DEPARTMENT OF THE INTERIOR

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MINERAL RESOURCES OF THE RAWAH WILDERNESS, LARIMER COUNTY, COLORADO

By

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with a section on Interpretation of aeromagnetic data

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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 currently being studied. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Rawah Wilderness, Roosevelt National Forest, Larimer County, Colorado.

SUMMARY

The mineral resource potential of the Rawah Wilderness, as enlarged in 1981, and some adjacent area were appraised by the U.S. Geological Survey and U.S. Bureau of Mines. The mineral resource potential is interpreted to be low, and no locatable or leasable mineral resources are known or inferred from available geological, geophysical, and geochemical data.

Geochemical data indicate minor local enrichment of uranium, fluorspar, tungsten, and molybdenum, and although deposits of these commodities could be present the probability is considered low.

The Rawah Wilderness occupies about 119 mi^2 (309 km^2) on the east flank of the southern Medicine Bow Mountains in north-central Colorado. The crest of the Medicine Bow Mountains is sharp, between 11,800 ft (3,600 m) and 12,800 ft (3,900 m) high, and scalloped by a series of cirques. East of the crest and about 1,000 ft (about 305 m) lower is a 3-mi-wide (5 km) bench that slopes generally eastward. The east boundary of much of the study area is along the edge of the Laramie River valley, which is a steep-sided, glacially eroded canyon sharply incised about 1,300 ft (400 m) below the bench.

The mineral appraisal was accomplished by interpreting the geologic, geochemical, and aeromagnetic data and the results of studies of mining claims and prospect diggings.

Most of the area is occupied by part of the Rawah batholith, a Proterozoic X granitic body within which are many inclusions of country rock gneisses. Three slabs of Permian-Triassic sedimentary rocks are preserved as fault blocks between walls of Proterozoic rocks. Trachyandesite lavas of Tertiary age lie on the Proterozoic rocks in an area about 2.5 mi (4 km) long along the southeast side of the area, and a single small Tertiary porphyry dike cuts Proterozoic rocks on the crest of the range. Quaternary deposits are chiefly till and colluvium that together blanket bedrock in much of the southern two-thirds of the area.

Structurally, the Medicine Bow Mountains in Colorado comprise the southern end of a north-northwest-trending anticlinal uplift flanked by synclinal intermontane basins. Rocks in the study area, which are in the core of this uplift, have been strongly deformed by faulting and shearing. The nature of the shear products in these structures and the relations of faults and shear zones to Proterozoic intrusive rocks of two ages show that deformation took place at least four times in the Proterozoic. Tabular zones of blastomylonitic rock in gneisses engulfed by granitic rocks of the Rawah batholith indicate pre-Rawah shearing, and the syntectonic emplacement of the Rawah batholith was accompanied by shearing. At least two episodes of post-Rawah brittle deformation are in evidence, and the roughly northwest and northeast rectilinear pattern of faults that dominate the area apparently evolved from that tectonic activity. Many of that Proterozoic faults were reactivated at various times, including Laramide and younger periods of faulting. Laramide faulting was profound; it, coupled with the large anticlinal uplift, was largely responsible for shaping the Medicine Bow Mountains and positioning them relative to adjacent structural blocks. A pivotal Laramide thrust fault on the east flank of the Medicine Bow Mountains begins about 6 mi (10 km) north of the study area. As eastward displacement on the thrust increases to the south, Phanerozoic sediments are progressively over-ridden by the crystalline rocks, and no sediments are present at the surface along the east side of the study area. The trace of the thrust probably continues south in the Laramie River and Joe Wright Creek valleys and may merge with the Middle Fork tear fault half a mile (1 km) south of the

study area. The formation of high-angle, northwest-trending, east-dipping reverse faults in the southwest portion of the study area probably accompanied thrusting. Most high-angle faulting occurred in late Laramide and middle and late Tertiary time.

The salient aeromagnetic features are several magnetic highs in the central and northern parts of the study area and a linear magnetic low along the Laramie River valley. Some of the magnetic highs can be shown to be the result of topography; others are interpreted as resulting from deeply buried bodies of mafic rock. The magnetic low may result from a buried wedge of sedimentary rocks, but it is not caused by topography. None of the magnetic features suggest an association with mineral resources.

The study area is situated in a part of Colorado in which few "hard-rock" mineral resources have been found. The highly productive Colorado Mineral Belt is more than 30 mi (50 km) to the south, and the intervening area contains only a few small precious-metal mining districts. The Northgate fluorspar district 10 mi (15 km) northwest of the study area has been a large producer. Thus, attention is focused on the possible occurrence of fluorspar in the area, although none has yet been found. Uranium minerals in a fault zone in Proterozoic rocks 4 mi (6.5 km) east of the study area suggest the possibility of similar deposits in the study area, but the traces discovered thus far are too small to permit an inference of uranium resources.

No mining has taken place in the study area, and little evidence of prospecting or claim staking were found. One mining claim southeast of Montgomery Pass was staked in an area of fractured, sheared, and faulted granitic rocks and Permian-Triassic red beds. The rocks are locally silicified, but no ore minerals were found, and chemical analysis of samples did not disclose the presence of significant amounts of metals. Several small prospect pits in a gneiss xenolith west of Glendevey and north of McIntyre Creek contain minor amounts of rutile and topaz; however, excavation activity at this site was probably triggered by the local presence of lazulite, which may have been mistaken for a blue copper mineral. A few prospects in the northeastern part of the study area contain minor amounts of copper and silver but no suggestion of mineable deposits.

The geochemical survey disclosed only a few weak anomalies of copper, silver, arsenic, tungsten, uranium, thorium, and molybdenum. Anomalous amounts of copper and silver were obtained from rock samples taken from small veins west of and in the prospect pits in the northeast part of the study area. The highest silver value is 1.5 ppm. Arsenic was found in sheared, silicified, argillized, and pyrite-bearing granitic rocks at small prospect pits in the southern part of the area in amounts that range from 500–2,000 ppm. Tungsten was detected in a few stream-sediment and panned-concentrate samples in areas that suggest weak tungsten mineralization along some of the major faults. Uranium was found in anomalous amounts in a few samples, the highest of which (>120 ppm) was in a very small carbonate vein. Thorium that is commonly detected in stream-sediment samples in amounts ranging from about 50–150 ppm is probably present in allanite and other trace minerals from the granitic rocks. Molybdenum is present in low amounts (mostly 5–10 ppm) in many stream-sediment samples and in a few samples of fractured and altered granitic rocks along faults. The geochemical survey suggests the possibility of tungsten and uranium resources in deposits along major faults although no specific exploration targets are indicated.

INTRODUCTION

The Rawah Wilderness in north-central Colorado occupies most of the eastern flank of the southernmost Medicine Bow Mountains. The crest of the mountains is the western boundary of Roosevelt National Forest and also the western boundary of Larimer County. The west flank of the mountains is in Jackson County. It is partly Colorado State Forest land, which also extends east of the crest in several places as small triangular tracts, and partly Routt National Forest land. A 27,460-acre (11,113 ha) Rawah Wilderness was established in 1965 by passage of Public Law 88-577. In 1981, Public Law 96-560 provided for enlargement of the Rawah Wilderness by 48,930 acres (19,802 ha). The additions formerly constituted the East Rawah and East Rawah A Roadless Areas (RARE II areas). In addition to the combined 76,390 acres (30,915 ha), this report covers some other contiguous land, chiefly a narrow fringe around all but the northeast margin of the wilderness. The entire area (about 155 mi^2 or 250 km^2) investigated, which is about 26 mi (42 km) long and 5 mi (8 km) wide, will be referred to in this report as the Rawah study area or simply study area. These general relationships are shown on figure 1.

The 1981 additions to the Rawah Wilderness were made after completion of the fieldwork for this study. Consequently, an area of a few square miles in the northeast corner was given only cursory attention. However, based on that preliminary examination, the geology of the small area is believed to be rather simple and uniform. Two mineral occurrences within the area were examined fairly carefully, thus it is with only slight hesitancy that the limited investigation is considered to be adequate for the purpose of this report.

The study area is drained mostly by streams that flow east and northeast into the Laramie River, which for a distance of about 12 mi (20 km) marks the east boundary of the area. Several small streams in the southern part of the area flow easterly into Chambers Lake or into Joe Wright Creek, a tributary of the Cache La Poudre River that flows through Chambers Lake. Faults exert a strong control on the drainage, particularly in the northern half of the area. The upper tributaries of La Garde Creek flow northwest and southeast in a fault-line valley into Shipman Park, where they join, and the resulting stream flows northeast across the structural grain through a narrow canyon. The headwater valley of McIntyre Creek follows the same fault for almost 7.5 mi (12 km). West Branch Laramie River flows along the trace of a northeast-trending fault for over 2.5 mi (4 km).

The south-central part of the Rawah study area is characterized by a series of steep-walled cirques alined along the crest of the Medicine Bow Mountains for a distance of about 6 mi (10 km). This is the highest part of the range and includes Clark Peak (12,951 ft [3,950 m]), South Rawah Peak (12,644 ft [3,860 m]), and North Rawah Peak (12,473 ft [3,805 m]) (fig. 1). South of Clark Peak the effects of glaciation gradually become less noticeable as the altitude becomes somewhat lower, although Diamond Peak, at the south end of the study area, is 11,852 ft (3,600 m) in altitude. Northward from North Rawah Peak the altitude of the range becomes lower, and in less than 6 mi (10 km) the crest is below timberline, which in this area is at an altitude of about 10,800 ft (3,300 m). About two-thirds of the study area is below timberline, and virtually all the lower eastern and northern parts are timbered--principally with Englemann spruce and lodgepole pine. Most of the cirques contain small lakes.

