Wet Mountains, Colorado, Thorium Investigations 1952-1954

By R. A. Christman, M. R. Brock, R. C. Pearson, and Q. D. Singewald

Trace Elements Investigations Report 354

(Figs. 2+3) GS-M-MF-37; Part I open filed 3/31/55

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Geology and Mineralogy

This document consists of 52 pages,
plus 2 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

WET MOUNTAINS, COLORADO, THORIUM INVESTIGATIONS, 1952-1954*

By

R. A. Christman, M. R. Brock, R. C. Pearson,
and Q. D. Singewald

August 1954

Trace Elements Investigations Report 354
(Figs. 2 + 3) GS-M-MF-37; Part 1, open filed 3/31/55.

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

When separated from Part II, handle Part I as UNCLASSIFIED.

CONTENTS

ILLUSTRATIONS

TABLES

WET MOUNTAINS, COLORADO, THORIUM INVESTIGATIONS

1952-1954

By R. A. Christman, M. R. Brock, R. C. Pearson,
and Q. D. Singewald

ABSTRACT

A 22-square mile tract (McKinley Mountain area) of pre-Cambrian rocks and veins containing thorium was mapped at the scale of 1:6,000. This tract lies on the west flank of the Wet Mountains, Custer and Fremont Counties, northeast of Westcliffe, Colo.

The bedrock is a complexly interlayered sequence of gneisses of metasedimentary origin, migmatite and granitic gneisses that have 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; pyroxene-scapolite, garnet, sillimanite, and quartzite zones are locally present. The most prominent rock is a poorly foliated, microcline, alaskitic granite gneiss which occurs as layers ranging from more than 500 feet in thickness down to migmatitic "lit-par-lit" type of injections less than an inch thick. Of less wide distribution, but of similar occurrence, are quartz monzonite and leuco-granodiorite gneisses. Although the foliation of the rocks generally is steep and trends northeast over most of the area, several northeast-trending folds have been mapped in the northern half of the area; a vertically plunging fold occurs in the southwest. The albite syenite is nonfoliated and is about 595 million years old (late pre-Cambrian) by the Larsen zircon method of age determination. Many of the dikes are related to the stock.

More than 800 radioactive occurrences were found along the northwest-trending veins. Almost all the radioactivity is due to thorium which in its purest form occurs as a hydrated thorite-like mineral. The veins also contain carbonate minerals, barite, quartz, red and yellow iron oxides, and minor sulfides; no genetic relation of these minerals to the thorium has been established. Although most of the deposits are only weakly radioactive, richer concentrations are scattered as pockets and lenses along the veins.

INTRODUCTION

During the summers of 1952 and 1953 geologic mapping at a scale of 1:6,000 was done in an area, designated in this report as the McKinley Mountain area, about 10 miles northeast of Westcliffe on the western flank of the Wet Mountains in Custer and Fremont Counties, Colo. (fig. 1). The pre-Cambrian complex of igneous and metamorphic bedrock was mapped in great detail (fig. 2) in order to discover new vein-thorium deposits and to determine the structural setting of these deposits. More than 800 radioactive localities were found (fig. 3) within the 22 square miles that were mapped. The deposits occur irregularly along northwest trending fractures without apparent relation either to the country rock or to changes in strike of the fractures.

Previous work in the McKinley Mountain area consisted of reconnaissance of a few of the thorium deposits and a plane table map of a small tract at the Tuttle ranch. This work, as well as descriptions of some other thorium deposits and of a drilling program at Haputa ranch, is set forth in "Thorium investigations, 1950-52, Wet Mountains, Colorado" by Christman, Heyman, Dellwig and Gott (1953). The 1953 report outlined the known thorium province as at least 20 miles long and 10 miles wide. It now is known to be at least 30 miles long and 12 miles wide. To the southwest the Rosita and Silver Cliff mining districts, containing silver, lead, gold, zinc, and copper veins associated with Tertiary volcanic rocks, have been described by S. F. 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 remainder was done by the State of Colorado Geological Survey Board and the Geological Survey on a cooperative basis. This report was prepared by Christman, Brock, and Pearson, under the general supervision of Singewald.

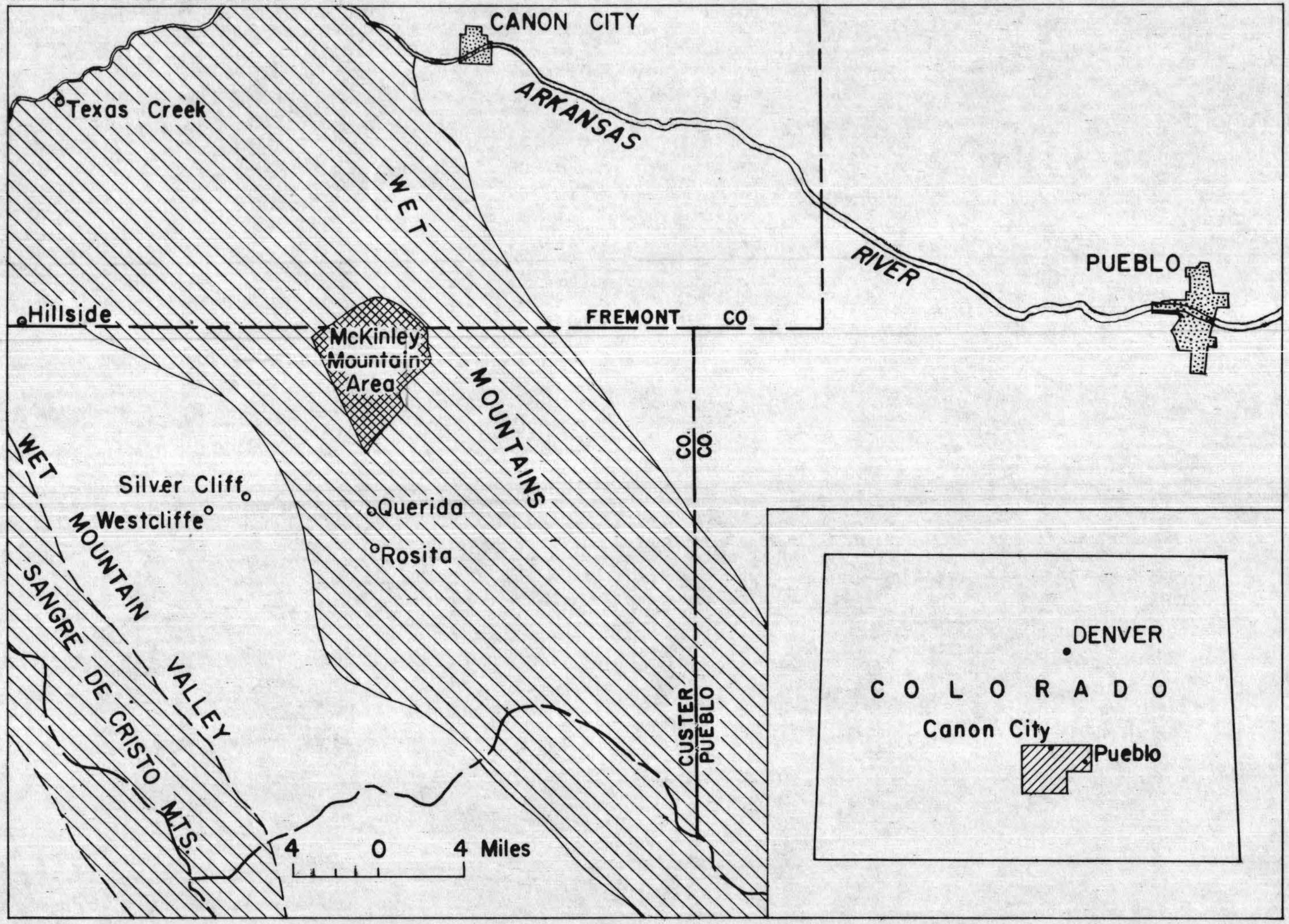

FIGURE 1.-INDEX MAP OF WET MOUNTAIN AREA, COLORADO.

SUMMARY OF THE GEOLOGY

Regional setting

The pre-Cambrian 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 the Wet Mountain uplift during the Laramide revolution. This belt is the southward en echelon extention of the ancient Front Range highland (Lovering and Goddard, 1950). Most of the belt lies east of the mapped area and forms the higher portions of the Wet Mountains. Just east of the mapped area is the northwest-trending Ilse fault which apparently represents a structural break between the northeast-trending rocks in the McKinley Mountain area and the rocks on the crest of the Wet Mountains.

Most of the area is fairly rugged; relief ranges from 7,900 to 9,500 feet. Water is scarce. Rather thin, somewhat scrubby stands of evergreen cover most of the ridges, but good stands cover some of the north slopes.

West and southwest of the mapped area a discontinuous belt of Tertiary volcanic rocks lies between the pre-Cambrian rocks on the east and the alluvial fill in the Wet Mountain Valley on the west. Farther to the west are the high Sangre de Cristo Mountains composed of folded Paleozoic sedimentary rocks and several small Tertiary intrusions (Burbank and Goddard, 1937). Associated with the Tertiary volcanic rocks are vein deposits of gold, silver, lead, zinc, and copper near Rosita, Silver Cliff, Querida, and Westcliffe. Although one of the volcanic bodies near Hillside is slightly radioactive, Tertiary mineralization appears unrelated to the thorium deposits in the pre-Cambrian rocks.

General geology

The bedrock consists of metasedimentary, migmatitic, and granitic gneisses which form complex interlayered sequences of interfingering and gradational rock types (fig. 2). Except along the crests and troughs of several folds, the layers of gneiss dip steeply and form narrow bands which trend northeast across the area. Distinctive lithologic "marker beds" in some places are important aids in determining the geologic structure. Units of hornblende-plagioclase gneiss, biotite-quartz-plagioclase gneiss, and undivided metasedimentary gneisses probably are the metamorphosed representatives of the oldest pre-Cambrian rocks in the area. Units of migmatite, quartz monzonite gneiss, alaskitic granite gneiss (abbreviated to "granite gneiss" in the report), and leuco-granodiorite gneiss are younger; their origin is not known. These gneisses are cut by metamorphosed gabbroic and ultra-mafic rocks and by unmetamorphosed stocks, plugs, and dikes. Inasmuch as an albite syenite stock (N. W. corner fig. 2) is one of the youngest rock types and has been determined to be late pre-Cambrian by the Larsen age determination method, all the rocks, with the possible exception of some of the dikes are proven to be pre-Cambrian. The majority of the dikes are syenitic in composition.

A doubly plunging anticline in the northwest part of the area and an unusual fold structure with vertical foliation and a nearly vertical plunge in the southwest are the most prominent folds shown on the geologic map. A series of poorly defined anticlines and synclines occur in the northeastern part of the area, and an anticlinal nose, that plunges to the southwest, probably exists in the west-central part.

