Thorium and Rare-Earth Minerals in Powderhorn District, Gunnison County, Colorado

By J. C. OLSON *and* S. R. WALLACE

A CONTRIBUTION TO ECONOMIC GEOLOGY

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By Jerry C. Olson and Stewart R. Wallace

ABSTRACT

Thorium has been found since 1949 in at least 33 deposits in an area 6 miles wide and 20 miles long in the Powderhorn district, Gunnison County, Colo. The district is underlain largely by pre-Jurassic metamorphic and igneous rocks, most of which, if not all, are pre-Cambrian in age. These rocks are overlain by sandstone of the Morrison formation of Jurassic age, and by volcanic rocks of the Alboroto group and the Hinsdale formation of Miocene and of Pliocene(?) age, respectively.

The thorium deposits occur in or near alkalic igneous rocks in which such elements as titanium, the rare-earth metals, barium, strontium, and niobium are present in greater-than-average amounts. The greatest mass of the alkalic igneous rocks—the Iron Hill composite stock—occupies an area of 12 square miles in the southeastern part of the district. The thorium deposits, like the alkalic igneous rocks, have not been dated more precisely than pre-Jurassic.

The thorium deposits are veins and mineralized shear zones that range from a few inches to 18 feet wide and from a few feet to 3,500 feet long. The veins are composed of calcite, dolomite, siderite, ankerite, quartz, barite, pyrite, sphalerite, galena, goethite, apatite, alkali feldspar, and many other minerals. At least part of the thorium occurs as thorite or thorogummite. A small amount of what has been tentatively identified as xenotime is found in one deposit. Several minerals containing the rare-earth metals of the cerium group as major constituents are found in carbonate veins near Iron Hill. Bastnaesite and synchisite have been identified by X-ray methods, and cerite is probably present also. The fluorapatite in some veins and in parts of the mass of carbonate rock that occupies 2 square miles in the central part of the Iron Hill composite stock contains rare-earth elements of the cerium group, generally in amounts of a fraction of a percent of the rock.

The radioactivity of the deposits appears to be due almost entirely to thorium and its daughter products. The thorium oxide content of selected high-grade samples from the Little Johnnie vein is as much as 4 percent, but in most veins is generally less than 1 percent, and is only from 0.05 to 0.1 percent in many of the veins studied.

The Little Johnnie vein, which was mapped in detail, is a mineralized fault zone that ranges from less than 6 inches to 5 feet in width and can be traced discontinuously for a distance of more than 3,500 feet. The thorium-bearing

material occurs as irregular veinlets and thin films introduced along the fault zone. Near its west end the vein is broken by many faults in a zone that marks the edge of a roughly circular fault block, 1½ miles in diameter, that has dropped 1,000 feet or more since the deposition of Miocene volcanic rocks that now floor the Milkranch Gulch basin.

INTRODUCTION

In 1949 thorium deposits were discovered in the Powderhorn district of Gunnison County, Colo. The district has long been known for its alkalic igneous rocks, of which the best known are those of the Iron Hill composite stock (Larsen, 1942). Some of these alkalic rocks contain titanium, barium, strontium, rare-earth metals, thorium, and niobium in greater percentages than in most igneous rocks. A study of the thorium deposits was made to learn more about the geologic relation of minor elements, particularly the rare-earth metals and thorium, to alkalic igneous rocks, and to determine the potentialities of the thorium deposits.

GEOGRAPHIC SETTING

The Powderhorn district is an elongate area about 20 miles long and 6 miles wide that extends northwestward from the vicinity of Iron Hill to the Lake Fork of the Gunnison River, in the southwestern part of Gunnison County, Colo. (fig. 86). Powderhorn, a small

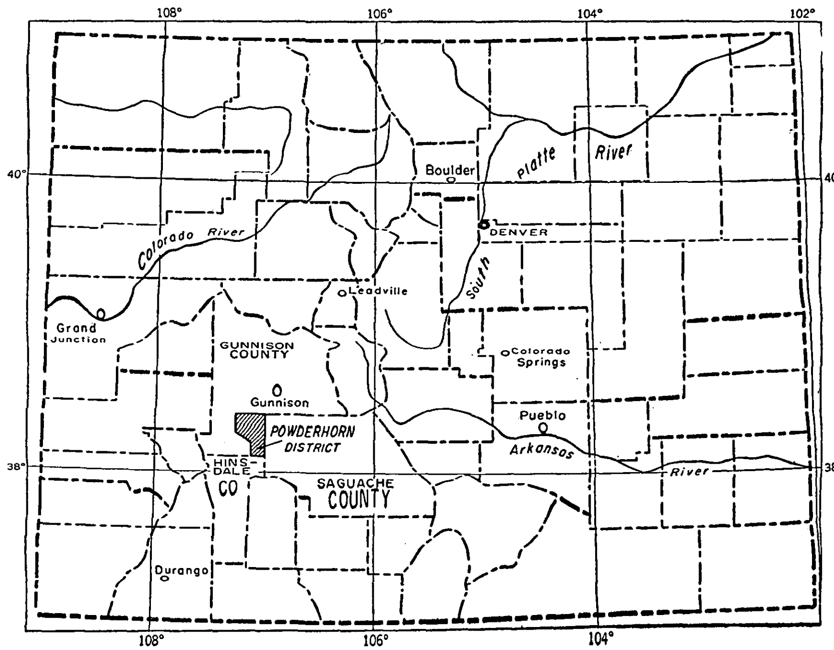

FIGURE 86.—Index map showing location of the Powderhorn district; shaded part indicates area shown on plate 55.

settlement in the south-central part of the district, is about 30 miles by road southwest of Gunnison, the nearest town.

The district is drained by three northward-flowing tributaries of the Gunnison River: Willow Creek, Cebolla Creek, and the Lake Fork of the Gunnison. These streams and their tributaries are deeply incised and in places have cut canyons as much as 1,000 feet deep in the pre-Cambrian rocks which underlie most of the district. The interstream areas consist of dissected mesas that slope gently northward toward the Gunnison River. Many of these are capped by remnants of nearly flat-lying Mesozoic sedimentary rocks and Tertiary volcanic rocks. The altitude ranges from 7,500 feet on the Lake Fork of the Gunnison to more than 10,000 feet in the southeastern part of the district.

PREVIOUS WORK

The first comprehensive geologic study of the area that includes the Powderhorn district was made by Hunter (1925), who studied the pre-Cambrian rocks of the Gunnison River region in 1911–13. In part of this work Hunter was associated with E. S. Larsen, Jr., and Whitman Cross (Cross and Larsen, 1935). Larsen also studied the area subsequently, and his Professional Paper (Larsen, 1942) on the Iron Hill complex contains a wealth of data on the petrography, mineralogy, and geochemistry of the alkalic rocks.

In 1950, soon after the discovery of thorium deposits in the district, J. W. Adams and F. B. Moore of the U. S. Geological Survey examined the Little Johnnie, Jeanie, and Red Rock claims. In 1951, during reconnaissance for radioactive materials in the San Juan Mountain region, W. S. Burbank examined thorium deposits in the Lake Fork-Dubois area and veins in the vicinity of Iron Hill (Burbank and Pierson, 1953).

FIELD WORK AND ACKNOWLEDGMENTS

This report is the result of a brief reconnaissance for thorium-bearing deposits by J. C. Olson during the period August 11–25, 1952, and planetable mapping of the Little Johnnie thorium deposit by S. R. Wallace and J. E. Roadifer from July 1 to August 6, 1953, with the assistance of J. C. Olson for 8 days. Notes, sketch maps, and other unpublished data obtained by W. S. Burbank in 1951 and by J. W. Adams and F. B. Moore in 1950 contributed much to the field study and the preparation of the report. In the laboratory, samples from the Powderhorn district were studied by chemical, spectrographic, and x-ray methods.

The investigations of the Powderhorn thorium deposits were made by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission.

GENERAL GEOLOGY

Thorium deposits have been found in an area 6 miles wide and 20 miles long, extending from the Iron Hill complex to the Lake Fork of the Gunnison River (pl. 55). The area is underlain chiefly by pre-Cambrian metamorphic and igneous rocks. The metamorphic rock complex is intruded by pre-Jurassic alkalic igneous rocks. Flat to gently dipping strata of the Morrison formation, of Jurassic age, overlie the complex of metamorphic and igneous rocks. Tertiary volcanic rocks were deposited on an early Tertiary erosion surface that in places nearly coincides with the late Paleozoic or early Mesozoic erosion surface on which the Morrison formation was deposited.