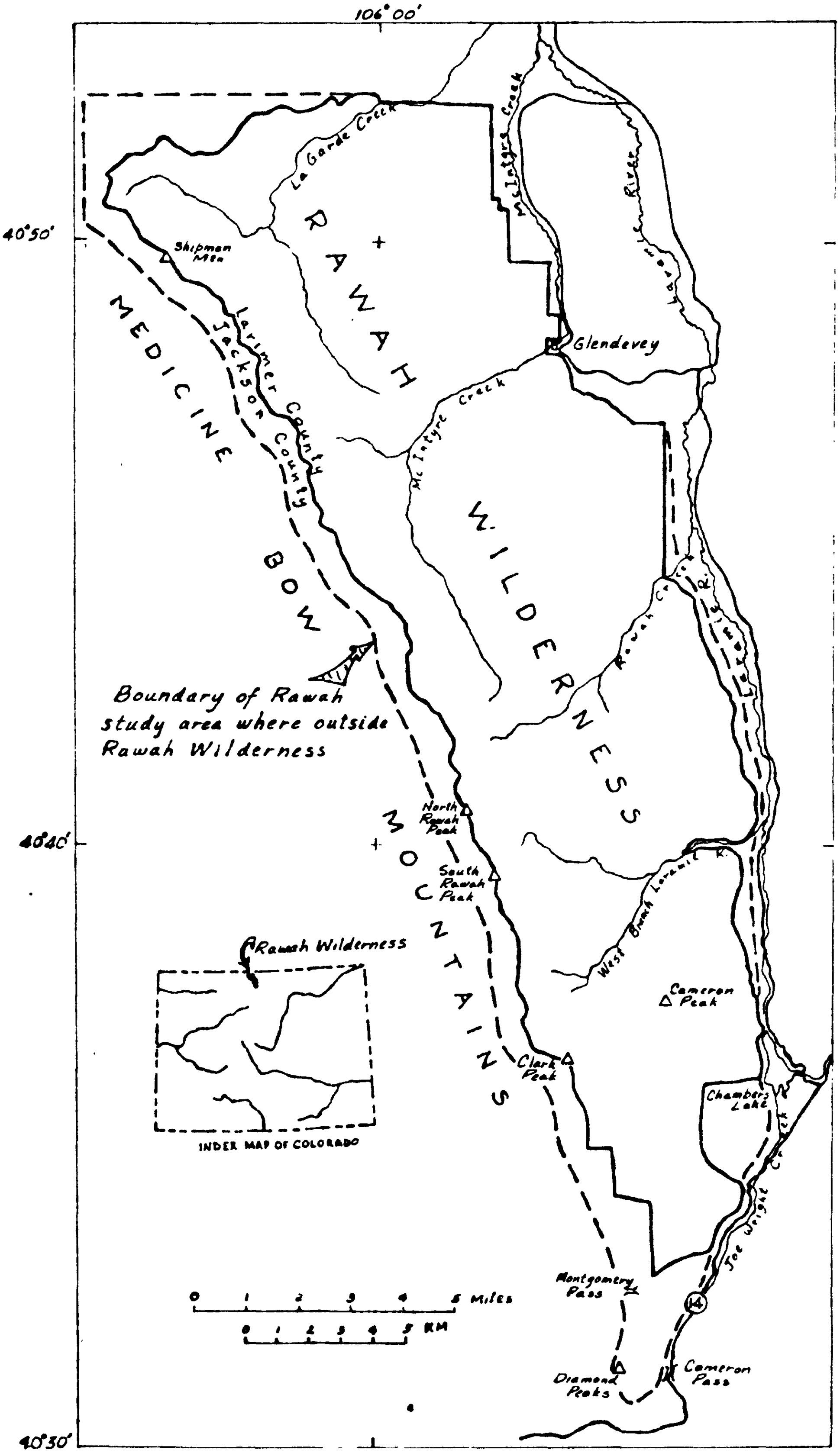

Figure 1.--Index map showing Rawah Wilderness and adjacent roadless areas, north-central Colorado.

Vehicular access to the study area is provided by State Highway 14, a principal east-west highway across the mountains, and by a maintained gravel road (State Highway 10) in the Laramie River valley that branches from highway 14 near Chambers Lake (fig. 1). Highway 14 parallels the southeastern edge and skirts the southern tip of the area near Cameron Pass. A road that branches from the Laramie River road leads to the small settlement of Glendevey near the northeast edge of the area (fig. 1).

Five principal trails head along these roads to provide foot and stock access to the study area. Trails follow McIntyre Creek, Rawah Creek, West Branch Laramie River, and Fall Creek (tributary to Chambers Lake); the fifth trail leads southwest from the road a half mile (1 km) southeast of Glendevey. These trails are interconnected in the study area and with lesser used trails that enter the area from the Colorado State Forest to the west. One such trail is a primitive road near Montgomery Pass that crosses the range near the south end of the area; at the time of this study it was closed to vehicular traffic.

Previous studies

Prior to the present investigation, the bedrock in the Rawah study area had been studied only in the Shipman Mountain area and in a small area near Montgomery Pass. The Shipman Mountain 7 1/2-minute quadrangle was mapped geologically by M. E. McCallum in 1971 and 1972 and that mapping has been used in the compilation of plate 1. Additional mapping was done in the Shipman Mountain area by Filson (1973), and a petrographic evaluation of the crystalline rocks in the northernmost part of the wilderness is included in a study by Hartman (1973). Gorton (1953) in reconnaissance studies and Ward (1957) in a compilation of student mapping evaluated the fault slices of sedimentary rocks at Montgomery Pass and at the southern tip of the Medicine Bow Mountains but did not subdivide the Precambrian rocks. Gorton (1953) also described the trachyandesite of Zimmerman Lake that extends west onto the southern flank of the Medicine Bow Mountains. K. W. Grove (written commun., 1973) subdivided Precambrian rocks in the southern part of the range. Some rocks called hornblende gneiss and schist by Grove are interpreted to be gneissic hornblende granodiorite in this report.

No studies of economic geology in the study area are known.

Present investigations

The study of the mineral resources of the Rawah area represents a cooperative effort by the U.S. Geological Survey and U.S. Bureau of Mines. Pearson, McCallum, and Griswold mapped the geology and examined the area for evidence of mineral deposits. Geochemical samples were collected of sediment from all streams and of fresh and altered rocks. The samples were analyzed by spectrographic, chemical, and instrumental techniques in U.S. Geological Survey laboratories in Golden, Colorado. Most of the spectrographic analyses were done by Jerry Motooka and chemical analyses by Craig Curtis. Delayed neutron analyses for uranium and thorium were done by H. T. Millard, Jr., and others, and equivalent-uranium determinations were made by J. C. Negri. Lowell Patten examined county courthouse records in Fort Collins and Walden, Colorado, for records of mining claims staked in the area, studied the relevant literature, examined and sampled mining claims and prospects, and made a reconnaissance of the area.

Acknowledgments

Fieldwork in the Rawah study area benefited greatly from cooperation of numerous ranchers, who permitted access across private land, and of the U.S. Forest Service staff, particularly those at Stub Creek Guard Station for providing a camp site, and at offices in Fort Collins and Walden. Personnel in the County Clerk's offices in Jackson and Larimer Counties gave assistance that is greatly appreciated.

GEOLOGY

Geologic setting

The southern part of the Medicine Bow Mountains is a narrow rugged north- to north-northwest-trending range composed chiefly of Precambrian crystalline rocks. Although a separate orographic entity, the Medicine Bow Mountains are geologically a part of the Front Range (fig. 2) to the east and southeast. The Front Range has been considered a broad plateau bounded by oppositely facing monoclines (Tweto, 1968) that are composed of Paleozoic and Mesozoic sedimentary units lying unconformably on the Precambrian crystalline rocks in the core of the range. Locally broken by thrust and tear faults, one of the monoclines defines the west flank of the southern Medicine Bow Mountains. In this monocline, Permian and Mesozoic sedimentary rocks dip west beneath North Park, a broad intermontane structural basin that contains thousands of feet of Tertiary beds. Geomorphically the northern part of the Front Range is separated from the Medicine Bow Mountains by the fault-line valley of the Laramie River. Were it not for erosion of the Laramie River valley along the fault zone, the Medicine Bow Mountains would be merely the western edge and highest part of the Front Range plateau, which extends about 35 mi (55 km) east of the Laramie River to its margin with the Great Plains.

The Precambrian rocks in the Rawah study area are chiefly a heterogeneous granitic batholith called the Rawah batholith (McCallum and others, 1975). Abundant inclusions in the batholith, some exceeding half a mile (1 km) in length, consist of various metasedimentary and metaigneous gneisses. The south edge of the batholith is approximately coincident with the southern tip of the study area, but the gradational, irregular, and poorly exposed nature of the contact make precise determination of its position difficult. Both the batholith and inclusions have been intruded by a few northerly trending diabase dikes, the age of which is Proterozoic according to W. A. Braddock (oral commun., 1981). Trachyandesite and andesite lavas and a younger group of rhyolitic volcanic rocks make up a small, Tertiary volcanic field lying south of the study area. Remnants of the trachyandesite lavas occur in the study area along the southeast margin of the Medicine Bow Mountains. Tertiary intrusive rocks are extremely rare in the Medicine Bow Mountains despite the fact that they and related volcanic rocks of Tertiary age are abundant a few miles (several kilometers) to the south.