Faults, shear zones, and joints transect the foliation at large angles. Although several faults can be traced considerable distances, the vertical displacements are not known, and the largest known horizontal displacement is about 400 feet. The faults can be shown to be younger than the folding by the displacement of the anticlinal axis along the faults in the northwest part of the area. Veins and dikes occupy many of the fractures, particularly joints and faults of small displacement.

Small quantities of barite from veins, and vermiculite from altered mafic gneiss have been produced in the past from the McKinley Mountain area. In addition, many prospect pits and adits have been dug to search for silver, gold, and lead along veins containing quartz and sulfide minerals.

More than 300 veins along northwest-trending fractures exhibit radioactivity anomalies due to thorium (fig. 3). The thorium minerals invariably are accompanied by red and yellow iron oxides and generally are masked by them. Some veins contain only these minerals; others contain abundant quartz, barite, and iron-bearing carbonate--alone or together--and may have galena, pyrite, fluorite, or secondary copper minerals as subordinate constituents. In a few high-grade deposits, the thorium occurs in red, greasy blebs or veinlets which are mixtures of barite, specularite, and a thorite-like mineral. Spectrographic studies indicate that trace amounts of rare earths normally accompany the thorium.

The thorium is distributed erratically within the veins, and the richer concentrations are in scattered pockets and lenses. No correlation was noted between distribution of thorium minerals and changes in strike of the veins or the type of country rock. Many of the deposits, however, are concentrated along a sinuous zone of transverse faults (fig. 2, west half) and the associated sheared and altered zones.

The thorium mineralization may be genetically related to the albite syenite intrusives of late pre-Cambrian age. The stock (NW corner of fig. 2) is abnormally radioactive due to thorium, and two radioactive syenite dikes originate from two of the smaller albite syenite bodies (91W, 259N; 83W, 271N). Similar radioactive syenite dikes occur throughout the area; spectrographic analyses indicate that thorium rather than uranium is present in these dikes.

ALLUVIUM, TALUS, AND SOIL

Alluvium, talus, and soil are mapped as a unit which completely conceals the bedrock of an estimated 30 to 35 percent of the map area.

ROCKS

The bedrock has been divided into 36 map units, of which 20 are individual rock types, and 16 are layered sequences. Of the 20 rock types, only 8 are abundant; 7 of them in various combinations and proportions form the 16 layered sequences. The individual rock types will first be described, then the actual map units.

Individual rock types

The eight most abundant rock types are (1) hornblende-plagioclase gneiss, (2) biotite-quartz-plagioclase gneiss, (3) migmatite, (4) quartz monzonite gneiss, (5) alaskitic granite gneiss, (6) metamorphosed gabbroic and ultramafic rocks, (7) leuco-granodiorite gneiss, and (8) 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 (1) pyroxene-scapolite gneiss, (2) quartzite, mostly garnetiferous, (3) sillimanitic gneisses, (4) garnetiferous gneisses, (5) pegmatite, (6) breccia, (7) altered rock, (8) syenite dikes, (9) melanocratic syenite dikes, (10) andesite, andesite porphyry, and basalt dikes, (11) lamprophyre dikes, and (12) gabbro dikes.

For discussion purposes, these rocks have been arranged into three groups, each of which has 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.

Metasedimentary gneisses

Designated collectively as metasedimentary gneisses are rocks believed to be the products of high grade metamorphism either of sediments alone or of sediments interlayered with tuffs, flows, or sills of pre-Cambrian age.

The most widespread rocks in this group are biotite-quartz-plagioclase gneiss and hornblende-plagioclase gneiss, including hornblende-pyroxene-plagioclase gneiss. These rocks are gradational with each other and might be considered the "end members" of a metasedimentary series. Narrow layers of garnetiferous gneiss, sillimanitic gneiss, garnetiferous quartzite, and pyroxene-scapolite gneiss were mapped locally as "marker beds"; they were very helpful in determining the structure. At many places the rocks were mapped as a unit of undivided metasedimentary gneisses, either because no single type predominates within a thinly interlayered sequence or because exposures are too poor to determine which type does predominate. In places, this unit contains biotite schist which is too uncommon or too poorly exposed to be mapped even as a "marker bed".

One of the principal lines of evidence for a metasedimentary origin for these rocks is the occurrence of "marker beds" as long, narrow layers of a mineralogically distinctive rock type which 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 and sillimanitic zone, having an average thickness of about ten feet, has been traced nearly 18,000 feet (extending from 115W, 179N to 15W, 310N) 1/; others have been traced for shorter distances. In the

1/ Numbers refer to coordinates on the geologic map (fig. 2).

valley north of McKinley Mountain in the eastern part of the area, a pyroxene-scapolite gneiss extends 6,800 feet in four discontinuous pods and a narrow layer 1,500 feet long at nearly the same stratigraphic position. Its 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 pre-existing sedimentary sequence. Elsewhere lenses of quartzite extend discontinuously along the same stratigraphic position. Much of the quartzite is a distinctive and uncommon variety rich in garnet.

If these long, narrow, continuous, or nearly continuous, bands of "marker beds" along the same strike reflect original compositional variations, the foliation must be at least locally parallel to the original bedding. On the other hand, where individual segments of a discontinuous "marker bed" are not aligned precisely along the strike, the original bed may have been disrupted and reoriented in segments perpendicular to the compressional forces so that the foliation is not exactly parallel to the overall trend of the original bedding. South of McKinley Mountain the overall trend of several discontinuous garnetiferous zones is slightly divergent from the general trend of the foliation of the individual rocks (45E, 220N; 26E, 200N; and 12E, 188N). Without knowing the extent of metasomatism and metamorphic differentiation it is unsafe to estimate how closely the foliation parallels the original bedding in most areas.

Hornblende-plagioclase gneiss and hornblende-pyroxene-plagioclase gneiss.--The hornblende-plagioclase gneiss and to a lesser extent the associated hornblende-pyroxene-plagioclase gneiss are common rock types, underlying an estimated 15 to 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; it is suspected that they 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.

The hornblende-plagioclase gneiss is a variable rock type; it is gradational with the biotite-quartz-plagioclase gneiss and grades into hornblende-pyroxene-plagioclase gneiss, which in turn appears to grade into gabbroic and ultramafic rocks. The hornblende-plagioclase gneiss is typically dark-colored and well foliated; it contains 47 to 60 percent plagioclase, 24 to 47 percent hornblende, less than 10 percent pyroxene, and minor amounts of quartz, biotite, magnetite, apatite, and zircon. (See modes in table 1.) A similar rock was termed amphibolite in the Haputa ranch area (Christman, and others, 1953).

The hornblende-pyroxene-plagioclase gneiss is moderately well foliated, but locally it is massive and shows poor foliation. Unless the light green or brown pyroxene grains are abundant, this rock is difficult to distinguish from the hornblende-plagioclase gneiss. The plagioclase, which is more calcic where pyroxene is more abundant, makes up from 13 to 40 percent of the gneiss. The hornblende content ranges from 33 to 70 percent and the pyroxene content, which may be either augite or hypersthene, from 16 to 41 percent. (Table 1.) These rocks appear similar to the ones described by S. F. Emmons (1896) and Cross (1896) as augite-hornblende gneiss in the pre-Cambrian area they studied about 6 miles to the southwest.

Biotite-quartz-plagioclase gneiss.--The biotite-quartz-plagioclase gneiss 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. It is estimated that this gneiss underlies 10 to 15 percent of the area. The rock is more resistant to erosion than the hornblende-plagioclase gneiss and is less resistant than the alaskitic granite gneiss.

The biotite-quartz-plagioclase gneiss has well-developed foliation due to the orientation of biotite, hornblende, and, in part, quartz. Its color ranges from pink through light brown to light gray. The gray varieties grade into hornblende-plagioclase gneiss and the pink varieties either grade into the granite gneiss or are interlayered with granite gneiss in such a manner that the two are nearly indistinguishable. Where the two rocks are indistinguishable by the naked eye, an attempt was made to estimate the microcline content either with a hand lens or, in some specimens, by microscopic examination of a

Table 1.--Modes (volume percent) of hornblende-plagioclase gneiss and hornblende-pyroxene-plagioclase gneiss.

Specimen	Feldspar (variety)	Feldspar (percent)	Quartz (percent)	Hornblende (percent)	Pyroxene (percent)	Biotite (percent)	Accessories (percent)
1.	Calcic oligoclase.	60	-	35	3	1	1
2.	Calcic oligoclase.	59	3	24	8	2	4
3.	Sodic andesine.	47	-	47	2	2	1
4.	Calcic andesine.	13	-	70	16	-	1
5.	Sodic labradorite.	58	-	37	5	-	-
6.	Sodic labradorite.	50	-	41	6	-	2
7.	Sodic labradorite.	40	-	33	25	-	2
8.	Sodic labradorite.	28	-	48	24	-	-
9.	Calcic labradorite.	15	-	44	41	-	-

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 sillimantic 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 leuco-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 and 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 (56W, 316N).

* Numbers refer to coordinates on the geologic map (fig. 2).

powdered sample in 1.53 index oil. Rocks low in microcline were mapped as biotite-quartz-plagioclase gneiss; laboratory studies have shown that these rocks contain less than 30 percent microcline, the average being about 10 percent. The rock also contains 35 to 60 percent oligoclase, 24-45 percent quartz, and about 10 percent biotite and hornblende; locally, it is garnetiferous. In general, the biotite content of the thicker bodies mapped individually in the southern part of the area is decidedly less than that of the thinner bodies interlayered in the unit of undivided metasedimentary gneiss.

Pyroxene-scapolite gneiss.--The pyroxene-scapolite gneiss is uncommon and was mapped as a "marker bed" only in the valley north of McKinley Mountain. Small pods of gneiss contain scapolite locally elsewhere, but they are included as part of the unit of undivided metasedimentary gneisses. The rock is characterized by a streaked appearance due to the irregular distribution of the foliate 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, 265N) contained 65 percent scapolite, 23 percent green diopside, 8 percent quartz, 3 percent brown garnet, and 3 percent sphene.

Quartzite.--Quartzite, mostly garnetiferous, also is common. It has been found only as small lenses, few of which are more than a hundred feet long or more than 10 feet thick, in the metasedimentary sequence in the northwestern part of the area (80W, 198N; 11W, 304N; and 50W, 229N). The lenses are mapped as "marker beds". In places, a series of discontinuous lenses occupy essentially the same stratigraphic position. The quartzite may be light gray, dark gray, or dark red. The dark-red variety, which is very rich in garnet, is the most widespread; it is sugary, fine grained, and vaguely banded due to slight differences in grain size and in concentrations of garnet and quartz. Two thin sections contained, respectively, 50 and 63 percent quartz, and 30 and 35 percent pink garnet, probably almandite, and minor amounts of magnetite, apatite, zircon, and biotite; one of the sections contained 10 percent diopside.

