Uranium Deposits in the Eureka Gulch Area Central City District Gilpin County Colorado

GEOLOGICAL SURVEY BULLETIN 1032-A

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By P. K. SIMS, F. W. OSTERWALD, *and* E. W. TOOKER

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By P. K. SIMS, F. W. OSTERWALD, and E. W. TOOKER

ABSTRACT

The Eureka Gulch area of the Central City district, Gilpin County, Colo., was mined for ores of gold, silver, copper, lead, and zinc, but there has been little mining activity in the area since World War I. Between 1951 and 1953 nine radioactive mine dumps were discovered in the area by the U. S. Geological Survey and by prospectors. The importance of the discoveries has not been determined as most of the mines are inaccessible, but the distribution, quantity, and grade of the radioactive materials found on the mine dumps indicate that the area is worthy of additional exploration as a possible source of uranium ore.

The uranium and other metals are in or adjacent to steeply dipping mesothermal veins of Laramide age that cut pre-Cambrian metasedimentary rocks, granite gneiss, pegmatite, and Laramide intrusive rocks. Pitchblende is present in at least four veins, and metatorbernite, which is associated at places with kasolite, is found along two veins for a linear distance of about 700 feet. The pitchblende- and metatorbernite-bearing ores appear to be mutually exclusive and seem to occur in different veins. Colloform grains of pitchblende were deposited in the veins essentially contemporaneously with pyrite. The pitchblende is earlier in the sequence of deposition than galena and sphalerite. The metatorbernite replaces altered biotite-quartz-plagioclase gneiss and altered amphibolite, and to a lesser extent forms coatings on fractures in these rocks adjacent to the veins; the kasolite fills vugs in highly altered vein material and in altered wall rocks. Much of the pitchblende found on the dumps has been partly leached and is out of equilibrium. Selected samples of metatorbernite-bearing rock from one mine dump contain as much as 6.11 percent uranium.

The pitchblende is a primary vein mineral deposited from uranium-bearing hydrothermal solutions. The metatorbernite probably formed by oxidation, solution, and transportation of uranium from primary pitchblende, but it may be a primary mineral deposited directly from fluids of different composition from those that deposited pitchblende.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

Prior to World War I, the Central City district, Gilpin County, Colo., was an important domestic source of pitchblende, the black oxide of uranium, but since that time no uranium has been produced in the district.[1] As early as 1871, pitchblende was noticed on the Wood mine dump in the Quartz Hill area by Pearce (1898); since 1872, when uranium production started, the Quartz Hill area has yielded 324 tons of high-grade ore containing 110,575 pounds of U_3O_8.[2]

During and after World War II, because of the strategic importance of uranium, interest was revived in the Central City and adjacent mining districts, and as a result several new discoveries have been made by prospectors and Government agencies. Many of the finds are outside of the previously known productive area on Quartz Hill, and some of them appear to be of possible commercial importance.

Uranium was first discoverd during 1951 in the Eureka Gulch area, which is in the northern part of the Central City district (fig. 1). A prospector found the dump of the adit on the Rara Avis millsite to be radioactive and submitted a sample of the ore to the Atomic Energy Commission. Subsequently, several additional uranium occurrences have been found in this area by the U. S. Geological Survey. Although pitchblende is the uranium mineral in most of the deposits, several veins on the north slope of Nigger Hill (pl. 1B) contain green metatorbernite; this mineral was formerly believed to be sparse in the Central City district. Aside from the McKay shaft, on the R. H. D. claim, the discoveries of radioactive minerals have been made on the dumps of abandoned mines. Subsequent to the discovery of uranium minerals on the dumps, private mining interests have started rehabilitation of the Carroll, Two Sisters, R. H. D., and Claire Marie mines, to determine the economic potential of the uranium occurrences; in September 1954, only the Carroll mine was accessible for examination. The Eureka Gulch area formerly yielded gold, silver, lead, zinc, and copper, but mining has been sporadic since World War I.

This report, prepared because of the potential economic importance of the new discoveries in the Eureka Gulch area, presents a preliminary account of the geology and economic aspects of the uranium deposits in this part of the district. A more comprehensive report will be included in a later publication.

PREVIOUS GEOLOGIC STUDIES

Several reports describing the uranium deposits in the Central City district were published before World War I. The most important are Pearce (1898), Rickard (1913), Moore and Kithil (1913), Alsdorf (1916), Bastin (1916), and Bastin and Hill (1917). The report by Bastin and Hill gives a comprehensive summary of the information

[1] Since the preparation of this manuscript (1954), a few tons of uranium ore has been shipped from the district.

[2] Armstrong, F. C., Unpublished report.

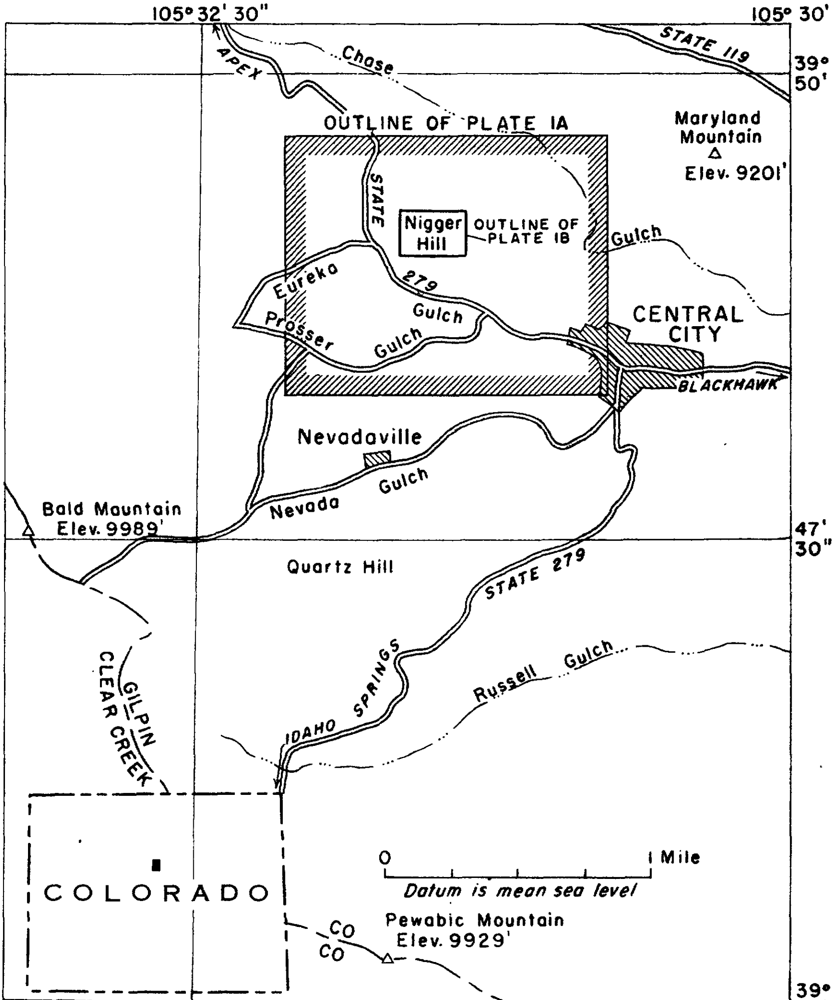

FIGURE 1.—Index map showing location of Eureka Gulch area, Gilpin County, Colo.

