Geology and Thorium Deposits of the Wet Mountains, Colorado A Progress Report

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GEOLOGICAL SURVEY BULLETIN 1072-H

This report concerns work done partly on behalf of the U.S. Atomic Energy Commission and is published with the permission of the Commission; the rest of the work was done in cooperation with the State of Colorado Geological Survey Board and Colorado Metal Mining Fund Board

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Geology and Thorium Deposits of the Wet Mountains, Colorado A Progress Report

By R. A. CHRISTMAN, M. R. BROCK, R. C. PEARSON, *and* Q. D. SINGEWALD

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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By R. A. CHRISTMAN, M. R. BROCK, R. C. PEARSON, and Q. D. SINGEWALD

ABSTRACT

The McKinley Mountain area, a 22-square mile tract of Precambrian rocks that contain thorium-bearing veins, lies on the west flank of the Wet Mountains, Custer and Fremont Counties, Colo. The bedrock in this area is a complexly interlayered sequence of gneisses of metasedimentary origin, migmatite, and granitic gneisses that has been transected by an albite syenite stock and numerous northwest-trending dikes, veins, and fractures. Hornblende-plagioclase and biotite-quartz-plagioclase gneisses are the principal metasedimentary rocks; garnet, sillimanite, quartzite, and pyroxene-scapolite zones are locally present. A poorly foliated alaskitic granite gneiss is common as layers ranging from more than 500 feet in thickness to migmatitic lit-par-lit type layers less than an inch thick. Of less wide distribution, but of similar occurrence, are quartz monzonite gneiss and light-colored granodiorite gneiss. The albite syenite, one of the youngest rocks in the area, is not foliated and is about 595 million years old (late Precambrian), by the Larsen zircon method of age determination. Many of the dikes are similar in composition to the albite syenite stock.

The foliation of the gneisses generally is steep and trends northeast in most of the area. Several northeasterly trending folds have been mapped in the northern half of the area; a vertically plunging fold occurs in the southwest quarter of the area. Faults, shear zones, and joints, some filled with veins and dikes, trend northwest across the area and cut the foliation at large angles.

More than 800 radioactivity anomalies were found along northwesterly trending veins within the area, and 29 localities were examined outside the area. Most anomalies do not exceed 5 times the background count, but relatively rich concentrations of radioactive elements giving strong anomalies are scattered along the veins in pockets and lenses. The radioactivity, as shown by representative analyses, is due almost entirely to thorium. A hydrated thoritelike mineral is visible at some localities; the same mineral doubtless is finely disseminated among red, yellow, and brown iron oxides and (or) hydroxides at radioactive localities where no thorium-bearing mineral is visible. Besides iron oxides and, locally, thorium minerals, many veins contain abundant carbonate minerals, barite, quartz, and minor quantities of sulfide minerals.

INTRODUCTION

This progress report gives results of the first 2 years of systematic geologic mapping within a thorium province along the western slope of the Wet Mountains in Custer and Fremont Counties, Colo. It also gives reconnaissance data to supplement U.S. Geological Survey Circular 290 (Christman and others, 1953). During 1952 and 1953 about 22 square miles, here designated the McKinley Mountain area (fig. 18), was mapped at a scale of 1:6,000 to search for new vein-thorium deposits and to study their structural setting. This area, which lies northeast of Westcliffe, is fairly rugged, with altitudes ranging from 7,900 to 9,500 feet. Water is scarce. Rather thin and somewhat scrubby stands of evergreen trees cover most of the ridges, but good stands cover some of the north slopes.

Previous work in the McKinley Mountain area and parts nearby of the thorium province consisted of reconnaissance examination of some 25 deposits, planetable mapping of 3 local areas, and a drilling program at Haputa ranch. Results were set forth in the report by Christman and others (1953). That report outlined the thorium province as being about 20 miles long and 10 miles wide. The present investigation extends the province to at least 30 miles long and 12 miles wide. The nearby Rosita and Silver Cliff mining districts, which contain silver,

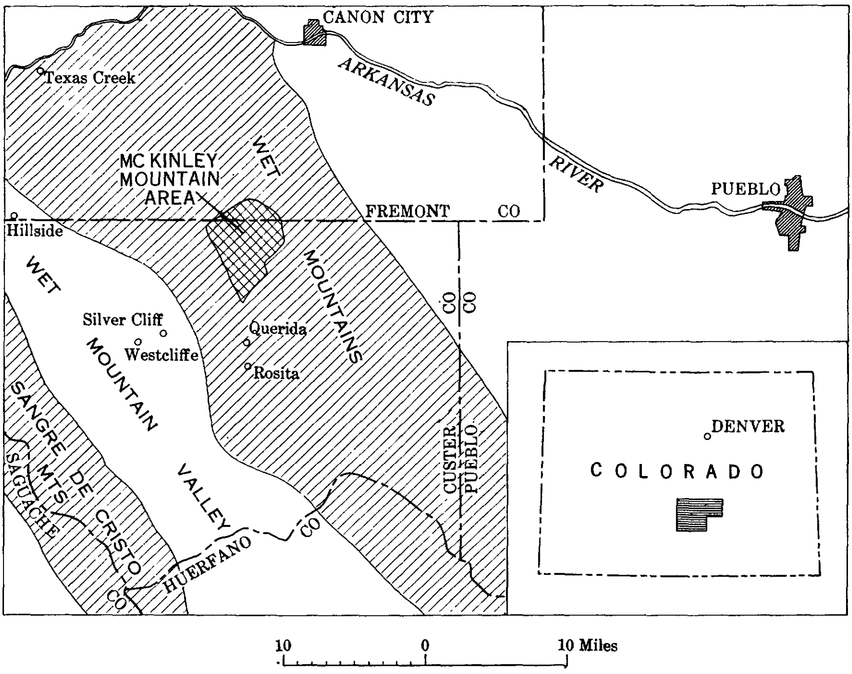

FIGURE 18.—Index map of Wet Mountains area, Colorado.

lead, gold, zinc, and copper veins associated with Tertiary volcanic rocks, have been described by Emmons (1896) and Cross (1896).

About two-thirds of the work by the U.S. Geological Survey was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission; the rest was done on a cooperative basis with the State of Colorado Geological Survey Board and Colorado Metal Mining Fund Board. This progress report was prepared under the general supervision of Q. D. Singewald.

GENERAL GEOLOGY

REGIONAL SETTING

The Precambrian rocks in the McKinley Mountain area are part of a north-trending belt of gneisses, schists, and granites which are exposed as a result of erosion following the uplift of the Wet Mountains during the Laramide revolution. This belt is the southward in echelon extension of the ancient Front Range highland (Lovering and Goddard, 1950). Just east of the mapped area is the northwest-trending Ilse fault, which the State Geologic Map of Colorado (Burbank, Lovering, and Eckel, 1935) shows as a structural break more than 10 miles long through the Precambrian terrane. West and southwest of the mapped area, a discontinuous belt of Tertiary volcanic rocks lies between the Precambrian rocks on the east and the alluvial fill in the Wet Mountain Valley on the west. Near Rosita, Querida, and Silver Cliff, vein deposits of gold, silver, lead, zinc, and copper are associated with these Tertiary volcanic rocks; thorium has not been found in them; however, one volcanic body near Hillside is slightly radioactive. Bordering the Wet Mountain Valley on the west are the high Sangre de Cristo Mountains, composed of folded Paleozoic sedimentary rocks and several small Tertiary intrusions (Burbank and Goddard, 1937).

ROCKS

The bedrock mostly consists of metasedimentary, migmatitic, and granitic gneisses which form complex interlayered sequences of interfingering and gradational rock types (pl. 15). Twenty different rock types are distinguished. The eight most abundant rock types are hornblende-plagioclase gneiss, including varieties that contain pyroxene; biotite-quartz-plagioclase gneiss; migmatite; alaskitic granite gneiss; quartz monzonite gneiss; light-colored granodiorite gneiss; metamorphosed gabbroic and ultramafic rocks; and albite syenite. They constitute nearly 95 percent of the bedrock, in part as individually mappable units and in part as interlayered sequences. The less abundant rock types are garnetiferous gneisses; sillimanitic gneisses; quartzite, mostly garnetiferous; pyroxene-scapolite gneiss;

pegmatite; breccia; altered rock; syenite dikes; dark-colored syenite dikes; andesite, andesite porphyry, and basalt dikes; lamprophyre dikes; and gabbro dikes.

For discussion purposes, these rocks have been arranged into three groups; each group contains rocks of similar age and postulated origin. The oldest is a group of metasedimentary gneisses; intermediate in age is a group of granitic gneisses of unknown origin; and the youngest is a group of igneous and other rocks.

Alluvium, talus, and soil, mapped as a unit, completely conceal the bedrock of an estimated 30–35 percent of the mapped area.

METASEDIMENTARY GNEISSES

The rocks, designated as metasedimentary gneisses, are believed to be the products of high-grade regional metamorphism during Precambrian time either of sediments alone or of sediments interlayered with igneous rocks. The chief representatives, in order of abundance, are hornblende-plagioclase gneiss, biotite-quartz-plagioclase gneiss, and hornblende-pyroxene-plagioclase gneiss. The last two might be considered as end members of a gradational metasedimentary sequence, for all gradations may be found—from biotite-quartz-plagioclase gneiss to hornblende-pyroxene-plagioclase gneiss. Other rocks in the metasedimentary group are garnetiferous gneiss, sillimanitic gneiss, garnetiferous quartzite, and pyroxene-scapolite gneiss that tend to form narrow layers. The metasedimentary gneisses were mapped as an undivided unit at some places, either because no single type predominates within a thinly interlayered sequence or because exposures are too poor to determine which type does predominate. This unit also may contain biotite schist which is too sparse or too poorly exposed to be mapped separately.

One of the principal lines of evidence for a metasedimentary origin for these rocks is the occurrence of marker beds as long, narrow layers that are of a mineralogically distinctive rock type that lie parallel to the foliation. These layers probably reflect original differences in composition of the parent rock. Many contain minerals generally regarded as indicating a sedimentary derivation. One garnetiferous zone, containing sillimanite, has an average thickness of about 10 feet and can be traced nearly 18,000 feet (extending from 115W, 178N to 15W, 310N);[1] many others have been traced for shorter distances. In the valley north of McKinley Mountain in the eastern part of the area, four discontinuous pods of pyroxene-scapolite gneiss extend 4,000 feet along essentially the same stratigraphic level, as deduced from the dips and strikes of the foliation; and farther east a narrow layer 1,500 feet long is in nearly the same stratigraphic position. Its

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[1] To facilitate locating points on the geologic map (pl. 15), a 2,000-foot grid system is shown on the map. Areas described in the text will be identified by coordinate numbers similar to the ones given here.

composition of scapolite, diopside, garnet, and sphene suggests that it was derived from a calcium-rich parent rock—possibly a calcareous lens or bed in the preexisting sedimentary sequence. Elsewhere, lenses of quartzite, many of which are rich in garnet, occur along the same general strike of the foliation.

HORNBLENDE-PLAGIOCLASE GNEISS AND HORNBLENDE-PYROXENE-PLAGIOCLASE GNEISS

Hornblende-plagioclase gneiss and, to a lesser extent, associated hornblende-pyroxene-plagioclase gneiss are common rock types that underlie an estimated 15–20 percent of the area. Because these rocks are less resistant to weathering than the others, they are found in the valleys and on the hill slopes; they probably underlie much of the covered areas. Although these rocks occur singly or together as a distinct rock unit, they are most abundant as one of the major components in layered units, particularly the unit of undivided metasedimentary gneisses.

The hornblende-plagioclase gneiss is a variable rock type, but typically is dark, medium grained, and well foliated and contains plagioclase, hornblende, and lesser amounts of pyroxene. The color ranges from medium gray to nearly black; the lighter colored rocks contain more plagioclase. In detail, light and dark minerals are intermixed either uniformly or in layers owing to partial segregation into small lenses or laminae. The average grain size differs from place to place and in general ranges from about 1 to 5 square millimeters in cross sectional area. Although the rock is prevailingly near equigranular, local facies contain larger hornblende crystals as much as 100 square millimeters in size. Foliation is readily seen at nearly all good exposures but may be obscure at poor ones. The foliation may be due to subparallel arrangement of dark minerals, particularly where biotite is present, to alternating lenses, laminae, or thin layers having slightly different composition or texture, or to partial segregation of the light and dark minerals into small lenses and laminae. Distinct lineation is seen at relatively few places; it may be due either to minor crinkles and folds or to subparallel orientation of mineral lenses.

Hornblende-plagioclase gneiss is composed of 48–60 percent of plagioclase, 24–47 percent of dark-green hornblende, less than 10 percent of pyroxene, and minor amounts of quartz, biotite, magnetite, apatite, and zircon. (See table 1.) A similar rock was termed "amphibolite" in the Haputa ranch area (Christman and others, 1953).