Sillimanitic gneisses.--Sillimanite commonly is associated with garnet in "marker beds" over much of the area but is less widespread than garnet. Being relatively sparse and restricted to thin stratigraphic zones, sillimanite-bearing gneiss was mapped only as layers within the migmatite and undivided metasediments, rather than as a distinct rock type. In some areas (3E, 185N) sillimanite occurs with quartz plagioclase to form a distinctive white to cream, greasy-appearing schist.

Garnetiferous gneisses.--Layers of rock, containing red almandite garnets, were mapped as "marker beds". Some of these layers can be traced several miles, and probably reflect a compositional variation in the parent rock; to what extent they may also reflect the effect of metasomatism, is not known. Garnetiferous layers occur in biotite-quartz-plagioclase gneiss, migmatite, and granite gneiss. In general, most of the garnetiferous layers were mapped as part of a migmatite or undivided metasedimentary gneiss unit.

Granitic gneisses of unknown origin

Migmatite, alaskitic granite gneiss, quartz monzonite gneiss, and leuco-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 two most probable modes of origin for these gneisses (excluding the migmatite) are (1) intrusion of igneous material along the foliation planes of the metasedimentary rocks during the waning stages of metamorphism, and (2) granitization of favorable layers of the metasedimentary rocks by a process that may have been a combination of metasomatism and metamorphic differentiation. 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.

Except for a few unusual occurrences, these gneisses form elongate bodies parallel to the foliation which terminate by interfingering with the adjacent rocks. Contacts may be very sharp or gradational. Although their broad outcrop pattern on the geologic map appears to exhibit cross-cutting relations to the older rocks, only about five such relations were found in the field. At the few localities where granite forms cross-cutting dikes, the granite is not typical; in one instance (182N, 109W) it is slightly aplitic and cross-cuts typical granite gneiss.

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 banding, without implication as to the origin of the gneissic structure; locally the gneissic structure may be obscure. The terms "granite, quartz monzonite, and leuco-granodiorite" are used in their compositional sense without implication as to the mode of origin.

Migmatite.--Rocks designated as migmatite are estimated to underlie between 5 and 10 percent of the map area. 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. Semi-homogeneous gneisses in which occur local concentrations or porphyroblasts of potash feldspar that appear to have been introduced by metasomatism were also called migmatites.

The prevailing granitic component of migmatite probably is alaskitic granite gneiss at most places and quartz monzonite gneiss in local areas where that rock appears either as a mappable unit or as a member of a layered sequence. As the bulk composition of the migmatite is variable, depending on both the composition and the relative proportion of metasediment and granitic additive locally present, no attempt has been made to determine an average composition.

Quartz monzonite gneiss.--The quartz monzonite gneiss is estimated to underlie between 1 and 4 percent of the map area. It occurs principally in three elongated areas: as narrow layers, in part as "marker beds" on the south side of McKinley Mountain (84E, 264N and 110E, 300N); as a series of layers near Highway 277 in the western part of the area (100W, 190N and 26W, 208N); and as a series of narrow layers about one-fourth 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 40 E, 374N). Most outcrops of quartz monzonite gneiss were mapped as diagnostic components of layered units.

The gneiss is characterized by oriented microcline phenocrysts (or porphyroblasts), a low quartz content, moderate biotite content, good foliation, and a distinctive weathered appearance. In contrast to the granite gneiss which weathers to smooth, angular fragments, the quartz monzonite gneiss weathers to rounded, crumbly fragments. The average of five modal analyses shows the gneiss to contain 46 percent microcline, 38 percent oligoclase, 7 percent biotite, 7 percent quartz, and 2 percent magnetite, 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 of the microcline twinning are bent.

In one locality where an age relationship was observed, the granite gneiss appears to cross-cut the quartz monzonite gneiss. It is possible that the quartz monzonite gneiss is a facies of the granite gneiss, but it is equally possible that they are unrelated. In some places, the physical resemblance of the granite gneiss to the Pikes Peak granite suggests a possible correlation.

Alaskitic granite gneiss.--The alaskitic granite gneiss, or more simply "granite gneiss", is the most abundant rock type, covering an estimated 25 to 30 percent of the area. It forms tabular bodies parallel to the regional foliation. Many occurrences are large enough to be mapped individually, and some of them cover relatively large areas. Innumerable other occurrences are included as noteworthy members in units of layered rocks. All gradations may be found from bodies that are hundreds of feet thick to seams less than a foot thick. The granite gneiss resists erosion, and therefore caps most ridges and hills in the area. The most conspicuous is McKinley Mountain, which is supported by 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.

The granite gneiss is light brown to pink, medium grained, and equigranular. The fabric where the quartz content is high commonly resembles that of quartzite, due to the rounded appearance of the quartz grains. Gneissic banding or foliation is apparent at most places, but is very obscure at others. The foliation is most apparent megascopically in rock containing biotite or magnetite. It invariably parallels the regional foliation. Except in small scale features it does not bend around the end of a digitation; nor does the foliation in the adjacent gneiss bend around the granite. Biotite and hornblende-rich wisps, lenses, pods, and narrow continuous bands are common in the granite gneiss. Although generally found near the contact, they also occur in the interior of granite gneiss bodies. Those containing biotite have gradational contacts and appear mainly as relict wisps or ghosts; those containing hornblende generally have fairly sharp contacts and are commonly recognizable as well-foliated hornblende-plagioclase gneiss.

The rock contains about 42 percent microcline, 33 percent quartz, 22 percent oligoclase, 1 percent biotite and about 2 percent of combined hornblende, magnetite, zircon, apatite, and rarely allanite; garnet occurs in some of the gneisses, (table 2). The microcline is perthitic in which soda plagioclase may comprise as much as 50 percent of the mineral; Tuttle (1952, p. 120) says, "Perthites consisting of nearly equal amounts of albite and microcline. . . .are prima facie evidence of magmatic ancestry." On the other hand the crystals of oligoclase are either untwinned or simply twinned; some geologists suggest this may indicate that the feldspar may be of metamorphic origin, (Turner, 1951 and Emmons, R. C., 1953). Thin section study shown that a few of the gneissic bands have developed by granulation and recrystallization of the quartz and feldspar; this is interpreted as having formed by stress under sufficient confining pressure to prevent clear-cut cataclasis.

Leuco-granodiorite gneiss.--Leuco-granodiorite gneiss underlies less than 2 percent of the area. It occurs mostly with the metasedimentary gneisses in layered units. The leuco-granodiorite gneiss is moderately prominent in the eastern part of the area (102E, 251N) and in the northwestern part (80W, 306N and 140W, 246N). 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, 192N).

The leuco-granodiorite gneiss is characterized by its white or light-pink color. The grain size ranges from medium to coarse; some bands of the coarse-grained material are pegmatitic. Insufficient thin sections were studied to give an average composition; three from one locality contain about one-third each of microcline, oligoclase, and quartz. The microcline content is lower at most localities, and garnet is present at a few.

Table 2. Modes (volume percent) of alaskitic granite gneiss.

Specimen	Potash feldspar (percent)	Quartz (percent)	Plagioclase (percent)	Biotite (percent)	Hornblende (percent)	Accessories (percent)
1.	41.5	27.0	29.2	3.0	---	0.3
2.	36.4	27.7	33.2	2.3	---	0.4
3.	26.9	30.5	37.8	3.7	---	1.0
4.	42.8	35.2	20.0	Tr.	---	1.9
5.	35.7	45.5	18.1	Tr.	---	0.9
6.	38.0	33.0	25.0	2.0	---	2.0
7.	49.0	32.0	15.0	Tr.	---	5.0
8.	49.0	28.0	17.8	Tr.	5.1	Tr.
9.	54.3	27.8	18.7	Tr.	---	Tr.
10.	49.0	32.6	16.9	---	---	0.4
11.	36.7	50.2	11.5	---	---	1.5
12.	42.5	37.4	15.6	---	4.4	Tr.
13.	41.3	35.6	22.4	---	---	0.7
14.	43.8	22.6	31.0	2.0	---	0.4
Average	41.8	33.2	22.2	0.9	1.7	1.0

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 on prominent anticlinal ridge (20E, 300N).
5. Granite gneiss from along crest at the east end of McKinley ridge (92E, 287N).
6. Granite gneiss from layer near contact with leuco-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).

Table 2. Modes (volume percent) of alaskitic granite gneiss--Continued.

10. Granite gneiss from layer in unit of quartz monzonite gneiss, migmatite 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 portion 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).

*Numbers refer to coordinates on the geologic map (fig. 2).

Igneous and other rocks

This group of igneous and other rocks includes (1) metamorphosed gabbroic and ultramafic rocks, (2) pegmatite, (3) breccia, (4) albite syenite, (5) altered rocks, and (6) dike rocks. The pegmatite, albite syenite, and dike rocks 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 or metasomatic alteration.

Metamorphosed gabbroic and ultramafic rocks.--The unit of metamorphosed gabbroic and ultramafic rocks consists of a group of basic rocks which have been arbitrarily grouped together. It includes mafic bodies of igneous origin and mafic bodies of unknown origin which are associated with hornblende-pyroxene-plagioclase gneiss. The group is characterized by dark colored rocks having noticeably high specific gravity and cross-cutting relations with the surrounding rocks.

The igneous bodies occur as small irregular to circular shaped, plug-like bodies which may be related to the basic dikes. The rock is essentially nonfoliated and usually weathers to rounded massive boulders. It is dark gray to black, medium grained. Locally, it is strongly magnetic. Orthorhombic pyroxene is ordinarily present; either labradorite or olivine may comprise as much as 50 percent of the rock. Pale brown biotite is abundant in one thin section. Dark green spinel makes up as much as 5 percent of some rocks as small vermicular blebs and equant grains associated with hornblende. Hornblende, some of the biotite, and possibly the spinel are thought to be metamorphic minerals formed by recrystallization of the igneous minerals.

The origin of the bodies associated with the hornblende-pyroxene-plagioclase gneiss is unknown; an igneous origin is suggested by the cross-cutting relations, but a metasedimentary origin is suggested by the relationship to the hornblende-pyroxene-plagioclase gneiss. The igneous-appearing rock grades so gradually into the enclosing metasediment that contacts are difficult to map; the relations suggest that the "intrusive" might actually have formed by anatexis and be derived from the surrounding gneisses.

The foliation in these bodies is parallel to the regional foliation; some are weakly foliated throughout and others are foliated only at their margins. The bodies generally lie with their long dimension parallel to the regional foliation as if their emplacement were controlled by the foliation. The largest of these, 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 a body about 3,500 feet long and 600 feet wide is inferred to lie beneath an alluvium cover (180N, 30W). It is exposed at the base of the adjoining hills and in stream cuts. It appears to be cut by two faults.