known to that time. Lovering and Goddard (1950) described the geology of the entire Colorado Front Range and their report is the most authoritative source of information on the ore deposits of this vast region.

The results of the work of the various government agencies investigating the uranium resources of the Central City region have not for the most part been published. A report on the Wood and Calhoun mines (Moore and Butler, 1952) was released, and a report on the Quartz Hill area is being prepared for publication by Armstrong (see footnote, p. 2).

FIELD WORK AND ACKNOWLEDGMENTS

The U. S. Geological Survey's uranium investigations in the Colorado Front Range began in 1944. The work at first was on behalf of the Manhattan Engineer District, and later on behalf of the U. S. Atomic Energy Commission. In 1952 the Geological Survey began a comprehensive geologic study of a 60-square mile area in the Central City and Idaho Springs region, largely on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. As a part of this survey, a systematic reconnaissance for radioactivity was made in the Eureka Gulch area by A. E. Dearth and A. R. Krueger during the 1953 field season; both a ground scintillation counter and a rate meter with a 6-inch probe were used. A geologic map of the area was prepared by P. K. Sims and E. W. Tooker (pl. 1A).

Most of the mine dumps in the area were checked during the radioactivity survey, and ten were found to contain radioactive materials. These were the Buckley shaft, Bullion No. 2 shaft, Carroll shaft, Claire Marie shaft, J. P. Whitney shaft, adit on Rara Avis millsite, Two Sisters shaft, R. H. D. shaft, St. Anthony shaft, and McKay shaft (pl. 1B). Aside from the dump on the Rara Avis millsite, none of the localities had previously been reported as radioactive. Because of the possible economic interest in the uranium deposits on Nigger Hill, a detailed map of the north slope of the hill was made during August and September 1953 by F. W. Osterwald, using a plane table and alidade (pl. 1B). The McKay shaft on the R. H. D. claim was mapped and samples were collected by Sims and A. A. Drake in September 1953 (fig. 2); the Carroll mine is being studied by Sims. E. W. Tooker collected samples of the altered rocks in the McKay shaft workings and on the Two Sisters shaft dump; these samples have been partially studied by X-ray diffraction and microscopic methods. A. E. Dearth and R. H. Campbell of the Geological Survey assisted in the preparation of the plane-table map.

The writers are indebted to several local people, and particularly to Henry DeLinde, Claude McKay, Van McKay, Joseph Pughes, W. C. Russell, Jr., and Noah Williams for information on inaccessible mines in the Eureka Gulch area. Many discussions of problems pertaining to the work were held with personnel in the Denver Exploration Branch of the U. S. Atomic Energy Commission.

GENERAL GEOLOGY

Most of the region described in this report is on the northwest flank of a northeast-trending, broad, upright anticline, which is the dominant structural feature in this part of the Central City district (pl. 1A). Granite gneiss of pre-Cambrian age, described by Bastin and Hill (1917, p. 30–32), constitutes the core of the anticline. It contains abundant, small, discontinuous, folded layers and lenses of metasedimentary rocks and lenticular bodies of granite pegmatite. Pre-Cambrian metasedimentary rocks, principally interlayered sillimanitic biotite-quartz gneiss and biotite-quartz-plagioclase gneiss, that contain conformable layers of granite pegmatite, flank the granitic core on the northwest. The metasediments and granite gneiss dip gently away from the crest of the anticline and locally are deformed into broad warps or drag folds.

Intrusive porphyritic monzonite and quartz bostonite dikes, Tertiary in age, cut the pre-Cambrian rocks. Most of the dikes occupy northwest- and northeast-trending fractures.

Many metalliferous veins cut all the rock types in the Central City district. Most of the veins contain quartz gangue and have been the source for the gold, silver, lead, zinc, copper, and uranium that have been produced in the district.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks in the Eureka Gulch area consist predominantly of biotite-quartz-plagioclase gneiss, sillimanitic biotite-quartz gneiss, amphibolite, lime silicate gneiss, cordierite-anthophyllite-garnet gneiss, granite gneiss, and granite pegmatite. All the rocks except some of the granite pegmatite have been deformed and recrystallized and have a metamorphic texture. Altered biotite-quartz-plagioclase gneiss and amphibolite constitute the host rocks for metatorbernite-bearing uranium deposits on Nigger Hill.

The biotite-quartz-plagioclase gneiss, sillimanitic biotite-quartz gneiss, amphibolite, and lime silicate gneiss are believed to be of metasedimentary origin, and are widespread in the Central City district and the adjacent region. Bastin and Hill (1917) and Lovering and Goddard (1950) included these rocks in the pre-Cambrian Idaho Springs formation. In the northwest part of the region (pl. 1A) biotite-quartz-plagioclase gneiss is interlayered with sillimanitic biotite-quartz gneiss and accordingly the rocks are mapped as interlayered biotite gneisses. The cordierite-anthophyllite-garnet gneiss is probably also of metasedimentary origin, and had not been described previously from this part of the Front Range; so far as known it occurs sparsely in the Central City district. The granite gneiss, as mapped by Bastin and Hill, is a metamorphic rock of uncertain origin. Studies of this rock indicate that it has an average composition of quartz monzonite; accordingly in a later report it will be defined as quartz-monzonite gneiss. In this report, however, the writers follow the usage of Bastin and Hill and refer to it as granite gneiss. The granite pegmatite has a simple composition and is clearly younger than the granite gneiss. It is similar and probably correlative to the granite gneiss and pegmatite that is widely distributed south of the Central City district in north-central Clear Creek County (Harrison and Wells, 1955).