PRE-CAMBRIAN METAMORPHIC AND IGNEOUS COMPLEX

The pre-Cambrian rocks, as mapped by Hunter (1925), are divided into the Black Canyon schist, the Dubois greenstone, and the Powderhorn granite group. In the Powderhorn district (pl. 55) the Black Canyon schist of Hunter (1925) is dominantly biotite schist, quartz-mica schist, and micaceous quartzite. Granite gneiss and amphibole schist make up a small part of the Black Canyon schist.

The Dubois greenstone occurs in an east-trending band from 1 to 4 miles wide in the north-central part of the district. The dark-green rocks of this formation consist chiefly of hornblende schist, hornblende gneiss, amphibolite, metadiorite, and chlorite schist.

The Black Canyon schist underlies most of the area of pre-Cambrian rocks north of the belt of Dubois greenstone, whereas the Powderhorn granite predominates to the south.

The Powderhorn granite group of Hunter (1925) comprises granitic rocks of relatively uniform composition but includes such diversified textural varieties as schistose metarhyolite porphyry, coarsely porphyritic granite, and aplite. Granites of the Powderhorn group cut the Dubois greenstone, and therefore are younger than it, but some foliated amphibolite appears to form dikes that cut Powderhorn granite. The porphyritic texture and quartz phenocrysts of the metarhyolite porphyry suggest that this variety was either extrusive or intruded at relatively shallow depth. Other facies of the Powderhorn granite are almost certainly plutonic.

Except for some facies of the Powderhorn granite, all the rocks described above are well foliated and have been metamorphosed to a much greater degree than any of the Paleozoic sedimentary rocks of central Colorado and the San Juan Mountains.

INTRUSIVE ROCKS

Many dikes and small irregular bodies of only poorly foliated or massive igneous rocks intrude the pre-Cambrian metamorphic and igneous complex. These igneous rocks include diorite, quartz diorite, gabbro, syenitic rocks ranging from leucosyenite to shonkinite, and the alkalic rocks of the Iron Hill composite stock, which occupies an area of about 12 square miles in the southeastern part of the district. In composition, about 70 percent of the stock is pyroxenite, 17 percent is a dolomitic carbonate rock, and the rest is uncompahgrite (melilite rock that contains pyroxene and magnetite), ijolite (nepheline-pyroxene-garnet rock), soda syenite, nepheline syenite, nepheline gabbro, and quartz gabbro. The mineralogic and chemical features of these uncommon alkalic igneous rocks have been described by Larsen (1942, p. 35–36).

The Iron Hill stock has been dated no more precisely than pre-Jurassic (Larsen, 1942, p. 2), and that dating is based on the fact that certain heavy minerals in the Iron Hill alkalic rocks are found in the basal Morrison beds. The age of the outlying dikes and irregular bodies of diorite, gabbro, and the variety of syenitic rocks ranging from leucosyenite to shonkinite relative to the Iron Hill stock is unknown. The chemical and structural features of these rocks, however, are generally similar to those of the Iron Hill rocks and indicate a probable genetic relationship. According to Hunter (1925, p. 78), quartz diorite and augite syenite in Wildcat Gulch are cut by dikes of pegmatite. If the pegmatite is pre-Cambrian in age, the age assigned to most of the pegmatite in this region, the quartz diorite and the augite syenite would also be pre-Cambrian. The age is speculative, however, for intrusion of pegmatite in the district may have occurred in more than one period.

CARBONATE ROCK OF IRON HILL

A mass of carbonate rock, the marble of Iron Hill (Larsen, 1942), occupies about 2 square miles near the center of the Iron Hill composite stock. Most of the carbonate of the mass is dolomite, but some calcite is present (Larsen, 1942, p. 5). Apatite, which contains small amounts of rare earths, makes up several percent of the carbonate rock; other accessory minerals locally present include phlogopite, magnetite, aegirite, and soda-amphibole.

The carbonate rock is not bedded, but generally is massive, although locally it has a conspicuous steeply plunging to vertical lineation formed mainly by streaks of apatite along shear planes; the lineation is especially well developed near the margins of the mass. In a few places, as at locality 13 (pl. 55) and in the isolated mass (locality 12) south of the mouth of Beaver Creek, it has a layering or banding resulting from streaks of such minerals as phlogopite and magnetite.

Numerous carbonate veins similar in composition to the large carbonate-rock mass of Iron Hill cut the pyroxenite and other intrusive rocks of the Iron Hill stock. Several small isolated bodies of carbonate rock, generally similar to the carbonate rock of Iron Hill, occur both in the pyroxenite and in the pre-Cambrian rocks surrounding the Iron Hill stock, a mass of white carbonate rock at least 200 feet in diameter is enclosed in Powderhorn granite at the point indicated by a prospect pit 1 mile N. 45° E. of Powderhorn on plate 55.

Locally, the carbonate rock is both older and younger than the alkalic dike rocks. The numerous carbonate veins that cut the pyroxenite and other igneous rocks clearly are younger than the main mass of the stock. The opposite of this age relationship is seen at a prospect pit in Sammons Gulch 1.3 miles east of Powderhorn, where a body of carbonate rock about 20 feet wide is cut by pyroxenite dikes 1 to 8 inches wide (Larsen, 1942, p. 4–5). At locality 12 just south of the mouth of Beaver Creek, an outlying body of carbonate rock and the pyroxenite adjacent to it are cut by thin micaceous dikes. The relations at these two localities show that at least some dikes are younger than some carbonate rock.

The age relationships of the large Iron Hill mass of carbonate rock to the rest of the stock are not known because contacts are poorly exposed, and the mode of origin is uncertain. Larsen favored the concept that the main mass is a large hydrothermal deposit formed in the throat of a volcano, though it may have been intruded as a carbonate magma or it may be an inclusion of pre-Cambrian or Paleozoic marble (Larsen, 1942, p. 6–9).

SEDIMENTARY AND VOLCANIC ROCKS

The metamorphic and igneous rock complex is overlain unconformably by thin remnants of sandstone and siltstone of the Morrison formation of Jurassic age, which were deposited on a nearly flat surface. The Mancos shale of Cretaceous age occurs in two small areas on the Lake Fork of the Gunnison River. Volcanic rocks of the Alboroto group of the Potosi volcanic series of Miocene age lie unconformably on the Morrison formation, and in turn are overlain unconformably by rhyolite of the Hinsdale formation of Pliocene(?) age (Cross and Larsen, 1935). The sedimentary and volcanic rocks are found chiefly as erosional remnants on mesas and ridges, and have been removed from most of the district by erosion.

STRUCTURE

The foliation and individual layers of the pre-Cambrian metamorphic rocks strike generally within 45 degrees of east and dip steeply throughout most of the district. Many of the dikes and veins in the district were emplaced parallel to this foliation and the layers. The Mesozoic and Cenozoic sedimentary and volcanic rocks dip gently northward except locally where disturbed by faults.

The largest fault known in the region (pl. 55), the Cimarron fault of Hunter (1925, p. 88), is a southward-dipping normal fault that has a throw of more than 1,500 feet in the Powderhorn district (Hunter, 1925, p. 90). It extends at least 35 miles northwestward from Powderhorn but has not been mapped southeast of Powderhorn. Its probable location in the valley of Cebolla Creek is marked by hot springs and spring deposits. The movement on this fault occurred chiefly in late Cretaceous or early Tertiary time but continued after the volcanic rocks were formed. Several other northwest trending faults in the district were mapped by Hunter (1925).

MINERAL DEPOSITS

Mineral deposits in the Powderhorn district are related to three or more distinct periods of mineralization. There are sulfide-bearing quartz veins and massive-sulfide replacement deposits associated with pre-Cambrian rocks, various types of veins and segregations associated with the alkalic rocks of the Iron Hill composite stock and with the related intrusive rocks in other parts of the district, and small veins associated with the Tertiary volcanic rocks.

Sulfide-bearing quartz veins in pre-Cambrian rocks near Dubois, Spencer, Midway, and Vulcan, were mined or prospected principally during the period 1870–1900. Similar veins in the Cochetopa district to the east are considered to be pre-Cambrian by Hill (1909, p. 29); therefore the quartz veins of the Powderhorn district are probably of pre-Cambrian age. The veins are composed chiefly of quartz and chlorite, but tourmaline is present in some. The dominant metallic minerals are pyrite, chalcopyrite, and sphalerite, but the deposits were worked for the gold and minor amount of silver they contained. A small quantity of sulfur was produced from massive-sulfide (pyrite, chalcopyrite, sphalerite) bodies which replace chloritic schist near Vulcan.