These rocks are similar to the hornblende-pyroxene-plagioclase gneiss in appearance except that the foliation is absent or less well-developed and the rock is coarser grained. In addition to calcic plagioclase and hornblende, one of the dominant minerals is orthorhombic pyroxene (bronzite ?). Clinopyroxenes are also abundant; the pyroxenes may occur together or separately. Large phenocrysts of orthorhombic pyroxene in the elongate body in the northern part of the area (54W, 320N) are particularly striking.

Pegmatite.--Simple pegmatite bodies too small to be mapped are scattered throughout the area. A few of the larger bodies were mapped in the southeastern part of the area (44W, 47N). They are pink pegmatites composed of quartz, microcline, plagioclase, and minor amounts of magnetite, biotite and/or hornblende. Most likely they are related to the granite gneiss. In several places, white pegmatites were found to contain principally plagioclase and quartz with only minor amounts of microcline; doubtless they represent a different generation than the pink pegmatites.

Breccia.--Breccia occurs associated with the albite syenite stock in the northwestern portion of the area and as several small bodies elsewhere.

The breccia near the border of the stock is older than the main body of the stock but younger than some of the smaller masses of syenite. The largest body of breccia (110W, 270N) is an irregular-shaped mass having an average diameter of about 1,500 feet, whose contact transects metasedimentary and granite gneisses. The breccia is composed of angular fragments as much as several feet in diameter of hornblende-plagioclase gneiss, granite gneiss, unidentified dark-colored metasedimentary gneisses, and the older facies of the albite syenite stock. The mixture of large and small fragments is so compact that no introduced cementing material is apparent. Small white seams of albite between some of the fragments suggest that much of the rock has been feldspathized.

The shape and position of the breccia body exclude the possibility that it is a fault breccia and suggests 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, yet 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 smaller bodies of breccia (near 115E, 263N; 66W, 182N; and 91W, 261N) are distant from the stock. They are composed of angular, highly altered fragments of the country rock in a matrix of dark, aphanitic igneous rock. They probably represent a type of breccia pipe. 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 nearly half a square mile in the northwest corner of the area. The stock has been traced 2 miles to the northwest beyond the limits 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 near the border. The albite syenite is not foliated and as it cuts across the foliation of the metasedimentary and granitic gneisses and contains inclusions of these rocks, it is post-metamorphic in age.

The albite syenite in the stock is typically light brown but locally ranges from pink to gray. It is generally medium-grained. The color differences are due to variations in abundance of hornblende and/or biotite. In thin section, the albite syenite contains albite antiperthite, non-perthitic albite, microcline (possibly including orthoclase), quartz, hornblende, biotite, zircon, apatite, magnetite, fluorite, epidote, chlorite, sericite, and calcite. Albite comprises about 65 to 80 percent of the rock. Most of the albite is subhedral and antiperthitic but some is anhedral and seems to have replaced microcline and earlier albite; this is believed to represent albitization by late stage fluids. Microcline, possibly including some orthoclase, generally makes up less than 25 percent of the rock. The quartz content in most thin sections is about 2 percent, but in certain facies of the rock is as high as 35 percent. In some sections the zircon and apatite make up an estimated 2 to 3 percent of the rock. Where the zircon is adjacent to or within biotite grains, radiogenic haloes are observed in the biotite.

The readings of radioactivity of the albite syenite 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 the small amounts of thorium and uranium which are probably associated chiefly with the zircon. Spectrographic analyses for these elements suggests that most of the radioactivity is due to thorium (table 3).

An age determination by the Larsen zircon method by Howard Jaffe of the U. S. Geological Survey indicates that the stock is of late pre-Cambrian 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 younger. However, even if all the radioactivity of the zircon were due to thorium, which it is not, the age would not be more than 16 percent younger, i. e. late pre-Cambrian.

Of the smaller bodies of albite syenite south of the main stock, the ones associated with the breccia are considered to be slightly older; age relations of the southernmost bodies are not known. Although some facies of these bodies are identical to 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 off-shoots of the small bodies of albite syenite, thereby, proving a genetic relationship.

Table 3. Selected analyses of albite syenite stock and syenite dike.

Specimen	Equivalent uranium (percent)	Chemical uranium (percent)	Equivalent ThO_2 1/ (percent)	U 2/	Th 2/	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb	Ba
						Spectrographic analyses											
1. 4/	0.004 6/	0.0011 6/	0.016	0	0	0.0X	0.0X	0.0X	0	0.00X	0.000X	0	0	0.000X	0.0X	-	-
2. 4/	.019 6/	.004 6/	.084	0	.0X	.0X	.0X	.0X	0	.0X	.00X	0	0	.00X	.0X	-	-
3. 8/	.004 7/	-	.02	0	0	0.0X	.0X	.00X	0	.00X	.000X	0	0	.000X	.0X	.00X	.0X
4. 5/	-	-	-	0	.0X	-	-	-	-	-	-	-	-	0	.0X	.00X	.0X
5. 5/	-	-	-	0	.X	-	-	-	-	-	-	-	-	.000X	.0X	.00X	.0X

1. Normal facies of albite syenite stock, part of sample used in age determination (133W, 296N 3/).
2. Pegmatitic facies of albite syenite stock (95W, 285N).
3. Syenite dike (56E, 345N).
4. Syenite dike, different sample than No. 3, (56E, 345N).
5. Red coating on fracture surface of syenite dike, sample same as No. 4, (56E, 345N).

1/ Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying by the conversion factor of 5.6.
2/ The lower limit of detection in spectrographic method employed is 0.05 for uranium and thorium.
3/ Numbers refer to coordinates on the geologic map (fig. 2).
4/ Spectrographer: R. G. Havens
5/ Spectrographer: G. W. Boyes
6/ Analysts: S. Furman, W. Mountjoy, P. Schuch
7/ Analysts: S. Furman, D. Stockwell
8/ Spectrographer: P. J. Dunton

Altered rock. --This unit of altered rock includes feldspathized zones in the southern part of the area and altered gneisses related to a zone of shearing and faulting in the northwest.

The best exposures of the feldspathized zones are found in three areas (20E, 140N; 25E, 100N; and 40E, 108 N) in the southern part of the map. The rock is white to pink, fine to coarse grained, and has a "spongy" appearance due to numerous small cavities. The cavities are lined with limonite and are thought to represent leached carbonate and/or quartz. In most places feldspar is the only mineral that can be identified; quartz is present in the easternmost zone. The contact between the altered rock and the surrounding gneisses is gradational and the altered rock extends farther into certain layers of biotite-quartz-plagioclase and granite gneisses. Layers of hornblende-plagioclase gneiss which are more resistant to this type of alteration are continuous on either side of the zone but end rather abruptly at the contact where the effects of feldspathization may be observed. Altered fragments as well as completely altered ghosts or relicts of fragments of the country rock occur within the zone. Veins also occur within the zone and isolated localities are slightly radioactive.

Microscopically, the rock is composed principally of cloudy feldspars, probably microcline and albite; the patchy distribution suggests that they are perthitic. In addition to calcite, zircon, and opaque dust outlining relict biotite or hornblende, some rocks contain from 1 to 3 percent apatite. The rocks containing apatite emit a fetid gas when the rock is broken.

The rocks in the altered zone in the south central part of the map area (25W, 172N) in addition to being feldspathized, have been chloritized, sheared, and fractured. A blue soda amphibole coats some of the fractures. Much of the zone is slightly radioactive. The western margin of a similar zone in the west central part of the area (45W, 196N) displays considerable radioactivity.

The altered rocks in the northwest (110W, 230N) are similar to the ones in the other zones except that they are less feldspathized. The zone is highly fractured and sheared and a soda amphibole has been introduced into the rock giving it a bluish color.

Dike rocks. --Five groups of dikes have been distinguished; 1) syenite, 2) melanocratic syenite, 3) andesite, andesite porphyry, and basalt, 4) lamprophyre, and 5) gabbro. Of these, the syenites are the most common and most continuous; individual dikes have been traced several miles. Most of the continuous dikes trend northwest, but a few trend nearly east-west. All are inferred to occupy joints and other fractures. The apparent displacement of many of the dikes is attributed chiefly to emplacement along pre-existing en echelon fractures, rather than to later displacement by faulting; at only a few localities were the dikes proven to be faulted. The surface mapping and drilling at Haputa ranch (Christman, and others, 1953) showed that at least some of the dikes have been emplaced along faults. These same studies showed that wide dikes may be weathered so deeply that surface exposures are seldom found. Limited exposures in prospect pits and road cuts suggest that, despite the large number of dikes already mapped, many unmapped dikes occur in the area.

Many of the dikes have been altered; some have been completely replaced by carbonate and other vein minerals. Where this has occurred, the dike is considered a vein; thus, along the strike some dikes change into veins. Where the alteration is incomplete, it is difficult to decide where to map the change.

The relative ages of the dikes are incompletely known. In general the syenite dikes are younger than most of the basic dikes. As the syenite dikes are related to the albite syenite stock, most of the dikes are considered to be pre-Cambrian. A few lamprophyre and andesite dikes are younger than the syenite dikes, so it is possible they may be as young as Tertiary.

The syenite dikes are light pink to salmon pink, aphanitic to fine-grained, and resistant to erosion. A few aplite dikes are included in this group. Most of the syenite dikes, however, are composed almost entirely of pink feldspar with minor amounts of quartz, biotite, hornblende, aegerine, and secondary minerals. They have a trachytic texture. The rock weathers to smooth resistant fragments which are found long distances down the slope from the dikes. Dikes less than 10 feet wide were observed to form the crest of minor ridges or hills. The syenite dikes can be shown to be related to one of the smaller bodies of albite syenite related to the stock.

Many of the pink syenites are radioactive--some give readings as much as ten times background. Spectrographic analysis of one such dike showed that the highest thorium-bearing material occurs as a red coating along a fracture (table 3). Smaller amounts of thorium occurred in the central unaltered portion of the rock.

The melanocratic syenite dikes, in the field, exhibit a variety of appearances. Some are medium-grained gray rocks similar to the gray facies of the albite syenite stock; some are dark gray aphanitic rocks; some are pink to gray fine-grained porphyritic rocks, with phenocrysts of hornblende and red feldspar; and some are dark colored aphanitic rocks with phenocrysts of pink or white feldspar. In thin section all facies contain albite and other minerals characteristic of alkali-rich rocks. Minerals identified in these dikes include arfvedsonite, riebeckite, hedenbergite, aegerine, biotite, apatite, fluorite, magnetite, sodalite(?), and nepheline(?). Because the melanocratic syenite dikes were not recognized as a separate type until after the field work was completed, a few dark aphanitic ones may be wrongly included within the group of andesite, andesite porphyry, and basalt dikes.