BIOTITE-QUARTZ-PLAGIOCLASE GNEISS

Biotite-quartz-plagioclase gneiss is intimately interlayered with sillimanitic biotite-quartz gneiss in the northwestern part of the Eureka Gulch area (pl. 1A), and it forms generally thin, discontinuous layers and lenses within the granite gneiss. Nearly all of the rock contains conformable, but locally crosscutting, bodies of pegmatite ranging from a few inches to several feet thick.

The gneiss is a variable, generally medium-grained rock that consists principally of quartz, oligoclase, and biotite. Within the McKay shaft workings the gneiss consists of two principal facies—a light-gray uniform gneiss containing a maximum of 15 to 20 percent biotite and a dark-gray well-layered gneiss containing as much as 30 percent biotite. Individual layers in the mine generally range from 6 inches to 3 feet in width. Soft biotite-quartz schist layers, commonly a foot or less thick, are present at places in the rock. Some parts of the gneiss contain scattered crystals of red garnet.

Altered facies of biotite-quartz-plagioclase gneiss on the dump at the Two Sisters shaft contain discrete crystals of metatorbernite, disseminated through the rock or on fracture surfaces.

SILLIMANITIC BIOTITE-QUARTZ GNEISS

Sillimanitic biotite-quartz gneiss is the predominant rock type in the northwestern part of the mapped area (pl. 1A), but it contains abundant interlayers of biotite-quartz-plagioclase gneiss. It is distinguished from biotite-quartz-plagioclase gneiss by the presence of visible white sillimanite and by smaller quantities of plagioclase feldspar. Pegmatite bodies, generally conformable to the structure of the gneiss, occur throughout the rock.

Typically, sillimanitic biotite-quartz gneiss is a light-gray to dark-gray, medium-grained, granoblastic rock that has a conspicuous gneissic structure because of an excellent preferred orientation of biotite and sillimanite. Weathered surfaces commonly are light gray or silvery gray to grayish brown. The sillimanite occurs as delicate fibers and bunches or in elliptical aggregates intergrown with quartz.

LIME SILICATE GNEISS

Lime silicate gneiss consists of massive to layered rocks that principally contain variable quantities of quartz, garnet, and pyroxene, and smaller amounts of hornblende, plagioclase, epidote, apatite, and sphene.

Two irregular zones of lime silicate gneiss crop out on opposite sides of the major anticline, close to the trace of the axial plane (pl. 1A). Individual layers within each zone are discontinuous and contorted and are intimately associated with layers of amphibolite and epidote-rich hornblendic rocks.

CORDIERITE-ANTHOPHYLLITE-GARNET GNEISS

Rocks composed principally of cordierite, anthophyllite, garnet, cummingtonite, and quartz are present at places within the Central City district. A few small bodies that are generally less than 500 feet in length have been mapped in the Quartz Hill area;[3] one body, near the crest of Nigger Hill, is known in the Eureka Gulch area (pl. 1). The gneiss is a medium-gray, generally medium-grained, but locally coarse-grained, layered rock of variable composition. Fresh surfaces commonly have a greasy, lustrous appearance. Weathered surfaces are grayish brown to reddish brown and at places are ribbed. One layer is composed almost entirely of coarse, matted or felted anthophyllite and cummingtonite crystals. Cordierite layers that are an inch or less thick and are parallel to the gneissic structure of the rock are common.

AMPHIBOLITE

Small, discrete, lenticular or podlike bodies of dark-gray to nearly black, medium-grained, equigranular amphibolite are scattered through the granite gneiss and biotite-quartz-plagioclase gneiss. The amphibolite is composed of nearly equal parts of oligoclase-andesine and hornblende and has as much as 10 percent clinopyroxene; accessory minerals include microcline, apatite, sphene, and epidote.

Several long discontinuous layers of amphibolite are associated with lime silicate gneiss and make up a conspicuous stratigraphic marker bed near the axis of the major anticline. In the McKay shaft workings (fig. 2), contorted pods of amphibolite that range from about 1 foot to 7 feet in diameter occur within biotite-quartz-plagioclase gneiss. The amphibolite in the mine is largely altered to clay minerals, and it is the principal host rock for metatorbernite.

MIGMATITE

Interlayered rocks, which are termed migmatite in this report, consisting of roughly 50 percent biotite-quartz-plagioclase gneiss and 50 percent granite pegmatite were mapped in the McKay shaft workings (fig. 2). In the gneiss the pegmatite forms closely spaced, generally conformable layers and lenses that range in thickness from less than a foot to about 3 feet. At places the pegmatite cuts across the foliation of the gneiss.

[3] Sims, P. K., Drake, A. A., and Moench, R. H., Unpublished report.

GRANITE GNEISS

The granite gneiss consists essentially of quartz, plagioclase, microcline, and biotite. The composition varies from granodiorite to quartz monzonite, according to Johannsen's classification (Johannsen, 1931, p. 143–147). The rock is generally medium grained, and on freshly broken surfaces is light gray to dark gray, but generally changes to buff when weathered. Characteristically, granite gneiss has a well-defined foliation marked by alternating biotite-rich layers and layers rich in quartz and feldspar which are a fraction of an inch thick, and by a subparallel arrangement of the tabular and platy minerals. Some outcrops of the gneiss, which appear to be massive, show a fair to good preferred orientation of biotite on close inspection; the biotite is more or less evenly distributed through this rock. Some of the granite gneiss contains abundant, closely spaced, relatively continuous mafic layers, but at many outcrops the mafic minerals consist only of discontinuous, parallel streaks. Discrete lenses, layers, and irregular-shaped bodies of metasedimentary rocks, usually only a few tens of feet wide and a few hundreds of feet long, are scattered through the gneiss at places. Younger granite pegmatite intrudes the gneiss.

Granite gneiss is the predominant rock in the area and crops out in the core of the major anticline (pl. 1A). Contacts of the gneiss are sharp and conformable to the layering of adjacent rock types.

GRANITE PEGMATITE

The granite pegmatite is generally white and coarse grained; it consists predominantly of quartz and feldspar. Magnetite and biotite are conspicuous accessory minerals; magnetite is more abundant and widespread.

Pegmatite bodies ranging from a few feet to a few tens of feet in width form generally conformable bodies in granite gneiss and the biotite gneisses. The pegmatite bodies within granite gneiss are discrete, discontinuous layers along the limbs of folds and small, irregular-shaped masses in the crests of minor folds (pl. 1A). Pegmatites in the biotite gneisses are partly discrete bodies, some large enough to be mapped (pl. 1A), and partly thin, conformable, discontinuous layers along the foliation.