The Precambrian rocks within the Rawah study area are fractured and sheared by large numbers of faults and broad crushed zones, the most continuous of which trend parallel to the range and continue far to the northwest. Relations of fault movement to rocks and structures of known age show that faulting took place several times in the Proterozoic, during the Laramide, and in probably more than one episode in mid- to late-Tertiary time. The southern end of the Medicine Bow Mountains is interpreted to be allochthonous, the block having moved east on a west-dipping Laramide

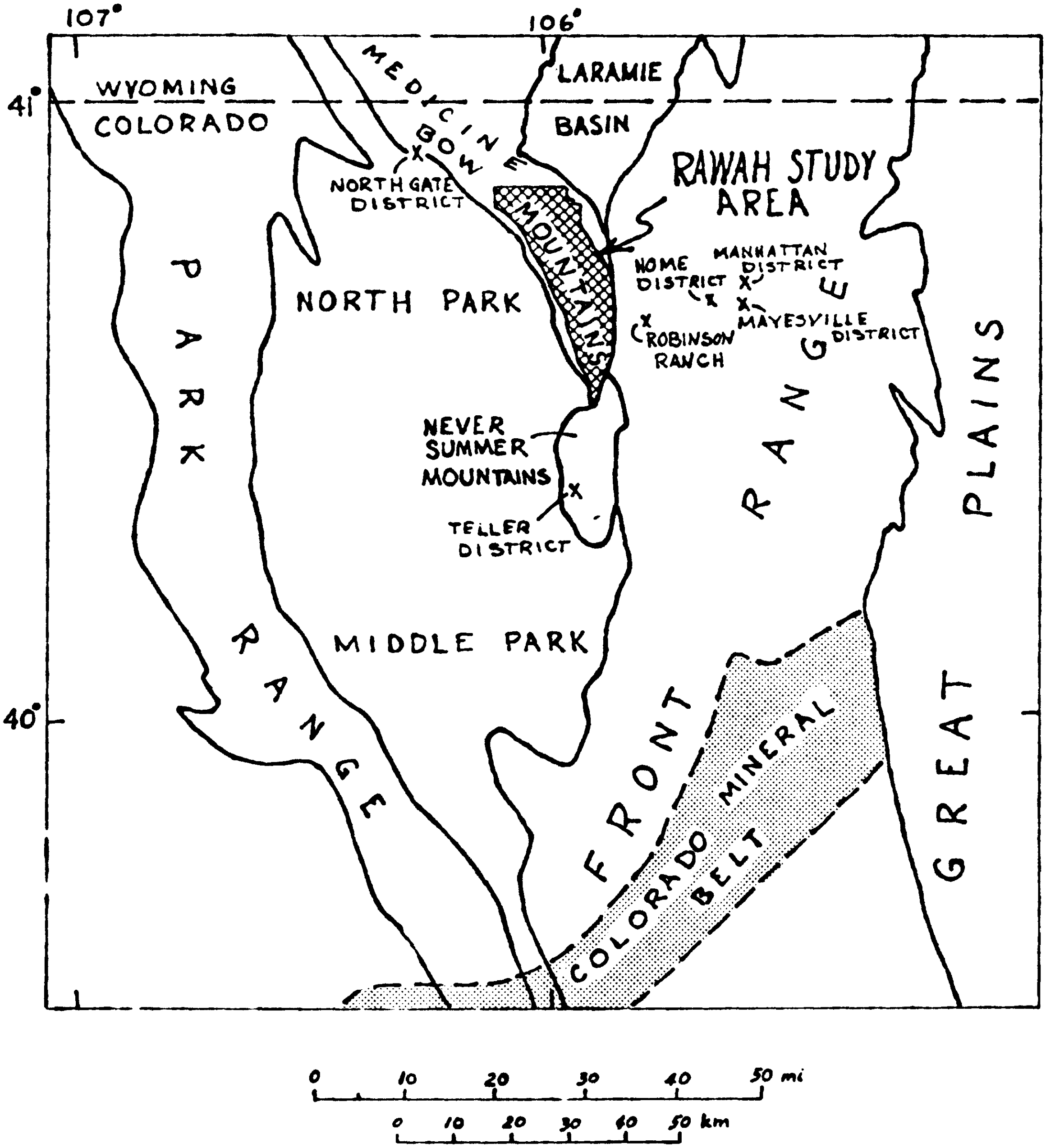

Figure 2.--Map showing features in the vicinity of the Rawah study area.

thrust. Blocks and slices of Mesozoic sedimentary rocks have been preserved between walls of Precambrian crystalline rocks. Several faults also extend from the Precambrian crystallines into flanking sedimentary units.

Quaternary deposits consist mainly of moraines that were formed by glaciers that moved out of the numerous cirques along the crest of the range and coalesced to cover most of the eastern edge of the study area; thick morainal sequences characterize all major stream valleys. Several major glacial advances are represented by the deposits, the last of which was confined to cirque areas only a few hundred years ago.

Precambrian rocks

The oldest rocks in the Rawah study area are inclusions of metasedimentary and metaigneous rocks scattered throughout the Rawah batholith. These wall-rock inclusions are similar to pre-batholithic units exposed in adjacent areas to the east and south and in the Park Range some 25 mi (40 km) to the west. The inclusions comprise about 3 to 5 percent of the batholith at the level now exposed. These rocks are probably comparable in age to similar units in the Front Range that are older than 1.75 b.y. (Hedge and others, 1967; Peterman and others, 1968).

Most inclusions are tabular and elongate parallel to the internal layering and foliation, although many are very irregular and they interfinger and intergrade with the batholithic rocks. They are all intruded by dikes, sheets, and irregular bodies of pegmatite, aplite, and other granitic phases of the batholith. Most inclusions are less than 300 ft (100 m) wide and 500 ft (1,500 m) long. Plate 1 shows only the largest individual inclusions. In general, large inclusions are most prevalent in the southern part of the area, probably as a result of proximity to the southern margin of the batholith.

The inclusions are composed of a wide variety of rock types that, for convenience in mapping at the scale used in this study, have been combined into three groups: metasedimentary, metaigneous, and hornblendic gneisses of uncertain origin, principally amphibolite. Most of these rocks are to some extent migmatitic. The metasedimentary rocks are dominantly biotitic gneisses rich in quartz, feldspar, and commonly muscovite as well as biotite. Garnet, sillimanite, and cordierite are locally abundant, either singly or in combination. Quartz gneisses that contain variable amounts of rutile, ilmenite, sphene, topaz, and sillimanite crop out 2 mi (3 km) north as well as 2.5 mi (4 km) west of Glendevey. These rocks were studied in more detail because of their rutile content and are discussed in a later section of this report. The locality west of Glendevey contains tourmaline and the uncommon mineral lazulite (magnesium-iron-aluminum phosphate). Inclusions composed of rocks of igneous origin range in composition from metapyroxenite to meta-quartz diorite, quartz diorite, tonalite, trondhjemite, and granodiorite. It is uncertain how many of these inclusions are early phases of the Rawah batholith. Inclusions mapped as amphibolite, hornblende gneiss, and biotite hornblende gneiss have been lumped as amphibolite and most are probably metavolcanic.

The lithologically heterogeneous Rawah batholith constitutes the bedrock in most of the study area. The batholith has been dated by a Rb/Sr whole-rock isochron at approximately 1.71 b.y. (McCallum and Hedge, 1976), which is similar to the age of the Boulder Creek batholith and related rocks to the south (Peterman and others, 1968). The dominant rock is biotite monzogranite and porphyritic biotite monzogranite (plutonic rock names according to IUGS classification, Streckeisen, 1976). Hornblende-bearing granodiorite and quartz monzodiorite are also common, and alaskitic and pegmatitic phases in veins, narrow dikes, conformable layers, and irregular masses are locally abundant. Wall-rock contamination is evident in the variation in composition and texture associated with varying degrees of migmatization and assimilation, particularly in the vicinity of country-rock inclusions. Most of the batholithic rocks are foliated. Primary foliation is defined by the alinement of microcline phenocrysts and locally mafic schlieren and (or) concentrations of strongly alined biotite, hornblende, or mixtures hereof. Secondary foliation, commonly parallel or subparallel to primary foliation, is defined by the parallel orientation of biotite and hornblende and planes of cataclasis. The cataclastic foliation apparently is younger than the mineral-orientation foliation, but the geometry of shear planes was controlled by the strong preferred orientation of the minerals defining the earlier formed planar fabric. This episode of cataclasis probably occurred during the final stages of or shortly following the termination of batholith crystallization. Another episode of clearly post-crystallization cataclasis generated a weak but locally prominent cataclastic cleavage that crosscuts earlier foliations.

North- to northwest-trending diabase dikes of probable late Proterozoic age are exposed discontinuously along the east and northeast edge of the study area, where they cut rocks of the Rawah batholith. Short faulted segments of the dikes are exposed for several miles along the steep lower wall of the Laramie River valley north of Chambers Lake (fig. 1). From Springer Creek north to Stub Creek (pl. 1), a distance of 7 mi (11 km), the dikes are faulted out or covered by surficial deposits. Northwest of Stub Creek one or two parallel dikes are continuous except for small offsets along northeast-trending faults. These dikes are part of a northwest-trending dike system that has been traced almost continuously from west of Boulder, Colorado, where it is called the Iron Dike, to the Colorado-Wyoming border, a distance of 80 mi (130 km) (Lovering and Goddard, 1950; Wahlstrom, 1956; Braddock and Cole, 1978; and M. E. McCallum, unpub. mapping, 1975). Dikes with a similar trend also occur within the south-central part of the Rawah study area, but these can rarely be traced for more than several hundred feet (100 m or so).