The hornblende-pyroxene-plagioclase gneiss tends to be darker and less foliated than the hornblende-plagioclase gneiss. The two rocks intergrade, however, and may be difficult to distinguish where light-green or brown pyroxene grains are not abundant. Plagioclase constitutes from 13 to 40 percent of the gneiss, hornblende from 33 to 70 percent; and pyroxene, either augite or hypersthene, from 16 to 41 percent. Locally, the pyroxene grains are clustered and give the rock a spotted appearance. Much of the hornblende-pyroxene-plagioclase gneiss of the McKinley Mountain area is similar in appearance to the augite-hornblende gneiss in Precambrian rocks about 6 miles to the southwest described by Cross (1896).

TABLE 1.—*Modes (volume percent) of hornblende-plagioclase gneiss and hornblende-pyroxene-plagioclase gneiss*

[Analyses by U.S. Geological Survey]

Sample[1]	Feldspar		Quartz	Hornblende	Pyroxene	Biotite	Accessory minerals
	Variety	Percent					
1	Calcic oligoclase	60	------	35	3	1	1
2	do	59	3	24	8	2	4
3	Sodic andesine	48	------	47	2	2	1
4	Calcic andesine	13	------	70	16	------	1
5	Sodic labradorite	58	------	37	5	------	--------
6	do	51	------	41	6	------	2
7	do	40	------	33	25	------	2
8	do	28	------	48	24	------	--------
9	Calcic labradorite	15	------	44	41	------	--------

[1] Numbers in parentheses following description of sample refer to coordinates on the geologic map (pl. 15).

1. Fine-grained foliated hornblende-plagioclase gneiss from a layered sequence of metasedimentary and granite gneisses (4E, 196N).
2. Fine-grained foliated hornblende-plagioclase gneiss from a layered sequence of biotite-quartz-plagioclase and sillimanitic gneisses (22E, 200N).
3. Fine-grained foliated hornblende-plagioclase gneiss from a pod-shaped body in biotite-quartz-plagioclase gneiss (18E, 166N).
4. Fine-grained well-foliated hornblende-pyroxene-plagioclase gneiss interlayered with granite gneiss (84W, 194N).
5. Medium-grained poorly foliated hornblende-plagioclase gneiss associated with light-colored granodiorite gneiss in long narrow unit (84W, 205N).
6. Medium-grained poorly foliated hornblende-plagioclase gneiss from a sill-like body in the layered sequence (82W, 200N).
7. Massive hornblende-pyroxene-plagioclase "spotted" rock from the same body as 6 (77W, 203N).
8. Fine-grained poorly foliated hornblende-pyroxene-plagioclase gneiss from layered sequence of metasedimentary and granite gneisses (3E, 193N).
9. Medium-grained well-foliated hornblende-pyroxene-plagioclase gneiss associated with an ultramafic body (57W, 316N).

Table 1 gives the modal compositions determined by point-count method of nine thin sections of hornblende-plagioclase gneiss and hornblende-pyroxene-plagioclase gneiss, which are listed in order of increasing calcium content of the plagioclase. In general, plagioclase becomes more calcic and less abundant as the pyroxene content increases. Biotite appears only in facies having the least calcic plagioclase. These data conform with field evidence that biotite-quartz-plagioclase gneiss, which also is metasedimentary, grades through hornblende-plagioclase gneiss to hornblende-pyroxene-plagioclase gneiss. Nevertheless, it should be noted that gradation also exists in the field between typical hornblende-pyroxene-plagioclase gneiss and metamorphosed gabbroic and ultramafic rocks.

BIOTITE-QUARTZ-PLAGIOCLASE GNEISS

The biotite-quartz-plagioclase gneiss, which underlies about 10–15 percent of the area, was mapped as an individual unit only in the southern part of the area; elsewhere, it is less abundant and is included as a constituent of the unit of undivided metasedimentary gneisses. The rock is more resistant to erosion than the hornblende-plagioclase gneiss and is less resistant than the alaskitic granite gneiss.

The rock is well-foliated pink to brown to light-gray medium-grained gneiss consisting essentially of biotite, quartz, oligoclase, and at places of microcline and (or) hornblende. The gneissic structure is due to parallel orientation and segregation into layers of biotite, hornblende, and, in part, quartz. With an increase in amount of hornblende, the gray varieties, at places, grade into hornblende-plagioclase gneiss; and, with a decrease in hornblende and biotite, the pink varieties are nearly identical with the alaskitic granite gneiss. At places, the biotite-quartz-plagioclase gneiss, which either grades into the granite gneiss or is interlayered with it, can be distinguished from the granite gneiss only by the predominance of plagioclase over microcline. The relative abundance of plagioclase and microcline was estimated with a hand lens in the field or examined as a powdered sample in 1.53 index oil with a petrographic microscope in the field office.

The texture, as seen in thin section, is crystalloblastic as evidenced by absence of idioblastic feldspars, the interlocking boundaries between quartz and feldspar, and the irregularly shaped microcline patches within oligoclase grains. The grain size of the quartz and feldspar is 1.0–1.5 millimeters.

Modal analyses of nine thin sections (table 2) show that the rock consists of quartz and oligoclase with variable amounts of biotite, microcline, and hornblende. The oligoclase is xenoblastic, is clear or slightly clouded by alteration, and either has simple albite twinning or is untwinned. Where oligoclase is in contact with microcline, myrmekite is common. Some of the oligoclase is antiperthitic. Microcline, where present, forms irregular patches in oligoclase and small xenoblastic grains. The quartz is clear and xenoblastic, shows a small amount of undulatory extinction, and has few inclusions. Although the biotite content is variable, its characteristic presence in the field justifies using it in naming the gneiss. Biotite commonly is in close association with hornblende but does not appear to have formed from the hornblende. Other minor constituents are magnetite, zircon, apatite, garnet, and sillimanite. In general, the thicker bodies that were mapped individually have decidedly less biotite than the thinner bodies interlayered in the unit of undivided metasedimentary gneiss.

TABLE 2.—*Modes (volume percent) of biotite-quartz-plagioclase gneiss*

[Analyses by U.S. Geological Survey]

Sample [1]	Microcline	Quartz	Oligoclase	Biotite	Hornblende	Other minerals
1		37	51	8	2	2
2	9	52	34	1	3	1
3	4	29	61	3	2	1
4	Trace	44	35	2	17	2
5		20	35	25		20
6		26	57	17		
7	29	30	34	6		1
8	1	43	39	17		Trace
9	14	28	54	Trace	3	1

[1] Numbers in parentheses following description of sample refer to coordinates on the geologic map (pl. 15).

1. Biotite-quartz-plagioclase gneiss from large area of outcrop (18E, 166N).
2. Biotite-quartz-plagioclase gneiss from area of alaskitic granite gneiss (14E, 171N).
3. Biotite-quartz-plagioclase gneiss from large area of outcrop (47E, 199N).
4. Biotite-quartz-plagioclase gneiss layer interfingered with granite gneiss and metasedimentary gneisses (2E, 196N).
5. Biotite-quartz-plagioclase gneiss from narrow layer containing gradational rock types; rock is garnetiferous and contains as much as 1 percent of apatite (22E, 200N).
6. Biotite-quartz-plagioclase gneiss from same layer as specimen 5; rock is finely layered (24E, 202N).
7. Biotite-quartz-plagioclase gneiss from same layer as specimens 5 and 6; rock has a slight pink color (24E, 202N).
8. Biotite-quartz-plagioclase gneiss from same layer as specimens 5, 6, and 7; rock is layered and contains sillimanite (31E, 208N).
9. Biotite-quartz-plagioclase gneiss from large area of outcrop (28E, 181N).

GARNETIFEROUS GNEISSES

Red garnet, variety almandite, locally occurs in every type of gneiss except the quartz monzonite gneiss, but it is most common in migmatite and in units of undivided metasedimentary gneiss. The garnet tends to be restricted to relatively thin layers, most of which were mapped as marker beds. Some layers were traced as much as several miles. The thin garnetiferous layers must reflect compositional variation in the parent rock; whether the garnets represent original composition or metasomatism along favorable beds is not known.

SILLIMANITIC GNEISSES

Sillimanite commonly is associated with garnet in marker beds over much of the area; however, it is less widespread than garnet and is restricted to thin stratigraphic zones. Sillimanite-bearing gneiss appears on the geologic map (pl. 15) as layers within the migmatite and undivided metasedimentary rock units, rather than as a distinct rock unit. Where most abundant, sillimanite occurs in about equal amounts with quartz and feldspar to form a distinctive white to cream greasy-appearing schist.

QUARTZITE

Quartzite forms small lenses in the metasedimentary sequence in that part of the area north of Highway 277. These lenses, few of which are more than a hundred feet long and more than 10 feet wide, were mapped as marker beds because they occur discontinuously along the strike direction of the foliation of the other rocks in the sequence.

The quartzite is light gray where it contains few impurities, dark gray where it contains much magnetite, and dark red where it contains much garnet. The red variety is most widespread; it is sugary, fine grained, and vaguely layered owing to slight differences in grain size and in concentrations of garnet and quartz. Two thin sections contained, respectively, 50 and 63 percent of quartz, 30 and 35 percent of garnet, and minor amounts of magnetite, apatite, zircon, and biotite; one of the sections contained 10 percent of diopside. The gray varieties have much the same texture and composition but variable amounts of magnetite; at a few outcrops magnetite constitutes more than one-half of the volume of the rock.

PYROXENE-SCAPOLITE GNEISS

The pyroxene-scapolite gneiss was mapped as a marker bed only in the valley north of McKinley Mountain. Elsewhere, small pods of gneiss that contain scapolite are included as part of the unit of undivided metasedimentary gneisses. The rock is moderately foliated, medium grained, and characterized by a streaked appearance owing to the irregular distribution of the layers of dark-green pyroxene and white scapolite. Minor amounts of bright-green epidote and dark-red garnet are commonly present. One thin section (from 63E, 255N) contained (volume percent by modal analysis) 63 percent of scapolite, 23 percent of green diopside, 8 percent of quartz, 3 percent of brown garnet, and 3 percent of sphene.

GRANITIC GNEISSES OF UNKNOWN ORIGIN

Migmatite, alaskitic granite gneiss, quartz monzonite gneiss, and light-colored granodiorite gneiss are included in one group because they have similar modes of occurrence, and all appear to be younger than the metasedimentary gneisses. The term "gneiss" is applied to these rocks in a structural sense as defined, for example, by Holmes (1920) to imply relatively coarse foliation or layering without implication as to the origin of the gneissic structure; locally the gneissic structure may be obscure. The terms "granite," "quartz monzonite," and "light-colored granodiorite" are used in their compositional sense and without implication as to the mode of origin.

Except for a few unusual occurrences, these gneisses form elongate bodies which parallel the foliation and terminate by interfingering with the adjacent rocks. Contacts may be very sharp or gradational. Only about five of the multitude of granite gneiss occurrences shown by plate 15 are crosscutting dikes. One (109W, 182N) is slightly aplitic. These dikes may be younger than the remainder of the granite gneiss with which they are combined on the map.

The two most probable modes of origin for these gneisses (excluding the migmatite) are intrusion of igneous material along the foliation planes of the metasedimentary rocks and granitization of favorable layers of the metasedimentary rocks. In like manner, depending upon the origin of the granitic layers, the migmatite may be considered either a mixed rock partly of igneous and partly of metasedimentary origin or a partly granitized metasediment.

MIGMATITE

Rocks designated as migmatite are estimated to underlie between 5 and 10 percent of the mapped area, but only in a few places has migmatite been mapped as a separate unit. At most places it is part of a layered sequence which includes combinations of granite gneiss, quartz monzonite gneiss, and metasedimentary gneiss. Migmatite very commonly contains garnet and, to a lesser extent, sillimanite.

As used in this report, a migmatite is a mixed rock exhibiting lit-par-lit structure of interlaminated metasedimentary gneisses and granitic material, usually granite gneiss or quartz monzonite gneiss. Arbitrarily, layers less than a foot thick were considered migmatitic, whereas layers more than a foot thick were considered components of layered sequences. At a few localities a gneiss containing abundant large crystals of potash feldspar along thinner layers of granitic material also was mapped as migmatite, even though it is atypical.

The alaskitic granite gneiss, on the basis of its wide distribution and its megascopic resemblance to granite layers in migmatite, is inferred to be the granitic component of most of the migmatite. However, quartz monzonite locally is the granitic component of some migmatite. No attempt has been made to determine an average composition of the migmatite because its bulk composition is variable, depending on both the composition and the relative proportion of the metasedimentary rock as well as that of the granitic additive.

ALASKITIC GRANITE GNEISS

The alaskitic granite gneiss, more simply termed "granite gneiss," is the most abundant rock type and covers an estimated 25–30 percent of the area. As the granite gneiss resists erosion, it is the chief constituent of most ridges and hills in the area. The most conspicuous mountain in the area, McKinley Mountain, consists primarily of a body of steeply dipping granite gneiss more than 4 miles long and 400 feet in average width; near the west end this body splits into two layers. In the northeast part of the map, in an area of gentle folding, the granite gneiss constitutes much of the bedrock. Many occurrences are large enough to be mapped individually, but innumerable other occurrences are included as noteworthy members in units of layered rocks.

The granite gneiss forms tabular bodies which are parallel to the regional foliation. All gradations may be found—from bodies that are hundreds of feet thick to layers less than a foot thick. Granite gneiss bodies change in thickness, sometimes abruptly, down the dip as well as along the strike. Contacts between granite gneiss and adjacent rocks were difficult to map in many places, owing in part to interfingering and in part to blending of the components of the rocks.