TERTIARY ROCKS

The intrusive dike rocks in the Eureka Gulch area—monzonite porphyry and quartz bostonite—belong to the Tertiary intrusive sequence in the Front Range, which is among the most radioactive igneous series in the world.[4] The quartz bostonites of Eureka Gulch contain

[4] Phair, George, Unpublished report.

from 0.010 to 0.024 percent equivalent uranium and are 10 to 20 times more radioactive than the surrounding pre-Cambrian rocks.

MONZONITE PORPHYRY

Fresh monzonite porphyry is gray, medium grained to fine grained and contains abundant feldspar phenocrysts. The rock is altered and bleached to gray or white at most places; weathered surfaces where feldspar phenocrysts have weathered out are characteristically deeply pitted.

A monzonite porphyry dike, generally less than 5 feet thick, crops out at places on the south slope of Nigger Hill (pl. 1A). It can be traced from the vicinity of the Tom Martin mine (13) southwestward to the road in Eureka Gulch. A branching dike, which is exposed at places on the south side of Eureka Gulch, probably is correlative. Two analyses from the dike gave 0.001 and 0.002 percent chemical uranium (Phair, oral communication).

QUARTZ BOSTONITE

Bostonite, a fine-grained rock resembling trachyte, is widespread and conspicuous in the Central City district (Bastin and Hill, 1917, p. 52). Fresh bostonite is lilac colored to reddish brown and contains abundant to sparse salmon-pink feldspar phenocrysts. Light-gray altered and bleached bostonite is common in the district; feldspar phenocrysts are changed to soft, green aggregates of sericite, or to a chalky, white clay mineral, and the groundmass is bleached to gray or white.

Three types of bostonite have been distinguished in the Central City district by Phair. These are quartz bostonite porphyry, nonporphyritic quartz bostonite, and syenitic bostonite porphyry; only nonporphyritic quartz bostonite is found in the Eureka Gulch area. The nonporphyritic quartz bostonite is shown on plate 1 as quartz bostonite.

Two long, narrow, branching quartz bostonite dikes traverse the Eureka Gulch area (pl. 1A). One dike trends northwestward from the reservoir in Central City, about 1 mile south of the area shown on plate 1A, to Mammoth Gulch, west of Apex, which is about 8 miles north of Central City (Bastin and Hill, 1917, pl. 1). Phair called this dike the Nigger Hill dike. Another dike trends northeastward from Bald Mountain, across the center of the mapped area; this has been called the Prosser Gulch dike.

Most nonporphyritic quartz bostonites are uniformly fine grained, but at a few outcrops they contain visible feldspar phenocrysts. A faint to pronounced planar flow structure parallels the walls of the dikes at most places. Outcrops of the dikes are usually low, rounded ridges mantled with angular fragments of bostonite; even where exposures are poor the dikes can be traced by float.

The Nigger Hill dike is younger than the monzonite because it cuts and offsets the monzonite porphyry on the southeast side of Nigger Hill, about 250 feet northwest of the Iowa mine (18). The apparent horizontal displacement is 75 feet, the northeast side having moved northwestward relative to the southwest side.

The unbleached parts of the Nigger Hill dike contain an average of about 0.022 percent equivalent uranium, generally less than 0.010 percent uranium, and about 0.020 percent thorium (see footnote p. 8); one analysis from the Prosser Gulch dike gave 0.018 percent equivalent uranium, 0.006 percent uranium, and 0.049 percent thorium. A sample of bleached bostonite from the Nigger Hill dike contained 0.010 percent equivalent uranium, 0.003 percent uranium, and 0.020 percent thorium.

STRUCTURE OF PRE-CAMBRIAN ROCKS

FOLIATION AND LINEATION

The pre-Cambrian rocks have a fair to excellent lithologic layering and subparallel alinement of tabular and platy feldspar, biotite, and hornblende. The foliation in the metasedimentary rocks everywhere parallels the layering produced by differences in mineral composition; hence, it is assumed that the foliation parallels the original bedding in the rocks. The contacts and megascopic gneissic structure of the granite pegmatite generally are conformable but at places they cut across the gneissic structure of the older rocks.

Subparallel alinement of elongate minerals, streaking, crinkling, warps, and minor fold axes is conspicuous in all rocks except pegmatite. The most prominent lineation trends about N. 40° E. and plunges northeast or southwest at angles of less than 20°. The angle of plunge varies considerably, even within individual outcrops, because of cross warps described below. This lineation is marked chiefly by mineral parallelism, by streaking, and by minor fold axes; it essentially parallels the axis of the major fold in the region.

A second locally conspicuous lineation plunges northwest and is marked by warps in the foliation planes. Less commonly the warps plunge southeast. Most warps in the mapped area plunge 20°–40° N. 50°–70° W. The warps vary greatly in size, and the ratio of amplitude to wave length is usually greater than 1 : 3.

FOLDS

The attitude of the foliation and the outcrop patterns of the various rock units indicate that the pre-Cambrian rocks are folded along northeast-trending axes (pl. 1A). The predominant fold in this part of the Central City district is a large, broad, symmetrical anticline that trends about N. 40° E. Locally the fold axis plunges gently either northeastward or southwestward because of minor variations in the plunge angle. On the flanks of the anticline the rocks generally dip less than 45° away from the crest, but at some places the dips are steeper. The structures on the flanks of the anticline are principally minor open folds with gently dipping limbs. Some minor folds are asymmetrical; the axial planes converge upward toward the axes of the major anticline. Cross warps plunging northwest on the northwest limb of the anticline and southeast on the southeast limb are common and locally abundant. The folds on the flanks of the major anticline are essentially parallel to the major fold axis and represent drag folds related to the major fold.

STRUCTURE OF TERTIARY DIKE ROCKS

The Tertiary dikes are long and continuous and rarely are over 25 feet thick. They fill steeply dipping fractures in the older pre-Cambrian rocks and are in different fracture systems than the metalliferous veins. Because the dikes are fractured (pl. 1B) and offset along planes roughly parallel to some of the veins, it is inferred that the dikes fill older fracture systems than the metalliferous veins.

Although the general trend of each dike is consistent over long distances, local trends deviate considerably from the average. The Nigger Hill dike trends about N. 45°–50° W.; it occupies two sets of fractures, one of which strikes between N. 40°–60° W. and the other about N. 10° W. Near the I. X. L. mine (25) a branch of the Nigger Hill dike trends about N. 50° E. The apparent displacement along the dike-filled fractures is small. On Nigger Hill, the Nigger Hill dike cuts and offsets a small lens of cordierite-anthophyllite-garnet gneiss; the apparent horizontal displacement is about 12 feet, with the northeast side relatively displaced to the southeast. The same dike cuts the Tertiary monzonite porphyry dike about 500 feet southeast of the cordierite-anthophyllite-garnet gneiss lens; the monzonite is displaced about 75 feet with relative northwestward motion of the northeast block. The difference in apparent horizontal displacement of the lens and monzonite dike probably is due to the difference in dip of the two intersected rock bodies.