Iron and manganese oxides, vermiculite, and minerals containing titanium, rare earths, thorium, and niobium are found locally in veins or segregations in the alkalic igneous rocks and carbonate rock of the Iron Hill stock and are present in sufficient quantity to encourage some prospecting. Except for a small production of vermiculite and manganese, the output of these materials in the Powderhorn district has been insignificant.

The vermiculite, an alteration product of biotite, has been mined at several places from biotite-rich facies of the pyroxenite. Iron occurs in veins and irregular bodies of hematite and limonite in the carbonate rock of Iron Hill, and in lenticular bodies of magnetite and very fine-grained perovskite in the pyroxenite which are commonly from 20 feet to as much as 75 feet wide. The iron-bearing veins in the carbonate rock are relatively small and contain abundant phosphorus in the form of apatite.

Titanium minerals are abundant in some of the pyroxenite of the Iron Hill stock, and considerable exploratory work and investigation of recovery methods has been done, chiefly by the Humphreys Gold Corp., during the past three years. Many cuts have been excavated by bulldozer, and large samples have been obtained for study of beneficiation of the titanium ore.

Titanium oxide averages 7.4 percent in the pyroxenite and exceeds 35 percent in some of the bodies of perovskite-magnetite rock (Larsen, 1942, p. 57–58). The bulk of the titanium occurs as the calcium titanate, perovskite, but some is present as sphene and ilmenite, and small amounts are contained in melanite, biotite, pyroxene, and other minerals.

Titanium-rich alkalic rocks commonly contain a relatively high percentage of niobium. The rocks of the Iron Hill stock contain niobium in amounts greatly exceeding those of average igneous rocks but analyses to date indicate a somewhat lower content of niobium than has been found in certain other alkalic-rock complexes (*see* Fleischer and others, 1952). Perovskite concentrates from the pyroxenite of Iron Hill generally contain 0.X to 0.0X percent niobium. Spectrographic analyses of 11 samples of veins and carbonate rocks are given in table 1.

TABLE 1.—*Niobium content of 11 samples of veins and carbonate rocks, Powderhorn district, Colorado*

[Spectrographic analyses by R. G. Havens and P. R. Barnett U. S. Geological Survey]

Type of rock	Number of samples	Nb (percent)
Little Johnnie thorium-bearing vein	1	0.X
Do	2	.0X
Apatite-bearing Iron Hill carbonate rock	1	.X
Do	1	.0X
Calcite-apatite-martite vein in Iron Hill carbonate rock	1	.X
Do	1	.0X
Carbonate vein in pyroxenite east of Iron Hill	3	.0X
Do	1	.00X

Sulfide-bearing carbonate veins in the Iron Hill stock have been prospected for silver, and small amounts of manganese are found both in the Iron Hill composite stock and in unrelated deposits in the Tertiary volcanic rocks (Harder, 1910).

A few of the gold-bearing quartz-chlorite veins in pre-Cambrian metamorphic rocks have been tested for radioactivity, but with minor exceptions radioactivity appears to be negligible (Burbank and Pierson, 1953, p. 2). Essentially all significant radioactivity known in the district seems to be associated with the Iron Hill composite stock and its related intrusive rocks and veins.

THORIUM DEPOSITS

The known radioactive deposits in the Powderhorn district are of three types: (1) mineralized shear zones in pre-Cambrian foliated rocks; (2) carbonate-rich, tabular veins formed along other fractures, especially abundant in rocks of and adjacent to the Iron Hill intrusive complex; and (3) weakly radioactive zones in nontabular masses of carbonate rock, such as the marble of Iron Hill.

The radioactivity in the deposits sampled appears to be due almost entirely to thorium and its daughter products, mostly in the form of thorite and thorogummite (hydrothorite). Of 33 samples analyzed chemically for uranium, the maximum uranium content found in any sample is 0.005 percent; most contain from 0.001 to 0.002 percent. Radium has been determined in four samples from thorium-bearing veins, and the highest radium content obtained is 2.7×10^{-11} percent. The thorium oxide content of selected high-grade samples from the Little Johnnie vein is as much as 4 percent. The ThO_2 content of the veins is generally less than 1 percent, however, and is only 0.05 to 0.1 percent in many of the veins indicated on the geologic map (pl. 55) as abnormally radioactive.

The greatest radioactivity in the district comes from material found in mineralized shear zones, a foot to several feet wide, in which the introduced material forms numerous closely-spaced films and veinlets in fractures in the country rock. Near the veinlets the wall rock commonly is partly replaced and greatly altered. Masses of wall rock, generally iron-stained, are found in many places within the mineralized shear zones, which are commonly discontinuous and variable in width.

The large mass of carbonate rock at Iron Hill is radioactive in at least two localities (12 and 13, pl. 55), where readings on a scintillation-type counter were locally as much as 0.3 and 0.14 mr per hr,[1] respectively (background 0.03 mr per hr). At both these localities the carbonate rock, unlike most of that at Iron Hill, is banded because of streaks of minerals such as magnetite and phlogopite. In general, the carbonate rock of Iron Hill and in several smaller masses, such as the ones in Sammons Gulch, which is 1.3 miles east of Powderhorn, and on the ridge south of Milkranch Gulch, shows negligible radioactivity.

STRUCTURAL FEATURES

The thorium-bearing veins are a few inches to 18 feet wide and a few feet to more than 3,500 feet long. Most of the veins dip essentially vertical; few dip less than 60 degrees. The strikes of the veins are not consistent throughout the district. In general, the veins near Iron

[1] Milliroentgens per hour.

Hill have a crude radial arrangement with respect to the central mass of Iron Hill carbonate rock. The veins and mineralized shear zones near the Little Johnnie claims generally strike northeast to east, and those in the Dubois-Lake Fork area strike variably northwest to northeast.

The thorium deposits have not been exposed at depth, with the exception of a few exposures underground in adits at Dubois. The length and tabular form suggest that some thorium veins may persist to depths of hundreds of feet. Thorium-bearing veins are exposed in the bottom of Lake Fork Canyon, 1,000 feet below exposures of similar veins on the mesa to the east; the Little Johnnie vein is exposed for a vertical distance of more than 700 feet.

Well-defined carbonate veins are particularly common in the Iron Hill complex. Locally these veins contain fragments of wall rock. The great lengths, 3,500 feet or more, of some of these veins and the rather constant widths suggest that they were emplaced in fractures. Many of the carbonate veins have a foliation or banding, shown by the concentration of various minerals in streaks parallel to the walls of the vein.

Among the deposits in the rocks surrounding the Iron Hill complex, the few veins or mineralized shear zones in relatively massive granite, such as deposit 31 (pl. 55), appear to be shorter and less persistent than veins in foliated or layered rocks, such as amphibole and chlorite schists and gneisses near Dubois and the interlayered quartzite, schist, and metarhyolite porphyry in the vicinity of the Little Johnnie claims.

MINERALOGY

The thorium-bearing deposits are composed of calcite, dolomite, siderite, ankerite, quartz, barite, pyrite, sphalerite, galena, hematite, goethite, apatite, thorite or thorogummite, xenotime(?), and alkali feldspar. In addition, rare-earth minerals, including bastnaesite, cerite(?), and synchisite, were found in carbonate veins near Iron Hill. The carbonate veins in the Iron Hill complex also contain several silicate minerals; among them are aegirite, sodic amphibole, phlogopite, zeolites, idocrase, melilite, diopside, garnet, and other minerals (Larsen, 1942, p. 31).

Thorium is known to occur as thorite or thorogummite in some of the deposits, but many of the radioactive deposits have not been studied sufficiently to identify the thorium-bearing mineral or minerals. Among the carbonate-rich veins near Iron Hill, the more radioactive deposits appear to be those containing unweathered sulfide minerals, such as pyrite, but such unoxidized material is not common in surface exposures. The more oxidized veins and mineralized shear zones in near-surface exposures, characterized by abundant powdery goethite, also are appreciably radioactive, and the thorium is apparently chiefly associated wtih the iron oxides, perhaps in part as thorite or thorogummite.

Several minerals containing the rare-earth metals of the cerium group occur in the Iron Hill carbonate rock and in veins east of Iron Hill. The fluorapatite in parts of the large mass of Iron Hill carbonate rock and in many of the carbonate veins contains rare-earth metals of the cerium group. In addition to the widespread rare-earth-bearing apatite, X-ray patterns by A. J. Gude, U. S. Geological Survey, show that bastnaesite is one of the rare-earth minerals present in a sample from a prospect 0.2 mile southwest of locality 10 (pl. 1). Another mineral in this same sample has an X-ray pattern that matches the pattern of cerite(?) from Jamestown, Colo., although the identity of the Jamestown cerite(?) used as a reference standard is not certain. A third mineral containing abundant rare-earth metals of the cerium group was found in samples from localities 8 and 10 (fig. 2). This mineral is provisionally considered to be synchisite by Fred A. Hildebrand of the U. S. Geological Survey, on the basis of X-ray powder patterns. It seems likely that several other minerals containing rare earths as major constituents, such as monazite and rare-earth carbonates and fluocarbonates, may be found by additional detailed mineralogical studies.