The granite gneiss is typically light brown to pink, medium grained, and equigranular. Quartz, pink feldspar, and minor amounts of magnetite and biotite are easily identified in the hand specimen; at some outcrops garnet is common. The granite weathers to angular fragments with smooth surfaces that are darker than fresh surfaces. Poorly developed gneissic structure or foliation is apparent throughout most of the granite gneiss, but locally it is either absent or very obscure. Foliation is most apparent megascopically in rock containing biotite or magnetite. The foliation within the gneiss invariably parallels that of the adjoining rocks.

Biotite- and hornblende-rich wisps, septa, layers, lenses, and pods paralleling the foliation are common in the granite gneiss. These features are most abundant near the contact, but they are also found in the interior of the granite gneiss. The small bodies containing biotite, some of which are an inch or two thick and several feet long, commonly grade into the surrounding rock and are similar to relict inclusions. Those rich in hornblende generally have sharp contacts, are well foliated, and are identical in appearance to some of the large hornblende-plagioclase gneiss bodies. Near 100W, 221N two such hornblende-plagioclase gneiss layers, 2–3 inches apart and each about an inch thick, were at one time continuous layers; but they have been broken, and the many resulting fragments of the layers are now separated by 2–6 inches of granite. Most of the fragments in the outcrop are 3–12 inches across, and some have slightly rounded edges, but most edges are angular. Good foliation within the fragments, the angular edges of the fragments, and the similarity of the granite around the fragments to that of the remainder of the granite gneiss layer suggest that the fragments were separated by mobile granite.

Garnet-rich layers, which probably represent relict compositional variations of the country rock, continue along the strike from a metasedimentary gneiss into a tongue of granite gneiss (59W, 156N), and layers of garnets are abundant within a body of granite gneiss (9W, 240N).

The rock contains about 42 percent of microcline, 33 percent of quartz, 22 percent of oligoclase, 1 percent of biotite, and about 2 percent of combined hornblende, magnetite, zircon, apatite, and rarely allanite; garnet occurs in some layers (table 3). Much of the microcline is microperthitic, and the intergrowths of sodic plagioclase range from a negligible amount to as much as 50 percent of a grain. Much of the quartz is irregularly shaped, has lobate apophyses, and forms an interlocking network with the other minerals. It has few inclusions. Magnetite, zircon, and apatite are minor constituents. In the course of mapping, it was noted that magnetite in the granite at many places is sufficient to deflect compass readings by several degrees.

The texture is dominantly granoblastic. Foliation in the granite gneiss may result from alinement of the dark minerals, commonly along parallel planes and more rarely from weakly developed orientation of aggregates of slightly flattened quartz grains. Irregular sub-

TABLE 3.—*Modes (volume percent) of alaskitic granite gneiss*

[Analyses by U.S. Geological Survey]

Sample[1]	Microcline	Quartz	Plagioclase	Biotite	Hornblende	Accessory minerals
1	41	27	29	3	----------	0.3
2	36	28	33	2	----------	.4
3	27	30	38	4	----------	1.0
4	43	35	20	Trace	----------	1.9
5	36	45	18	Trace	----------	.9
6	38	33	25	2	----------	2.0
7	48	32	15	Trace	----------	5.0
8	49	28	18	Trace	5	Trace
9	54	28	18	Trace	----------	Trace
10	49	33	17	--------	----------	.4
11	37	50	12	--------	----------	1.5
12	43	37	16	--------	4	Trace
13	41	36	22	--------	----------	.7
14	44	23	31	2	----------	.4
Average	42	33	22	0.9	0.6	1.0

[1] Numbers in parentheses following description of sample refer to coordinates on the geologic map (fig. 15).

1. Granite gneiss from dike, 5 feet thick, cutting metasedimentary gneisses (49E, 158N).
2. Granite gneiss from long, narrow layer cutting slightly across foliation of biotite-quartz-plagioclase gneiss (18E, 166N).
3. Granite gneiss from slightly garnetiferous layer 50 feet thick (60W, 225N).
4. Granite gneiss from large area of outcrop (20E, 300N).
5. Granite gneiss from along crest at the east end of McKinley Mountain (92E, 287N).
6. Granite gneiss from layer near contact with light-colored granodiorite gneiss (62W, 229N).
7. Granite gneiss from layer interfingering with migmatite and hornblende-plagioclase gneiss (4E, 196N).
8. Granite gneiss from McKinley Mountain near contact with unit containing metasedimentary gneisses (4W, 195N).
9. Granite gneiss from small pod in unit containing migmatite and metasedimentary gneisses (22E, 200N).
10. Granite gneiss from layer in unit of migmatite, and granite and metasedimentary gneisses (75E, 203N).
11. Granite gneiss from exposure at west end of ridge in stream cut; the high quartz content gives the rock a quartzitic appearance (83W, 190N).
12. Granite gneiss from central part of McKinley Mountain (36E, 226N).
13. Granite gneiss from layer with a maximum thickness of 100 feet and length of 8,000 feet which forms small ridge (13E, 196N).
14. Granite gneiss from narrow but continuous layer in area of biotite-quartz-plagioclase gneiss; the granite gneiss is slightly radioactive (55E, 197N).

parallel gneissic bands, 0.1–0.5 millimeter wide, of small grains of quartz and feldspar occur in several thin sections. These are discontinuous, merge and separate, in a few places cut mineral grains, and are generally parallel to the other planar features, suggesting granulation and recrystallization. Bent twin lamellae in a few plagioclase and microcline crystals and undulatory extinction of both quartz and feldspar are also interpreted as deformational features.

QUARTZ MONZONITE GNEISS

The quartz monzonite gneiss is estimated to underlie between 1 and 4 percent of the mapped area. It occurs principally in three elongate areas: as narrow layers, in part as marker beds, on the south side of McKinley Mountain (84E, 274N and 102E, 300N); as a series of layers near Highway 277 in the western part of the area (100W, 185N and 26W, 208N); and as a series of narrow layers about a quarter of a mile north of Highway 277 that extend more than 4 miles eastward across the mapped area to larger bodies in the northeast (86W, 198N to 40E, 374N).

The gneiss is medium to coarse grained, slightly porphyritic, gray to pink, with moderately well developed foliation. It is characterized by large (5 by 10 millimeters) oriented microcline crystals, a low quartz content, moderate biotite content, and good foliation. In contrast to the granite gneiss, which weathers to angular fragments with smooth surfaces, the quartz monzonite gneiss weathers to rounded, crumbly boulders. The average of five modal analyses (volume percent) of typical quartz monzonite gneiss is 46 percent of microcline, 38 percent of oligoclase, 7 percent of biotite, 7 percent of quartz, and 2 percent of magnetite, hematite, pyrite, zircon, and apatite. Thus, it has a lower quartz content and higher microcline content than biotite-quartz-plagioclase gneiss and a lower quartz content and higher plagioclase content than granite gneiss. The microcline contains inclusions of other minerals and is slightly perthitic. Some of the lamellae in the microcline twinning are bent.

No age relations were established between the quartz monzonite gneiss and the other granitic gneisses. In some places the physical resemblance of the quartz monzonite gneiss to the Pikes Peak granite (Lovering and Goddard, 1950, p. 28) suggests a possible correlation.

LIGHT-COLORED GRANODIORITE GNEISS

Light-colored granodiorite gneiss, which underlies less than 2 percent of the area, occurs mostly with the metasedimentary gneisses in layered units. The light-colored granodiorite gneiss is moderately common in the eastern part of the area (100E, 251N) and in the northwestern part (80W, 307N and 140W, 245N). Also, it is associated with hornblende-plagioclase gneiss to form an almost continuous layered unit extending about 14,000 feet along the south side of the major anticline in the northwestern part of the area (from 116W, 181N to 26W, 292N).

The light-colored granodiorite gneiss is characterized by its white or light-pink color. The grain size ranges from medium to coarse; some layers of the coarse-grained material are pegmatitic. The light-colored granodiorite gneiss, by analyses of four thin sections, is 50–55 percent quartz by volume; plagioclase, ranging from oligoclase to andesine, constitutes 25–45 percent; and microcline 0–13 percent. One section contains about 20 percent of muscovite. Accessory minerals are present in trace amounts in all but one thin section which contained about 7 percent total of biotite, garnet, ilmenite, sphene, and calcite.

IGNEOUS AND OTHER ROCKS

The group collectively designated as igneous and other rocks includes metamorphosed gabbroic and ultramafic rocks; pegmatite; breccia; albite syenite; altered rock; and dike rock. The pegmatite, albite syenite, and dike rock are igneous; and the metamorphosed gabbroic and ultramafic rocks are believed to have an igneous origin. The breccia appears to have a cryptovolcanic origin, and the altered rocks represent hydrothermal alteration.

METAMORPHOSED GABBROIC AND ULTRAMAFIC ROCKS

The metamorphosed gabbroic and ultramafic rocks, a heterogeneous group arbitrarily grouped together, underlie less than 1 percent of the area. Some of these rocks seem closely related to hornblende-pyroxene-plagioclase gneiss, in that they occur within the gneiss, intergrade with it, and form bodies elongated parallel with the regional foliation. Other, perhaps genetically dissimilar rocks form small, irregular to nearly circular, pluglike intrusive bodies.

The largest body, exposed in the northwest part of the area (130W, 270N), is about 2,500 feet long and 800 feet wide; it is cut off on the northeast by the albite syenite stock. In the south-central part of the area (30W, 180N), a body about 3,500 feet long and 600 feet wide is inferred to lie beneath an alluvium cover. It is exposed at the base of the adjoining hills and in stream cuts. It appears to be cut by two faults. In the northernmost part of the mapped area is a mixed unit of hornblende-plagioclase gneiss, hornblende-pyroxene-plagioclase gneiss, and gabbroic and ultramafic rocks. Here, the gabbroic and ultramafic rocks are too intimately mixed and interlayered with the gneisses to show them separately at the scale of mapping.

Some of the mafic bodies associated with hornblende-pyroxene-plagioclase gneiss are weakly foliated throughout; others are foliated only near the margin. All are composed of dark-gray to nearly black moderately coarse grained massive rocks. At many places the rock closely resembles hornblende-pyroxene-plagioclase gneiss; elsewhere the absence of feldspar or the presence of brownish pyroxene is distinctive. Large phenocrysts of pyroxene are particularly striking in the elongate body in the northern part of the area (54W, 320N). The dominant minerals are calcic plagioclase, hornblende, orthorhombic pyroxene (bronzite?), and clinopyroxene. The two kinds of pyroxene may occur together or separately. Olivine is an essential mineral in thin sections that contain little or no plagioclase. The chief accessory mineral is opaque black iron oxide, but spinel is abundant locally. A few of these mafic bodies associated with hornblende-pyroxene-plagioclase gneiss seem to crosscut enclosing gneiss. Elsewhere the transition with the hornblende-pyroxene-plagioclase is so gradual that a contact is difficult to map. The elongation and foliation of the bodies conform with regional foliation.

Mafic rocks that occur in small irregular-shaped to nearly circular pluglike bodies, almost certainly igneous in origin, range from fine to medium grained, tend to be more nearly black than gray, are essentially not foliated, weather to rounded massive boulders and are strongly magnetic locally. Some are enclosed in gneiss other than hornblende-pyroxene-plagioclase. Thin sections disclose pyroxene and very pale-green hornblende, along with either labradorite or olivine, or both, as essential minerals, and opaque black iron oxide as the most widespread accessory mineral. Orthorhombic pyroxene is ordinarily present but may be accompanied by a monoclinic pyroxene. Either labradorite or olivine may constitute as much as 50 percent of the rock. A few thin sections show an igneous-looking fabric of interlocking subhedral labradorite and pyroxene. Pale-brown mica occurs in one thin section. Dark-green spinel makes up as much as 5 percent of some rocks as small vermicular blebs and equant grains in hornblende and, less commonly, in pyroxene. Hornblende and spinel, at least in part, are tentatively concluded to be metamorphic minerals formed by recrystallization of igneous minerals.

PEGMATITE

Small bodies of pegmatite are scattered throughout the area, but, with the exception of a few bodies in the southeastern part of the area (40W, 45N), they are too small to be shown on the map. The mapped pegmatites are composed of quartz, microcline, plagioclase, and minor amounts of magnetite, biotite, and (or) hornblende. They probably are a facies of the granite gneiss. White pegmatites, none of which were mapped, contain plagioclase and quartz with only minor amounts of microcline and doubtless represent a generation different from that of the granitic pegmatites.

BRECCIA

A very irregular-shaped body of breccia, 2,500 feet long and 1,500 feet in maximum width, transects metasedimentary and granitic gneisses and adjoins the albite syenite stock in the northwestern part of the area. Several decidedly smaller breccia bodies are elsewhere in the northern part of the area.

The large breccia body is composed mainly of angular fragments of several kinds of gneisses, especially hornblende-plagioclase gneiss and granite gneiss; but also included are fragments of albite syenite. Some fragments have a maximum diameter greater than a hundred feet. The chaotic mixture of large and small fragments is very compact. Neither interstitial voids nor introduced cementing material are visible. A few narrow black aphanitic dikelets cut both the breccia and the country rock at a few places near the edge of the breccia body. Thin white borders of albite on many of the fragments suggest the rock has been feldspathized by hot vapors or solutions.