The average trend of the Prosser Gulch dike is about N. 50° E., but at places it occupies fractures that strike N. 80°–90° E.; these are probably joints, as there has been little or no offset along the fractures.

The monzonite porphyry dike has many short branches and is more irregular in trend than the bostonite dikes. Throughout most of its length the monzonite fills fractures trending northeastward, which are probably the same as the N. 50° E. set occupied by the Prosser Gulch dike, but near Eureka Gulch the monzonite fills eastward-trending fractures (pl. 1A).

URANIUM DEPOSITS

The gold, silver, copper, lead, zinc, and uranium deposits of the Central City district are found in veins, or less commonly in stockworks, that are believed to have formed at intermediate temperatures. These deposits are early Tertiary in age and are genetically related to the intrusion of porphyritic rocks (Lovering and Goddard, 1950, p. 170–191; see also footnote p. 8). Gold and silver accounted for most of the dollar value of the ore produced.

Two main types of deposits give the district a zonal arrangement. A core of pyrite-quartz veins, about 2 miles in diameter, is surrounded by a rather wide outer zone of silver-lead-zinc veins (King and others, 1953, p. 6). In the zone of overlap between the two zones, transitional veins contain gold, silver, copper, zinc, and lead. All the known uranium deposits in the Central City district except those in the Eureka Gulch area are in the transition zones as outlined by Leonard (1952).

The uranium deposits in the Eureka Gulch area are of two types, one carrying pitchblende and the other metatorbernite. So far as known the two types of ores are mutually exclusive. Pitchblende occurs at places along metalliferous veins; it was formed earlier than sphalerite, galena, chalcopyrite, and most of the pyrite. The metatorbernite primarily is in altered biotite-quartz-plagioclase gneiss and amphibolite wall rocks adjacent to veins in the oxidized zone.

MINERALOGY AND GRADE

Pitchblende, metatorbernite [$Cu(UO_2)_2(PO_4)_2\cdot 8H_2O$], and kasolite [$Pb(UO_2)SiO_4\cdot H_2O$] have been identified in the Eureka Gulch area. Some of the metatorbernite may contain torbernite [$Cu(UO_2)_2(PO_4)_2\cdot 8\text{–}12H_2O$]. The pitchblende and metatorbernite are sufficiently concentrated locally to be of possible commercial value; kasolite has been found only on the Two Sisters mine dump in small quantities.

Black, heavy pitchblende with a dull metallic luster was found on the dumps of the J. P. Whitney shaft (33), Bullion No. 2 shaft (32), Carroll shaft (6), and the adit on the Rara Avis millsite (34). Under a reflecting microscope, the pitchblende from the J. P. Whitney shaft shows a colloform structure with radiating syneresis cracks. The pitchblende is brecciated at places, and is veined by sphalerite, galena, pyrite, and chalcopyrite of a later age.

Metatorbernite (identified by W. F. Outerbridge, Denver X-ray laboratory, U. S. Geological Survey) was found on the dumps of the Two Sisters, R. H. D., McKay, and Claire Marie shafts (pl. 1B) and underground at the McKay shaft (fig. 2); it is also present at places in the upper part of the Carroll mine. Except at the Carroll mine, the metatorbernite is disseminated as tiny, apple-green crystals or forms fracture coatings in altered biotite-quartz-plagioclase gneiss and amphibolite. At the Carroll mine metatorbernite locally coats partly leached pitchblende.

Yellowish-brown kasolite occurs in thin mats of closely spaced fibers, rosettes, and tabular crystals that coat fractures and partly fill vuggy openings in highly altered, porous, hydrous-iron vein material and in altered wall rocks.

The grade of selected material from radioactive dumps in the Eureka Gulch area is given in table 1; the grade of samples taken from the mine workings of the McKay shaft (fig. 2) is given in table 2.

Dump samples of material containing pitchblende differ widely in grade (table 1), and in many of them the equivalent-uranium content, which is determined by radioactivity analysis, far exceeds the chemical uranium. Sample N16 from the Carroll dump contains 6.4 percent equivalent uranium, but only 0.62 percent chemical uranium; and sample N16–C from the same dump contains 10.5 percent equivalent uranium but only 0.095 percent chemical uranium. Radium and other daughter products of uranium, principally radon and radiogenic lead, account for the disequilibrium. Phair and Levine (1953) demonstrated that pitchblende from pyritic dumps in the Central City district oxidizes rapidly. The uranium is leached by sulfuric acid derived from pyrite, and both radium and lead remain in the original material in approximately proportional amounts. Accordingly, many of the highly radioactive "hot spots" on pyritic dumps in the Central City district are caused by residual concentrations of radium and other decay products of uranium. For this reason the equivalent-uranium analyses indicate the approximate uranium content of the original material when removed from the vein.

Sample analyses of selected metatorbernite-bearing material from the Two Sisters mine dump show as much as 6.11 percent chemical uranium (table 1). A grab sample of metatorbernite-bearing rock from the 40-foot level of the McKay shaft workings assayed 0.24 percent chemical uranium, and two other samples assayed more than 0.1 percent chemical uranium (table 2). Two analyses of radioactive material from the Claire Marie dump (table 1) indicate a low uranium content.