Hematite and goethite are sufficiently abundant in some deposits, particularly in mineralized shear zones, such as the Little Johnnie deposit, to impart a red- to yellow-brown color to them that is an aid in prospecting. This color is not an infallible guide to thorium, however, for some zones relatively rich in hematite and goethite have no radioactive minerals.

RELATION TO ALKALIC IGNEOUS ROCKS

The map of the district (pl. 55) indicates a spatial relation between thorium-bearing deposits and alkalic igneous rocks. Most of the known thorium deposits are in three areas: near Dubois, near the Little Johnnie claims, and in the Iron Hill composite stock. In each of these areas alkalic igneous rocks are present.

Among the elements that characterize the mineralized shear zones, the carbonate veins, and the alkalic igneous rocks are titanium, barium, strontium, niobium, phosphorus, and the rare-earth metals. The abundance of these elements in the mineralized shear zones and the carbonate veins is indicated in table 2. These elements are also present in greater-than-average amounts in the alkalic igneous rocks, and the geographic and geochemical relations of the thorium-bearing veins and the alkalic rocks strongly suggest a genetic tie between them.

TABLE 2.—*Abundance of certain minor elements in spectrographic analyses of samples from mineralized shear zones and carbonate veins*

[R. G. Havens and P. R. Barnett, U. S. Geological Survey, analysts]

Element	Number of samples in which element exceeds 0.1 percent		Element	Number of samples in which element exceeds 0.1 percent	
	Mineralized shear zones (6 samples analyzed)	Carbonate veins (8 samples analyzed)		Mineralized shear zones (6 samples analyzed)	Carbonate veins (8 samples analyzed)
Ba	6	8	Sm	1	0
Ti	5	4	Y	3	0
Sr	0	4	Nb	1	1
Th	4	0	P	0	3
La	0	4	V	0	2
Ce	0	4	Zr	0	2
Nd	0	4			

Larsen (1942, p. 29) has pointed out the abundance of potash in many of the alkalic rocks of the areas surrounding the Iron Hill complex, in contrast to the relative abundance of soda and lime in the igneous rocks within the complex. However, some sodic dikes, such as those composed of soda syenite, have also been found beyond the Iron Hill composite stock. Thorium appears to be associated with alkalic rocks of both the potassic and sodic types, and this suggests that other thorium deposits may be found by prospecting in the vicinity of the syenitic rocks in Wolf Gulch, Wildcat Creek, and Willow Creek.

AGE

The thorium deposits are known to be older than the Alboroto rhyolite of the Potosi volcanic series of Miocene age. Thorium-bearing veins cut the pyroxenite and other igneous rocks in the Iron Hill complex. The association of the veins with the rocks of the Iron Hill composite stock and with other alkalic igneous rocks in the district suggests that the thorium-bearing veins formed during the late stages of the Iron Hill igneous activity. The vein on the Little Johnnie claims, however, may be cut by a gabbro dike. The contacts between the Little Johnnie vein and the dike are not exposed, but no abnormal radioactivity was detected across a 100-foot width of the dike along the projected strike of the vein. The gabbro contains anatase and brookite along fractures, and the presence of these titanium minerals suggests the dike is related to the Iron Hill complex. Accordingly the thorium deposits may be older than some of the alkalic rocks, but have not been dated other than pre-Jurassic.

EFFECTS OF WEATHERING AND ALTERATION

The rocks of the district have been altered through weathering during pre-Jurassic, pre-Miocene, and Recent erosion cycles. Oxidation, leaching, and jasperization of the vein material during one or more of the three erosion cycles may have dispersed some of the radioactive material in parts of deposits that are near the erosion surfaces.

The veins on the mesa between Dubois and Lake Fork are altered in places to a jaspery material, which has chiefly replaced the carbonate gangue, locally forming pseudomorphs of carbonate minerals of the veins (Burbank and Pierson, 1953, p. 3). The jasper retains some of the radioactivity of the original vein matter. In some places where the veins are exposed beneath the volcanic capping of the mesas, jasperization extends to depths of 50 to 100 feet beneath the volcanic rocks; veins exposed on the lower slopes of recently cut valleys are not jasperized where examined. The volcanic rocks rest on an early Tertiary erosion surface that is closely coincident with the late Paleozoic or early Mesozoic erosion surface on which the Jurassic sedimentary rocks were deposited (Burbank and Pierson, 1953, p. 2). Thus, the jasperization of the veins probably results from weathering and leaching during one or both of the earlier of the three cycles of erosion; it may be partly related to hot-spring activity.

Several deposits show some evidence of increase in amount of radioactivity, and presumably an increase in thorium content, with depth. The apparent variation may be due to oxidation and leaching, as well as to jasperization of veins near the pre-Miocene erosion surface. At locality 20 (pl. 55), much of the vein outcrop shows radioactivity of 0.07 to 0.10 mr per hr (background 0.03 mr per hr), whereas less altered rock from the vein, found on the dump of a 30- to 40-foot shaft, has a maximum radioactivity of 0.5 mr per hr. Locality 20 is just north of and below the exposure of the pre-Miocene erosion surface on which the volcanic rocks rest; hence this vein has been subjected to both pre-Miocene and the Recent cycles of erosion. At locality 10 (pl. 55), a carbonate vein 1,500 feet or more long shows radioactivity of about 0.07–0.10 mr per hr (background 0.3 mr per hr) along much of the oxidized surface outcrop, but unweathered carbonate material from this vein containing abundant siderite and pyrite, on the dump of a shaft slightly more than 25 feet deep, shows radioactivity of 0.15–0.20 mr per hr. The greatest radioactivity measured by Burbank in the Dubois area was found 500 feet underground in one of the adits at Dubois, in a relatively unoxidized carbonate vein containing sulfide minerals. Vein exposures in the adit near the portal were more limonitic and showed less radioactivity, suggesting that oxidation of the veins and dispersal of radioactive material are related to the present erosion surface.

The jasper that has replaced part of the carbonate vein material on mesas is locally radioactive, but the most radioactive material in the district is not jasperized, and it is possible that some of the radioactive material in the jasperized veins was removed at the time of jasperization. At locality 25 (pl. 55), greater radioactivity was noted in vein matter containing some carbonate mineral than in more thoroughly jasperized rock.

Although the high radioactivity of the deposits examined in the district is due to thorium, it is conceivable that some uranium was leached from the surficial parts of veins, especially those near the erosion surfaces on which the Mesozoic and Tertiary rocks were deposited. Although there are indications that some radioactive material may have been removed near the surface, and that less weathered rock at depth may contain a somewhat greater concentration of radioactive material, the fact that relatively unweathered radioactive rocks that have been analyzed contain no more than 0.005 percent uranium suggests that the variations in radioactivity probably result from variations in thorium content.

DISTRIBUTION OF RARE EARTHS

Rare-earth-bearing minerals have been found in the Powderhorn district in carbonate rocks, pyroxenite, and thorium-bearing veins. Rare-earth metals of the cerium group predominate and were detected by field observation of absorption bands, due to neodymium, in a hand spectroscope.

The most widespread rare-earth-bearing mineral in the carbonate rock is apatite, which constitutes several percent of the carbonate rock. The hand spectroscope indicates that the rare-earth content of the apatite is not uniform in different parts of the Iron Hill carbonate mass. In some areas several hundred feet wide the apatite contains rare earths, but in other areas the apatite apparently contains little or no rare earths, on the basis of tests with the hand spectroscope.

The apatite is pale green to white and occurs in linear streaks along shear planes in the carbonate rock. The apatite grains commonly stand out in relief on weathered surfaces. Apatite in apatite-martite veins from a few inches to 3 feet wide that cut the carbonate body also contains rare earths. Near the top of Iron Hill, 4 pits have been dug in a zone of carbonate rock at least 10 feet wide and 300 feet long that is richer in rare-earth-bearing apatite and more iron-stained than the common type of carbonate rock. Rare-earth-bearing apatite also occurs in some of the carbonate veins both in the pyroxenite and in pre-Cambrian rocks surrounding the Iron Hill complex.

Rare-earth metals have been found in small percentages in apatite from many localities, probably substituting for calcium in the apatite structure. Specimens of apatite having a range in rare-earth content from a trace to 3.18 percent have been reported by Starynkevich-Borneman (1924, p. 41). The rare-earth content ranges from a trace to about 5 percent in apatite samples from various types of occurrences tabulated by Fersman (1924, p. 43–44).