Field relations show that the breccia is older than the main stock but younger than a small outlier. Bordering the breccia on the north, the main albite syenite stock contains many large angular blocks of breccia near the contact. By contrast, a small body of slightly darker albite syenite at the southeast edge of the breccia not only is strongly broken near its contact with the breccia but also blocks of this variety of albite syenite are abundant near the contact and are sparsely scattered throughout the remainder of the breccia.

The shape and the position of the breccia body exclude the possibility that it is a fault breccia but suggest that it is related to the stock. The breccia may represent an escape vent through which pent-up volcanic gases related to the igneous body explosively found their way to the surface. The country rock was brecciated, but little or no igneous material was deposited. This mode of origin is similar to that for which the term "cryptovolcanic" has been used by Bucher (1933).

Five relatively small bodies of breccia (near 115E, 260N; 70W, 185N; and 91W, 261N) are composed of angular highly altered fragments of the country rock in a matrix of dark aphanitic igneous rock. They probably are breccia pipes. The largest of these bodies makes an elliptical outcrop pattern about 500 feet long. Black basalt dikes extend short distances from it into the surrounding rock.

ALBITE SYENITE

Part of an albite syenite stock covers about half a square mile at the northwest corner of the area. The stock has been traced 2 miles northwestward beyond the limit of the mapped area and is slightly elongate in that direction; the total area of the stock is about 3 square miles. Several small outliers have been mapped near the margin of the main stock. Three of them are older than a breccia body which in turn is older than the stock. Inclusions of older facies of albite syenite and of breccia are found in the stock. The albite syenite is not foliated, and because it cuts across metasedimentary and granitic gneisses and contains inclusions of these rocks, it postdates the regional metamorphism.

The albite syenite in the stock is equigranular, medium to coarse grained, and typically light brown, but locally pink, or gray. Color differences are due to variations in abundance of hornblende, biotite, and microcline. The rock weathers to rounded boulders, and in nearly all exposures limonite stains are found on joint surfaces.

Thin sections of the albite syenite contain albite antiperthite, nonperthitic albite, microcline (possibly including orthoclase), quartz, hornblende, biotite, zircon, apatite, magnetite, fluorite, epidote, chlorite, sericite, and calcite. Albite comprises 65–80 percent of the rock. Most of the albite is subhedral and antiperthitic; some of the albite is anhedral and replaces earlier albite. The late-stage anhedral albite does not simply fill interstices, as does quartz, but occurs irregularly along mineral bounderies. Microcline generally makes up less than 25 percent of the rock. Some is intergrown with albite and has patchy distribution and ragged borders, which suggest that it either was formed by exsolution or has been replaced by the albite. At places, the margins of the hornblende crystals are more sodic than the interiors as is indicated by bluish rims. The quartz content averages about 2 percent but in certain local facies of the rock is as high as 35 percent. Zircon and apatite are relatively abundant and make up an estimated 2–3 percent of some of the thin sections. Where zircon is adjacent to or within biotite grains, radiogenic halos are observed in the biotite.

Radioactivity readings of the albite syenite made with a gamma scintillation detector range from 2 to 10 times normal background and average about 5 times background. These abnormal readings result from the mass effect of small amounts of thorium and uranium which are probably associated chiefly with the zircon. Spectrographic analyses suggest that most of the radioactivity is due to thorium (table 4).

An age determination by the Larsen zircon method by Howard Jaffe, of the U.S. Geological Survey, indicates that the stock is of late Precambrian age. The determinations on 5 fractions of zircon gave an average age of 595 million years. As these calculations assume a normal uranium thorium ratio, whereas the rock has an abnormally high thorium content, it is possible that the actual age is somewhat

TABLE 4.—*Selected analyses (percent) of albite syenite stock and syenite dike*

[Analyses by U.S. Geological Survey]

Sample[1]	Equivalent uranium	Chemical uranium	Equivalent[2] ThO_2	Spectrographic analyses													
				U[3]	Th[3]	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb	Ba
1	0.004	0.0011	0.016	0	0.0X	0.0X	0.0X	0.0X	0	0.00X	0.000X	0	0	0.000X	0.0X	------	------
2	.019	.004	.084	0	.0X	.0X	.0X	.0X	0	.0X	.00X	0	0	.00X	.0X	------	------
3	.004	------	.02	0	0	.0X	.0X	.00X	0	.00X	.000X	0	0	.000X	.0X		
4	------	------	------	0	.0X	------	------	------	----	------	------	----	----	0	.0X	0.00X	0.0X
5	------	------	------	0	.X	------	------	------	----	------	------	----	----	.000X	.0X	.00X	.0X

[1] Numbers in parentheses following description of sample refer to coordinates on the geologic map (pl. 15).
[2] Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying by the conversion factor of 5.6.
[3] The lower limit of detection in spectrographic method employed is 0.05 for uranium and thorium.

1. Normal facies of albite syenite stock, part of sample used in age determination (133W, 296N); R. G. Havens, spectrographic analyses; and S. P. Furman, Wayne Mountjoy, and J. P. Schuch, eU and U analyses.
2. Pegmatitic facies of albite syenite stock (95W, 285N); R. G. Havens, spectrographic analyses, and S. P. Furman, Wayne Mountjoy, and J. P. Schuch, eU and U analyses.
3. Syenite dike (56E, 345N); P. J. Dunton, spectrographic analyses; and S. P. Furman and D. Stockwell, eU analysis.
4. Syenite dike, different sample than sample 3, (56E, 345N); G. W. Boyes, spectrographic analyses.
5. Red coating on fracture surface of syenite dike, sample same as sample 4, (56E, 345N); G. W. Boyes, spectrographic analyses.

younger. However, even if all radioactivity of the zircon were due to thorium, the age would not be more than 16 percent younger.

Of the smaller bodies of albite syenite south of the main stock, the ones associated with the breccia are considered to be slightly older than the breccia; age relations of the southernmost bodies are not known. Although some of the rock of these bodies is identical in appearance with the main stock, the average rock is slightly darker in color. Microscopically, no significant mineralogical differences are noted. At two localities syenite dikes, typical of those occurring throughout the area, occur as offshoots of the small bodies of albite syenite. This is significant in that it indicates the syenite dikes, in part at least, are related to the larger albite syenite bodies.

ALTERED ROCK

Two relatively large areas along a major zone of discontinuous faults between 115W, 235N and 40E, 110N and several much smaller areas elsewhere are noncommittally designated on plate 15 as altered rock. Similar material is found along many veins, where it is not shown as a separate map unit. The altered rock typically appears in shattered, brecciated, and sheared ground; but it also is found locally, for example at 132W, 233N, where the bedrock is not abnormally broken.

The most intensely altered material has a vuggy texture, ranges from pale pink to dark red, and consists mainly of pink feldspar. The vugs may be almost wholly filled by soft limonite. Individual feldspar crystals and aggregates may range from fine grained to very coarse grained. Subordinate quantities of quartz and a pale-green mafic mineral may or may not be present. Thin sections contain as much as 85 percent of microcline, by volume. Other constituents are plagioclase that ranges from albite to andesine, sodium-bearing pyroxene, sodium amphibole, quartz, hematite, limonite, leucoxene, apatite, rutile, and zircon. Thin sections of altered rock from a few localities show fractures that contain fine-grained microcline. Pore space constitutes up to 10 percent by volume of the thin sections; some cavities are lined by opal. The feldspars generally are cloudy due to hematite, sericite, and clay minerals. Some feldspars are almost opaque owing to disseminated hematite dust, and it is evident that much of the red of the rock is due to the hematite.

Products intermediate between the feldspar-rich material and unaltered rock appear within the areas mapped as altered rock as the contacts between these rocks generally are transitional, in places through a distance of more than a hundred feet. Even intensely altered material tends to retain the structure and fabric of the parent rock. Granitic rocks in general are more extensively altered than rocks such as hornblende gneiss. Epidote and chlorite appear in places at the margins of the altered rock zone where this zone crosses gneisses rich in hornblende and biotite. Thin sections of partly altered gneiss show skeletal leucoxene outlines of former biotite and hornblende grains; boundaries of later microcline grains pass through some of these relicts. Carbonate minerals are common in the partly altered rock, as disseminated replacement grains and as veinlets.

The altered rock between 115W, 335N, and 65W, 215N has a characteristic bluish-green cast. A thin section contains about 40 percent of sodium-bearing pyroxene having optical properties intermediate between those of augite and aegerine, and 2 percent of blue arfvedsonite; the remainder is mostly oligoclase and microcline. Elsewhere along the same fault zone, the altered rock is the typical pink variety rich in feldspar.

The alteration discussed in the paragraphs above probably resulted from alkalic fluids at very high temperature. However, its relations in time and space to ore deposition are not known, because a thorough study of wallrock alteration in the district has not been completed.

DIKE ROCKS

Five groups of dikes have been distinguished: syenite; dark syenite; andesite, andesite porphyry, and basalt; lamprophyre; and gabbro. Their relative ages are incompletely known, but in general, the syenite dikes are younger than the basic dikes, and the dark syenites are commonly younger than the other syenites. As the syenite dikes are related to the albite syenite stock, most of the dikes are considered to be Precambrian. A few lamprophyre and andesite dikes, however, are younger than the syenite dikes. Individual dikes have been traced for several miles, but most of those mapped are between 500 and 2,000 feet long and from 2 to 3 feet wide. Most of the longer dikes trend northwest, but a few trend nearly east-west. The apparent displacement of many of the dikes is attributed chiefly to emplacement along preexisting in echelon fractures, rather than to later displacement by faulting; at only a few localities were the dikes proved to be faulted. Most dikes occupy fractures that show no displacement, but a few dikes were mapped along faults. Drilling at Haputa ranch (Christman and others, 1953) revealed mafic dikes weathered so intensely that surface exposures are scarce. Limited exposures in prospect pits and roadcuts suggest that, despite the large number of dikes already mapped, many unmapped weathered dikes occur in the McKinley Mountain area. At many localities, dikes extend into the covered areas as small ridges at a scale too small to show the alluvium contact on each side of the dike; in these places, the dike is shown on the map by solid or dashed lines rather than a dotted line for a concealed contact.

Many of the dikes have been mineralized and altered; and some have been completely replaced by carbonate and other vein minerals. Where this replacement is great, the dike is considered a vein; thus, along the strike some dikes change into veins.

The syenite dikes are more abundant and more continuous than any other group. They are fine grained and light brown, pink, or salmon. They usually appear equigranular, but in some dikes pink feldspar phenocrysts 2–4 millimeters long are present in small amounts. They tend to resist erosion—dikes less than 10 feet wide at places form the crest of minor ridges and hills. The rock weathers to smooth angular fragments which are found long distances down the slope from the dikes.

The syenite, as seen microscopically, is composed dominantly of potash feldspar with minor amounts of quartz, albite, magnetite, ilmenite, aegerine, biotite, hematite, limonite, epidote, leucoxene, sericite, scapolite(?) and clay minerals. The potassium feldspars are usually tabular and subparallel, thus forming a trachytic texture not apparent in hand specimen. They are clouded by clay alteration and by finely divided hematite dust which gives the rock its pink color. In the fine-grained varieties, poorly developed spherulites are found. Quartz is present in small amounts in most of the syenites examined but is abundant in only a few; the latter may be more properly called aplites, but are grouped with the syenites for convenience. Quartz is anhedral and is interstitial between feldspar laths, but it also may occur as phenocrysts ½ to 2 millimeters across. Albite, usually partly altered to scapolite(?), is found intergrown with potassium feldspar and as distinct grains. Magnetite is altered to hematite and limonite, and ilmenite is partly altered to leucoxene and limonite.

Many of the pink syenites are anomalously radioactive; some give readings as much as 10 times background on a gamma scintillation detector. Readings more than three times background, not associated with veins, were recorded as isolated radioactive localities on plate 16. Spectrographic analysis of one such dike showed that the red coating along a fracture (table 4) had a high thorium content. Smaller amounts of thorium occurred in the central unaltered part of the rock.

The dark syenite dikes are subalkalic rocks that contain sodium amphiboles and sodium pyroxenes. They are darker than syenite dikes, and more apt to be porphyritic. Some of the porphyritic varieties are medium grained gray rocks similar to the gray facies of the albite syenite stock; some are pink to gray fine-grained porphyritic rocks with phenocrysts of feldspar and hornblende; and others are dark-gray fine-grained rocks with pink or white feldspar phenocrysts. The weathered surfaces of nonporphyritic varieties locally exhibit concentric colors that look like oolites. Because of the diversity in color and texture, these rocks were recognized as a related group only after microscope studies. Most dikes appear consistent in composition along their strike, but a few syenite dikes grade into dark syenite. The increase of dark minerals in this transition zone was also accompanied by an increase of albite and a decrease of potassium feldspar. The feldspar in the gray varieties is almost entirely albite, whereas the pink varieties contain some potassium feldspar. Other minerals identified in the dikes include arfvedsonite, riebeckite, hedenbergite, aegerine, biotite, apatite, fluorite, magnetite, sodalite(?), nepheline(?), and zircon; quartz is absent. The texture is very similar to that of the syenite dikes, except that porphyritic varieties are more common. The phenocrysts commonly are albite microantiperthite; they range from white to gray to pink and are as much as 2 inches long. The dark syenite dikes, as well as the syenite dikes, may be related to the albite syenite stock.

