concentrate samples (77SL023, 77EB027, 77DT005, 77LA014, 77DT006, and 77SL025) that are anomalous in a rather distinctive suite of elements: gold, silver, arsenic, bismith, niobium, thorium, and possibly yttrium and lanthanum. There are few prospects in the area, other than Jackson Creek. Rock samples collected from this prospect show no particular enrichment in this distinctive suite of elements, with the exception of one sample (77SL057), which contains >1,000 ppm bismuth and 0.5 ppm silver. None of the other rock samples from these drainages are enriched in any of the elements under consideration. These anomalies may indicate undiscovered deposits of gold, silver, arsenic, bismuth, niobium, and thorium.

Group 2—Rare-Metal Anomalies (Mo-W-Nb-La-Y-Th)

The 21 panned-concentrate samples which were highly anomalous in rare metals are conveniently grouped into 6 areas: (1) Golconda, (2) South Fork Warm Springs Creek, (3) Dutchman Creek, (4) Nursery Creek, (5) Hidden Lake, and (6) Lava Mountain.

The Golconda area, already described, appears to contain a copper-molybdenum porphyry system, and it seems reasonable to suspect that the rare-metal anomalies detected in the panned concentrates from that area may be related to the porphyry deposit. In the other areas, few geologic features suggestive of mineralization were seen. The designation of these areas as having mineral potential rests largely on the geochemistry of panned concentrates.

Thirteen rock samples from the South Fork of Warm Springs Creek show molybdenum contents ranging from <5 to 50 ppm and copper contents ranging from <5 to 500 ppm. Tin and tungsten were not detected. Of four samples containing 5 ppm or more molybdenum or 70 ppm or more copper, two are from precious-metal veins. One of the others (77SL099) is of aplite; it contains 50 ppm molybdenum and 30 ppm copper. Molybdenite is common as an accessory mineral in the late-stage aplites of the Boulder batholith (Becraft and others, 1963). The fourth sample (77SL108) is of a pyritic metavolcanic rock; it contains 10 ppm molybdenum and 20 ppm copper. It is believed that the anomalous molybdenum in samples from this area is present as accessory molybdenite in the precious-metal veins, and possibly in aplite enriched in molybdenum.

One of fifteen rock samples from the Dutchman Creek area in the west-central part of the study area (77SL120) contains detectable molybdenum. The quartz monzonite that underlies the area shows little hydrothermal alteration. The source of the geochemical anomaly is not known, but it may be the precious-metal veins in the area.

Three rock samples (77SL079, 77SL080, and 77SL082) from the Nursery Creek drainage, west of the study area, show detectable tin or molybdenum. Sample 77SL082, which contains 50 ppm molybdenum, is stained by iron oxides and contains hydrothermal alteration sericite, whereas the other two samples, anomalous only in tin, appear to be fresh. Alteration is not widespread in the Nursery Creek area; however, the low but anomalous tin and molybdenum in rock samples, coupled with local hydrothermal alteration, suggest that the Nursery Creek area has a moderate mineral potential for molybdenum.

Analysis of eleven rock samples from the Hidden Lake area in the southern part of the study area reveals three samples (77SL088, 77SL089, and 77BG152) with detectable molybdenum or tin. Two samples have high copper contents. A composite sample of brecciated andesite cemented by magnetite and stained by copper carbonates (77BG288) contains 15,000 ppm copper and 2,000 ppm zinc. This rock also contains 200 ppm boron, although tourmaline was not visible in the hand specimen. The breccia is exposed in the walls of a shallow exploration pit and is undercut about 50 ft (15 m) below by one of the adits of the Iron mine. A sample (77SL087) of a similar rock was collected in talus just northeast of Elkhorn Peak. This sample consists of brecciated andesite cemented by what appears to be tourmaline, and it contains 300 ppm copper, 1,500 ppm lead, and 1,500 ppm zinc. Boron was not found to be high in this sample.

The copper-rich breccias and molybdenum-tin-tungsten anomaly in this area may indicate breccia-pipe deposits similar to that at the Skyline mine.