Andesite, andesite porphyry, and basalt dikes are grouped together to include most of the basic dikes in the area. They are dark gray to black, aphanitic to medium-grained, and may either be equigranular or contain phenocrysts of feldspar. The feldspar normally is calcic andesine or sodic labradorite, but a few basalt dikes contain calcic labradorite. The mafic minerals are augite and biotite, except in some of the basalt which also contains olivine.

A few dikes were mapped as lamprophyre. They have large phenocrysts of augite, hornblende, or biotite in a fine-grained, gray groundmass. Though not abundant, the lamprophyres are of interest because they may be the youngest of the dikes.

At three localities (52W, 325N, 96E, 256N, and 16E, 80N) dikes of gabbro about 50 feet wide were mapped. They weather readily, and so are poorly exposed; they are traced by means of a few scattered boulders and by depressions in the topography. The rocks are medium-grained and composed of labradorite, augite, and olivine with small amounts of biotite, magnetite, and chlorite.

Bedrock map units

Two catagories of rock units were mapped, one consisting mainly of a single rock type, the other of a layered sequence. Essentially all units mapped as a single rock type actually contain impurities in the form of local lenses and thin layers of other rock types. Nevertheless, wherever one type of rock comprised more than 80 percent of a unit, the impurities were ignored. In general, no thickness less than 50 feet was mapped as a single rock type.

Sequences containing more than 20 percent of two or more types of rock in layers more than a foot thick are mapped as layered units. 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 approximated.

The seventeen units of layered sequences need little explanation inasmuch as each of the components has been described. On the geologic map, for the 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 dash. Thus, "a-h" is a layered unit of predominantly alaskitic granite gneiss with subordinate (20 to 50 percent) hornblende-plagioclase gneiss, and "h-a" is predominantly hornblende-plagioclase gneiss with subordinate alaskitic granite gneiss. Where dashes are not used, any one of the listed components may predominate. To be included in the unit name, however, the rock type must be present in excess of 20 percent.

GEOLOGIC STRUCTURE

The most prominent structural features shown on the geologic map (fig. 2) are the general northeast trend of steeply dipping, foliated rocks; the northwest trend of the faults, shears, veins, and dikes transecting these rocks; and several broad folds.

Foliation and lineation

All the rocks except the albite syenite and the dikes are foliated. The foliation most commonly is due to the preferred orientation of biotite and hornblende. The foliation is parallel to the lithologic banding of the rock units. Small scale gneissic banding may be due in part to metamorphic differentiation. Primary foliation which may have existed in the granitic gneisses of possible igneous origin is not distinguishable from foliation inherited from pre-existing gneiss or developed by regional metamorphism.

Lineation is exhibited by grooves, crenulations, mineral lenticles, and alignment of elongate minerals. 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 are generally 1 to 2 mm in amplitude. The smallest grooves appear as thin black lines on foliation planes, presumably due to concentrations of dark minerals along the troughs of the grooves. Whether the grooves resulted from movement along the foliation planes, from miniature folding, from alignment of mineral grains, or a combination of these could not be determined. Although common in some areas crenulations that range in amplitude from a fraction of an inch to several inches are much less widespread than grooves. They appear mostly in alaskitic granite gneiss, migmatite, and hornblende-plagioclase gneiss, and in the metasedimentary rocks may appear as well-developed fluting. Elongate mineral lenticles and aligned crystals of elongate minerals are much less common than the other two types of lineation. Hence, most lineations recorded on the geologic map represent either grooves or crenulations.

Lineations are self-consistent throughout the northern and central parts of the mapped area. As some of them are parallel to axes of major or minor folds, all may be interpreted as representing the fold axis direction, i.e., 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 directly north of Highway 277. By contrast with the foregoing, along the southeast border of the area steeply dipping lineations plunging at right angles to the strike of foliation in a narrow granite gneiss layer apparently represent some type of shearing. Non-uniform lineations in the southwest represent structural complexities not yet fully understood.

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, drag folds, and warps 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 map 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 located 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.

Northwest of Highway 277, in the central and north-central 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 longitudinal distance, and then eventually pass into simple homoclines. Throughout much of this portion of the area, scattered non-consistent dips, some of which are nearly flat, disclose that structural warps or 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.

On the northwest flank of the major anticline in a zone about 3,000 feet wide, the trends of structural terraces and the axes of drag folds and gentle warps parallel the anticlinal axis. Adjacent to this zone to the north is another belt in which the foliation exhibits much crinkling and some drag folding. It is 1,000 to 2,000 feet wide and extends about 6,000 feet northwest of 80W, 290N. The folding suggests that this belt represents the crumpled core of a tightly compressed syncline and is very likely the continuation of the synclinal structure that lies farther eastward (25W, 345N) along the same trend.

On the southern limb of the central-western part of the major anticline, some 5,000 feet from the axis, is an inferred subordinate anticline which plunges to the southwest and narrows into a nearly isoclinal nose which still farther to the southwest passes into an apparent homocline. The inferred anticlinal nose is outlined by two ledges of granite gneiss that diverge northeastward from 72W, 195N, but whether the two ledges represent two different layers that diverge as a fold between them broadens, or the same layer on opposite limbs of a fold that has been pinched and stretched at the southwest end is not known. Inconsistent dips, some nearly flat and others steep, suggest that the inferred anticlinal nose opens northeastward into a broad fold with a warped crest. Still farther to the northeast, beyond about 30W, 210N the fold is concealed by alluvium, but it may continue and eventually merge with a series of subordinate anticlines and synclines.

South of the Highway 277 the gneisses form a conspicuous series of steep, northwest-dipping layers. As shown on cross section A-A' and B-B' and the geologic map (fig. 2) four parallel ridges, the most conspicuous of which is McKinley Mountain, represent resistant rock units in this interlayered sequence. Although the dips conceivably could reflect isoclinal folding, an essentially complete absence of small drag folds or warps, a scarcity of groove or crumple lineations, and no apparent duplication of major sequences suggest that the structure is truly homoclinal. Whether the steep northwest dips represent an overturned portion of the south limb of the major anticline to the north or a normal succession on the south limb of an intervening tight syncline is not known.

In the southwest part of the area is a large fold structure which has characteristics anomalous to the rest of the area mapped. It apparently is an anticline and syncline with a nearly vertical plunge; the foliation in the gneisses is steeply dipping. The lineations, which are the groove type, plunge steeply from 40°-85° and are not consistent with a simple fold, i.e., they do not seem to parallel a fold axis but rather vary in trend from N. 65° E. to N. 25° W. and back to N. 60° E. as the foliation bends around the fold. The relation of this fold to the regional structure probably will not be understood until additional mapping is done to the west.

Fractures

The dominant trend of the fractures in the area is northwest and, as well as could be determined, most have a nearly vertical dip. The fractures are related to faults, shear zones, and joints; the numerous dikes and veins (fig. 2) seem to occupy joints or faults of small displacement.

A statistical study was made of the fractures in the map area. The trends of veins and dikes are shown on figure 4; too few readings on joints and faults were available for diagramming in this report. In order that the trends of the longer fractures be weighted by length, the plot was made by recording every fracture in each 2,000-foot square of the grid system. Thus, on the geologic map the trend of a fracture represented by a dike or vein extending through three squares was recorded three times. Although the weighting of the data was arbitrary and the number of fractures not recorded in the field is unknown, it is felt that these diagrams are the best that can be easily obtained from data available. Each diagram represents a plot of over 700 points.

Although a cursory examination of the geologic map suggests that several diverse fracture systems are present, the distribution of the trends of the dikes and veins on the diagrams (fig. 4) shows that each has a dominant trend with wide deviations and minor secondary trends. The average trend of the dikes is about N. 75° W. and the average trend of the veins is about N. 60° W. Not shown with the diagrams are about 170 plots for the faults and 130 for the joints. Although neither gave significant patterns, the pattern for the faults appeared to be similar to that of the veins.

Some of the fractures apparently extend long distances, as is indicated by the continuity of some of the veins and dikes. A somewhat discontinuous 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 distances. In many places their discontinuties suggest that they occupy en echlon fractures.