Permian to Jurassic sedimentary rocks

Sedimentary rocks of latest Paleozoic and of Mesozoic age occur as fault blocks and slices at three places within the study area. These rocks are the Permian and Triassic Chugwater and the Jurassic Sundance Formations which are the lowest sedimentary units exposed along the southwest flank of the Medicine Bow Mountains and along Highway 14 south of the study area. The largest block is in Shipman Park in the northern part of the study area where scattered outcrops of Chugwater redbeds protrude through surficial deposits and indicate the presence of a half-graben about 4 mi (6 km) long and as much as 0.6 mi (1 km) wide. At Montgomery Pass in the southern part of the study area, a north-northwest-trending fault slice of the Chugwater and Sundance Formations, about half a mile (1 km) long and as much as 525 ft (160 m) wide, may be bounded by west-dipping thrusts. According to Gorton (1953), this slice continues west of the crest of the range for only several hundred feet, where it is truncated by an east-trending tear fault. The southern end of the fault slice is concealed beneath colluvial debris, but it seems to be thinning to the south. The third fault block of sedimentary rock is revealed by float of partly silicified gray limestone and red sandstone and siltstone north of Blue Lake. The limestone is probably the Forelle Limestone that lies several feet above the base of the sedimentary section and which is mapped with the Chugwater Formation in this report.

Tertiary trachyandesite

Lava flows of trachyandesite crop out in the valley of Joe Wright Creek along the southeast margin of the study area and were designated the Zimmerman Andesite (pl. 1). These flows are largely covered by surficial deposits and are confined to a narrow belt which extends for about 12 mi (20 km) from about 0.6 mi (1 km) south of Chambers Lake to the crest of the Never Summer Mountains east of Cameron Pass. Trachyandesite is best exposed in roadcuts along Highway 14 near the mouth of the North Fork Joe Wright Creek and near Joe Wright Reservoir. The flows lap onto the flank of the Medicine Bow Mountains (pl. 1) to an altitude of about 11,150 ft (3,400 m). East of Joe Wright Creek (east of the area shown on pl. 1) the belt of lavas is bounded by a north-trending fault which juxtaposes them against Precambrian granitic rocks. This fault projects northward beneath Joe Wright Reservoir but has not been traced farther to the north. The eastern portion of the belt of lava flows is concealed by surficial deposits except at the crest of the Never Summer Mountains at an altitude of about 12,000 ft (3,670 m), where the trachyandesite is in fault contact with younger rhyolitic volcanic rocks.

The trachyandesite is a brown-weathering, gray, aphanitic rock that tends to weather into outcrops of low relief covered by small brown angular chips. The rock has been described by Gorton (1953, p. 91) as consisting of "small interlocking labradorite laths, slightly larger sanidine crystals, considerable interstitial augite, and a small amount of glass." Corbett (1968, p. 12-14) has analyzed the rock chemically and describes it as a vesicular, hypocrystalline, porphyritic trachyandesite having a trachytic texture; phenocrysts are alkali feldspar, hornblende, and augite. No vesicles or phenocrysts were seen by the authors.

Tertiary dike

Only one small Tertiary dike is present within the study area although such intrusives are common to the south (O'Neil, 1976). The dike is light gray, porphyritic, and of intermediate composition; it trends about N. 5° E. across the crest of the Medicine Bow Mountains at an elevation of about 11,400 ft (3,740 m), 0.7 mi (1.1 km) southwest of Cameron Pass. It is about 10 ft (3 m) thick.

Quaternary surficial deposits

Surficial deposits in the study area are mainly of glacial origin. Till is distributed extensively in the central regions where glaciers originated in the higher peaks and flowed eastward. The northern third of the study area has not been glaciated, and slopes are mantled by a thin veneer of colluvium that merges with alluvium in the valleys. Slight evidence of glaciation is present in the extreme south, but the debris that mantles those slopes is largely colluvial. The glacial history of most of the area was investigated by Kiever (1968).

Till was deposited mostly by large glaciers of Bull Lake and Pinedale ages. Ground moraine predominates, but well-developed lateral moraines are present along many valleys. Younger, very bouldery moraines of Temple Lake and Gannett Peak age occupy many cirques or extend at most a mile (2 km) beyond the cirques. These moraines have not been differentiated on plate 1.

Sandy and gravelly alluvium occupies narrow strips along the stretches of streams where the gradient is low. In part, the alluvium represents reworked morainal debris and colluvium. These accumulations generally underlie meadows covered by grasses, sedges, and willows. In nonglaciated stream valleys, the detritus is less well rounded and consists primarily of water-transported grus and colluvium.

Structure

The Medicine Bow Mountains in Colorado represent the southern extension of a large anticlinal uplift cored with Precambrian rocks. This and related north- to northwest-trending anticlinal uplifts nearby, such as the Park Range, Front Range, and Laramie Range (fig. 2) are separated by synclinal intermontane basins and together comprise part of the Rocky Mountain foreland tectonic province. These major tectonic features are products of Laramide (Late Cretaceous and early Tertiary) and Ancestral Rocky Mountains (Pennsylvanian and Permian) orogenic events that include thrusting as well as uplift. These structures have been modified locally by minor post-Laramide tensional structures. Many faults and shear zones reflect reactivation of earlier formed features, and some major structures show evidence for multiple episodes of reactivation since beginning in Precambrian time.

Evidence for at least four periods of Precambrian faulting has been recognized in the Rawah study area. Some inclusions of gneiss in granitic rocks of the Rawah batholith contain tabular zones of blastomylonite. Intense shearing is indicated, and translational movement clearly predated batholith emplacement.

The syntectonic emplacement of granitoid rocks of the Rawah batholith into a predominantly pelitic-quartzofeldspathic metamorphic complex about 1.7 b.y. ago (McCallum and Hedge, 1976) was accompanied by widespread shearing. Consequently, batholithic rocks commonly exhibit either a pervasive or locally intense cataclastic to mylonitic or blastomylonitic fabric. Such features are prominent near Shipman Mountain in the extreme northwest part of the study area (pl. 1).

A third episode of shearing occurred after the crystallization of the Rawah batholith but before emplacement of the Boswell Creek stock of the 1.41±.045 b.y. Sherman Granite (dated by Peterman and others, 1968), which is exposed a few miles (several kilometers) north of Shipman Mountain (McCallum and Burch, 1980; M. E. McCallum, unpub. mapping, 1974). Well-defined shear zones, which are as wide as a thousand feet (300 m) and as long as many miles (tens of kilometers), cut both Rawah batholithic rocks and metamorphic host rocks but are cut by the Boswell Creek stock. Shear zones of this age are recognized throughout the area but are concentrated in the north part and in the headwaters of West Branch Laramie River. Many of them, particularly most of the major fault zones such as the Shipman Park fault (pl. 1), show evidence of reactivation. Sheared rock within the zones is typically recrystallized to blastomylonite, and the major zones are generally silicified and epidotized. The retrograde metamorphic minerals stilpnomelane and piedmontite are commonly present.

The fourth major episode of Precambrian faulting postdated emplacement of Sherman Granite, although some minor faulting apparently accompanied the 1.41-b.y.-old magmatic event. Faults developed during this late Precambrian tectonic event are generally much narrower and more sharply defined than the earlier formed shear zones but may be difficult to distinguish from them. However, the younger faults are commonly annealed by specular hematite in addition to quartz and epidote. These faults are moderately abundant throughout the study area, but few can be traced definitely for long distances. Some faults of this age that cut the Boswell Creek stock of Sherman Granite to the north near the Wyoming State line have been traced a few miles.

Post-Precambrian faults are relatively abundant in the Rawah study area, but, because of their generally nonresistant character, exposures are rare. Traces of these faults commonly are defined by saddles in ridges, swales, and linear stream drainages.

Phanerozoic sedimentary rocks are preserved as blocks or slices along some of the major faults such as the Blue Lake, Montgomery Pass, and Shipman Park faults. In addition, Proterozoic crystalline rocks have overridden Permian to Cretaceous sedimentary rocks immediately south of the area of plate 1 along high-angle reverse faults. Shipman Park is floored by a synclinal remnant of Permian-Triassic red beds that were dropped down by high-angle reverse movement on the Shipman Park fault, which is a portion of a major fault system that is the most prominent structural element in the Colorado Medicine Bow Mountains. This system includes the Blue Lake and Grassy Pass faults within the Rawah study area and also the Independence Mountain fault that forms the north boundary of North Park about 15 mi (25 km) to the northwest. Initial movement on this fault system, like many others in the area, began in Precambrian time, as indicated by the presence of abundant mylonite and blastomylonite. Episodes of reactivation apparently were numerous, but only those periods of movement related to Laramide and Tertiary tectonic activity can be established with any degree of certainty.