Spectrographic, chemical, and radioactivity analyses of carbonate rock containing rare-earth-bearing apatite are summarized in table 3. In addition to the apatite, five samples of perovskite concentrates from the pyroxenite all have lanthanum, cerium, and neodymium in amounts of tenths of a percent, and yttrium in the hundredths, on the basis of spectrographic analyses by A. T. Myers, P. J. Dunton, and J. D. Fletcher of the U. S. Geological Survey. Samarium and praseodymium were determined in three of these perovskite samples in amounts of hundredths of a percent. All the samples from the vicinity of Iron Hill, whether of apatite-bearing carbonate rock, perovskite concentrates from the pyroxenite, or carbonate veins, show a high ratio of cerium group to yttrium group of rare-earth metals.

TABLE 3.—*Analyses, in percent, of carbonate rock containing rare-earth-bearing apatite, Iron Hill, Powderhorn district*

Location of sample	Equivalent uranium [1]	Combined rare-earth and thorium oxide [2]	[3] La	[3] Ce	[3] Nd	[3] Y	[2] P_2O_5
1. West side, carbonate mass, Cebolla Creek	0.001	(4)	0.0×	0.0×	0.0×	0.00×	----------
2. South side, carbonate mass, Beaver Creek	.001	----------	.×	.×	.×	.0×	----------
3. Northeast side, carbonate mass Deldorado Creek	.014	----------	.×	.×	.×	.0×	----------
4. Area at least 100 by 300 feet, south side, carbonate mass, Beaver Creek	.001	.07	----------	----------	----------	----------	3.6
5. Apatite-rich zone at least 10 by 300 feet, on ridge near top of Iron Hill	.002	.07	.×	.×	.×	.00×	7.4
6. Apatite-martite vein 2 to 3 feet thick, adit on west slope of Iron Hill	.005	.10	.×	.×	.×	.00×	13.8
7. Apatite-martite vein 150 feet east of sample 6	.002	.09	----------	----------	----------	----------	13.4
8. Lens 4 by 18 inches, largely coarse apatite, on ridge west of top of Iron Hill	.001	.09	----------	----------	----------	----------	35.1

[1] Determined by radiometric analysis by S. P. Furman, U. S. Geological Survey.
[2] Determined by chemical analysis by J. W. Meadows, W. Mountjoy, and J. P. Schuch, U. S. Geological Survey.
[3] Determined by spectrographic analysis by P. R. Barnett, R. G. Havens, U. S. Geological Survey.
[4] Dashes indicate that element was not looked for.

The results of 6 spectrographic analyses indicate that mineralized shear zones at localities 18, 17, 16, and 15 (pl. 55) several miles northwest of Iron Hill contain more yttrium than cerium, lanthanum, and other metals of the cerium group of rare earth metals. Of the 6 samples, 2 have 0.× percent yttrium, 1 has 0.0× percent, and 3 have 0.00× percent. These values may be compared with the lanthanum content which is 0.0× percent in 3 of the samples, 0.00× percent in one, and only a trace in the other two. Yttrium also constitutes 0.× percent of one sample collected by Burbank (Burbank and Pierson, 1953, p. 8) from the vein at locality 21 (pl. 55).

Although these analyses do not indicate that concentrations of rare-earth minerals are of commercial grade, they are of geologic interest for they show, together with the large area in which the rare-earth-bearing apatite and perovskite occur, that the Iron Hill composite stock as a whole contains a relatively large quantity of rare-earth metals. The presence of rare-earth metals is reflected also by the presence of bastnaesite, cerite(?), and synchisite in carbonate veins in the pyroxenite east of Iron Hill.

LITTLE JOHNNIE CLAIMS

The Little Johnnie group of claims (loc. 18, pl. 55) is in secs. 14, 15, and 22, T. 47 N., R. 2 W., near the northeastern margin of the Milk-ranch Gulch drainage basin; the west end of the area shown in plate 56 is about a quarter of a mile east of the Lot mine. Radioactivity was detected on the Little Johnnie claims in 1949 by Neil Foreman and J. A. McGregor, of Powderhorn. Analyses of samples by the U. S. Geological Survey in 1950 indicate that the radioactivity is due chiefly to thorium and its daughter products.

GENERAL GEOLOGY

Most of the Little Johnnie area is underlain by pre-Cambrian meta-sedimentary and meta-igneous rocks. The foliation of these rocks strikes N. 50°–65° E. and dips steeply north or south, commonly within 15 degres of vertical. The rocks are cut by carbonate-rich veins, small bodies of alkalic intrusive rock, and a large gabbro dike of alkalic affinities that are believed to be related to the Iron Hill composite stock, which is about 4 miles to the south. The Alboroto rhyolite of the Potosi volcanic series (Tertiary) and the sandstone of the Morrison formation are exposed in the southwestern part of the Little Johnnie area. These rocks are in fault contact with one another and with the pre-Cambrian rocks.

The thorium deposit is a mineralized fault that strikes at a small angle to the foliation of the enclosing metamorphic rocks, and is offset at several places by faults younger than the Alboroto rhyolite.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks on the Little Johnnie claims include quartz-biotite schist, quartzite, and amphibolite belonging to the Black Canyon schist of Hunter, and metarhyolite and granite of his Powderhorn granite group (Hunter, 1925).

QUARTZ-BIOTITE SCHIST AND QUARTZITE

The oldest and most abundant rock exposed in the area is a quartzitic metasedimentary rock that includes several closely related facies, The most common facies is a medium-gray, fine- and even-grained, biotitic quartzite which contains an estimated 5 percent biotite. With increasing biotite this rock grades into a quartz-biotite schist and, with decreasing biotite, into an almost pure, massive quartzite. Some specimens appear to be feldspathic, and fine-grained feldspar is probably a constituent of most of the quartz-biotite rocks. A few specimens contain a small quantity of amphibole, and these are difficult to distinguish from some specimens of feldspathic varieties of amphibolite.

Outcrops are scarce or lacking in many parts of of the area, and some metarhyolite, syenite, and various types of amphibolite occur in the area mapped as underlain by this quartz-biotite rock unit shown on the map (pl. 56).

METARHYOLITE PORPHYRY

Metarhyolite porphyry is one of the lithologic types included by Hunter (1925, p. 41–44) in the granite porphyry of the Powderhorn granite group. Within the map area (pl. 56) it forms dikes that generally parallel the foliation and layering of the quartzitic metasediments. Pinch-and-swell features are common; in a few places the dikes bifurcate. At the eastern end of the area a metarhyolite body of unknown size and shape cuts sharply across the foliation of the quartzose metamorphic rocks. A similar discordant mass occurs on the southern edge of the area about 800 feet to the west.

The metarhyolite porphyry is readily distinguished from the quartz-biotite schist and quartzite by the presence of oval masses of quartz from 1 millimeter to more than 1 centimeter in diameter which commonly have a characteristic grayish-blue cast. Under the microscope many of these masses of quartz appear to be distorted phenocrysts, and the degree of distortion appears to vary with the size of the original crystals. Some of the smaller crystals have the outline of perfect bipyramids. Medium-sized crystals commonly have broken and displaced crystal faces, and some of the larger masses exhibit strong granulation.

The porphyritic texture of the rock varies with the size and abundance of the quartz masses. Individual phenocrysts are as small as 1 millimeter but commonly range from 3 to 6 millimeters; at the Lot mine they attain a maximum length of nearly 2 centimeters. The quartz phenocrysts constitute from 10 to 15 percent of the typical metarhyolite porphyry.

The quartz crystals are set in a fine granular aggregate of quartz, alkali feldspar, and biotite. A thin section of a specimen collected by J. W. Adams from the sheared and silicified wall of a vein on the Jeanie No. 6 claim (loc. 16, pl. 55) shows orthoclase; albite; quartz, in part secondary; biotite, partly altered to chlorite; and sericite as the principal constituents. Apatite, zircon, pyrite, iron oxides, and allophane are present in minor amounts.

AMPHIBOLITE

Amphibolite forms dikes and irregular bodies that intrude both the quartz-biotite rocks and the metarhyolite porphyry. Most of the dikes parallel the foliation of the country rocks, but several discordant dikes strike nearly east.