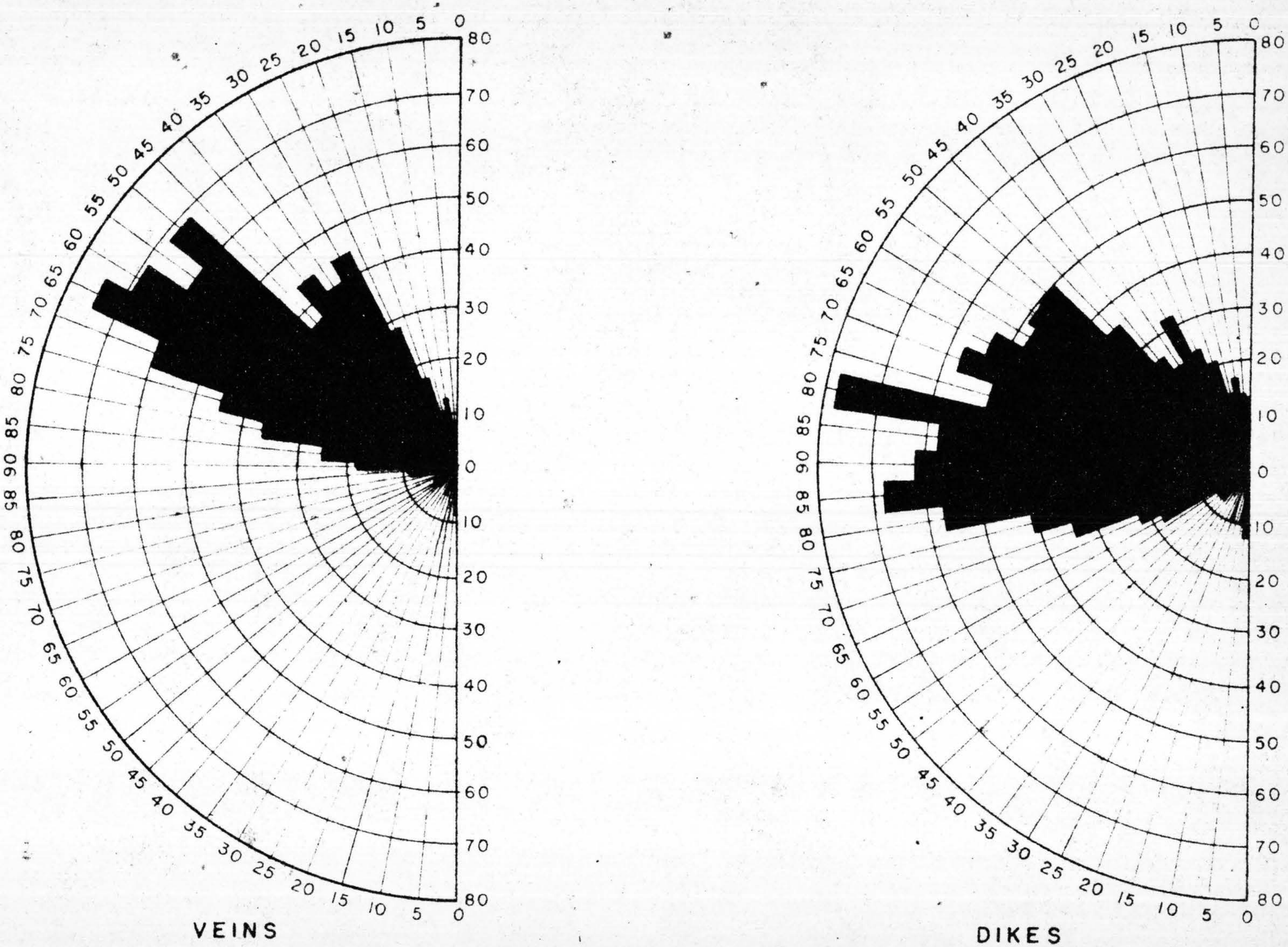

FIGURE 4 - DIAGRAMS SHOWING TRENDS OF VEINS AND DIKES, McKINLEY MOUNTAIN AREA, COLORADO

Faults having a small horizontal displacement are abundant in the area. Five large faults are discussed below. The most continuous fault is expressed topographically by Dead Mule Gulch, so most of it is covered by stream gravel. The fault trends N. 60° W. and the northeast side has a minimum relative displacement of 200 feet to the northwest. A fault that is part of a long sinuous fault zone cuts McKinley Mountain at 33W, 178N, where it has a horizontal displacement of between 300 and 450 feet. The fault zone 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 an en echelon 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 specific units could 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) may possibly continue several thousand feet to the southeast and northwest. No information is available on the vertical displacements of the faults; they are presumed to be greater than the horizontal displacements.

Although all the faults, to some degree, contain shear zones, the only conspicuous shear zone mapped extends discontinuously 15,000 feet (from 116W, 236N to 3E, 161N). This is a sinuous zone of discontinuous faults, veins, and altered rock. In the northwest part of the zone, the granite gneiss is altered to a bluish color by the introduction of a soda amphibole. The zone continues to the northwest as a fault, and probably to the southeast as part of a zone of altered rock (20E, 140N).

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 around the turn of the century 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 by the U. S. Geological Survey has renewed the interest of prospectors in the area.

Description of veins

Between 350 and 400 veins were mapped (fig. 3). Most of them are less than 5 feet wide and can be traced along the outcrop only for 100 to 1,000 feet. However, a few are as much as 50 feet wide and/or can be traced as much as 5,000 feet. The vein minerals formed along fractures as coatings, open space fillings, or replacements of the wall rocks. Therefore, like the fractures, the veins have steep dips, are rather constant in strike, and trend dominantly N. 60° W. but range in strike from east-west to N. 20° W. In places, dikes have been partly or completely mineralized to veins; in other places unaltered dikes and veins occupy the same fracture. Generally 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 and yellow iron oxide minerals in such veins occur as stains, coatings, veinlets, or disseminations along zones of closely spaced fractures. In places, the fractured country rock has been feldspathized. Abnormal radioactivity along these veins gives clear evidence of mineralization even though gangue such as quartz, barite, and carbonate minerals are absent.

Well-defined quartz, barite, and iron-bearing carbonate veins are fairly abundant throughout much of the area. Quartz generally is white and massive, but well-developed crystals commonly are smoky and zoned. The barite ranges from aggregates of white, coarse grains that exhibit well-developed cleavage to red, aphanitic masses of microcrystalline grains. The iron-bearing carbonates are generally fine grained, massive, and from green to reddish brown. Ankerite (?) bands and tiny calcite stringers may occur in the rock. Many of the iron-bearing carbonate veins represent the complete replacement of dike rocks.

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 thorite-like mineral along with the iron-bearing minerals of limonite, specularite, and earthy hematite are common minor constituents of most of the veins. Minor amounts of pyrite, chalcopyrite, tetrahedrite (?), galena, fluorite, and secondary copper minerals are locally present but none has been found in sufficient quantity to be economically mined. 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 silicified or feldspathized they may form slight ridges in areas of flat topography. In granite ridges, veins commonly occupy the gaps where fracturing has occurred.

Thorium deposits

The distribution of thorium is shown by more than 800 radioactivity anomalies which are recorded on figure 3. Circles, squares, and triangles represent weak, moderate, and strong radioactivity, respectively, as measured by a gamma-scintillation detector held at hip level (2 to 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 represent, respectively, large and small amounts of radioactive material in which the indicated reading was obtained over an area of more or less than 50 square feet. 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 radioactive minerals are present in concentrated form. These localities are ones that might be profitably explored.

Analyses of 37 samples from the McKinley Mountain area are given in tables 4 and 5, to supplement the detailed data of figure 3.

Table 4.--Analyses of samples from the McKinley Mountain area, Custer and Fremont Counties, Colorado

Sample number	Location 1/	Type of sample	Equivalent uranium (percent)	Chemical uranium (percent)	Equivalent ThO_2 2/ (percent)	Chemical ThO_2 (percent)	Total rare-earth oxides and ThO_2 (percent)	Rare earth oxides 3/ (percent)	Spectrographic analyses 4/ U	Th	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb	P	Ba	Sr	Other data
RA-103	92W,221N	4½-foot channel	0.063 5/	0.001 8/	0.35	0.25 8/	—	0.52 8/	—	.X	.0X	.X	.X	.0X	.X										
RA-104	92W,221N	12-inch channel	.89 5/	.005 8/	4.96	4.03 8/	—	1.98 8/	—	X.	.X	.X	.X	.0X	.X										
RA-109	Darby Extension 119W,236N	Grab of vein material	.25 5/	.001 8/	1.39	1.39 8/	—	.18 8/	—	X.	.X	.X	.X	.0X	.0X										
RA-110	92W,214N	6-inch channel	.46 5/	.002 10/	2.56	2.06 9/	2.83 9/	.77																	
RA-111	90W,221N	14-inch channel	.26 5/	.003 10/	1.44	1.27 9/	1.62 9/	.35																	
RA-112	121W,237N	10-inch channel	.19 5/	.001 10/	1.06	.73 9/	1.20 9/	.47																	
Ra-113	122W,238N	18-inch channel	.20 5/	.003 10/	1.10	.96 9/	1.39 9/	.43																	
RA-114	129W,247N	6-inch channel	.084 5/	.001 10/	.46	.26 9/	.35 9/	.09																	
RA-115	56W,213N	Grab of vein material	.075 5/	.001 10/	.41	.28 9/	.43 9/	.15																	
RA-116	62W,210N	Selected vein material	.52 5/	.001 10/	2.91	2.41 9/	2.88 9/	.47																	
53B-66	Tuttle ranch 6E,354N	14-inch channel	.71 7/	.001 7/	3.97	—	—	—																	
53B-36	89W,320N	Selected vein material	.63 12/	.001 12/	3.52	—	—	—	0	X.	.0X	.0	.0X	.0	.X	.0X	.X	.X	.000X	.0X	—	—	—	—	—
KR-6	General Ike 37W,112N	Selected vein material	.094 5/	.004 6/	.50		.38 6/	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.08 percent chemical Pb
KR-10	do.	4-foot chip channel	.033 5/	.004 11/	.16	—	—	—	0	.X	.0X	.0X	.0X	0	.0X	.00X	.00X	0	0	.00X	X.	0	XX.	.X	—
KR-7	Thorium Mountain 52W,118N	Selected vein material	.21 5/	.010 6/	1.12	1.26 6/	1.64 6/	.38	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
KR-11	do.	Grab of vein material	.033 5/	.001 11/	.18	—	—	—	0	.X	.00X	.0X	.00X	0	.0X	.00X	.00X	0	.00X	.0X	.0X	0	XX.	.X	—
KR-12	Atomic Mountain 11E,81N	Grab of vein material	.034 5/	.001 11/	.18	—	—	—	0	.X	.00X	.00X	.00X	0	.0X	.00X	.00X	0	.000X	.00X	.0X	0	.X	.0X	—
KR-13	Little Maud 11E,83N	Grab of vein material	.031 5/	.001 11/	.17	—	—	—	0	.X	.00X	.0X	.0X	0	.0X	.00X	.00X	0	.000X	.0X	.X	0	.X	.0X	—

1/ Numbers refer to coordinates on the geologic map.
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. Furman
6/ Analysts: R. DuFour, Tripp, Mallory, Meadows, Skinner
7/ Analysts: S. Furman, R. DuFour
8/ Analysts: R. DuFour, Mallory
9/ Analyst: Mallory
10/ Analyst: W. Mountjoy
11/ Analysts: W. Mountjoy, P. Schuch
12/ Analysts: S. Furman, W. Mountjoy, P. Schuch

70134

Table 5.—Previously reported analyses from the McKinley Mountain area, Custer and Fremont Counties, Colorado 1/

Sample number	Location 2/		Type of sample	Equivalent uranium 5/ (percent)	Chemical uranium (percent)	Equivalent ThO_2 3/ (percent)	Chemical ThO_2 (percent)	Total rare earth oxides and ThO_2 (percent)	Rare earth oxides 4/ (percent)
KR-9	Atomic Mountain,	11E,81N	Grab of vein material	0.17	0.001 6/	0.95	0.82 6/	0.82 6/	—
RA-23	do.	do.	Selected vein material	.38	.001 9/	2.12	1.98 9/	—	—
LD-22	Darby Extension,	122W,236N	Grab of vein material	.022	.001 10/	.12	—	—	—
LD-26	Lucky Find,	42W,28N	20-foot channel	.006	.001 10/	.03	—	—	—
LD-27	do.	42W,28N	7-foot channel	.004	.001 10/	.02	—	—	—
LD-28	do.	34W,26N	3-foot channel	.013	.001 10/	.07	—	—	—
KR-4	do.	36W,27N	Selected vein material	.14	.002 6/	.77	.55 6/	.73 6/	0.18
LD-21	Penny Poker,	130W,252N	Grab of vein material	.064	.001 10/	.35	—	—	—
RA-25	Starbuck,	6W, 81N	3-foot channel	.021	.001 9/	.11	—	—	—
RA-26	do.	do.	1-foot channel	.18	.002 9/	1.00	.84 9/	—	—
RA-27	do.	10W,86N	½-foot channel	.06	.001 9/	.33	—	—	—
RA-28	do.	13W,87N	Selected vein material	.30	.001 9/	1.67	1.59 9/	—	—
KR-8	do.	6W,81N	do.	.18	.001 6/	1.00	.81 6/	.93 6/	.12
LD-50	Tuttle ranch,	21E,343N	5-foot channel	.14	.002 11/	.77	—	—	—
LD-51	do.	do.	Grab of vein material	.094	.001 11/	.52	—	—	—
LD-52	do.	22E,342N	4-foot channel	.11	.002 11/	.60	.57 8/	—	—
LD-53	do.	do.	4-foot channel	.007	.001 11/	.03	—	—	—
LD-54	do.	do.	0.4-foot channel	.36	.002 11/	2.00	1.91 8/	—	—
LD-65	do.	19E,341N	Grab of vein material	.063	.001 7/	.35	—	—	—

1/ These are a few of the analyses previously reported in U. S. Geol. Survey Circular 290 that relate to the present study.
2/ Numbers refer to coordinates on the geologic map.
3/ Calculated from the equivalent uranium by subtracting the chemical uranium and multiplying the difference by the conversion factor of 5.6.
4/ Obtained by subtracting the chemical percent ThO_2 from the chemical percent of total rare-earth oxides and ThO_2.
5/ Analyst: S. Furman
6/ Analysts: R. DuFour, Tripp, Mallory, Meadows, Skinner
7/ Analyst: G. W. Boyes
8/ Analyst: Skinner
9/ Analysts: W. Mountjoy, P. Schuch, Skinner
10/ Analysts: G. W. Boyes, R. DuFour, Morris, Miskowiec
11/ Analyst: R. DuFour

70134

Thorium-bearing vein minerals,--as distinct from thorium-bearing accessory rock 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 tenuously 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 such areas are depicted on figure 3 as veins. Pipes thought to represent hydrothermally altered and mineralized breccia contain minor quantities of thorium. Eight such bodies (four between 26W, 246N and 53W, 200N, and four between 50E, 352N and 55E, 376N), which are roughly circular in plan, resemble some of the veins in composition.