LOCALIZATION

Pitchblende, associated with gangue quartz and sulfide minerals, is a primary vein mineral. Metatorbernite is principally confined to altered rocks adjacent to oxidized veins or is sporadically distributed within the upper parts of some veins. So far as known, the metatorbernite is associated with gold- and silver-bearing veins of the galena-sphalerite type (Bastin and Hill, 1917, p. 110). Veins con-

TABLE 1.—*Uranium analyses of selected dump material, Eureka Gulch area*

[Analyses by Denver laboratory of the U. S. Geological Survey. All are grab samples]

Field no.	Locality	Equivalent uranium (percent)	Chemical uranium (percent)	Rn (Curies×10^{-9})	Pb^{210} (Curies×10^{-9})	Remarks
B1	Boodle mine	0.013	0.003			Probably middlings from radioactive ore milled from Wood mine.
N109	Buckley mine	.31	.33			Black uranium oxide, probably pitchblende.
N20	Bullion mine	.021	.007			Pitchblende.
N20	do	6.7	6.87			
N16	Carroll mine	6.4	.62	45	45	Pitchblende has been leached.
N16-A	do	1.7	.025			
N16-B	do	.93	.68			
N16-C	do	10.5	.095	64	68	
N23	Claire Marie mine	.027	.017			Green secondary mineral.
N23-A	do	.054	.034			
N45	J. P. Whitney	8.9	5.92			Pitchblende.
N18	Adit, Rara Avis millsite	.80	.59			
S1-53	do	.17	.15			
E1	do	.22	.03			
E2	do	1.7	.94			
N44	Two Sisters shaft	.92	1.42			Uranium principally contained in metatorbernite.
N44-C	do	5.6	6.11			Do.
N44-A	do	4.4	4.70			Do.
N44-B	do	2.6	3.05			Uranium principally contained in kasolite.

taining pitchblende are not known to bear appreciable quantities of metatorbernite, and no pitchblende has been observed in the metatorbernite-bearing rock. Pitchblende and metatorbernite ores, therefore, seem to be mutually exclusive in the Eureka Gulch area and appear to occur in different veins (pl. 1A).

Pitchblende has been observed in place only at the Carroll mine and is confined to several small shoots along the Carroll vein. On the 177-foot level, which was partly mined during earlier operations, and in the stopes above this level, the pitchblende-bearing ore appears to occur in steeply-plunging shoots that have a maximum height of 30 feet, a stope length from 10 to 15 feet, and a width from an inch or less to 12 inches. To judge from the limited exposures of ore left in the stopes, individual shoots are alined en échelon. Within each shoot the pitchblende ore forms small pods and lenses, generally only a few feet in maximum dimension. A small pod of ore extracted from the underhand stope below the 177-foot level occurred at the junction of two pitchblende-bearing seams and plunged 20° NW.; it averaged about 12 inches in width and was 10 feet long.

The pitchblende shoot on the 228-foot level has a known horizontal length of nearly 40 feet and possibly is as much as 65 feet long; its height has not been determined. The shoot consists of three principal subparallel pitchblende seams that are from an inch to about 4 inches thick and at places are separated by radioactive vein and altered wall rock. At junctions of the seams the intervening rock is veined by abundant pitchblende seams a fraction of an inch thick; the whole constitutes minable ore. The distribution and quantity of pitchblende and the concentration of radioactive material in two or more distinct places on the J. P. Whitney shaft (33) and the Rara Avis adit (34) dumps indicate that uranium-bearing material probably was mined from at least two places in each mine. At the Bullion mine dump (32), radioactive rock was localized in one spot; hence, the pitchblende probably came from a single body.

Metatorbernite-bearing rock on the dumps at the McKay, R. H. D., and St. Anthony shafts (pl. 1B) probably came entirely from the R. H. D. vein; because most mines are inaccessible the writers do not know definitely which veins are radioactive. The uranium-bearing material on the Two Sisters dump (pl. 1B) could have been mined from either or both the Two Sisters or the Claire Marie veins, because both veins are reported to have been worked underground in the Two Sisters mine.

WALL-ROCK ALTERATION

The wall-rock alteration of vein deposits in the Eureka Gulch area is not fully known; however, some preliminary observations can be presented. The alteration was studied in the McKay shaft workings (R. H. D. vein), on three levels of the Carroll mine (Carroll vein), and in dump samples from the Two Sisters mine (Two Sisters and Claire Marie veins).

The wall rocks were altered by two types of solutions: hydrothermal, related to base metal and uranium ore deposition, and supergene, related to circulating ground water of a later time. The supergene alteration was superimposed upon the hydrothermally altered rock. A transition from the supergene zone to the primary zone has been observed only in the Carroll mine.

The mineralogy and width of wall-rock alteration zones are complicated by the occurrence of diverse rock types; however, the rocks studied have related trends of alteration. Plagioclase feldspar was the first mineral to completely change to montmorillonite and minor amounts of kaolinite, chlorite, and illite. Hornblende, where present, was partly replaced by biotite. Biotite in turn was converted into chlorite, kaolinite, and possibly some montmorillonite. Illite is present in small amounts in the supergene zone, but is nearly absent or masked in hydrothermally altered rock. Sericite occurs as an alteration product in the immediate vein zone in the hydrothermal environ ment. Silicified wall rock is apparent megascopically only in the hydrothermal zone. Supergene action seems to have intensified argillic alteration at the expense of sericite and outlying host rock; however, no well-defined argillic subzones are evident. Montmorillonite is concentrated in the most intense phase, but occurs throughout the clay-mineral alteration zone. Chlorite and illite are concentrated in the moderately altered rock, but in smaller amounts than montmorillonite; kaolinite is present in small amounts throughout the altered zone. These relations suggest a moderate temperature for hydrothermal altering solutions.

SUPERGENE ZONE

A study of the metatorbernite-bearing rocks—biotite-quartz-plagioclase gneiss and amphibolite—indicates that clay-mineral alteration predominates in the supergene zone. The principal clay-mineral constituent is montmorillonite.

The alteration of biotite-quartz-plagioclase gneiss produced the following mineralogical changes: Plagioclase feldspar was first converted to a mixture of montmorillonite and kaolinite (mont.>kaol.); biotite later was altered to chlorite, illite, and, with more intense alteration, in part to kaolinite and montmorillonite.

The fresh rock is dense, hard, and has a prominent foliation resulting from a subparallel arrangement of biotite crystals. A study of thin sections indicates that the plagioclase (An_{25-30}) has been slightly altered to montmorillonite along crystal margins, cleavages, twin planes, and less frequently irregularly over the crystals. With more intense alteration—either closer to the vein or along open foliation planes away from the vein—the rock was softened, and white and light-green clay-mineral mixtures of kaolinite and illite-montmorillonite replaced the plagioclase feldspar. Biotite initially was not visibly altered.

In the most intense stage of alteration the gneiss was changed to a soft mass of plastic green clay, primarily 15A type montmorillonite. At places along subsidiary shear surfaces, foliation planes, and other irregular surfaces within the green clay, fragile sericite-like aggregates, and less commonly, aggregates of biotite were developed. Both new minerals are oriented irregularly with respect to the original rock structure. Within the supergene zone there is no visible silicification; sericite, if present as a true phase of alteration, is poorly developed.