Andesite, andesite porphyry, and basalt dikes are grouped together to include most of the mafic rocks in the area. They are dark gray to black, very fine to medium grained, and commonly porphyritic. The most abundant mineral normally is plagioclase, which may vary from calcic andesine to calcic labradorite. Augite is also abundant in most of the rocks. Other minerals are biotite, apatite, olivine, magnetite, quartz, hornblende, and pyrite. Secondary minerals include scapolite, chlorite, clinozoisite, sericite, calcite, and tremolite-actinolite. Because many of the dark syenite dikes were not recognized as such until after the fieldwork was completed, plate 15 may incorrectly include with the group of andesite, andesite porphyry, and basalt dikes, a few dark syenite dikes that are aphanitic and darker than normal.

The lamprophyre dikes, though not abundant, are of interest because they may be the youngest of the dikes. They have large phenocrysts of augite, hornblende, or biotite in a fine-grained dark-gray groundmass.

Six gabbro dikes were mapped within three local areas (45W, 320N; 100E, 256N; and 10E, 89N); they are about 100 feet wide. The gabbro weathers readily, and therefore the dikes are poorly exposed; they were mapped by tracing scattered residual boulders and depressions in the topography. The rocks are medium grained and are composed of labradorite, augite, and olivine with small amounts of biotite, magnetite, and chlorite.

MAP UNITS

Some map units in plate 15 are designated by a single rock name, others by two or more rock names. In general, units of the gneiss complex that are designated by a single rock name are not less than 50 feet thick. Nearly all contain local lenses and thin layers of other rock types, but wherever one type of rock comprises more than 80 percent of a unit, the impurities were ignored in naming the rock.

Sequences of gneiss that contain at least 20 percent of each of two or more rock types in layers more than a foot thick are mapped as layered units. In general, the layered units are not less than 100 feet thick. Some contain as many as four different types of rock. Inasmuch as choices for subdividing a heterogeneous sequence inevitably are multiple, the specific units chosen for mapping are in a sense arbitrary. In general, however, persistent mappable layers were selected as boundaries of units. Commonly the composition of such a unit changes gradationally or by interfingering along the strike. Where exposed, the interfingering was mapped; where exposures are poor, or where the change is transitional over a wide area, the contact was approximately located.

Each of the components of the 17 map units designated as layered sequences has already been described. On the geologic map, for the more common sequences of two rock types, the rock comprising more than 50 percent of the unit is given first and separated from the second component by a hyphen. Thus, "a-h" is a layered unit of predominantly alaskitic granite gneiss with subordinate (20–50 percent) hornblende-plagioclase gneiss, and "h-a" is predominantly hornblende-plagioclase gneiss with subordinate alaskitic granite gneiss. Where hyphens are not used, any one of the listed components may predominate. To be included in the unit name, however, a rock type must be present in excess of 20 percent.

GEOLOGIC STRUCTURE

The most conspicuous structural features shown on the geologic map (pl. 15) are the general northeast trend of steeply dipping, foliate rocks; the northwest trend of the faults, shears, veins, and dikes transecting these rocks; and several broad folds.

FOLIATION AND LINEATION

All the rocks other than albite syenite and dike rocks are foliated, most commonly owing to gneissose structure and to planar orientation of biotite. The extent to which the foliation reflects original bedding or was formed by metamorphic differentiation or metasomatism is not known. The foliation is believed to be parallel to the original bedding, because no evidence to the contrary was found. Foliation which may have formed in the granitic gneisses during their intrusion, if they are igneous, is not distinguishable from the foliation in the metasedimentary gneisses. The most obvious feature of the foliation is its consistent dip and strike within a given area and the general northeast strike throughout most of the area.

Lineation is exhibited by grooves, crenulations, mineral lenticles, alinement of elongate minerals, and fold axes. Groove lineation is the most conspicuous and widespread. It appears most commonly on surfaces of alaskitic granite gneiss, perhaps because this rock is more widely exposed than any other gneiss. The grooves are long and straight, and generally are 1 to 2 millimeters in amplitude. The smallest grooves appear as thin black lines on foliation planes, presumably owing to concentrations of dark minerals along the troughs of the grooves. Whether the grooves resulted from movement along the foliation planes, from miniature folding, alinement of mineral grains, or a combination of these could not be determined. Crenulations that range in amplitude from a fraction of an inch to several inches are common in some areas but are much less widespread than grooves. The crenulations appear mostly in alaskitic granite gneiss, migmatite, and hornblende-plagioclase gneiss; in the metasedimentary rocks they may appear as well-developed fluting. Elongate mineral lenticles and alined crystals of elongate minerals are much less common than the other two types of lineation. Only a few major and minor fold axes were mapped because of the difficulty in accurately locating the traces of major folds and scarcity of minor folds that could be recognized as such. Hence, most lineations recorded on the geologic map represent either grooves or crenulations.

Lineations are approximately parallel to axes of observed major or minor folds throughout the northern and central parts of the mapped area. All lineations in these areas are interpreted as representing the fold axis direction; that is, fabric axis b. These b-lineations plunge at small to moderate angles to the southwest in the northwestern part of the area, and to the northeast in the north-central and northeastern part. Nearly horizontal lineations are found along a major anticline in the northwest (70W, 250N) and farther east in folds immediately north of Highway 277.

At a few places lineations occur which are not fully understood. Along the southeast border of the area steeply dipping lineations plunge northward nearly at right angles to the strike of foliation in a narrow granite gneiss layer. In the southwest, lineations range in strike from north to southwest with most striking northwest.

FOLDS

Highway 277 coincides in a general way with a structural boundary between a folded area to the north and a homoclinal area to the south. The folded area includes one well-defined, fairly open, major anticline, subordinate and minor folds, and flexures that are incompletely deciphered. Perhaps other folds remain unrecognized because exposures that yield structural data are too few. Crenulations, contortions, and small-scale structural features, such as drag folds and warps having amplitudes of not more than a few feet, are exposed only within a few local areas. Throughout most of the homoclinal area, the rock layers dip consistently at steep angles to the northwest. In the southwestern part of the mapped area is a conspicuous fold with a nearly vertical plunge, unlike the folds farther north. In the southernmost part of the area, abrupt lateral gradations of thick layers and inconsistent plunges of the lineation suggest structural complexities that remain to be understood.

A major anticline trends N. 45°–50° E. in the northern part of the area (from 120W, 193N to 4W, 325N). The top of the anticline is a fairly broad arch, along which appear scattered, small-scale contortions, drag folds, and warps. The limbs are asymmetric; the prevailing dip of the foliation is about 45° on the north limb and 70°–80° on the south limb. Lineations indicate that the axis plunges gently northeast and southwest from a dome approximately at 70W, 250N. The doubly plunging anticline is shown on the geologic map by the outcrop pattern of a layer of hornblende-plagioclase gneiss that underlies resistant alaskitic granite gneiss near the crest. To the west, the anticlinal axis is displaced southward along each of two transverse fault systems. Toward the eastern border, the major anticline merges into subordinate anticlines and synclines.

On the northwest flank of the major anticline in a zone about 3,000 feet wide, minor folding is represented by moderately sparse structural terraces, gentle warps, and drag folds that trend parallel to the anticlinal axis. Adjacent to this zone to the north is a more intensely deformed zone in which the foliation exhibits much crinkling and some drag folding. It is 1,000–2,000 feet wide and extends about 6,000 feet northeast of 80W, 290N and is interpreted as the crumpled core of a tightly compressed syncline. It may be related to a syncline that lies farther eastward (25W, 345N) along the same trend.

On the southern limb of the west-central part of the major anticline, the rocks dip steeply to the south, and the structure is not fully understood. Some 5,000 feet from the axis, two ledges of granite gneiss that diverge northeastward from 72W, 195N may be interpreted as an anticlinal nose which plunges to the southwest and opens to the northeast.

North of Highway 277, in the east-central and northeastern parts of the mapped area is a series of subordinate or minor anticlines and synclines. The axes of several are shown on the geologic map; the axes of several others are not shown because exposures exhibiting the attitude of foliation are too scattered to locate the fold axes. At least some of the folds pass into structural terraces within a relatively short distance along their axial trend and eventually pass into simple homoclines. Throughout much of this part of the area, scattered nonconsistent dips, some of which are nearly flat, disclose that structural warps of folds exist. Towards the eastern margin of the area, prevailing dips of the foliation are low and nearly at right angles to the prevailing dips elsewhere.

South of Highway 277 in the eastern part of the area the gneisses form a conspicuous series of steep, northwest-dipping layers. As shown on cross section *B–B′* and the geologic map (pl. 15), four parallel ridges, the most conspicuous of which is McKinley Mountain, represent resistant rock units in this interlayered sequence. Because of the absence of small drag folds or warps, a scarcity of groove or crumple lineations, and no apparent duplication of major sequences, the structure is interpreted as homoclinal rather than isoclinal.

In the southwest part of the area, a large fold structure has characteristics anomalous to the rest of the area mapped.

FAULTS, SHEAR ZONES, AND JOINTS

Faults, shear zones, and joints generally trend northwest, and thus transect the foliation at large angles (pl. 15). Five of the faults are a mile or more in length, and the largest is more than 2½ miles long. In part, the trends of the larger faults are expressed by topographic lows and breaks in the ridges. The amount of vertical displacement on the faults is not known; the largest horizontal displacement is about 400 feet. They range in width from a few inches up to broad zones of faulting and shearing 250 feet wide. Shear zones are zones of intensely broken rock that generally are altered and mineralized. Two of the largest of these zones are on major faults; each is nearly a mile long and has a maximum width of about 250 feet. Numerous other shear zones occur throughout the area; where strongly mineralized, they were mapped as veins. Joints are abundant in all the rocks and are most conspicuous in granitic gneisses. Many joints are filled with dikes and veins.

The dip of the faults, shear zones, and joints is generally vertical with variations of 5°–10° in either direction. As most of the fractures in the McKinley Mountain area are expressed as nearly straight-line features without deflection that is due to topography, they are interpreted as being nearly vertical. An exception is the curve in the trend of the shear zone on a ridge in the northwestern part of the area (90 W, 220 N) where the shear zone dips about 50° NE.

The faults shown on plate 15 are fractures along which displacement has been inferred, either by matching specific layers of rock in opposite walls or, more commonly, by observing an abrupt change in lithology across the fracture. Along none is the total slip known, and only where rock layers may be matched in opposite walls can the horizontal component of displacement be measured. Fractures that contain vein material or igneous rock are shown as veins or dikes rather than as faults, even though the walls are displaced. Not shown on plate 15 are fractures that may possibly be faults, but along which evidence for displacement is inconclusive, because both walls contain nondistinctive sequences of gneiss that may or may not be the same unit.

Five faults, each having a measured horizontal component of displacement greater than 200 feet, are described below. There may be others having a comparable displacement, which cannot be measured, that are not described. The longest fault, expressed topographically as Dead Mule Gulch, is mostly covered by stream gravel. It trends N. 60° W., and its northeast wall has moved not less than 200 feet northwestward relative to the southwest wall. About 3,000 feet east of Dead Mule Gulch, a fault that is part of a long sinuous shear zone cuts McKinley Mountain at 33W, 188N, where it has a horizontal displacement between 300 and 450 feet. The fault appears to die out southeastward under Ralph Gulch and northwestward about 4,000 feet northwest of McKinley Mountain. Near its northwest end is the southeast limit of another fault zone, whose horizontal displacement is about 300 feet at 74W, 216N. The displacement along this fault zone is believed to increase northwestward, though no units could assuredly be correlated across it. In the eastern part of the area, McKinley Mountain is cut by two faults which are topographically expressed by breaks in the ridge; both exhibit a horizontal displacement of about 400 feet where they cut the ridge. The westernmost of these two faults (60E, 250N) strikes about N. 80° W., dips 90°, and may possibly continue several thousand feet to the southeast and northwest. The easternmost of the two (100E, 290N) strikes N. 55° W. and probably also has a vertical dip.

Two of the faults mentioned above are parts of a sinuous zone of discontinuous faults, veins, and altered rock—interpreted as a major shear zone—that may be traced with few interruptions across the entire mapped area, from 150W, 266N to 42E, 106N. The northernmost 4,500 feet, north of 116W, 236N, is a relatively narrow zone of crushed rock, much of which is vein matter. Between 116W, 236N and 5E, 150N, a total distance of 15,000 feet, the major shear zone is relatively wide but pinches and swells. In the northern part of this segment, the gneisses are prevailingly altered to a bluish color owing to the introduction of sodium amphibole, whereas in the central and southern parts of the segment the gneisses have undergone extensive feldspathic alteration. Faults and veins abound within both types of altered rock. Southeastward from 5E, 150N, for a total distance of 6,000 feet, the shear zone is represented by a belt of feldspathized rock in which no mappable faults and few veins were observed.