The thorium content of veins varies radically and non-uniformly along the strike. It may likewise vary with depth, as suggested by results of a drilling project at Haputa ranch (Christman, and others, 1953). Thus, thorium-rich concentrations in the form of pockets, pods, or lenses are likely to be distributed erratically and discontinuously along the veins. The size, grade, and distribution of concentrations to be expected along any given vein cannot be predicted in advance of prospecting. The nearest approach to a guess for the McKinley Mountain area, where vein exposures generally are poor, is represented by the symbols of figure 3. 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).

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 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, (1) with smoky quartz crystals at the Atomic Mountain and Little Maud claims, (2) with barite at the Hidden Valley No. 1 and Valley View claims, (3) with barite and galena at the General Ike claim and (4) with a red feldspathized country rock and a syenite dike at the Thorium Mountain claim. 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 be due to minor amounts of 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 1W, 152N, 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 seem 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 had no major influence; high-grade deposits are found in both the siliceous and the mafic rocks. The thorium does show a slight affinity for silica-rich rocks, however, for 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 is strong, blebs and veinlets of a reddish-brown 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 between vitreous and greasey, and appears to be resistant to weathering. The thorium and uranium content of drill core from a depth of 400 feet at Haputa ranch was not appreciably different than at the surface (Christman, and others, 1953).

As seen under the microscope the thorium-bearing mineral from the Pine Tree claim (fig. 5) ranges from micro-crystalline to cryptocrystalline and from anhedral to euhedral. It is intimately intergrown with barite and with specularite. The well-formed crystals are short, square prisms with occasional pyramidal terminations. They rarely exceed 1 mm 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 are anisotropic and strikingly zoned; the rims are yellowish orange, the cores reddish orange. Veinlets of the rim material cut the core, thereby suggesting that the rim represents a higher degree of hydration.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 354

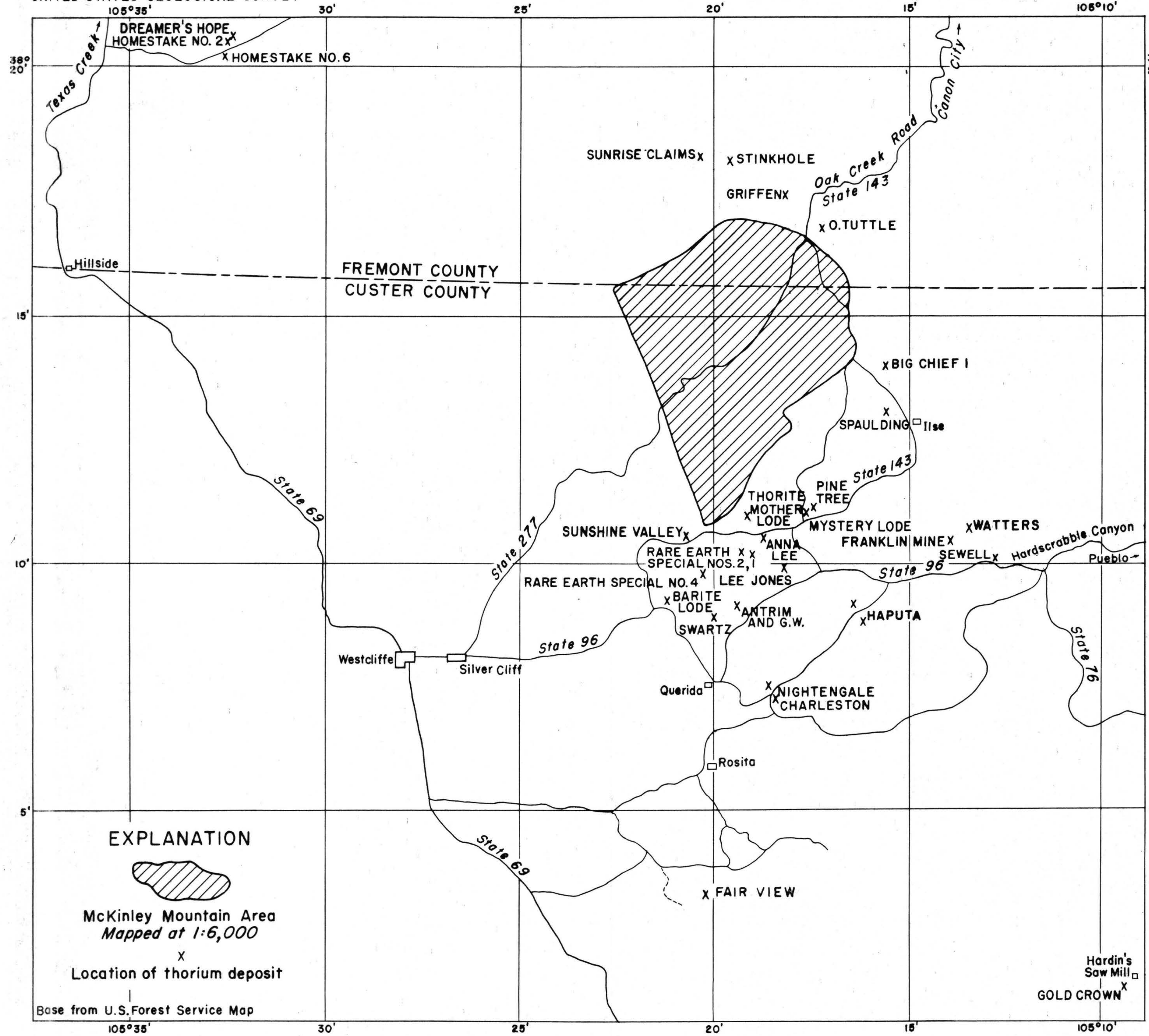

FIGURE 5—MAP OF KNOWN THORIUM DEPOSITS IN PARTS OF CUSTER AND FREMONT COUNTIES, COLORADO, EXCLUDING THE McKINLEY MOUNTAIN AREA.

1 0 4 Miles

GPO 834466

The chemical, optical, X-ray, and differential thermal analysis studies on the thorium-bearing mineral from the Pine Tree claim 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 the problems of nomenclature in the thorium group of minerals and the difficulty of making a specific identification, the term "thorite-like mineral" is used in this report.

Chemical and spectrographic analyses of the thorite-like mineral from the Pine Tree claim are given in table 6. Although this sample represented the purest natural occurrence, it was further purified by heavy liquid and electromagnetic separations. In the chemical analysis, the absence of uranium is noteworthy. The rare earths and ferric iron probably occur in the lattice of the thorite. Although specularite was identified in other, less pure samples, none was identified by X-ray in this sample. The X-ray patterns before and after ignition to 1000°C. gave tetragonal thorite patterns; no thorianite or huttonite lines were observed. The pattern 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° and a sharp exothermal peak at 840°.

At other deposits where the thorium-bearing mineral is visible, it is megascopically similar to the analysed thorite-like 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 pre-Cambrian in age. The stock is abnormally radioactive due largely to thorium. Moreover, syenite dikes believed to have a common origin with the stock are in most places radioactive due to thorium. Spectrographic analyses show that 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-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.

Table 6.--Analyses of the thorite-like mineral from Pine Tree claim, Custer County, Colorado

Chemical analysis 1/
(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		99.68
H_2O (-)	2.66	FeO	not found

Additional data from spectrographic analysis
(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

1/ Analyst: Harry Levine, U. S. Geological Survey.

Barite deposits

At several localities, nearly vertical veins of barite have been mined, usually by trenching. The most continuous barite vein, at the Hidden Valley No. 1 claim (10W, 96N), was worked 200 feet along the strike to an average depth of about 12 feet. Farther north, at 6W, 166N, extensive but discontinuous mining was done along another vein; the principal working apparently was an adit which is now caved. Other barite veins have been mined at 63W, 210N and 31E, 291N. The veins consist of relatively pure, massive, white or pink barite. Although they may be as much as 3 feet wide, the barite bodies are lens-shaped. 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 100 feet long. Smaller lense-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 inch thick. The expansion ratio is about 14:1; the expansion ratio of most vermiculite is in the order of 30:1. 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 5 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 Watters ranch are low in uranium.

The Gold Crown claims are near the crest of a hill southwest of Hardin's Saw Mill, more than 10 miles southeast of the nearest deposits hitherto known. 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 more than 500 feet but 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 containing 0.34 percent equivalent ThO_2 (table 7) in a gangue of quartz, barite, and red feldspar in pre-Cambrian country rocks. It exhibits the same composition, type of country rock, and relation to the country rock as some of the deposits to the north, and so may be regarded as extending the known limits of the thorium province.

The Fair View Lode, which is 5 miles from the nearest previously known thorium deposit, is located 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 and can be traced less than 100 feet. It occurs in pre-Cambrian hornblende-plagioclase gneiss and granite gneiss. A grab sample of the vein material contained 0.32 percent equivalent ThO_2.

Hardwick of Phair?

The Antrim and G. W. Lode claims (fig. 5) have been explored by seven small trenches and a 20-foot shaft under terms of a Defense Minerals Exploration Administration contract. In the shaft the vein is 5 feet wide at the surface and is 1 1/2 feet wide at a depth of 20 feet. The vein is believed to be continuous from the shaft 200 feet southeast to the crest of the hill. 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, the exact nature of the vein is not known. Grab samples of vein material from the claim range from 0.3 to 0.7 percent equivalent ThO_2. 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 No. 1 and No. 2 claims are on a vein that is as much as 4 feet wide and was traced almost continuously for 2,500 feet. 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. At Rare Earth Special No. 4 the thorium-bearing minerals are in a small isolated body of altered dike; the rock appears as globular masses of altered dike surrounded by calcite and iron oxides.