The alteration of amphibolite is predominantly argillic; the mineralogy is similar in many respects to that for biotite-quartz-plagioclase gneiss. Plagioclase feldspar was altered first, or more rapidly than hornblende, to montmorillonite; hornblende altered primarily to biotite; biotite altered to chlorite, illite, and probably later to kaolinite and montmorillonite.

Fresh amphibolite is a dark-gray to black, dense, poorly foliated rock that is composed of hornblende, plagioclase feldspar, and minor quartz. The rock occurs as small podlike bodies in biotite-quartz-plagioclase gneiss. Where altered, the amphibolite grades into a massive, soft, white and green clay-biotite-hornblende rock. Where intensely altered a soft, plastic, green clay was formed at the expense of biotite; however, the green clay often contains irregularly distributed flakes of mixed green-brown and red-brown biotite crystals. The former are partly altered to chlorite, whereas the latter are in part changed to kaolinite. The green color of the rock results from the large quantity of montmorillonite, 15A type; a small amount of white clay aggregate, separated during sedimentation, is kaolinite and illite (kaolinite>>illite).

Some amphibolite pods, not observed to be cut by the vein, are similarly altered but alteration was most intense at their centers and decreased outward. Metatorbernite is localized at the junction of green clay and moderately altered zones, or in some cases where the pod is completely converted to green clay, at the edge of the pod.

No silicification or sericitization of amphibolite wall rocks was observed at the McKay shaft workings.

At places granite pegmatite is cut by the vein, and, as noted elsewhere in the district, the potash feldspar is not as highly altered as plagioclase (sodium-calcium) feldspar.

The alteration of biotite-quartz-plagioclase gneiss from the Two Sisters mine dump and from the upper levels of the Carroll mine is generally similar to the foregoing description.

HYDROTHERMAL ZONE

The hydrothermal alteration, as determined from megascopic observations on the 228-foot level of the Carroll mine, differs from the supergene zone alteration in the presence of a conspicuous but narrow silicified and sericitized wall-rock zone. Away from the vein—outside of the silicified and sericitized zone—and in host-rock fragments in cockade ore, white and greenish clay and bleached biotite grains grade into soft white clay and biotite, and finally into fresh rock. Pods of amphibolite in the granite gneiss are partly altered to soft green clay and biotite.

RELATION OF METATORBERNITE TO ALTERED HOST ROCKS

The metatorbernite at the Two Sisters mine and the McKay shaft workings is disseminated through altered biotite-quartz-plagioclase gneiss and amphibolite pods in the gneiss; it replaces constituent minerals of the host rocks. At places it forms coatings on fractures in the rocks.

In the McKay shaft workings (fig. 2) the metatorbernite is concentrated in the margins of the altered amphibolite pods, but it is also abundantly disseminated through the green clay. Samples of altered biotite-quartz-plagioclase gneiss from the Two Sisters dump contain disseminated metatorbernite granules or aggregates of granules in the moderately altered rock. The granules are closely associated with biotite and commonly embay the biotite flakes as seen in two dimensions in thin sections. Evidence for replacement of the biotite by metatorbernite is inconclusive; however, many granules occur where the biotite has been bent or flexed. The grain boundaries are generally smooth and regular. A marked concentration of metatorbernite occurs in the more intensely altered moderate or bleached zone at its boundary with the moderately altered zone. In this environment the metatorbernite appears to replace the biotite along cleavage planes and crystal edges, and it assumes tabular or flake-shaped aggregations, rather than a granular form. Under the microscope it is seen to be intimately mixed with sericite and illite. Granules persist into the bleached zone, and, away from the zone of concentration of flake-type metatorbernite in the boundary zone, granules are present in about equal proportions with the flake type. Along fractures, and at places along folia in the rock, the flake type predominates over the granular type of metatorbernite in the bleached zone.

The two different morphological types of metatorbernite—granules and flakes—from the Two Sisters mine dump samples are difficult to explain from the present inadequate data. Two alternative explanations may be suggested for their development. Either they were formed at different times, perhaps under slightly different environmental conditions directly related to the degree of completion of the wall-rock alteration, meaning that flakes relate to very late supergene action; or they were more nearly contemporaneous, where the physical and structural conditions were such that the flake type was favored in the more accessible parts of the system. The granular phase may be slightly older than the flake phase, but there is no other relation of the granules to a particular texture or structure; the formation and concentration of the flake-type metatorbernite, however, appears to have a direct relation with the early stages of breakdown of biotite.

ORIGIN OF PITCHBLENDE AND METATORBERNITE

Pitchblende deposits and quartz bostonite dikes have a close spatial relationship within the Central City district (Alsdorf, 1916; Bastin, 1916; see also footnote p. 8). Phair concluded that the uranium was derived from a cooling quartz bostonite mass at depth; additional uranium could have been obtained by leaching of uranium from quartz bostonite during the rise of the uranium-rich solutions. The dikes also contain a relatively high proportion of thorium; the veins contain almost none. This suggests that either the uranium in the dikes was more readily available than thorium, or that the uranium in veins (and dikes) was derived from some other common source. The pitchblende was deposited in fractures which were open at the time of its formation.

The pitchblende in the Central City district was deposited early in the sequence of Tertiary vein formation; in some veins it crystallized essentially contemporaneously with pyrite; in others it formed before the pyrite. So far as known, it always formed earlier than sphalerite, galena, and chalcopyrite, and commonly was brecciated before the deposition of these metals.

Uranium minerals other than pitchblende are sparse in the Central City district. The occurrences of metatorbernite for a distance of about 700 feet along the Two Sisters and R. H. D. veins (pl. 1B) are unique in the district. The metatorbernite was probably formed by oxidation, solution, and transportation of uranium from primary pitchblende, but it may be a primary mineral deposited directly from mineralizing fluids of different composition from those which deposited pitchblende. The PO_4 ion, required for crystallization of metatorbernite, possibly was derived from apatite in the host rock or from adjacent rocks. The SiO_4 ion, required for the precipitation of kasolite, could have been derived from the silica within the quartz vein or from alteration of feldspar in wall rocks. The necessary copper and lead were primary vein constituents, because the veins are known to contain copper and lead sulfides.

ECONOMIC EVALUATION

If the metatorbernite and kasolite are secondary minerals deposited by circulating waters which dissolved uranium from pitchblende, then primary pitchblende deposits may be encountered at depth. The quantity and location of the pitchblende cannot be determined with the existing information, but it would be below the zone of oxidation. However, if the metatorbernite is a primary mineral deposited directly from a deep-seated source, it is unlikely that any pitchblende deposits will be found at depth. The grade, tonnage, and depth extension of the metatorbernite deposits cannot be estimated on the basis of existing information. The abundant disseminated metatorbernite in altered wall rocks in the Nigger Hill area so far as is known is a unique deposit in the United States.