Samples of extrusive and intrusive rhyolite from the Lava Mountain area, about 1 mi (1.6 km) northwest of the study area, contain unusually high amounts of tin, niobium, beryllium, fluorine, and lithium. Beryllium contents of 18 samples range from less than 1 to 20 ppm (median, 10 ppm), and tin contents for the same samples range from less than 10 to 50 ppm (median, 18 ppm). Such high beryllium and tin contents appear to be characteristic of the Oligocene rhyolite in the northern part of the Boulder batholith (D. R. Shawe, written commun., 1977). Molybdenum content of the rhyolite is low, ranging from less than 5 to 10 ppm (median, less than 5 ppm). Therefore, the anomalously high molybdenum observed in stream-sediment and panned-concentrate samples probably was not derived from the rhyolite. The molybdenum content of 12 samples of pre-rhyolite rocks in the Lava Mountain area ranges from less than 5 to 20 ppm (median, less than 5 ppm). The five samples of pre-rhyolite rocks that contain 5 ppm or more of molybdenum (77SL028, 77SL039, 77SL041, 77SL042, 77SL114) consist of either vein material or altered Butte Quartz Monzonite adjacent to veins. These veins have high silver, lead, and zinc contents and are probably similar to the White Pine vein, south of the Middle Fork Warm Springs Creek. The anomalous molybdenum in this area is probably related to accessory molybdenite in the precious- and base-metal veins.

Silver, lead, and zinc are present in four rhyolite samples (77SL036, 77SL037, 77SL038, 77SL040) from mine dumps on the south side of Lava Mountain. Silver in these samples ranges from 3 to 20 ppm, lead from 200 to 5,000 ppm, and zinc from <200 to 5,000 ppm. This mineralization appears to be similar to the local disseminations of galena and sphalerite in the rhyolite described by Smedes (1966). This lead-zinc-silver may be the result of a younger mineralization, but it may also be due to local assimilation and redistribution of sulfides in areas where rhyolite intruded pre-existing precious- and base-metal sulfide veins.

The rhyolite of Lava Mountain is a highly differentiated rock of the sort that is associated with tin and molybdenum deposits in many parts of the world. If such a target exists in this area, no direct expression of it appears at the surface, and any potential mineralization would probably be at depths of at least a mile.

Boron

The panned-concentrate drainage samples which are anomalous in boron form a particularly coherent pattern (pl. 4). In all cases, these samples represent areas underlain by Elkhorn Mountains Volcanics in a band as wide as 2.5 mi (4 km) along the contact with the Boulder batholith. This is compelling evidence that boron was fixed in this band by reaction of hydrothermal fluids moving upward and outward from the cooling batholith with the surrounding wall rocks. In this region, tourmaline very commonly coats the joint faces of the volcanic rocks.

The relationship of anomalous boron to economic mineral deposits is not so clear. Knopf (1913a) discussed at some length the significance of tourmaline in some of the precious- and base-metal deposits of the Greater Helena mining district. He felt that tourmaline-bearing deposits were earlier and formed at higher temperature than the other vein deposits of the area. This hypothesis fits well with the idea presented here that the batholith is the direct source of the boron, but a direct comparison cannot be made because none of the deposits Knopf discussed are near the study area, and no vein deposits in the study area are known to contain tourmaline.

Three breccia-pipe deposits that contain tourmaline do occur in and near the study area: the Tourmaline Queen, the Skyline, and the Blackjack, discussed in an earlier section of this report. They all occur near the eastern edge of the band of anomalous boron. It would seem that those breccia pipes could have formed late in the intrusive history of the Boulder batholith.

Several geologic traverses were made within drainages that panned-concentrate samples showed to be anomalous in boron. Some samples collected contain 100 to 2,000 ppm boron. Tourmaline occurs chiefly as coatings on joint faces, but some pieces of float were found which indicate the presence of undiscovered tourmaline-bearing breccia pipes. Several samples contained detectable molybdenum. An area west of Bullock Hill contains a large number of small trenches and prospect pits. Samples from these pits contained 1 to 2,000 ppm silver, 300 to 20,000 ppm lead, and 200 to 10,000 ppm zinc. These samples, however, did not contain anomalous boron or molybdenum and apparently belong to a different geochemical system.

Uranium and Thorium Potential

By Karen J. Wenrich, William R. Miller, Vivian J. Suits, and John B. McHugh

During the summer of 1977 an evaluation was made of the uranium and thorium potential in and adjacent to the Elkhorn Wilderness Study Area. Uranium-bearing deposits have been known since 1949 in the area west of Clancy, Mont., 4 mi (6.5 km) northwest of the study area. Despite comprehensive studies of these deposits (Becraft and others, 1963; Roberts and Gude, 1953b), no significant production of uranium has occurred. In the Clancy mining district, the uranium is present as pitchblende and secondary minerals located near silicified fracture zones in the quartz monzonite of the Boulder batholith or the younger alaskitic dike rocks. The uranium minerals are usually in silica stringers, along fractures, or in pore spaces of the altered host rock (Roberts and Gude, 1953b). According to Tilling and Gottfried (1969, p. E6), the Boulder batholith is higher in uranium and thorium than the surrounding wall rocks. Rocks of the batholith contain as much as 10 ppm uranium, and the wall rocks generally contain less than 5 ppm uranium. The batholithic rocks contain more than 15 ppm thorium and locally as much as 42 ppm, whereas the older rocks generally contain less than 15 ppm thorium. With a few exceptions, only the alaskitic dike rocks contain more than 20 ppm thorium.