North and northeast of the Rawah study area, the Proterozoic core of the Medicine Bow Mountains has been thrust east onto the Permian and Mesozoic sedimentary rocks in the southern end, or Laramie River Valley portion of the Laramie Basin (fig. 2). An increase in displacement from north to south suggests a pivotal motion of the whole southern part of the range about a hinge located a few miles south of the Wyoming State line. The extreme southeast margin of the Laramie Basin is marked at its contact with the Front Range by a high-angle reverse fault that dips eastward. Thus, the southern tip of the Laramie Basin is the point where oppositely directed faults meet. South of this point direct evidence for thrusting is absent, and Proterozoic rocks of the Medicine Bow Mountains impinge on similar rocks in the Front Range. Nevertheless it seems likely that thrusting continued well to the south and that a wedge of sedimentary rocks may be buried beneath the crystalline rocks. Though not demonstrably a thrust, visible evidence of one or more faults along the southeast margin of the Medicine Bow Mountains is nearly continuous south through Cameron Pass to the Middle Fork Michigan River where sedimentary rocks are again exposed (about 0.5 mi (0.8 km) south of pl. 1). The relations at those exposures show east-dipping reverse or thrust faults, which complicate the hypothesis of east movement of the range at its southern tip. However, the fault slice of sedimentary rocks at Montgomery Pass dips to the west and may be interpreted as an imbrication in the upper plate of an east-directed thrust.

The east-dipping reverse faults may be underthrusts that bottom against the Montgomery Pass thrust at depth defining a wedge-shaped block of crystalline rocks, in the Diamond Peaks area, that possibly has a significant component of vertical uplift. Eastward displacement of the southern tip of the Medicine Bow Mountains is at most only a few miles (several kilometers) if the degree of pivotal motion expressed on the flanking thrust in the Laramie River valley north of Glendevey is assumed to be at least relatively uniform along the southern extension of the thrust. A similar magnitude of displacement is suggested by the trend of the Proterozoic Iron Dike which shows a nearly colinear relationship between segments in the Medicine Bow Mountains and in the Front Range to the southeast. Furthermore, the similarity in azimuth of the two segments indicates that any pivoting of the Medicine Bow block was small.

Fault movement of Laramide age is difficult to distinguish from post-Laramide movement, except to the southeast where Tertiary volcanics are present, or in places where faults can be traced from the crystalline Precambrian rocks into flanking sedimentary rocks to establish displacement relations. In general, however, the mid- to late-Tertiary structures are characterized by higher concentrations of gouge, open-space breccia zones, and earthy hematite, whereas Laramide faults are generally somewhat more annealed. In the Northgate mining district northwest of the Rawah study area, post-Precambrian faults locally contain abundant fluorite. Steven (1960) has indicated that a purple, breccia-filling fluorite predominates in the Laramide faults, whereas light-colored, crustiform fluorite is more typical of late Tertiary structures. The only fluorite observed in the Rawah study area was a buff-white variety present as a minor component in a breccia in the West Branch Fault in an exposure just west of the range crest. Some late Tertiary faults contain thin 0.4-4 in. (1-10 cm) tabular masses of hydrothermal magnetite and, locally, minor enrichment of copper, molybdenum, and (or) uranium. A weakly to strongly developed propylitic alteration assemblage is associated with a number of the post-Precambrian faults.

Most of the faults in the Rawah study area, regardless of ages of movement along them, define a roughly northwest-northeast rectilinear pattern. This pattern apparently reflects the predominant stress field that prevailed at various times in the Proterozoic, and which apparently has not been modified significantly since. Some of the northeasterly trending Laramide faults, especialy those to the south, may reflect tear movement associated with differential northeast thrusting of the southern Medicine Bow Mountain block in Laramide time. A crudely radial fault pattern is centered at the intersection of the Blue Lake, Grassy Pass, and West Branch Faults. A similar radial fault pattern is combined with a concentric fault pattern on the West Branch-Clear Lake-Kelly Lake-Jewel Lake fault system on the west side of the range. The radial and concentric fault patterns may reflect local doming related to the intrusion of still-buried Tertiary plutons, although no other evidence for such plutons is known.

INTERPRETATION OF AEROMAGNETIC DATA
by V. J. Flanigan

The aeromagnetic data of the Rawah study area shown on plate 2 were compiled from two magnetic surveys that were made by the U.S. Geological Survey in 1970 and 1975 and released previously (U.S. Geological Survey, 1978). The magnetic surveys were flown at the same flight elevation (3,960 m barometric), but the data were compiled at different reference levels. In addition, the International Geomagnetic Reference field was removed from the 1975 survey field data and not from the 1970 data, and hence, no attempt was made to tie the data across mutual boundaries.

Regional geologic and geophysical data (Lovering and Goddard, 1950; Tweto, 1979; Zeitz and Kirby, 1972; Behrendt and Bajwa, 1974) provide background for the interpretation of aeromagnetic data of the Rawah study area. The elongate cluster of interwoven magnetic highs in the southern Medicine Bow Mountains (pl. 2) has a similar pattern and trend to a longer belt of highs coincident with the topographically highest part of the Front Range to the southeast (Zeitz and Kirby (1972). The two groups are offset left laterally about 10 mi (16 km) and are separated by a prominent northeast-trending magnetic low. In part at least, this low follows major faults suggesting that the 10-mile (16-km) offset is the result of strike-slip movement along these faults; however other, confirmatory geologic evidence for such offset is lacking. Sedimentary basins to the west (North Park) and north (Laramie Basin) are magnetically low relative to the crystalline mountain ranges. East of the Rawah study area, in a part of the Front Range where the altitude and relief are lower, the magnetic pattern is simpler than in the Medicine Bow Mountains or in the Front Range to the south and is dominated by a large, subcircular magnetic high that lies over the Log Cabin batholith of Proterozoic Y age. Regional gravity data compiled by Behrendt and Bajwa (1974) indicates that the Rawah study area lies along the east flank of a large gravity low centered 9-18 mi (15-29 km) to the southwest. Gravity data in the Rawah study area is too sparse to be useful in interpreting geology for the purpose of mineral resource appraisal.

The dominant magnetic feature of the Rawah study area (pl. 2) is a magnetic ridge surmounted by five smaller magnetic highs. Another major magnetic feature, not shown completely on plate 2, is a north-trending magnetic low that is nearly coincident with the Laramie River valley along part of the east edge of the study area.

The gross correspondence of magnetic highs and lows with topographic highs and lows suggests a cause and affect relationship. To test for such a relationship, a computer technique developed by B. K. Bhattacharyya (written commun., 1978) was used. This technique reduces the magnetic data that was acquired at a constant barometric flight elevation to a plane parallel to the topography. Two east-west profiles were constructed that compare the magnetic and topographic data. Figure 3 illustrates the results of the analysis of the profile through anomalies 2818 and 3100. The lower trace shows the topography along the profile and the upper solid line is the magnetic data reduced to an arbitrary datum and with a regional gradient removed. The dotted line shows the magnetic data computed to the plane which parallels the topography, in effect removing the effect of topography. By this procedure, anomaly 2818 is removed entirely, anomaly 3100 is reduced in amplitude by about 70 gammas, and the Laramie River low is reduced in amplitude by about 200 gammas. Thus, in areas of relatively high topographic relief, small, short wavelength magnetic anomalies, such as anomaly 2818, may be entirely or almost entirely caused by topographic highs and lows. The longer wavelength anomalies are generally real, although their actual peak values may be somewhat lower than the values shown on an aeromagnetic map uncorrected for topography. Analysis of a profile crossing anomaly 2760 indicates that despite its location less than 0.5 mi (1 km) north of Clark Peak, the highest in the range, the anomaly is in fact real and is similar to anomaly 3100. Anomaly 2760 has an amplitude of about 400 gammas and a width of 6-7 mi (10-12 km). Inasmuch as these anomalies are over the Rawah batholith of intermediate composition and such rocks do not normally give rise to local magnetic highs, the magnetic rocks must either be in the form of inclusions in the batholith or a large body at depth. Mafic inclusions such as metabasalt, metagabbro, or gabbro are present at anomaly 2760, but such inclusions are more abundant for 1.25 mi (2 km) to the south and no local magnetic high is present there. Thus it seems more