The amphibolite is typically a dark-green hornblende-rich rock containing as much as 85 percent hornblende in crystals from 1 to 5 millimeters long. Less common, lighter colored types contain plagioclase feldspar in varying amounts. A dark-gray amphibolite from the west end of the area contains an estimated 40 percent hornblende, 25 percent oligoclase, 20 percent quartz, and 10 percent biotite, with minor amounts of sericite, clinozoisite, apatite, and magnetite. Both the feldspar and the mafic minerals are corroded and embayed by quartz, which may have been introduced into the rock. Much of the amphibolite at the west end of the area is light to medium gray and contains small crystals of amphibole in a quartz-feldspar matrix. These rocks are transitional in appearance to some of the amphibole-bearing quartz-biotite schist. Schistosity is poorly developed in the amphibolites.

The darker amphibolites probably represent metamorphosed intrusive rocks of basic to intermediate composition. In a few places the light- to medium-gray amphibolites appear to be cut by metarhyolite. These older amphibolites are of unknown origin but may be metasedimentary.

GRANITE

In the southwestern part of the area (pl. 56) the rocks designated as undivided pre-Cambrian include the metarhyolite porphyry, the quartz-biotite metasedimentary rocks, and a few patches of pink, coarse-grained, equigranular and porphyritic granite. The granitic rocks are similar to those described and mapped by Hunter (1925, p. 44–46) as the porphyritic biotite granite of the Powderhorn group.

QUARTZ VEINS

Quartz veins ranging from a few inches to slightly more than a foot in width occur in the pre-Cambrian rocks in and adjacent to the map area (pl. 56). The veins cut the amphibolite, the quartz-biotite rocks, and the metarhyolite. The quartz veins are probably of pre-Cambrian age and are chiefly of two kinds: quartz-chlorite and quartz-tourmaline.

ROCKS RELATED TO THE IRON HILL COMPOSITE STOCK

The rocks described below occur as dikes and veins that cut the pre-Cambrian metamorphic rocks. The composition of these rocks is not uniform, but all show some chemical or mineralogic affinity—titanium minerals, sodic amphibole, sodic pyroxene, abundant alkali feldspar, and abundant carbonate—with one or more of the rock types of the Iron Hill composite stock, and they are probably the same age as the Iron Hill rocks. The age relationships of the different rock types in the Little Johnnie area (pl. 56) could not be determined because of poor exposures.

GABBRO

A gabbro dike cuts the quartzose metasedimentary rocks, the meta-rhyolite porphyry, and the amphibolite near the east end of the area. The dike is about 75 feet thick and strikes about N. 60° W. At one place the gabbro appears to cut a linear concentration of fragments of breccia that probably marks the location of a breccia vein.

The most common facies of the gabbro is a medium-gray equigranular rock that contains from 30 to 40 percent labradorite as lath-shaped crystals about 2 millimeters long. The feldspar laths are randomly oriented and intergrown with pyroxene, giving the rock a coarse ophitic texture. Magnetite is abundant and makes up an estimated 8 percent or more of the rock. This medium-gray facies grades into a dark-gray rock that probably contains only from 10 to 15 percent plagioclase, but which is otherwise similar to the more feldspathic varieties.

The pyroxene in all specimens examined with the microscope has a 2V of 20–30 degrees and probably is pigeonite. Primary accessory minerals include abundant prisms of apatite, magnetite, and a few small scattered phenocrysts of orthoclase. Several grains of greenish-brown hornblende, probably uralite, are present. Both the hornblende and the pigeonite are replaced locally by a fibrous, dark-blue, pleochroic soda-amphibole. Other alteration products include sericite, epidote, allophane, iron oxides, and carbonate. Except for the lack of quartz, this rock is similar to the quartz gabbro that Larsen (1942, p. 28–29) has described from the Iron Hill area.

In contrast to the equigranular rocks described above, a few specimens from the dike area are porphyritic. These rocks contain an estimated 10 percent labradorite as phenocrysts approximately 1 millimeter long, which are set in dark-gray aphanitic groundmass.

The distribution of the textural and compositional varieties within the dike is unknown, but the equigranular types are believed to be differentiates of approximately the same age. The association of the equigranular gabbro and the fine-grained porphyritic facies, and the similar composition of the plagioclase in these rocks, indicate a genetic relationship between them. The texture and relative scarcity of the porphyritic rocks suggest that they occur as small dikes within the main gabbro body.

Thin films of brookite and anatase coat fracture surfaces in parts of the gabbro dike where it crosses the ridge. Associated with these titanium minerals on the fracture surfaces are minor amounts of aegirine, quartz, albite, and potash feldspar (?). Both the quartz and the feldspar appear reddish brown when examined with the hand lens because of small amounts of included iron oxides (?). The aegirine ranges from medium green to very light green; under the microscope fragments as much as 0.04 millimeter thick are almost colorless with very little pleochroism. The quartz is biaxial and has a 2V estimated at from 15 to 30 degrees. The occurrence of anatase is similar to that described by Larsen and Hunter (1914, p. 470) from a locality about half a mile northeast of the Lot mine.

Samples of the anatase and brookite contain 0.06 percent niobium and 2 percent niobium respectively, on the basis of spectrographic analyses by Paul R. Barnett of the U. S. Geological Survey. The striking difference in niobium content of these polymorphs from the same geologic environment may be due in part to a difference in crystal structure. Anatase is tetragonal, whereas brookite and columbite are orthorhombic dipyramidal. The X-ray powder pattern of brookite matches that of columbite much more closely than does the anatase pattern. These facts suggest that niobium may substitute for titanium in the brookite structure more readily than it does in the anatase structure.

SYENITE

Pink to reddish-orange, fine-grained, porphyritic syenite dikes intrude the pre-Cambrian metamorphic rocks at several places in the area, and probably correspond to some of the syenite described by Hunter (1925, p. 76). No outcrops of syenite were found, but the linear pattern of syenite fragments in the float and a well-developed primary foliation in many of the fragments indicate that the syenite occurs as dikes. Potash feldspar, as phenocrysts from 1 to 3 millimeters long, is the only identifiable mineral in most hand specimens. In some rocks these phenocrysts are closely packed; in others they are sparsely disseminated. Under the microscope, almost all material from the fine-grained groundmass is seen to be cloudy alkali feldspar. Specimens from the syenite dikes near the west end of the area are altered, porous, and contain an unidentified mafic mineral.

CARBONATE VEINS

At three localities in the area there are linear concentrations of fine-grained carbonate rock in the float. These probably represent veins similar to those in the vicinity of Iron Hill. The vein material is predominantly fine-grained carbonate in grains less than 0.5 millimeter in diameter, mixed with and stained by iron oxides which color the specimens yellowish-brown. In thin section, sparse euhedral crystals of potash feldspar are seen to be surrounded and embayed by the carbonate, which is irregularly mottled in various shades of yellow and brown. Apatite is abundant, both as anhedral masses which in part replace the feldspar, and as euhedral crystals surrounded and in places embayed by the carbonate matrix. Small nests of quartz enclosing needles of apatite are sparingly present and appear to be older than the carbonate. A single immersion mount revealed the presence of a green pleochroic pyroxene and a little chlorite in addition to the minerals noted above.

BRECCIA VEINS

Several breccia veins occur in the east-central part of the area (pl. 56). The veins contain angular to subangular fragments, as much as 3 inches in diameter, of pre-Cambrian rocks in a matrix composed chiefly of carbonate. The most abundant fragments are pink coarse-grained granite similar to the porphyritic biotite granite of Hunter (1925, p. 44–46), but amphibolite and quartz-biotite (?) rock have both been observed. The fragments commonly constitute from 40 to 50 percent, rarely as much as 80 percent, of the rock.

The fine-grained, reddish- to chocolate-brown matrix contains a large percentage of carbonate, effervesces violently in acid, and is altered to a soft, brown, porous coating on weathered surfaces. The groundmass contains pink feldspar in euhedral tabular crystals and irregular fragments, many of which were probably derived from the granite inclusions. Fine-grained pyrite and galena (?) are sparsely disseminated in the groundmass of a few specimens.

In thin section the breccia veins are similar to the fine-grained carbonate veins except for the presence of the included fragments. Most of the fragments are quartz, potash feldspar, or aggregates of these two minerals. The minerals and rock fragments commonly are embayed and partially replaced by the carbonate matrix. Feldspar is the most strongly attacked, but the quartz grains in an inclusion of quartzite are also rimmed and partially embayed by the carbonate.

The abundant coarse-grained granite inclusions are unlike any of the rocks exposed near the breccia veins and have probably been transported hundreds of feet by the vein-forming fluids.

SODIC AMPHIBOLE ROCK

A small vein or dike about 2 inches thick, containing abundant blue amphibole, cuts the quartz-biotite schist in the north-central part of the area. Specimens from unaltered rock are bluish gray; altered-rock specimens are bluish gray, chalky gray, and light brown. Crushed fragments examined in index liquids show a fibrous pleochroic amphibole intergrown with a fine granular substance, either isotropic or very faintly birefringent. Other minerals include potash feldspar, apatite, chlorite, carbonate, soda-pyroxene, clay minerals, and iron oxides.