The study area was evaluated by means of a geochemical survey, using both surface waters and panned concentrates of stream sediments, and by an aerial gamma-ray survey. The water samples were collected only from streams draining the Boulder batholith, where the radio-element content was known to be considerably higher than in the older wall rocks. Both uranium and radon were determined in the water samples, uranium by extraction fluorometry and radon by an alpha-scintillation technique. Thorium was determined in the panned concentrates by semiquantitative emission spectroscopy. The aerial gamma-ray survey was flown over the northwest part of the study area, over the Clancy mining district, and over the intervening area. The data and results from the survey are presented by Duval and others (1978). The portions of flight lines from the aerial survey that show high eU-to-K and eTh-to-K ratios are shown on plate 5.

The thorium content of the panned concentrates delineates the contact between the Boulder batholith and its wall rocks to the east. With few exceptions the thorium content of samples from the eastern part of the study area is less than the detection limit of 200 ppm, whereas panned concentrates from streams draining the Boulder batholith range from less than 200 to 3,000 ppm thorium. We consider thorium contents greater than 2,000 ppm to be anomalous, and areas where high thorium values were obtained have been outlined on plate 5. Two of these areas, one in Muskrat and Rawhide Creeks and the other south of Prickly Pear Creek, are coincident with an anomalously high radiometric eTh-to-K ratio. High eTh-to-K ratios were also found in the vicinity of Burnt Mountain, Strawberry Butte, and Lava Mountain, where young rhyolitic lavas cap the batholith. Two samples from the upper part of the South Fork Warm Springs Creek contain some of the highest thorium concentrations.

Three small areas underlain by the Boulder batholith contain high amounts of radon in surface-water samples (pl. 5). The samples with the highest radon were collected from the upper part of Dutchman Creek—an area that straddles the study area boundary. The sample sites lie just downstream from a major northeast-trending fracture (pl. 5) identified by E. R. Verbeek (oral commun., 1977). The radon content of these surface-water samples shows no correlation with uranium concentrations. In general, the radon content in this entire area is abnormally high; radon contents elsewhere in and near the study area are rarely greater than 50 ρCi/L. A small area around the town of Alhambra (pl. 5) contains hot springs, hot flowing wells, and cold wells that show exceptionally high radon contents, 3,000–37,000 ρCi/L (Leonard and Janzer, 1977). These are among the highest radon contents found in the United States.

No large areas of significantly high uranium in surface water were found, although anomalous values were measured on samples from Badger Creek (13 μg/L), Rawhide Creek (13 μg/L), and an unnamed tributary of Clancy Creek (13 μg/L). All these drainages, except for the headwaters of Rawhide Creek, are outside the study area. In most areas except for Dutchman Creek and Prickly Pear Creek, where uranium concentrations are low, uranium in the surface waters ranged from 1 to 4 μg/L. These values are above average for uranium in surface water, particularly for small, first- and second-order streams of moderately high U conductivity ratios. With the exception of one sample at 7.2 μg/L, the wells of high radon content around Alhambra contain less than 1 μg/L uranium. High eU-to-K ratios determined in the aerial radiometric survey occur sporadically over the entire area (pl. 5) and do not correlate with uranium in surface water.

Although the uranium content of surface water in the western part of the study area and adjacent land to the west is not extremely high, the overall radio-element content of the water and stream-sediment samples, as well as the eU-to-K and eTh-to-K ratios, is high and merits further study. The extremely high radon content in the Dutchman Creek area might possibly be explained by southeast movement, along fractures, of radon originating perhaps from uranium occurrences in the Clancy district to the northwest. Movement of this radon may then have been impeded by the major fracture (pl. 5) southeast of the anomaly. However, this high radon concentration in the surface water is more likely due to a localized source because of the short half life of Rn_{222} and the large distance between the Clancy district (about 6 mi (10 km)) and Dutchman Creek. The area around Muskrat and Rawhide Creeks is high in all radio-elements and probably merits the most attention. Possibly, localized uranium occurrences are contributing to the high radon values in the wells and hot springs at Alhambra, as well as in surface water of areas outlined on plate 5.

Time was not available to conduct the follow-up field studies necessary to evaluate the possible resource potential that could be indicated by the anomalous samples described above. These results are reported for future reference.

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