The faults are younger than the metamorphism because they displace the foliate rocks. Faults are also younger than the folds as shown by the displacement of the axis of the large anticline in the northwest part of the area. Some faults are cut by, and therefore antedate, syenite dikes that are considered to be Precambrian(?). On the other hand, many of the syenite dikes have been displaced by later faults or by renewed movements on faults antedating the dikes. Faults in general antedate the veins, for many veins occupy fault fissures, but at a few places the veins are displaced either by faulting after mineralization or by movement along the old faults.

Joints are found throughout the area. As a careful study of joints was not made, most of those recorded were in the granite gneiss along the ridges where such features are prominent. These are not shown on the map, and no interpretation was made.

FRACTURE PATTERN

Fractures in the McKinley Mountain area prevailingly strike northwest and most dip 80° or more. The overall pattern is portrayed on plate 15 by faults, shear zones, dikes, and veins. The dikes and veins are included because they occupy preexisting faults, shear zones, or joints.

Figure 19 shows results of a statistical study of trends of fractures in the mapped area. The predominating trend of veins is N. 50°–70° W., but the diagram shows a secondary trend N. 30°–50° W. The dikes exhibit a relatively wide range in prevailing trend, from N. 50° W. to N. 75° E., but the diagram shows a maximum concentration at N. 80° W., secondary concentrations at N. 70° W. and N. 85° E., and also a very minor secondary trend at N. 30° W. The diagrams (fig. 19) were prepared by recording the bearing of every vein and dike within each 2,000-foot square of the grid system on the geologic map in order that trends represented by the longer fractures be weighted by length. Thus, the trend of a vein or dike extending through 3 squares was recorded 3 times. The prerequisite for this method is that the features have vertical or nearly vertical dips. Each diagram represents a plot of more than 700 bearings. Not shown on figure 19 are about 170 plots for faults, which are too few to give a significant pattern. The general trend for faults, however, appears to be rather similar to that for veins.

Some of the fractures extend long distances, as is indicated by the continuity of some of the veins and dikes. A syenite dike in the southwest part of the area (34W, 80N) can be traced 14,000 feet. Although other long dikes occur, most can be traced for only short

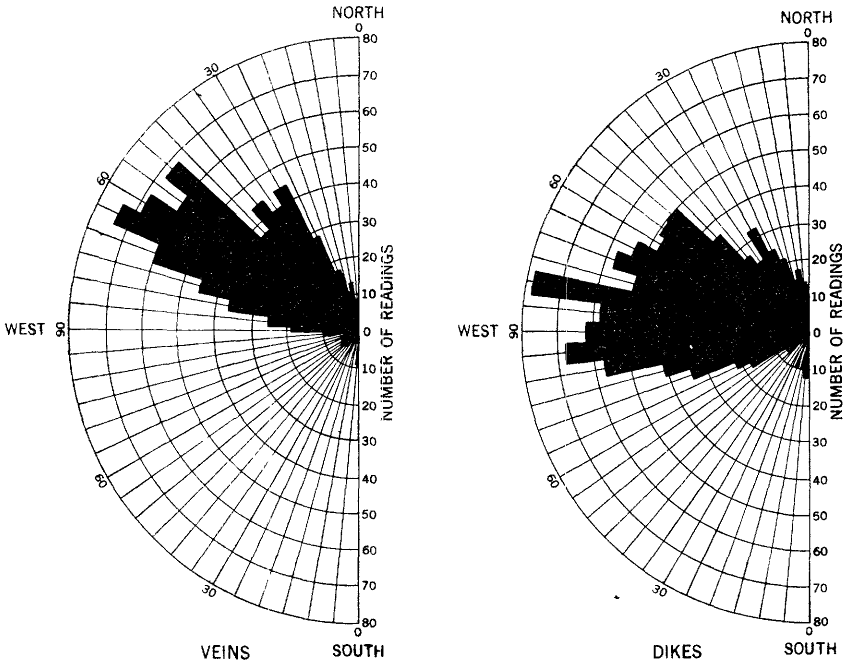

FIGURE 19.—Diagrams showing trends of veins and dikes, McKinley Mountain area, Colorado.

distances. In many places, their discontinuities suggest that they occupy in echelon fractures.

MINERAL DEPOSITS

The McKinley Mountain area has been extensively prospected by many pits and short adits and by a few shallow shafts. Most of the prospects were dug along veins, presumably to search for silver, gold, and lead in the late 1800's when the Rosita and Silver Cliff mining districts were prospering. However, the only minerals known to have been removed commercially from the mapped area are barite from veins and vermiculite from bodies of reconstituted or altered rock. No production records are available, but it is evident from the size of the workings that the aggregate output has been small. The recent discovery of thorium in the region by the U.S. Geological Survey has renewed the interest of prospectors in the area.

DESCRIPTION OF VEINS

All mapped veins, totaling between 350 and 400, are shown on plate 16. Most veins are less than 5 feet wide and can be traced along the outcrop for only 100–1,000 feet. However, a few are as much as 50 feet wide and can be traced as far as 5,000 feet. Vein minerals formed along fractures as coatings, open space fillings, or replacements of the wallrock. The veins have steep dips, are rather constant in strike, and trend dominantly N. 60° W.; northeast-trending veins are rare. In places, dikes have been partly or completely mineralized to veins; in other places, unaltered dikes and veins occupy the same fracture. Generally the larger faults have not been mineralized, but one long sinuous fault zone in the northwestern part of the area has served as an important structural control of mineralization.

In this report, in addition to being used in its conventional sense, the term "vein" is used to describe certain types of thorium mineralization where the amount of introduced material appears to be so small that no visible vein rock is present. The thorium and associated red, brown, and yellow iron-oxide and (or) hydroxide minerals in such veins occur as stains, coatings, veinlets, or disseminations along zones of closely spaced fractures. Abnormal radioactivity along these veins gives clear evidence of mineralization even though gangue—such as quartz, barite, and carbonate minerals—is absent. At places, the fractured wallrock has been feldspathized.

Well-defined veins containing quartz, barite, and iron-bearing carbonate are fairly abundant throughout much of the area. Most quartz is white and massive, but euhedral crystals are common and many are smoky and zoned. The barite ranges from red to white and from aggregates of coarse grains that exhibit good cleavage to fine-grained masses of microcrystalline grains. The iron-bearing carbonates are generally fine grained and massive and range from pale green to reddish brown. Ankerite(?) bands and tiny calcite stringers occur in some of the rock. Many of the iron-bearing carbonate veins represent almost complete replacement of dike rocks. Nearly all veins are heavily stained by red and brown iron-oxide and (or) hydroxide minerals.

Quartz, barite, iron-bearing carbonate, and thorium-bearing minerals may occur together or alone, and a vein composed predominantly of one may grade along the fracture into a vein composed predominantly of another. The thoritelike mineral and specularite are common minor constituents. Minor amounts of pyrite, chalcopyrite, tetrahedrite(?), galena, fluorite, and secondary copper minerals are locally present, but none has been found in sufficient quantity to form ore. Submarginal quantities of precious metals likewise are locally present. Riebeckite and arfvedsonite are abundant at some localities. No uranium minerals have been found to date. Many of the veins contain a fetid gas of unknown composition which escapes when the rock is broken; the gas may be a phosphorous compound.

The veins generally show little topographic expression, although where feldspathized or silicified they may form slight ridges in areas of flat topography. Veins commonly are in the gaps in granite ridges where fracturing has occurred.

THORIUM DEPOSITS

Thorium vein minerals—as distinct from thorium-bearing accessory rock-forming minerals such as zircon—occur as irregularly distributed constituents of veins, as disseminations and small local concentrations in broader areas of shattered rock, and as sparsely scattered components of bodies thought to be completely altered breccia pipes. Only the vein occurrences, presently, seem to hold economic interest. Disseminations in shattered rock are generally found within irregularly feldspathized or silicified masses; for example, at 45W, 195N; 25W, 172N; 111W, 234N; and 51E, 352N. Linear concentrations within these masses are depicted on plate 16 as veins. Pipes that are thought to represent hydrothermally altered and mineralized breccia contain minor quantities of thorium. Eight such bodies (4 between 28W, 246N and 53W, 250N and 4 between 50E, 352N and 55E, 367N), which are roughly circular in plan, resemble some of the veins in composition.

The distribution of thorium is shown by the more than 800 radioactivity anomalies that are recorded on plate 16. Circles, squares, and triangles represent weak, moderate, and strong radioactivity, respectively, as measured by a gamma-scintillation detector held at hip level (2–3 feet above the surface of the ground). The readings depend not only on the grade and quantity of radioactive rock actually present but also on how well it is exposed. At most localities the veins are poorly exposed. Large and small symbols indicate, respectively, whether the reading was obtained over an area greater or less than 50 square feet, which in turn indicates whether large or small amounts of radioactive material are exposed. Except in disseminated deposits, radioactivity readings increase as the detector is brought in contact with the source. Where this increase was greater than twofold, a dot appears in the center of the symbol to indicate that concentrations of radioactive minerals are present. These localities are ones that might be profitably explored. A lone dot indicates that the contact reading was more than three times background but that the hip-level reading was less than three times background.

The amount of radioactivity established as background was arbitrarily set as being an approximate average of readings obtained in areas containing no radioactive deposits. This value was intermediate between the low values obtained in areas of mafic-rich rocks and the higher values obtained in areas of granite gneiss. Because the background varies with the sensitivity of the various detectors and because a reference point might be needed for future work, one locality was

TABLE 5.—*Analyses (percent) of samples from the Mc*

[Analyses by U.S.

Sample	Location [1]	Type of sample	Equivalent uranium	Chemical uranium	Equivalent ThO_2 [2]	Chemical ThO_2	Total rare-earth oxides and ThO_2	Rare-earth oxides [3]
RA-103	92W, 221N	4½-foot channel	[5] 0.063	[6] 0.001	0.35	[6] 0.25	--------	[6] 0.52
RA-104	92W, 221N	12-inch channel	[5] .89	[6] .005	4.96	[6] 4.03	--------	[6] 1.98
RA-109	Darby Extension Lode, 119W, 236N.	Grab of vein material.	[5] .25	[6] .001	1.39	[6] 1.39	--------	[6] .18
RA-110	92W, 214N	6-inch channel	[5] .46	[7] .002	2.56	[8] 2.06	[8] 2.83	.77
RA-111	90W, 221N	14-inch channel	[5] .26	[7] .003	1.44	[8] 1.27	[8] 1.62	.35
RA-112	Darby Extension Lode, 121W, 237N.	10-inch channel	[5] .19	[7] .001	1.06	[8] .73	[8] 1.20	.47
RA-113	Darby Extension Lode, 122W, 238N.	18-inch channel	[5] .20	[7] .003	1.10	[8] .96	[8] 1.39	.43
RA-114	Penny Poker Lode, 129W, 247N.	6-inch channel	[5] .084	[7] .001	.46	[8] .26	[8] .35	.09
RA-115	56W, 213N	Grab of vein material.	[5] .075	[7] .001	.41	[8] .28	[8] .43	.15
RA-116	62W, 210N	Selected vein material.	[5] .52	[7] .001	2.91	[8] 2.41	[8] 2.88	.47
53-B-66	Tuttle ranch, 6E, 354N.	14-inch channel	[9] .71	[9] .001	3.97	--------	--------	--------
53-B-36	89W, 320N	Selected vein material.	[10] .63	[10] .001	3.52	--------	--------	--------
KR-6	General Ike, 37W, 112N.	do	[5] .094	[12] .004	.50	--------	[12] .38	--------
KR-10	do	4-foot chip channel.	[5] .033	[11] .004	.16	--------	--------	--------
KR-7	Thorium Mountain, 52W, 118N.	Selected vein material.	[5] .21	[12] .010	1.12	[12] 1.26	[12] 1.64	.38
KR-11	do	Grab of vein material.	[5] .033	[11] .001	.18	--------	--------	--------
KR-12	Atomic Mountain, 11E, 81N.	do	[5] .034	[11] .001	.18	--------	--------	--------
KR-13	Little Maud, 11E, 83N.	do	[5] .031	[11] .001	.17	--------	--------	--------

[1] Numbers refer to coordinates on the geologic map (pl. 15).

[2] Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying the difference by the conversion factor of 5.6.

[3] Obtained by subtracting the chemical percent ThO_2 from the chemical percent of total rare-earth oxides and ThO_2, except samples RA-103, RA-104, and RA-109 which were determined chemically.

[4] Spectrographer: R. G. Havens.

[5] Analyst: S. P. Furman.

[6] Analysts: R. F. DuFour, E. C. Mallory.

picked as giving a representative background reading. This point is on the east side of the cattle-guard on Highway 277 about 600 feet from the western margin of the mapped area.

Analyses of 37 samples from the McKinley Mountain area are given in tables 5 and 6 to supplement the detailed data of plate 16.

The thorium content of veins varies radically and nonuniformly along the strike. It may likewise vary with depth, as suggested by results of a drilling project at the Haputa ranch (Christman and others, 1953). Thus, thorium-rich concentrations in the form of pockets, pods, or lenses are likely to be distributed erratically along the veins. The size, grade, and distribution of concentrations to be expected along any given vein cannot be predicted in advance of

Kinley Mountain area, Custer and Fremont Counties, Colo.