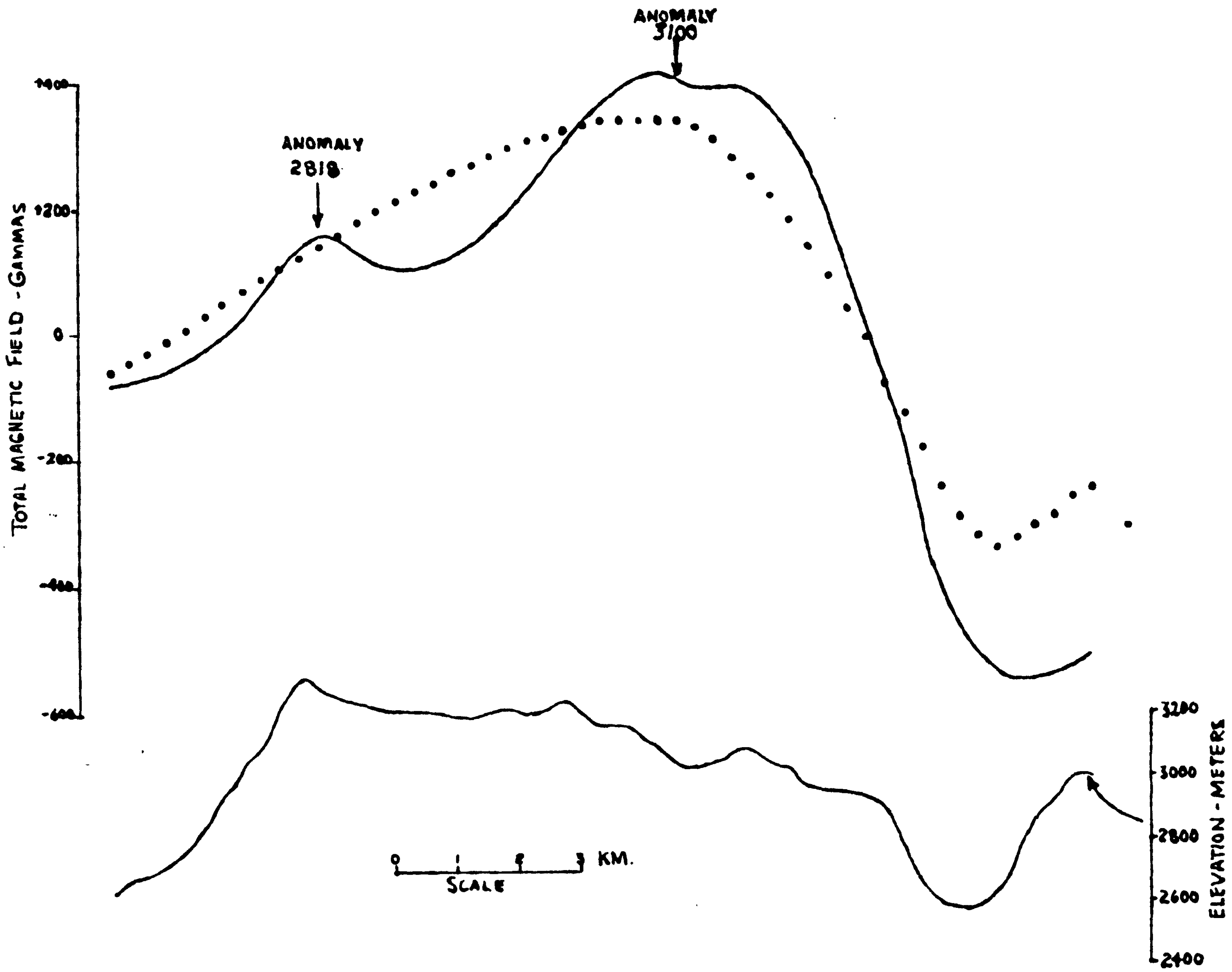

Figure 3.--Diagram showing topographic effect (lower trace) on magnetic data (upper solid line) observed at constant barometric flight height. The dotted line shows the magnetic data without the computed topographic effect.

likely that the causitive source is at some depth, a rough estimate suggests 2 mi (3 km) below the surface.

Magnetic anomalies 3100 and 1457 form a magnetic ridge in an area of low to moderate elevation and relief. Figure 3 illustrates that this ridge is little affected by topography and is the dominant magnetic feature within the study area. Anomaly 2760 is also on line with the ridge but is separated from anomaly 3100 by irregularities in the magnetic contours. The magnetic body that causes the ridge is not apparent in the surface geology. Considered together with its broad wavelength, this suggests that the source lies at some depth below the surface.

The cause of magnetic anomalies 3052 and 3330 in the northwest part of the Rawah study area is likewise unknown. The Rawah batholith in the study area is not notably different than elsewhere, and mafic inclusions, though common, are not abundant. If mafic rocks are the cause, they are chiefly buried.

A northeast-trending magnetic low crosses the Medicine Bow Mountains between magnetic highs 2818 and 3052. Where it crosses the crest of the range, the magnetic low is a shallow saddle that may be caused by large and abundant inclusions of metasedimentary schists and gneisses in the batholith. To the northeast the low deepens and enlarges in an area that is traversed by the major northwest-trending Shipman Park fault zone and lesser northwest- and northeast-trending faults; the low is also traversed by the 1,000-ft-deep (305 m) valley of McIntyre Creek. It thus seems likely that some combination of weakly magnetic inclusions, oxidation of magnetite along faults, and a topographic low has contributed to this magnetic low. A few miles to the northwest the Shipman Park fault and the slab of sedimentary rock along it are marked by a saddle in the magnetic contours.

The linear magnetic low that extends more than 12 mi (19 km) along the east side of the Rawah study area parallels the Laramie River valley and lies 0.5-1.5 mi (0.8-2.4 km) east of the valley bottom and generally 500-1,000 ft (150-300 m) above it. That topography has only a minor effect in causing this low is shown on figure 3 and by superimposing plates 1 and 2. Toward its north end the low passes east of Middle Mountain, whereas the main valley of the Laramie River is west of the mountain. Neither the river valley nor Middle Mountain produces an effect on the magnetic contours. The linear low ends abruptly to the south against a northwest-dipping magnetic gradient at a point about a mile (1.2 km) east of the valley and over 1,000 ft (305 m) above it. Middle Mountain is interpreted as a klippe of crystalline rocks that overlies a thick synclinal wedge of Phanerozoic sedimentary rocks. These nonmagnetic sediments crop out east of Middle Mountain, but farther to the south they are buried by surficial deposits in the valley, or are faulted out by an east-dipping, high-angle reverse fault along the east side of the valley, or both. The presence of the axis of the aeromagnetic low, about a mile east of the trace of the reverse fault, suggests that the axis of the sedimentary-rock wedge lies beneath the crystalline rocks at this point.

In summary, the large elongate magnetic high over the Rawah study area is produced largely by rocks of the Rawah batholith. Local magnetic highs are induced partly by topography, but the longer wavelength highs probably arise from bodies of more magnetic mafic rock at a depth of a mile or so (few kilometers), enhanced perhaps by clusters of magnetic mafic inclusions in the batholith. The linear magnetic low along the Laramie River probably is associated with a synclinal wedge of weakly magnetic Phanerozoic sediments, that has been overriden by Proterozoic crystalline rocks in the Front Range along a high-angle reverse fault from the east and possibly of the Medicine Bow Mountains along a thrust fault from the west.

MINERAL RESOURCES

Setting

The southern Medicine Bow Mountains are situated in a part of Colorado in which few mineral resources have been found except for mineral fuels in the nearby sedimentary basins. The principal metal-mining districts in the state lie more than 30 mi (50 km) to the south and southeast in the Colorado Mineral Belt (fig. 2). The intervening area contains numerous mineral occurrences, but very few of them have produced ore. The only "hard-rock" mining operation of consequence in the vicinity extracted fluorspar in the Northgate district 10 mi (15 km) northwest of the study area. Coal and petroleum have been produced from sedimentary rocks in North Park and in the Laramie Basin.

The nearest mines that produced metals are in small districts 8-13 mi (13-21 km) east of the study area. The Manhattan, Home, and Mayesville districts (fig. 2) (Lovering and Goddard, 1950, p. 285-286) yielded minor amounts of ore valued chiefly for its gold content. This ore was derived from veins in Precambrian granite and Tertiary porphyries. The Teller City district, which is located about 10 mi (15 km) south of the study area, is reputed to be a silver district, but there is no known record of production. Veins that have been prospected are associated with mid-Tertiary intrusive rocks. Uranium was found in a fault zone in Precambrian rocks on the Robinson Ranch near Spencer Heights 4 mi (6.5 km) east of the Rawah study area, but drilling thus far has failed to disclose economic levels of uranium or to encourage further exploration at this property (Pearson and others, 1981).

Mines and prospects

Records of Jackson and Larimer Counties and of the U.S. Bureau of Land Management disclosed that one unpatented mining claim has been located within the Rawah study area, and a few others have been located nearby. Prospects in the northeast part of the study area that contain minor amounts of copper minerals were examined and sampled. Sixteen samples taken by the Bureau of Mines were analyzed at the U.S. Bureau of Mines research center in Reno, Nevada.

The single mining claim within the area is southeast of Montgomery Pass (pl. 3). County records indicate that it was located in 1922. Two shafts about 2,300 ft (700 m) southeast of the pass were dug on a silicified fault zone that separates Permian-Triassic red beds from Precambrian rocks, chiefly pegmatite (pl. 1). Other small prospect pits are scattered through the fractured and silicified Precambrian rocks north and east of the shafts and near a cabin that is beside the Montgomery Pass road. The U.S. Bureau of Mines samples 9-12 (table 1), collected mostly from dumps, contain traces of copper. Sample P-100 (Motooka and others, 1979) from the dump of one of the shafts contains only 10 ppm copper and no other elements in economically significant amounts.

Several prospect pits and a shaft about 20 ft (6 m) deep were dug in granitic rocks of the Rawah batholith east of Shipman Park. This exploration was done many years ago--perhaps in the early 1900's--to test a weakly mineralized fault zone. Secondary copper minerals in pegmatite were found on the dump of the shaft (pl. 1), and a sample (no. 2, table 1) of the highest grade available yielded 2.3 percent copper and 17.1 g/t silver. Where exposed

Table 1.--Gold and silver assays of U.S. Bureau of Mines samples

[Sample localities shown on plate 3. Values in grams per metric ton. tr, trace; ---, not detected]

Sample no.	Gold	Silver	
1	tr	3.4	Granite.
2	tr	17.1	Quartz, granite, and gneiss from dump.
3	tr	---	Chip sample of pegmatite, 1.8 ft (55 cm) long.
4	---	6.9	Grab from contact zone.
5	---	3.4	Grab of fault gouge across 20 ft (6 m).
6	---	3.4	Quartz, 3 ft (1 m) chip.
7	---	---	Quartz and gneiss from dump.
8	tr	---	Pegmatite from dump.
9	---	---	Clay and quartz from dump.
10	---	---	Quartz and shale from dump.
11	---	---	Quartz, mica, and shale from dump.
12	---	---	Quartz and shale from dump.
13	---	13.7	Panned concentrate.
14	---	10.3	Do.
15	---	6.9	Do.
16	---	6.9	Do.

in the shaft, the copper-bearing rock appears to be very spotty. Sample 1 from a pit in the SE 1/4 sec. 2 contains 0.12 percent copper and 3.4 g/t silver. Sample 3 from a 6-ft-deep (2 m) pit near the shaft contains 0.04 percent copper.