Table 7.—Analyses of samples from outside the McKinley Mountain area, Custer and Fremont Counties, Colorado

Sample number	Location	Type of sample	Equivalent uranium (percent)	Chemical uranium (percent)	Equivalent ThO_2 1/ (percent)	Chemical ThO_2 (percent)	Rare earth oxides (percent)	Spectrographic analyses U	Th	La	Ce	Nd	Sm	Y	Yb	Dy	Er	Be	Zr	Pb
RA-100 2/	Homestake No. 2, dump of shaft	Grab of vein material	0.016 9/	0.0006 9/	0.09			0	.0X	.X	.X	.X	0	.0X	.000X	0	0	0	.00X	0
RA-101 2/	Homestake No. 2, 50 ft NE of shaft	Grab of vein material	.024 9/	.0004 9/	.13			0	.0X	.X	.X	.X	0	.00X	.000X	0	0	.000X	.00X	.X
RA-102 2/	Homestake No. 6, lower dump	Grab of vein material	.025 9/	.0011 9/	.13			0	.0X	.X	.X	.X	0	.0X	.00X	.0X	.00x	.000X	.0X	0
RA-103a 2/	Homestake No. 6, upper dump	Grab of vein material	.032 9/	.0011 9/	.17			0	.X	1.%	>1.%	.X	.X	.0X	.000X	.0X	.0X	.000X	.0X	0
RA-104a 2/	Homestake No. 6, lower pit	Selected vein material	.13 9/	.0013 9/	.72			0	.X	1.%	>1.%	.X	.X	.X	.0X	.0X	.0X	.000X	.00X	X.
RA-105a	Rare Earth Special No. 2	Grab of vein material	.089 6/	.004 6/	.48															
RA-106a	do.	do.	.079 6/	.002 6/	.43															
RA-108a	Rare Earth Special No. 4	do.	.20 6/	.005 6/	1.09															
RA-111a	Thorite Mother Lode	do.	.052 6/	.001 6/	.29															
RA-112a	Fair View Lode	do.	.058 6/	.001 6/	.32															
RA-105 2/	Franklin Mine, lower adit	2.5-foot channel, 160 ft from portal	.031 7/	.002 8/	.16	0.02 8/	0.01 8/	—	.X	.0X	.0X	.0X	.00X	.0X						
RA-106 2/	do.	Grab of clay seam, 175 ft from portal	.025 7/	.002 8/	.13	.03 8/	.18 8/	—	.X	.0X	.X	.X	.0X	.0X						
RA-107 2/	Antrim and G.W. Lode	Grab of vein material	.12 7/	.004 8/	.65	.40 8/	.23 8/	—	.X	.00X	.0X	.0X	—	.X						
RA-108 2/		9-foot channel	.087 7/	.003 8/	.47	.16 8/	trace 8/	—	.X	.00X	.0X	.0X	—	.0X						
THW 1-A	Antrim and G.W. Lode, dump 2	Grab of vein material	.12 3/	—	.65 *															
THW 1-B	do. dump 3	do.	.075 3/	—	.40 *															
THW 1-C	do. pit 1	Selected vein material	.86 3/	—	4.79 *															
THW 1-D	do. pit 2	Grab of vein material	.056 3/	—	.29 *															
THW 1-E	do. pit 3	do.	.13 3/	—	.71 *															
53C-114	Gold Crown, dump of shaft	do.	.061 6/	.001 6/	.34															
AH-71 4/	Watters' ranch	Grab of vein material	.24 5/	.10 5/	.78			.X	.0X	.0X	.X	.0X	.0X	.X	.0X	.0X	.0X	—	—	—

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/ Analyst: J. Patton
4/ Spectrographer: G. W. Boyes
5/ Analysts: S. Furman, J. McGurk, W. Mountjoy
6/ Analysts: S. Furman, R. DuFour
7/ Analyst: S. Furman
8/ Analysts: R. DuFour, Mallory
9/ Analysts: S. Furman, W. Mountjoy, P. Schuch

70134

At the Homestake No. 6 claim, northeast of Hillside (fig. 5), the rare earth content of two samples 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 rare earths (Christman, and others, 1953). This particular claim has not been studied.

Vein rock at the Franklin mine, Sunshine Valley claims, and Thorite Mother Lode is relatively low in thorium. Analyses from the Franklin mine are given in table 7.

A prospect on the Watters' ranch, 5 miles southeast of the mapped area and a mile north of Highway 96, contains significant amounts of uranium. The lessees shipped nearly a ton of hand-picked ore that assayed 0.10 percent U_3O_8 and 45 percent carbonate. If the excess radioactivity indicated by the equivalent uranium value (table 7) is assumed to be due to thorium, the ore may also contain 0.78 percent equivalent ThO_2. The uranium is found in a dense, purplish-red carbonate vein 1/2 to 1 1/2 feet wide and about 100 feet long. No prospecting has been done below a depth of 12 feet. Reconnaissance in the immediate vicinity failed to disclose a lateral extension of the vein.

SUGGESTIONS FOR PROSPECTING

Many of the localities containing radioactive materials in the McKinley Mountain area (fig. 3) 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 figure 3 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 very poorly exposed. At poorly exposed localities, of course, the amount of radioactivity shown on figure 3 does not fully represent the amount of radioactive materials actually present.

Many undiscovered radioactive localities undoubtedly occur in general proximity to the scattered localities shown by figure 5 in unmapped terrane outside the McKinley Mountain area. They may best be sought by utilizing a gamma-scintillation detector. Rocks that are stained red or yellow by iron oxides, as well as veins containing smoky quartz, barite, and carbonate or sulfide minerals should be particularly investigated, though none of these minerals necessarily is accompanied by thorium.

Most of the area appears to be unfavorable for prospecting for uranium, as all samples except the one collected at Watters' ranch, contained much less than 0.10 percent uranium (tables 4, 5, and 7). However, ground to the east and southeast of the Watters' property, which has not been examined by the Geological Survey, may contain other occurrences of uranium.

LITERATURE CITED

Bucher, W. H., 1933, Cryptovolcanic structures in the United States: 16th Internat. Geol. Cong., Rept. v. 2, p. 1055-1084.

Burbank, W. S. and Goddard, E. N., 1937, Thrusting in Huerfano Park, Colorado, and related problems of orogeny in the Sangre de Cristo Mountains: Geol. Soc. America Bull., v. 48, p. 931-976.

Christman, R. A., Heyman, A. M., Dellwig, L. F., and Gott, G. B., 1953, Thorium investigations 1950-52, Wet Mountains, Colorado: U. S. Geol. Survey Circ. 290, 40 p.

Cross, C. W., 1896, Geology of Silver Cliff and the Rosita Hills, Colorado: U. S. Geol. Survey, 17th Ann. Rept., p. 269-403.

Emmons, R. C., 1953, Selected petrogenic relationships of plagioclase: Geol. Soc. America Mem. 52, 142 p.

Emmons, S. F., 1896, The mines of Custer County, Colorado: U. S. Geol. Survey, 17th Ann. Rept., p. 411-472.

Frondel, Clifford, 1953, Hydroxyl substitution in thorite and zircon: Am Mineralogist, v. 38, p. 1007-1018.

Hagner, A. F., 1944, Wyoming vermiculite deposits: Wyoming Geol. Survey Bull. 34, 47 p.

Holmes, Arthur, 1920, The nomenclature of petrology, 284 p., London, Murby.

Lacroix, A., 1929, Ferrothorite: Am. Mineralogist, v. 14, p. 78.

Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Geol. Survey Prof. Paper 223.

Turner, F. J., 1951, Observations on twinning of plagioclase in metamorphic rocks: Am. Mineralogist, v. 36, p. 581-589.

Tuttle, O. F., 1952, Origin of the contrasting mineralogy of extrusive and plutonic salic rocks: Jour. Geology, v. 60, p. 107-124.

Part II

The work in the Wet Mountains to date, except for the 1952 exploration project at Haputa ranch, has been oriented toward systematic search for radioactive anomalies and concomitant detailed geologic mapping, rather than toward estimating tonnage and grade of individual deposits. Only data readily obtained at outcrops, supplemented by occasional samples, are available concerning the extent and the intensity of the radioactive localities. Thus, it would be premature to hazard a guess as to reserves, except in the broadest terms. From the tables of analytical data on some of the localities and the maps showing known radioactive localities (tables 4, 5, and 7; figs. 3 and 5), it may be inferred that the area in aggregate contains very large tonnages of 0.1 percent ThO_2, a moderate amount of 0.5 percent ThO_2, and only a limited amount of 1.0 percent ThO_2. Until a market develops for a low-grade thorium and a cut-off value is established, the economic potentials of the region are impossible to forecast. To date, the thorium deposits have been found in small and scattered concentrations so that a large-scale mining operation will probably not be possible; rather the area appears to be suited for numerous small operations each involving only a few thousand tons of rock.

Most of the data concerning the distribution and content of radioactive minerals are in the form of radioactivity readings made with the gamma-scintillation detector. Although these readings cannot be converted into percent ThO_2, they do provide valuable clues as to where thorium may be found, and how much. If, at some future date, it becomes desirable to ascertain accurately the reserves of the region, it is suggested that a sampling program be carried out in conjunction with bulldozing. This type of physical exploration is recommended because many of the veins are covered, and so the exact distribution and concentration of the thorium-bearing minerals along the surface cannot otherwise be determined. Inasmuch as the vertical distribution of thorium may be as irregular as the surface distribution, a drilling program is not considered to be as valuable as bulldozing and actual exploratory mining operations.

A search by gamma-scintillation detector for new localities in parts of the thorium province that have not yet been systematically covered should proceed concurrently with bulldozing-sampling at selected known localities.

Within the McKinley Mountain area, exploration would be advisable along the veins near the following localities (not listed by preference):

5E, 354N (Tuttle ranch)
21E, 342N (Tuttle ranch)
11E, 81N (Little Maud-Atomic Mountains claims)
45W, 195N
52W, 118N (Thorium Mountain claim)
92W, 221N
110W, 192N
119W, 236N (Darby Extension claim)

Outside the McKinley Mountain area, excluding the Haputa ranch property, the following are considered especially to merit further study:

Anna Lee claim
Antrim and G. W. claims
Gold Crown claims
Homestake No. 6 claim
Pine Tree claim
Rare Earth Special claims Nos. 1 and 2

The Haputa ranch property, Anna Lee claim, and Pine Tree claim are described by Christman, and others, (1953). The others have been examined in reconnaissance and are briefly described in this report.