Geological Survey]

Spectrographic analyses [4]																Other data
U	Th	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb	P	Ba	Sr	
----	0. X	0. 0X	0. X	0. X	0. 0X	0. X	----	----	----	----	----	----	----	----	----	----
----	X.	. X	. X	. X	. 0X	. X	----	----	----	----	----	----	----	----	----	----
----	X.	. X	. X	. X	. 0X	. 0X	----	----	----	----	----	----	----	----	----	----
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0	X.	. 0X	0	. 0X	0	. X	0. 0X	0. X	0. X	0. 000X	0. 0X	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	(13)
0	. X	. 0X	. 0X	. 0X	0	. 0X	. 00X	. 00X	0	0	. 00X	X.	0	XX.	0. X	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
0	. X	. 00X	. 0X	. 00X	0	. 0X	. 00X	. 00X	0	. 00X	. 0X	. 0X	0	XX.	. X	----
0	. X	. 00X	. 00X	. 00X	0	. 0X	. 00X	. 00X	0	. 000X	. 00X	. 0X	0	. X	. 0X	----
0	. X	. 00X	. 0X	. 0X	0	. 0X	. 00X	. 00X	0	. 000X	. 0X	. X	0	. X	. 0X	----

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[7] Analyst: Wayne Mountjoy.

[8] Analyst: E. C. Mallory.

[9] Analysts: S. P. Furman, R. F. DuFour.

[10] Analysts: S. P. Furman, Wayne Mountjoy, J. P. Schuch.

[11] Analysts: Wayne Mountjoy, J. P. Schuch.

[12] Analysts: R. F. DuFour, A. Tripp, E. C. Mallory, Jesse Meadows, D. L. Skinner.

[13] 1.08 percent chemical Pb.

prospecting. Symbols in plate 16 are intended only to aid in the finding of favorable areas for prospecting and are not intended to infer the size or grade for any deposit. Some veins within the McKinley Mountain area may contain thorium shoots comparable in magnitude and grade to shoots inferred on the Annie Lee and Haputa veins (Christman and others, 1953). No general change with depth, either an increase or a decrease in thorium or uranium content, was found in drill core to a depth of 400 feet at Haputa ranch (Christman and others, 1953).

The thorium vein mineral seems not to be particularly associated with any of the other vein minerals except iron oxides. It is as apt to be found in quartz, barite, or carbonate veins as in veins without

TABLE 6.—*Previously reported analyses (percent) from the McKinley Mountain area, Custer and Fremont Counties, Colo.*[1]

[Analyses by U.S. Geological Survey]

Sample	Location[2]	Type of sample	Equivalent uranium[3]	Chemical uranium	Equivalent ThO_2[4]	Chemical ThO_2	Total rare earth oxides and ThO_2	Rare earth oxides[5]
KR-9	Atomic Mountain, 11E, 81N.	Grab of vein material	0. 17	[6] 0. 001	0. 95	[6] 0. 82	[6] 0. 82	0. 0
RA-23	do	Selected vein material	. 38	[7] . 001	2. 12	[7] 1. 98		
LD-22	Darby Extension, 122W, 236N.	Grab of vein material	. 022	[8] . 001	. 12			
LD-26	Lucky Find, 42W, 28N.	20-foot channel	. 006	[8] . 001	. 03			
LD-27	Lucky Find, 42W, 28N.	7-foot channel	. 004	[8] . 001	. 02			
LD-28	Lucky Find, 34W, 26N.	3-foot channel	. 013	[8] . 001	. 07			
KR-4	Lucky Find, 36W, 27N.	Selected vein material	. 14	[6] . 002	. 77	[6] . 55	[6] . 73	. 18
LD-21	Penny Poker, 130W, 252N.	Grab of vein material	. 064	[8] . 001	. 35			
RA-25	Starbuck, 6W, 81N.	3-foot channel	. 021	[7] . 001	. 11			
RA-26	do	1-foot channel	. 18	[7] . 002	1. 00	[7] . 84		
RA-27	Starbuck, 10W, 86N.	½-foot channel	. 06	[7] . 001	. 33			
RA-28	Starbuck, 13W, 87N.	Selected vein material	. 30	[7] . 001	1. 67	[7] 1. 59		
KR-8	Starbuck, 6W, 81N.	do	. 18	[6] . 001	1. 00	[6] . 81	[6] . 93	. 12
LD-50	Tuttle ranch, 21E, 343N.	5-foot channel	. 14	[9] . 002	. 77			
LD-51	do	Grab of vein material	. 094	[9] . 001	. 52			
LD-52	Tuttle ranch, 22E, 342N.	4-foot channel	. 11	[9] . 002	. 60	[10] . 57		
LD-53	do	do	. 007	[9] . 001	. 03			
LD-54	do	0.4-foot channel	. 36	[9] . 002	2. 00	[10] 1. 91		
LD-65	Tuttle ranch, 19E, 341N.	Grab of vein material	. 063	[11] . 001	. 35			

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[1] These are a few of the analyses previously reported in U.S. Geol. Survey Cir. 290 that relate to the present study.

[2] Numbers refer to coordinates on the geologic map (pl. 15).

[3] Analyst: S. P. Furman.

[4] Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying the difference by the conversion factor of 5.6.

[5] Obtained by subtracting the chemical percent ThO_2 from the chemical percent of total rare-earth oxides and ThO_2.

[6] Analysts: R. F. DuFour, A. Tripp, E. C. Mallory, Jesse Meadows, D. L. Skinner.

[7] Analysts: Wayne Mountjoy, J. P. Schuch, D. L. Skinner.

[8] Analysts: G. W. Boyes, R. F. DuFour, Naomi Morris, Wanda Miskowiec.

[9] Analyst: R. F. DuFour.

[10] Analyst: D. L. Skinner.

[11] Analyst: G. W. Boyes.

these gangue minerals. The walls of fractures containing thorium may or may not be altered or feldspathized. Along the same general vein system the thorium occurs with smoky quartz crystals at the Atomic Mountain and Little Maud claims, with barite at the Hidden Valley 1 and Valley View claims, with barite and galena at the General Ike claim, and in red feldspathized country rock and a syenite dike at the Thorium Mountain claim (pl. 16). At places the thorium is associated with minor amounts of pyrite, fluorite, or copper minerals. Some of the yellow stain that occurs with the thorium may contain rare-earth oxides—shown to be present by spectrographic analyses.

A sinuous, narrow zone of compound fractures and altered rock that may be traced transversely across the mapped area from 150W, 265N to 5E, 150N served to localize many of the thorium veins in its immediate vicinity. To a lesser extent, veins elsewhere tend to cluster along transverse belts. Thorium deposits apparently are unrelated either to changes in strike of the veins or to any particular direction of strike. With the exception of the General Ike deposit, the thorium concentrations do not appear to be at vein intersections. The surrounding country rock apparently has no major influence; high-grade deposits are found in both the siliceous and the mafic rocks. The thorium vein minerals show a slight affinity for silica-rich rocks, however; at some localities the vein is more radioactive adjacent to a granitic layer than adjacent to a mafic layer.

The thorium-bearing minerals generally occur in small amounts and are not visible because of the masking effect of the iron oxides and (or) hydroxides. They can be detected only by their radioactivity; iron minerals may be present without the thorium. At some localities, however, where the thorium mineralization was strong, blebs and veinlets of a brownish-red mineral are found. It has a hardness of about 4.5 and a specific gravity of about 5.1. In some specimens, the blebs are surrounded by radiating fractures. The mineral is massive, breaks with a smooth fracture, has a high luster that is between vitreous and greasy, and appears to be resistant to weathering.

The chemical, optical, X-ray, and differential thermal analysis studies on the brownish-red thorium-bearing mineral from the Pine Tree claim (fig. 20) suggest that it is a hydrated thorite mineral similar to that described as thorogummite by Frondel (1953). It also is similar to that described as ferrothorite by Lacroix (1929). However, because of problems of nomenclature in the thorium group of minerals and the difficulty of making a specific identification, the term "thoritelike mineral" is used in this report.

As seen under the microscope, the thorium-bearing mineral from the Pine Tree claim (fig. 20) ranges from microcrystalline to cryptocrystalline and from anhedral to euhedral. It is intimately intergrown with barite and specularite. The euhedral crystals are short, square prisms with occasional pyramidal terminations. They rarely exceed 1 millimeter in length. The index of refraction ranges from 1.73 to 1.77. Small fragments are clearly anisotropic, and although their reddish-orange color masks any interference color, they probably have low birefringence. In polished section, euhedral crystals of the hydrated thorite mineral are anisotropic and strikingly zoned; the cores are reddish orange and the rims yellowish orange. Veinlets of the rim material cut the core as if they were a replacement along fractures; thus, the yellowish-orange rims and veinlets are interpreted as a higher degree of hydration.

Chemical and spectrographic analyses of the thoritelike mineral from the Pine Tree claim are given in the following tabulations. Although this sample was hand sorted under a microscope and appeared free of other minerals, it was further purified by heavy liquid and electromagnetic separations before analysis. In the chemical analysis, the absence of uranium is noteworthy. The rare earths and ferric iron probably occur in the lattice of the thoritelike mineral. Although specularite was identified in other less pure samples, none was identified by X-ray in this sample. The X-ray patterns both before and after ignition to 1,000° C gave tetragonal thorite patterns; no thorianite or huttonite lines were observed. The patterns of the ignited sample contained sharper lines than that of the unheated sample, suggesting that some metamict thorite may be present. The differential thermal curve gave a low endothermal peak at 220° C and a sharp exothermal peak at 840° C.

At other deposits where the thorium-bearing mineral is visible, it is megascopically similar to the analyzed thoritelike mineral from the Pine Tree claim. Where the identity of the thorium minerals is masked by and (or) mixed with iron-bearing minerals, it can only be inferred to be the same.

Thorium in the veins may be genetically related to the albite syenite stock, which is late Precambrian in age. The stock is abnormally radioactive owing largely to thorium. Moreover, syenite dikes believed to have a common origin with the stock are in most places radioactive owing to thorium. As determined by spectrographic analyses of samples, the thorium in some of the dikes occurs principally as coatings on fracture surfaces; however, some is disseminated through the dikes. Thus, a magma relatively rich in thorium existed, and it may have supplied thorium-rich emanations to form the veins. On the other hand, the thorium-rich igneous rocks and the thorium-

Chemical analyses of the thoritelike mineral from Pine Tree claim, Custer County, Colo.

[Analyst, Harry Levine, U.S. Geological Survey]

	Percent		*Percent*
SiO_2	21.22	CuO	1.64
Fe_2O_3	13.64	BaO	.31
ThO_2	46.02	PbO	.08
Rare-earth oxides	5.06	P_2O_5	.49
H_2O+	8.56		
H_2O-	2.66	Total	99.68

NOTE.—FeO looked for but not found.

Additional data from spectrographic analysis of the thoritelike mineral from Pine Tree claim, Custer County, Colo.

[Analyst, Catherine Valentine, U.S. Geological Survey]

	Percent
Ce, Cu	0.5 –1
La, Y, Nd, Ca, Ba, Pb	.1 – .5
Pr, Al, Ni, Co	.05 – .1
Dy, Gd, Er, Yb, Eu, Lu, B	.01 – .05
Zr, Mn, Mo, Sr	.005 – .01
V, Sc, Be, Mg	.001 – .005
Cr, Ti	.0005– .001
Ag	.0001– .0005

bearing veins may represent different products having different ages of a thorium metallogenic province—just as copper deposits having different ages represent different products of a copper metallogenic province in Arizona. An age determination of vein-thorium should shed further light. The only vein observed within the stock is one nonradioactive calcite vein which is probably unrelated to the other veins in the McKinley Mountain area.

BARITE DEPOSITS

Barite has been mined at several localities—usually by trenching. The most continuous barite vein, at the Hidden Valley 1 claim (10W, 96N), was worked 200 feet along the strike to an average depth of about 12 feet. Farther north, at 6W, 166N another vein was mined at several places; the principal workings apparently was an adit which is now caved. Other barite veins have been mined at 63W, 210N and 31E, 291N. These veins contain lenses as much as 3 feet wide of relatively pure massive white or pink barite. As all the large barite veins readily observed in the area have been prospected, any new large deposits are most likely to be found at depth.

VERMICULITE DEPOSITS

Low-grade vermiculite deposits have been mined at several localities in the McKinley Mountain area. The largest, which is in the northwestern part of the area (133W, 254N), is exposed in an open pit about 40 feet wide and 150 feet long. Smaller lens-shaped deposits occur near 63W, 312N and 22W, 335N. The vermiculite is confined to bodies of hornblende-plagioclase gneiss, hornblende-pyroxene-plagioclase gneiss, or metamorphosed ultramafic rocks and may be associated with veins or syenite dikes.

The vermiculite is black to greenish brown and occurs as books as much as three-fourths of an inch thick. The expansion ratio of 3 samples tested was about 14 : 1. Microscopically, the mineral is similar to biotite.

As in the Wyoming vermiculite deposits (Hagner, 1944), these deposits are believed to have formed by the hydrothermal alteration of mafic-rich rocks.