According to the records, approximately 20 claims were staked between Chambers and Lost Lakes east of the study area. The exact location of the claims is unknown, but a few shallow pits were found in this area, and two dump samples (7 and 8) contain traces of copper.

The Vail Group claims were located in 1958 outside the study area about 1.6 mi (2.5 km) northeast of Chambers Lake in the canyon of Joe Wright Creek. No workings or mineralized rock were found, and no samples were taken.

Sample 4 was taken west of Shipman Park just south of Ute Pass where a contact zone contains garnet. This sample contains traces of lead and silver.

Two samples were collected from the drainage basin of the West Branch Laramie River. Sample 5 from near Grassy Pass consists of a grab sample collected across a 20-ft-wide (6 m) fault zone; it contains trace amounts of lead and silver. Sample 6 from a shallow pit west of the pass between the West Branch Laramie River and Blue Lake also contains traces of lead and silver.

Geochemical studies

Sampling and analysis of samples

Plate 3 shows the locations of 391 samples of rock and stream sediment that were collected and analyzed in an attempt to locate concentrations of metals that might disclose the presence of mineral deposits. Of the 391 samples collected, 106 were of fresh rock or variously altered rock from faults or veins, and 285 were stream sediments. Sample localities are shown on plate 3. The samples were analyzed in the U.S. Geological Survey laboratories in Golden, Colorado. Numerous samples of rock collected earlier by other investigators are also discussed.

Stream-sediment sampling was done in two stages. In 1975 a pilot sampling program was undertaken, and in 1976 routine stream-sediment samples of the second stage were collected from all streams, principally those of first and second order.

Stream-sediment samples consisted of about 0.4 to 1 lb (200 to 500 g) of the finest grained active sediment that could be obtained. Fine-grained sediment is difficult to find along parts of many streams because of their steep gradients. However, organic muck or muddy sand generally could be sampled, and, upon drying and sieving to minus 180 m, this material provided sufficient silt- and clay-sized sediment.

Panned-concentrate samples (13-16, table 1) were collected by panning surficial debris from stream banks.

Rock samples were collected of typical and unusual fresh rocks and of sheared and altered rocks in order to contrast obviously unmineralized with possibly mineralized rocks. Generally, chips or small specimens, weighing about 0.1 to 0.4 lb (50 to 200 g) were submitted for analysis.

All rock and stream-sediment samples were analyzed by semiquantitative spectrography for 30 elements. Selected samples, both rock and stream sediments, were analyzed for gold, lead, and (or) zinc by atomic absorption and for uranium and thorium by the delayed-neutron technique. Selected stream-sediment samples were analyzed for copper, lead, and zinc by the colorimetric citrate-soluble heavy-metals test (CxHM) and cold-acid-extractable copper test (CxCu). All stream-sediment samples were checked for radioactivity and an equivalent-uranium value determined on them. The spectrographic analyses were made by J. M. Motooka and E. F. Cooley; equivalent uranium determinations were made by J. C. Negri and Z. C. Stephenson; and the uranium and thorium analyses were made by H. T. Millard, Jr., C. L. Shields, C. M. Ellis, R. L. Helms, and C. A. Ramsey. C. A. Curtis made the atomic absorption and colorimetric analyses. Fred Ward made three fluorimetric analyses for uranium.

Interpretation of geochemical data

Analytical results of the geochemical studies tend to confirm that the evidence for mineral deposits is minor, as indicated by the virtual absence of mines and prospects and minimal visual evidence of mineralization. Because the geochemical data offer few positive indications of mineralization, it was not considered necessary to include the analytical data in this report; however, all data are available in Motooka and others, 1979.

Data on elements commonly found in ores or associated with ores were examined with particular care. The elements of most interest are manganese, silver, arsenic, gold, bismuth, cadmium, copper, molybdenum, niobium, lead, antimony, tin, tungsten, zinc, thorium, and uranium. No bismuth, cadmium, antimony, or tin was detected in any of the samples. Manganese, niobium, and lead were found in most samples in amounts that are considered normal for the rock assemblage in the study area and hence are of no particular economic interest. Copper and lead are abnormally high in a few samples; molybdenum is present in low amounts in many samples; and silver, arsenic, tungsten, and zinc are present in a few samples. Occurrences of anomalous samples are discussed below.

Two samples contained visible copper minerals. Sample 20-125 (pl. 3) has the highest copper concentration and was collected from one of several narrow veinlets adjacent to a fault zone near Kelly Lake, which is located about 0.6 mi (1 km) west of the study area. This sample contains 5,000 ppm copper and 150 ppm lead, which is the highest lead value of any analyzed sample. The copper is present chiefly as chalcocite in veinlets as much as 0.5 in. (1 cm) thick that were emplaced along joint planes in monzogranite. The highest concentration of veinlets is confined to an area of about 30 by 60 ft (10 m by 20 m). Hydrothermal alteration is confined to bleaching of ferromagnesian minerals in a thin selvage along the joints. The locality is situated about 1,300 ft (400 m) east of the major north-trending fault that passes through Kelly Lake. Sample 6-170, which contains chalcopyrite and pyrite, was collected a short distance north of the West Branch Laramie River in the central part of the study area. This sample contains 200 ppm copper. The sulfides are disseminated in biotite-rich lenses in monzogranite. The lenses are a few inches thick and 1-2 ft (a few tens of centimeters) long and apparently are recrystallized inclusions of host rocks. Some samples of mafic rock (such as 6-166) contain as much as 150 ppm copper, values that are normal for rocks of that composition. No copper resources or prospective sites for exploration were discovered.

Molybdenum was detected by spectrographic analysis in 35 percent of the stream-sediment samples but in only a few of the rock samples. The highest value found in any of the stream-sediment samples was 20 ppm, and the mean value in all samples in which molybdenum was detected is 6.8 ppm. Samples containing the highest values (15 and 20 ppm) came from widely scattered localities. Nearly all stream-sediment samples from the central third of the study area contain detectable molybdenum, whereas only a few samples collected from other parts of the study area contain molybdenum. The areal variations in molybdenum content cannot be explained by any known aspects of the local geology, nor can the distribution be explained by possible analytical errors that might be reflected by order of sample collection or analysis. Because of the consistent, but low, amount of molybdenum in the central third of the study area, the element is believed to be a trace component of at least part of the batholith, perhaps mainly pegmatite, and it probably was transported to the sample site in solution rather than as detrital grains. An alternative hypothesis suggests that all batholithic rocks have about the same molybdenum content, but the molybdenum has been leached from rocks in the unglaciated, more deeply weathered rocks at the north and south. In the highly glaciated central part of the study area the molybdenum has not been leached.

Molybdenum was detected in only six rock samples, other than those from the rutile-bearing quartz gneiss which is discussed in a separate section of this report. All six of these samples, which contain at most 10 ppm molybdenum, are from the southern third of the study area. The sample containing 10 ppm came from a narrow calcite vein in which more than 120 ppm uranium and 20 ppm beryllium also were found. Most other molybdenum-bearing samples were from fractured and altered granitic rocks along faults suggesting a mineralizing process that was weak and ineffective. None of these sample sites is considered to have any economic importance.

Tungsten was detected in eight stream-sediment and two panned-concentrate samples but in no rock samples. Although the values are low in both the stream sediments (50 to 70 ppm) and panned concentrates (0.08 and 0.026 percent) (table 1), the distribution of the samples suggests that tungsten may have been introduced along some of the major faults. Five of the eight stream-sediment samples are from streams flowing along the northwest-trending Shipman Park fault, and two others are from the Laramie River valley near major faults. One of the panned concentrates is from McIntyre Creek, which a few miles (several kilometers) upstream, flows along the Shipman Park fault, and the other is from the West Branch Laramie River. Although it is unlikely that these very low amounts of tungsten indicate economic concentrations, the faults in the critical areas are covered by surficial deposits, and the exact source of the tungsten is not known.

Low amounts of zinc (less than 200 ppm) were detected in nine stream-sediment samples. Only two rock samples, both of them magnetite rich, contain detectable zinc. One from a fault zone contains 200 ppm and the other from pegmatite contains 1,000 ppm. Magnetite commonly has high concentrations of zinc, and no economic significance is indicated.

Silver was detected in two samples (20-11, 20-22; pl. 3) of apparently fresh rock from west of the crest of the range. Sample 20-11 is of monzogranite containing 1.5 ppm silver, and sample 20-22 is of an inclusion of diorite in monzogranite containing 0.5 ppm silver. These very low amounts of silver in fresh-appearing rock are not considered to have economic significance.

Arsenic was found in amounts ranging from 500 to 2,000 ppm in three samples (P-080, P-101, P-102; pl. 3) of altered rock from fracture zones in the southern part of the study area. The rocks were originally pegmatite and other granitic rocks that have been silicified and partly altered to clay minerals. Minor pyrite is present in sample P-102, and limonite in other samples is inferred to have been derived from oxidation of pyrite.

All rock samples containing low to moderate levels of molybdenum, arsenic, and zinc and most samples that contain above normal amounts of copper are from the southern part of the study area. These elements are characteristic of veins in the Never Summer Mountains to the south, and it is suggested that mineralization extended northward into the southern part of the Medicine Bow Mountains as a diffuse halo. Alternatively, the weak mineralization could be related to buried Tertiary plutons whose presence is suggested by the radial and concentric fault patterns such as in the West Branch Laramie River.