A small filled vug about 1 inch long in the sodic amphibole rock contains aegirite, dahllite, brookite, iron oxides, thompsonite(?) as fine botryoidal films, and probably other zeolites. The dahllite occurs as tiny hexagonal crystals about 0.3 millimeters across, with the following optical properties: biaxial negative, 2V about 15 degrees, $nY = 1.632$, $nZ - nX = 0.008$.

SEDIMENTARY AND VOLCANIC ROCKS

Sandstone and a little siltstone of the Morrison formation of Jurassic age crop out in the southwestern part of the Little Johnnie area. The sandstone is medium to coarse grained, well cemented, and commonly reddish brown and dark-reddish purple; some specimens are light gray. Banded and mottled rocks are common.

Light-gray to buff Alboroto rhyolite crops out along the southwestern margin of the area.

STRUCTURE

The drainage basin of Milkranch Gulch is a roughly circular depression about 1½ miles in diameter floored with Alboroto rhyolite and surrounded by hills composed of pre-Cambrian rocks. The east end of the map area (pl. 56) is on the divide which forms the northeast side of the basin; the southwestern part of the map area extends into the basin and includes the northeastern edge of the central area of volcanic rocks. Here, sandstone of the Morrison formation of Jurassic age is in fault contact with both the volcanic rocks and the pre-Cambrian rocks. Beyond the map area (pl. 56) the periphery of the central area of volcanic rocks was examined at four places, and discontinuous outcrops of Jurassic sandstone were found at three places along the north contact of the volcanic rocks and at one place on the south contact.

The nearest exposures of the sandstone of Jurassic age beyond the Milkranch Gulch basin are on Huntsman Mesa (see pl. 55), about 1 mile east of the Little Johnnie claims at an altitude of nearly 10,000 feet. Here the sandstone is almost horizontal and extends along the top of the mesa for about 4 miles. This position probably represents the common attitude of the Jurassic rocks in the district, and the sandstone in the basin is thought to mark the edge of a roughly circular fault block 1½ miles in diameter, in which beds of the Morrison formation and the overlying volcanic rocks have dropped at least 1,000 feet.

Where mapped, the margin of the subsided block is marked by a complex fault zone. In a few places the presence of individual faults is indicated by silicified breccia, altered and pyritized rock, and zones of sheared rock and gouge exposed in some of the bulldozed cuts. In general, the faults are poorly exposed; therefore they are only approximately located, and probably the true pattern is even more complex than that shown.

The overall structure in the fault zone is a jumble of tilted blocks bounded by faults which are irregular in strike, dip, and displacement, and the resultant pattern is difficult to interpret, except in a general way. Probably the major breaks are normal faults that dip toward the center of the basin. The net displacement of the zone is down on the south (basinward) side, but along many of the faults the northern block was downthrown. Many of the subsidiary faults probably dip to the north and some are thought to be reverse faults.

The full width of the fault zone is not shown on the map (pl. 56). South of the southernmost outcrops of pre-Cambrian rock, the Alboroto rhyolite contains several well-defined zones of altered and iron-stained rock. These zones are roughly parallel to the faults shown on the map and are believed to be related faults. The few faults that are shown in the central and eastern parts of plate 56 are also probably related to the fault zone between the volcanic rocks and the pre-Cambrian rocks.

THORIUM DEPOSIT

The Little Johnnie vein is a steeply-dipping mineralized fault at least 3,500 feet long. Irregular veinlets and seams containing quartz, hematite, goethite, alkali feldspar, thorite or thorogummite, and other minerals have been introduced along the fault in a mineralized zone ranging from less than 6 inches to 5 feet wide.

The Little Johnnie vein strikes N. 65° E., dips commonly within 10 degrees of vertical, and is exposed through a vertical range of 700 feet in a distance of 3,500 feet. At the bulldozed cut near the west end of the area the vein dips 38° N., but this departure from the generally steep dip is probably due to displacement along faults younger than the Alboroto rhyolite. The vein is nearly parallel with the foliation of the enclosing pre-Cambrian rocks, but in general it strikes a little more easterly than the strike of the foliation, and in a few places it cuts across the foliation of the country rock at an angle of as much as 15 degrees.

The vein is poorly exposed and in most places it was located by scintillation counter. Points where radioactivity is above normal are shown on the map (pl. 56). Readings are given in milliroentgens per hour; background radiation for the area was approximately 0.025 milliroentgens per hour on the counter used. The best exposure of the vein is in a 35-foot drift on the vein in the central part of the area;

here a small dike of altered and bleached amphibolite on the north wall of the drift is cut off by the vein, but the insufficient evidence does not indicate the direction or amount of movement. In places the vein is brecciated, indicating movement during or after mineralization.

Where exposed in trenches, the Little Johnnie vein ranges from less than 6 inches to about 5 feet in width; the average width along a length of 3,500 feet probably does not exceed 2 feet. At the east end of the map area (pl. 56) the vein either pinches out or contains no thorium. At the top of the ridge just northeast of the map area, the projection of the vein passes through an exposure of bedrock in which the vein does not crop out and the radioactivity does not appear to be abnormal. East of the ridge the bedrock is covered, but several abnormal radioactivity readings along the presumed projection of the vein suggest that the vein probably persists. About 1,100 feet eastward along strike from the east end of the vein as shown on the map (pl. 56), a narrow vein is exposed in a bulldozed cut (no. 19, pl. 55). This is probably a continuation of the Little Johnnie vein, although it possibly is a separate but related vein. Another vein about 6 inches wide and of unknown length strikes about N. 35° E. at the east end of the map area (pl. 55).

Exposures of the vein are commonly of a reddish- to yellowish-brown color that contrasts sharply with the dull hue of the pre-Cambrian wall rocks. The vein material is heterogeneous in composition and grain size. Three thin sections, provided by J. W. Adams of the U. S. Geological Survey, show potash feldspar, albite, and quartz as the dominant constituents. Typically these are intimately mixed in a fine-grained aggregate clouded with fine hematite, goethite, and some allophane; the percentages of quartz and the alkali feldspar vary, and parts of two thin sections contain little quartz. Euhedral crystals of hematite, as much as 0.5 millimeters across, are common. Many are partly altered to goethite. Associated with the hematite and goethite are small subhedral to anhedral masses of thorite or thorogummite. Apatite, as a felted mat of needles in the feldspar, is abundant in 1 of the 3 thin sections examined, but is rare in the other 2. Coarse-grained barite and carbonate are abundant in a few places in the vein, but were not identified in thin section. Some of the barite fluoresces pink.

Accessory minerals in the vein include clinozoisite(?), tourmaline, fluorite, and rutile. Small euhedral crystals of a uniaxial positive mineral are tentatively identified as xenotime and probably account for much of the yttrium content of the veins. An unidentified brownish-yellow mineral having high indices, moderate birefringence, probably biaxial negative with moderate 2V, is present in small anhedral grains.

The ThO_2 content of chip samples ranges from less than 0.03 percent to nearly 5 percent. Veinlets and thin stringers of thorium-bearing material are irregularly distributed in the mineralized fault zone. In the drift in the central part of the area of plate 56, several small thorium-bearing stringers branch from the main vein into the south wall. A similar subsidiary veinlet may account for the anomalous radioactivity about 18 feet south of the main vein 365 feet N. 70° E. of the portal of the drift.

Bedrock is not exposed where the vein intersects the gabbro, and the relative ages of vein and gabbro are unknown. Inasmuch as no anomalous radioactivity was detected within the gabbro along the line of strike of the vein, the thorium mineralization may have occurred before intrusion of the gabbro, but this is uncertain because of poor exposures.

The vein is offset at many places by faults that formed during the subsidence of the fault block that constitutes the Milkranch Gulch basin. Most of these faults are near the west end of the Little Johnnie map area.

OUTLOOK FOR FUTURE EXPLORATION

Except for the Little Johnnie claims, the district has been studied only in a brief reconnaissance. The conclusion seems warranted, however, that the district is a promising one in which to search for veins containing thorite and thorogummite. Many of the 33 radioactive deposits listed in table 4 appear to contain about 0.1 percent or less ThO_2, but some higher grade samples contain from 0.5 to 4.9 percent ThO_2. The finding of the thorium deposits in a large area through reconnaissance examination indicates that other veins, possibly containing on the order of 0.5 percent ThO_2, might be found by more detailed examination. Thorium deposits of this type have not been mined because of the limited market for thorium.