THORIUM DEPOSITS OUTSIDE THE MAPPED AREA

Although most of the thorium deposits shown on figure 20 were described in an earlier report (Christman and others, 1953), several of them were examined in reconnaissance subsequent to the 1953 report and remain to be described. All these deposits, except the one at the Watters ranch, are low in uranium.

The Gold Crown claims (fig. 20) are near the crest of a hill southwest of Hardins Saw Mill more than 10 miles southeast of the nearest known deposits. The intervening area and the region surrounding the claims have not been examined. The vein at the Gold Crown claims can be traced discontinuously by surface radioactivity for more than 500 feet, but it is not well exposed. The workings consist of a caved inclined shaft and a timbered 7-foot prospect pit. The vein consists of unidentified radioactive minerals in a gangue of quartz, barite, and red feldspar in Precambrian country rocks. A grab sample of vein material contained 0.34 percent of equivalent ThO_2 (sample 53C–114 on table 7). The vein exhibits the same composition, type of country rock, and relation to the country rock as some of the deposits to the north, and so is included within the limits of the thorium province.

The Fair View Lode claim is 5 miles from other known thorium deposits and is 3 miles south of Rosita. It also is similar to deposits to the north. The vein contains quartz, red barite, siderite, limonite, and radioactive minerals. It strikes N. 30° W. and can be traced for less than 100 feet. It occurs in hornblende-plagioclase gneiss and granite gneiss. A small trench is the only workings on the property. A grab sample (RA–112a) of the vein material from the dump of the trench contained 0.32 percent of equivalent ThO_2 (table 7).

The Antrim and G. W. Lode claims, 2 miles north of Querida (fig. 20), have been explored by 7 small trenches and a 20-foot shaft. The vein is steep and trends about N.50° W. In the shaft the vein is 5 feet wide at the surface and 1½ feet wide at a depth of 20 feet. The vein is believed to be continuous from the shaft to the crest of the hill

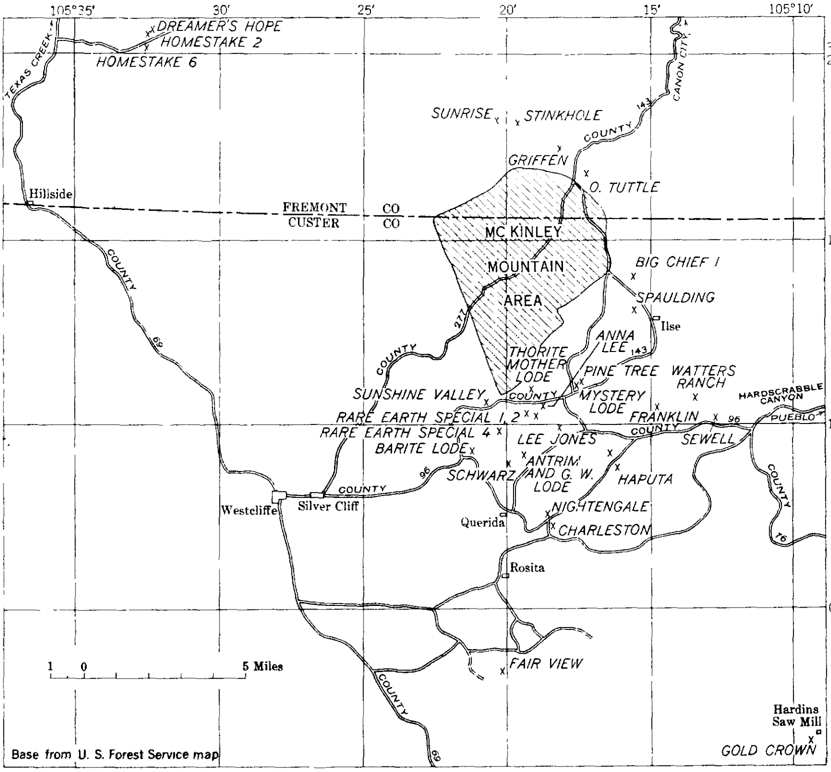

FIGURE 20.—Map of known thorium deposits in parts of Custer and Fremont Counties, Colo., excluding the McKinley Mountain area.

200 feet southeast. Considerable radioactive material occurs in the overburden downslope to the northwest from the shaft, but as the overburden is known to be as much as 10 feet thick, nothing is known about the inferred vein beneath. Grab samples of vein material from the claim (THW 1-A, THW 1-B, THW 1-D, and THW 1-E) range from 0.29 to 0.71 percent of equivalent ThO_2 and 1 selected sample (THW 1-C) contained 4.79 percent of equivalent ThO_2 (table 7). A rhyolite dike that extends from a rhyolite stock to the north follows the vein but appears to be younger than the thorium mineralization.

The Rare Earth Special 1 and 2 claims, about 3 miles north of Querida (fig. 20), are on a vertical vein that trends N. 50° E. The vein is as much as 4 feet wide and was traced almost continuously for 2,500 feet, and a few small pits have been dug along it. Concentrations of radioactive minerals occur discontinuously, although most of the vein is weakly radioactive. The vein, which has a strong fetid odor, is composed principally of red feldspar and quartz and has the appearance of a brecciated, coarse-grained dike. Two samples, RA–105a and

TABLE 7.—*Analyses (percent) of samples from outside the Mc*

[Analyses by U.S.

Sample	Location	Type of sample	Equivalent uranium	Chemical uranium	Equivalent ThO_2[1]	Chemical ThO_2	Rare earth oxides
RA-100 [2]	Homestake 2, dump of shaft.	Grab of vein material.	[3] 0.016	[3] 0.0006	0.09	--------	--------
RA-101 [2]	Homestake 2, 50 ft northeast of shaft.	do	[3] .024	[3] .0004	.13	--------	--------
RA-102 [2]	Homestake 6, lower dump.	do	[3] .025	[3] .0011	.13	--------	--------
RA-103a [2]	Homestake 6, upper dump.	do	[3] .032	[3] .0011	.17	--------	--------
RA-104a [2]	Homestake 6, lower pit.	Selected vein material.	[3] .13	[3] .0013	.72	--------	--------
RA-105a	Rare Earth Special 2	Grab of vein material.	[4] .089	[4] .004	.48	--------	--------
RA-106a	do	do	[4] .079	[4] .002	.43	--------	--------
RA-108a	Rare Earth Special 4	do	[4] .20	[4] .005	1.09	--------	--------
RA-111a	Thorite Mother Lode	do	[4] .052	[4] .001	.29	--------	--------
RA-112a	Fair View Lode	do	[4] .058	[4] .001	.32	--------	--------
RA-105 [2]	Franklin mine, lower adit.	2.5-foot channel, 160 ft from portal	[5] .031	[6] .002	.16	[6] 0.02	[6] 0.01
RA-106 [2]	do	Grab of clay seam, 175 ft from portal.	[5] .025	[6] .002	.13	[6] .03	[6] .18
RA-107 [2]	Antrim and G.W. Lode.	Grab of vein material.	[5] .12	[6] .004	.65	[6] .40	[6] .23
RA-108 [2]	do	9-foot channel	[5] .087	[6] .003	.47	[6] .16	[6] Trace
THW 1-A	Antrim and G.W. Lode, dump 2.	Grab of vein material.	[7] .12	--------	*.65	--------	--------
THW 1-B	Antrim and G.W. Lode, dump 3.	do	[7] .075	--------	*.40	--------	--------
THW 1-C	Antrim and G.W. Lode, pit 1.	Selected vein material.	[7] .86	--------	*4.79	--------	--------
THW 1-D	Antrim and G.W. Lode, pit 2.	Grab of vein material.	[7] .056	--------	*.29	--------	--------
THW 1-E	Antrim and G.W. Lode, pit 3.	do	[7] .13	--------	*.71	--------	--------
53C-114	Gold Crown, dump of shaft.	do	[4] .061	[4] .001	.34	--------	--------
AH-71 [8]	Watters ranch	do	[9] .24	[9] .10	.78	--------	--------

[1] Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying the difference by the conversion factor of 5.6. Those marked by an asterisk (*) were calculated by assuming that the chemical uranium at these claims is 0.004.

[2] Spectrographer: R. G. Havens.

[3] Analysts: S. P. Furman, Wayne Mountjoy, J. P. Schuch.

[4] Analysts: S. P. Furman, R. F. DuFour.

RA-106a, contained 0.48 and 0.43 percent of equivalent ThO_2 (table 7). At Rare Earth Special 4 (fig. 5), the thorium-bearing minerals are in an isolated body of altered dike that is 3 feet wide, about 15 feet long, and trends N. 10° W. The radioactive rock appears as globular masses of altered dike surrounded by calcite and iron oxides. One sample (RA-108a) of the vein material was 1.09 percent of equivalent ThO_2 (table 7).

At the Homestake 6 claim about 6 miles northeast of Hillside (fig. 20), the equivalent ThO_2 content was as much as 0.72 percent, and the rare earth content of 2 samples (RA-103a and RA-104a) probably runs as high as 3 percent (estimated from the spectrographic data on table 7). Another sample believed to come from this locality is reported to contain 6 percent of rare earths (Christman and others, 1953). This particular claim has not been studied. Samples RA-100

Kinley Mountain area, Custer and Fremont Counties, Colo.

U.S. Geological Survey]

Spectrographic analyses												
U	Th	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb
0	0.0X	0.X	0.X	0.X	0	0.0X	0.000X	0	0	0	0.00X	0
0	.0X	.X	.X	.X	0	.00X	.000X	0	0	.000X	.00X	.X
0	.0X	.X	.X	.X	0	.0X	.00X	.0X	.00X	.000X	.0X	0
0	.X	>1.	>1.	.X	.X	.0X	.000X	.0X	.0X	.000X	.0X	0
0	.X	>1.	>1.	.X	.X	.X	.0X	.0X	.0X	.000X	.00X	X.
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------	.X	.0X	.0X	.0X	.00X	.0X	------	------	------	------	------	------
------	.X	.0X	.X	.X	.0X	.0X	------	------	------	------	------	------
------	.X	.00X	.0X	.0X	------	.X	------	------	------	------	------	------
------	.X	.00X	.0X	.0X	------	.0X	------	------	------	------	------	------
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.X	.0X	.0X	.X	.0X	.0X	.X	.0X	.0X	.0X	------	------	------

[5] Analyst: S. P. Furman.
[6] Analysts: R. F. DuFour, E. C. Mallory.
[7] Analyst: J. W. Patton.
[8] Spectrographer: G. W. Boyes.
[9] Analysts: S. P. Furman, James McGurk, Wayne Mountjoy.

and RA–101 from Homestake 2 claim, half a mile north of Homestake 6, contained only traces of rare earths and 0.13 percent or less of equivalent ThO_2,

Vein rock at the Franklin mine, Sunshine Valley claims, and Thorite Mother Lode (fig. 20) is relatively low in thorium. Analyses from the Franklin mine are 0.16 and 0.13 percent of equivalent ThO_2 and 1 analysis from the Thorite Mother Lode is 0.29 percent (samples RA–105, RA–106, and RA–111a, table 7).

A prospect trench on the Watters ranch, 5 miles southeast of the mapped area and a mile north of Highway 96, exposes a vein that contains both thorium and uranium. The lessees shipped nearly a ton of hand-picked ore from the vein that assayed 0.10 percent of U_3O_8 and 45 percent of carbonate gangue. If the excess radioactivity indicated by the equivalent uranium value (sample AH–71 on table 7) is assumed to be due to thorium, the ore also contains 0.78 percent of equivalent ThO_2. The uranium is in a vertical vein of dense purplish-red carbonate. The vein strikes N. 70° W., is ½ to 1½ feet wide, and can be traced about 100 feet. No prospecting has been done below a depth of 12 feet.

SUGGESTIONS FOR PROSPECTING

Many of the localities containing radioactive materials in the McKinley Mountain area (pl. 16) will be worth prospecting when and if the demand and the price for thorium justify an intensive search for new sources of supply. Localities designated by large squares or by triangles on plate 16 may in general be regarded as the most favorable, but none of the more strongly radioactive anomalies should be ignored. A limited amount of prospecting likewise is warranted along the projected extensions of known radioactive veins into alluvium-covered areas. At some localities the veins are exposed in pits and other workings dug by the early prospectors for gold and silver; at others, the veins are covered or are very poorly exposed. At poorly exposed localities the amount of radioactivity shown on plate 16 does not, of course, fully represent the amount of radioactive materials present.

Many undiscovered radioactive localities undoubtedly occur in unmapped terrain outside the McKinley Mountain area in general proximity to the scattered localities shown by figure 20. They may best be sought by utilizing a gamma-scintillation detector. Rocks that are stained red or yellow by iron oxides and (or) hydroxides, as well as veins containing smoky quartz, barite, and carbonate or sulfide minerals, should be particularly investigated, though none of these minerals necessarily accompanies thorium.

Most of the area appears to be unfavorable for prospecting for uranium, as all samples except the one collected at the Watters ranch contained much less than 0.10 percent of uranium (tables 5, 6, and 7). However, ground to the east and southeast of the Watters property has not been searched by members of the Geological Survey for other occurrences of uranium.

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