Equivalent-uranium determinations shown in Motooka and others (1979) for stream-sediment samples should be disregarded because they do not correlate well with uranium or thorium determined by delayed-neutron analysis. In retrospect, it seems likely that any uranium in stream sediments would be out of equilibrium with its daughter products and, hence, not likely be detected by measurements of radioactivity. Equivalent-uranium determinations on rock samples, however, disclosed three samples that were sufficiently radioactive to warrant fluorimetric analysis for uranium. Two of these samples (20-120A and 20-219) were from east-trending calcite veins which contain 46 and >120 ppm uranium, respectively. The third sample (20-218B), a small mass of magnetite from a shear zone, contains 2.3 ppm uranium. The two calcite veins are very small and are themselves not a resource of uranium, although they do indicate uranium mineralization in east-trending fractures and suggest a slight potential for uranium deposits. A uranium prospect associated with a major east-northeast-trending fault zone at the Robinson Ranch about 4 mi (6.5 km) to the northeast has been explored by drilling, but insufficient uranium was found to mine.

Thorium in quantities as high as 450 ppm was found in stream-sediment samples from the northern part of the study area. Thorium is probably present in allanite, which is a common accessory mineral in the rocks in this part of the batholith. However, no thorium was detected by spectrographic analysis of rock samples, and the batholith does not represent a resource of thorium. The U.S. Bureau of Mines panned-concentrate samples 13, 14, and 15 contained 0.10, 0.024, and 0.045 percent lanthanum, respectively, by spectrographic analysis. The lanthanum also may be present in allanite or other accessory mineral in the granite.

As part of a separate study, 169 crystalline rock samples taken throughout the Colorado Medicine Bow Mountains were analyzed for uraniun and thorium by Skyline Labs, Inc., Wheatridge, Colorado; these data are available in McCallum and Burch, 1980. Uranium was determined by fluorimetry, and thorium determinations were made by X-ray fluorescence. A number of granitic rocks from the Rawah study area have uranium values as high as 7.0 ppm. However, the uranium background value for these rocks is considerably less than the 5.0 ppm average reported by Phair and Gottfried (1964) for similar age rocks in the Colorado Front Range (McCallum and Burch, 1980). These lower values may be a function of greater leaching of Rawah batholith rocks than their plutonic counterparts in the Front Range, a phenomenon that may well be related to the abundance of faults and shear zones, and the presence of locally pervasive cataclastic fabric in rocks of the Rawah study area. Such a leaching mechanism might be responsible for locally high uranium values in fault zones, and it appears that such occurrences have the greatest potential for economic levels of uranium in the study area. Thorium content of the samples ranges to as much as 110 ppm in the Rawah study area. The thorium levels in these samples, as in the stream sediment samples, probably reflect the presence of allanite as a significant accessory mineral in rocks of the Rawah batholith but are in no way sufficient to imply economic potential.

Gold was not detected by spectrographic analysis of any sample. The more sensitive atomic-absorption technique detected gold in only 4 of 25 altered- and mineralized-rock samples, three of which are at the detection limit or below, and none was detected in 20 stream-sediment samples. The only sample (P-079) above the detection limit contains 0.20 ppm (0.006 oz per ton), an amount not considered to be economically important.

Thirty-six samples, chiefly of igneous and metaigneous rocks from the northern part of the study area, were collected and analyzed prior to the present investigation in connection with Colorado State University thesis studies and with other Geological Survey studies by M. E. McCallum. The localities where these samples were collected are shown on plate 3 by the numbers with "KC" or "18" prefixes. Results of these analyses indicate no apparent economic mineralization, and they are not included in the tables of analytical data (Motooka and others, 1979) that resulted directly from this study of the Rawah study area. Fourteen of these 36 samples, principally of mafic rocks, were analyzed for platinum-group elements. In three samples paladium, the only platinum-group element detected, is present at levels near the detection limit of the fire-assay emission spectrographic analytical technique. A metagabbro sample (KC-147B) contains 0.003 ppm Pd, a diorite sample (KC-159) contains 0.003 ppm Pd, and another metagabbro sample (KC-169B) contains 0.002 ppm Pd. Five of the samples (KC-136, KC-143, KC-146, KC-169B, KC-173A) analyzed for platinum-group elements were also analyzed by atomic absorption for gold, silver, and copper; they were also analyzed by the specific ion technique for fluorine, and all of these except KC-146 were analyzed by emission spectrography for 30 elements. Sample 18-143 was analyzed by emission spectrography for 30 elements. Whole-rock chemical analyses on 25 of this group of samples were examined but not found to contain data of importance to the search for mineral resources.

Rutile, ilmenite, and topaz in quartz gneiss

About 2 mi (3 km) north of Glendevey a large xenolith in monzogranite of the Rawah batholith consists predominantly of quartz gneiss and sillimanite-biotite gneiss. Rutile, ilmenite, sphene, topaz, and sillimanite are minor minerals in some of the quartz gneiss. Bulk samples of the quartz gneiss were evaluated to determine if it might constitute a potential mineral resource; however, no mineral is present in sufficient quantities to be considered more than a speculative resource. These rocks are similar to gneisses described by Sheridan and others (1968) and Marsh and Sheridan (1976) at localities about 125 mi (200 km) to the south.

The xenolith is about 1,650 ft (500 m) wide and extends from the lower mountain slopes, where it is covered by surficial deposits, westward for about 0.6 mi (1 km). Foliation and layering in the gneisses dip steeply and strike generally west. The northern and western parts of the inclusion are mainly quartz gneiss and the southeastern part is predominantly sillimanitic biotite gneiss. The quartz gneiss is colorless, gray, or a resinous green to tan. The gray variety contains rutile and ilmenite, and the green to tan variety derives its color from sphene.

Nine bulk chip samples, each representing about 100 ft (30 m) of the rutile-bearing quartz gneiss, were collected across the eastern portion of the outcrop approximately at right angles to the strike of compositional layering. The samples, which weighed 7.5-10 lbs (3.4-4.6 kg), were ground to pass through a 250 m screen, deslimed by decanting, and passed over a laboratory-model Wilfley table. The heavy-mineral fraction from the Wilfley table was further concentrated in methylene iodide, which produced concentrates weighing from about 0.022-0.11 lbs (10-52 g) (table 2). Various magnetic fractions were obtained using an electromagnetic separator and a hand magnet. Ilmenite and rutile are variably magnetic, possibly as a result of magnetite inclusions. The minerals were identified by petrographic and X-ray diffraction techniques.

The heavy minerals concentrated in methylene-iodide are dominantly rutile and ilmenite. Ratios of rutile to ilmenite were visually estimated to range from as low as 1:12 and as high as 3:2 (table 2). Sphene makes up about 5-10 percent of three samples, and molybdenite and pyrite are trace constituents of three samples. Molybdenite occurs as small hexagonal platelets, and pyrite as small subhedral crystals. Spectrographic analyses of the bulk rock samples indicate that molybdenum is present in amounts ranging from 50 to 200 ppm confirming that the molybdenite in the concentrates was not an accidental contaminant. Topaz is present in other samples from the outcrop but was not found in the nonmagnetic heavy fraction of the nine samples.

Rutile ranges from red to opaque when viewed through an ordinary microscope, but much is dark yellow under a petrographic microscope. Crystals range from well rounded and equant to perfect, euhedral dipyramid-prism combinations. Knee twins are abundant, but most were broken during sample preparation.

Quantities of rutile and ilmenite recovered from these samples are very small, ranging from 0.27 to 1.3 percent (table 2). In the two samples that yielded more than 1 percent total rutile and ilmenite, the ilmenite greatly exceeds rutile (4:1 and 12:1). These samples contain little else except quartz. Sillimanite and topaz do not appear to be closely associated with the titanium minerals as they are in similar rocks elsewhere (Marsh and Sheridan, 1976). These factors combine to reduce the potential value of this rock. It may be possible that certain layers within the quartz gneiss sequence could have substantially higher content of rutile and ilmenite or topaz; however, such layers were not apparent in the examination of the outcrop. In their absence, there is little likelihood that the quartz gneiss represents a resource of titanium or fluorine. Marsh and Sheridan (1976, p. G16) do not consider gneisses containing less than 1 percent rutile to be a resource.

Table 2.--Heavy-mineral composition of quartz gneiss

[Heavy minerals concentrated in methylene iodide. Proportion of minerals estimated visually and calculated as weight percent of sample. Quartz in sample 6-26-1A present in grain aggregates. (---), not observed; tr, trace.]

Sample		Heavy-mineral fraction							
No.	Wt (g)	Wt (g)	Wt percent of Sample	Rutile	Ilmenite	Sphene	Quartz	Molybdenite	Pyrite
6-26-1AA	3,360	30.48	1.1	0.22	0.88	----	----	----	----
6-26-1A	3,993	52.39	1.3	.10	1.2	----	0.03	tr	tr
6-26-1B	4,276	24.21	.56	.31	.22	0.03	----	tr	tr
6-26-1C	3,788	10.21	.27	.16	.11	----	----	----	----
6-26-1D	4,371	20.85	.48	.17	.31	----	----	----	----
6-26-1E	4,255	25.46	.60	.18	.36	.06	----	----	----
6-26-1F	4,655	25.74	.55	.22	.33	----	----	----	----
6-26-1G	4,570	21.55	.47	.14	.31	.02	----	tr	----
6-26-1H	4,248	23.52	.55	.30	.25	----	----	----	----

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