Because the known thorium deposits in the district are related spatially to the alkalic igneous rocks, the areas in or near the bodies of alkalic igneous rocks are considered the most favorable in which to prospect for thorium. Concentrations of other minor elements, such as the rare-earth metals and niobium, are commonly found in the same geologic environment. Although commercial deposits of rare earths are not known in the district, the discovery of rare-earth minerals suggests that such minerals should also be looked for in future exploration.

Although significant amounts of uranium were not found in the analyses of samples given in this report, uranium has recently been found in the Cochetopa district 20 miles east of Powderhorn, in pre-Cambrian and Mesozoic rocks similar to those in the Powderhorn district, indicating that uranium should also be sought in future exploration.

TABLE 4.—*Deposits showing abnormal radioactivity, Powderhorn district, Colorado*

Locality no.: an asterisk (*) denotes that the data were derived in part from Burbank and Pierson (1952, p. 8-9). Radioactivity: field readings are given in milliroentgens per hour (mr per hr) on a scintillation counter; background for the Powderhorn district is generally 0.03–0.04 mr per hr. Sample content: thorium oxide (ThO_2) content is approximated by multiplying equivalent uranium (eU) by 5.6, the factor determined by the U. S. Geological Survey; it is assumed that all the radioactivity is due to thorium, as the uranium content of any of 33 samples is 0.005 percent or less.

Locality no. (pl. 55)	Type of deposit and exposure	Known dimensions (ft)		Attitude		Minerals	Radioactivity field readings (mr per hr)		Sample content (percent)		Wall rock
		Width	Length	Strike	Dip		Common	Maximum	eU	ThO_2	
1	Carbonate vein in prospect pit.	3-4		N. 55° W	80° NE	Carbonates, rare-earth-bearing apatite.	0.010	0.30			Magnetite-rich pyroxenite.
2	Carbonate vein poorly exposed in prospect pit.	1				Carbonates, hematite					Soda syenite(?)
3	Carbonate vein in shaft 25 ft deep.	3-4		E	75°-80° N	Carbonates, quartz, purple fluorite, hematite, goethite.		.25			Pyroxenite.
4	Carbonate vein in prospect pit for vermiculite.	1.3		do	Vertical	Carbonates					Vermiculite-rich pyroxenite.
5	Numerous carbonate veins in prospect pit for vermiculite.	0.5–3.5		do	Steep	do	.05–.15		0.043 .026 .011 .008 .006 .017 .067 .006	0.24 .15 .04 .04 .02 .08 .36 .03	Do.
6	Thin veins and staining along fault in outcrops near edge of Iron Hill composite stock.	Thin veinlets		N. W	Steep	Hematite, carbonates, quartz, goethite.	.05	.15			Pyroxenite.
7	Carbonate vein in two pits.	3-5	Exceeds 350	E	75°-80° N 75°-80° N	Siderite, goethite, quartz, apatite, pyrite, magnetite.	.2	.7	.025 .031 .014	.14 .17 .08	Do.
8	Carbonate vein in prospect pit.	5		N. 78° E	Vertical	Carbonates, barite, hematite, pyrite, phlogopite, chalcedony, quartz, synchisite.	.2				Do.
9	Several carbonate veins in bulldozer cuts for titanium-bearing minerals.	1-1.5		N. 70° W	Steep	Carbonates	.10	.40			Do.

10	Carbonate vein exposed in flooded shaft 25 ft or more deep.	10–15	Exceeds 1,500	N. 70° W	75° N	Siderite, barite, pyrite, goethite, apatite, zeolite(?).	.07–.20	.25	.011	.06	Do.
11	Carbonate vein in trench.	1(?)		Not exposed in place.		Carbonates		.3			Do.
12	Large satellitic body of Iron Hill carbonate rock, exposed in prospect pit.					Carbonates, magnetite, rare-earth-bearing apatite, colorless mica.	.09	.3			Do.
13	Prospect pit in Iron Hill carbonate body.			NE. (foliation).	50°–60° SE. (foliation).	Carbonates, rare-earth-bearing apatite, martite.	.05–.10	.14			Do.
14	Prospect pit in silicified zone.	8–10		N. 52° E	Vertical	Chiefly quartz	.09	.10	.002	.01	Granite gneiss.
15	Mineralized shear zones in 2 pits (Red Rock claims).	3	Only a few ft exposed (faulted).	E.(?)		Quartz, hematite, pyrite, goethite, carbonates.					Chlorite amphibolite, quartzite, granite porphyry.
16	Mineralized shear zones in 7 pits, (Jeanie No. 6 Claim)	1–2.5	Pits over 600-ft in length.	N. 60° E	Steep	Quartz, hematite, minor actinolite.			.007 .014 .018	.03 .07 .10	Quartzite, schist.
17	Mineralized shear zones in 5 pits. (Jeanie no. 2 claim).	1–5	300 or more (outcrops and radioactive float).	N. 55° E	75° NW 70° SE	Quartz, hematite, barite, carbonates.			.026 .009 .029 .007	.15 .05 .16 .03	Granitic gneisses and schist.
18	Mineralized shear zone, Little Johnnie claims (see fig. 7).	0.5–5	At least 3,000 (discontinuous).	N. 65°–70° E	Nearly vertical.	Quartz, hematite, goethite, thorite, barite, carbonates, alkali feldspar, apatite.	.1–3.0		.13 .045 .12 .12 .11 .88 .019 .034 .20 .031 .15 .009 .014	.73 .25 .67 .67 .61 4.9 .10 .19 1.12 .17 .84 .05 .08	Quartz-biotite schist, quartzite, metarhyolite porphyry.
19	Thin veins in bulldozer cut 70 ft long.	Several veins 0.1–0.5 ft in zone 4 ft wide.		N. 70° E	Steep	Quartz, hematite, goethite.		0.2	0.009	0.05	Schist.
*20	Vein exposed in shaft 30–40 ft deep and pit.	6–18 (average 10).	Exceeds 240	N. 52° W	Vertical	Quartz, jasper, hematite, goethite.	.09	.5	.004	.02	Chlorite amphibolite.
*21	Vein in prospect pit	3–4	Not exposed beyond pit.	N	Steep	Carbonate, goethite, quartz, hematite.	.09	.2			Do.
*22	do	1–2		N	Steep	Quartz, goethite		<.02			Do.
*23	do			N. 35° W		Quartz, jasper, goethite.	.05	0.25			Aplite in dominantly greenstone area.

TABLE 4.—*Deposits showing abnormal radioactivity, Powderhorn district, Colorado*—Continued

Locality No. (pl. 55)	Type of deposit and exposure	Known dimensions (ft)		Attitude		Minerals	Radioactivity field readings (mr per hr)		Sample content (percent)		Wall rock
		Width	Length	Strike	Dip		Common	Maximum	eU	ThO_2	
*24	Vein in 3 pits	2–8 (average 6)	Exceeds 365	N. 13° W	80° W	Quartz, jasper, hematite, goethite, thorite(?), minor chlorite.	.05–.2	.3			Chlorite schist and amphibolite.
25	Vein in prospect pit	2		N. 55° W	85° SW	Jasper, hematite, goethite, thorite(?), carbonate.		.2			Do.
26	do	1–2				Carbonate, quartz, goethite.		.2			Hornblende gneiss.
27	Carbonate vein in 3 adits and prospect pit.	Dumps only examined.				Carbonates		.15			Do.
*28	do	do		E	75° S	Quartz, carbonate, pyrite, sphalerite, galena.			.04	.22	Dubois greenstone.
*29	do			E	75° S	Quartz, carbonate, pyrite, sphalerite, galena.		2.0	.23 .086	1.3 .48	Do.
30	Vein in short drift	2		N. 75° W	Steep	Quartz, carbonate, hematite.	.05–0.2	.4			Do.
31	Quartz vein in pit 15 ft deep.	Small pod	Not exposed beyond pit.	Probably N 45° E.		Quartz, jasper, hematite, goethite. Quartz crystals common.	.2	.6	.010	.056	Gneissic granite.
*32	Mineralized shear zone in adit 25 ft long.	Zone 4–10 ft thick containing veins 0.5–1.5 ft thick and thinner veinlets.	At least 1,000	N. 88° W	88° N	Hematite, quartz, weathered carbonate, sphalerite, galena, thorite(?).		.2	.015 .016 .023 .041	.08 .08 .13 .23	Mica schist and quartzite.
*33	Vein in adit 25 ft long	0.3–0.5		N. 75° W	88° N	Quartz, carbonate, sphalerite, galena.		.2	.050 .034	.28 .18	Schist and pegmatite.

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