The pitchblende deposits of the area, to judge from the Carroll mine, are similar to those that have been mined in the Quartz Hill area. The ore forms small pods, lenses, and seams within pitchblende shoots along the veins. These deposits can best be mined together with other metals contained in the veins. Some of the veins, however, might contain bodies of sufficient size and grade to be mined profitably for uranium alone.

DESCRIPTION OF INDIVIDUAL MINES

Within the Eureka Gulch area there are 68 principal shafts and adits, locally referred to as tunnels. A list of mines with their corresponding numbers is given on plate 1A. Because most of the mines were worked several decades ago and subsequently have partly caved, few mine openings were accessible in 1953 and 1954.

In the following pages only those mines that are known to contain radioactive materials are described, and of these only two, the McKay shaft, R. H. D. claim (10), and the Carroll mine (8), were accessible for underground examination in 1953 and 1954.

BUCKLEY MINE (56)

The Buckley mine (pl. 1A), now inaccessible, was opened by a two-compartment shaft inclined 80° S. 15° W. The shaft is open at the collar but appears to be jammed at a depth of about 40 feet. To judge from the size of the dump, the mine contains several hundred feet of underground workings. Between 1902 and 1922, 57.42 ounces gold and 93 ounces silver were produced (A. J. Martin, Metal Economics Branch, U. S. Bureau of Mines). Considerable ore probably was extracted prior to that time.

The shaft was sunk on a vein trending N. 65°–70° W. The Wood shaft (55), 650 feet to the northwest across Prosser Gulch, probably was sunk on the same vein. According to Bastin and Hill (1917, pl. 4) the vein belongs to the pyritic gold type. Pyrite and sparse galena and sphalerite can be recognized on the dump.

A small radioactive area on the surface of the dump, about 2 feet in diameter, was sampled, and it assayed 0.31 percent equivalent uranium and 0.33 percent chemical uranium (table 1). The radioactive material is black and presumably contains pitchblende.

BULLION MINE (32)

The Bullion mine, on the Bullion No. 2 claim, is about 1,000 feet west of the portal of the Rara Avis tunnel, on the south side of Eureka Gulch (pl. 1A). The mine is inaccessible and little is known of the extent of the mine workings. According to W. C. Russell, Jr. (oral communication), the mine consists of two levels about 100 feet apart vertically, and a vertical shaft, now caved at the collar. Some drifting was done on both levels west of the shaft; probably little ore was extracted. The mine was last worked during World War II.

CARROLL MINE (6)

The Carroll mine is on the west slope of Nigger Hill near the southeast corner of the cemetery (pl. 1B). It was closed at the time of the discovery of radioactive materials on the dump in 1953, but subsequently it has been rehabilitated by United Mining and Leasing Corporation. It was last worked about 1903.

The mine workings consist principally of a two-compartment shaft, inclined about 65° NE., which is 230 feet deep; short levels at vertical depths of 102, 177, and 228 feet; and stopes above the 177-foot and 102-foot levels, southeast of the shaft.

The shaft is located at the approximate junction of three veins, as shown on plate 1B. The Carroll vein where opened underground strikes N. 70°–80° W. and dips on the average about 65° NE., but there are local minor deflections in dip and strike. The Claire Marie vein (pl. 1B) is inferred to be present in the shallow prospects pits between the Carroll and Claire Marie shafts; on this assumption it should junction with the Carroll vein near the Carroll shaft. The northwest-trending vein to the southwest of the Carroll vein (pl. 1B) probably was explored by the short drift on the southeast side of the shaft at a vertical depth of 52 feet.

The radioactive material discovered on the dump occurred within an area several feet in diameter. Although pitchblende was recognized in certain samples, the radioactivity largely resulted from residual concentrations of radium and other daughter products of uranium. (See p. 14). Four analyses of selected radioactive material are given in table 1. Subsequent rehabilitation has disclosed the presence of pitchblende and sparse colored secondary uranium minerals in the mine workings.

The Carroll vein cuts granite gneiss, biotite-quartz-plagioclase gneiss, and pegmatite that strike northeasterly and except locally dip moderately to gently northwestward. Granite gneiss is the principal wall rock except on the 228-foot level, where the wall rock is largely biotite-quartz-plagioclase gneiss at places containing conformable bodies of granite pegmatite.

The Carroll vein strikes N. 70°–80° W., and dips on the average 65°–70° NE. It is a strong structure consisting of two or more subparallel, but locally diverging, fractures that are separated by brecciated, altered, and mineralized wall rock. The width of the vein ranges from less than a foot to about 9 feet. The vein contains seams of massive sulfides as much as a foot thick, but generally less than 6 inches thick, and cockade ore formed by sulfides and quartz that coat breccia fragments of wall rocks. Vugs coated by terminated quartz crystals are common. Galena and sphalerite are the most abundant ore minerals; chalcopyrite and pyrite are sparse. Pitchblende and local colored secondary minerals are confined to shoots within the vein, as described below.

Pitchblende is the principal uranium mineral found in the mine; sparse colored secondary minerals are present at places in the upper parts of the mine. Colored uranium minerals—torbernite and a yellow unknown mineral—are present locally in the hanging wall of the vein exposed in the sublevel above the 102-foot level. Pitchblende-bearing ore, considerably out of equilibrium, is exposed in the footwall of the vein in the raise, about 10 feet below the 102-foot level, and in the stope at an altitude of about 8,875 feet. A sample, 12 inches thick, of the radioactive vein, from the raise gave 5.0 percent equivalent uranium and 0.88 percent uranium. In this specimen, sparse torbernite coats the black radioactive mineral, presumably leached pitchblende. Samples cut from the pillar in the raise, subsequently mined, showed that in part the equivalent-uranium content of this ore exceeds the chemical uranium. The disequilibrium is thought to result from leaching of uranium in place. Analyses from the body of pitchblende ore found on the 177-foot level, which subsequently was mined, indicate this ore is essentially in equilibrium. On the 228-foot level, pitchblende is present along the vein for a distance of at least 40 feet. Without exception this ore is in equilibrium.

The uranium minerals are not present everywhere along the Carroll vein; instead they are confined to shoots. Between the shoots the vein is essentially barren of uranium. The uranium ore shoots defined by mining above the 177-foot level are small; the shoot exposed on this level has a height of 30 feet, a stope length of 12 feet or less, and an average width from 4 to 6 inches. It is inferred that the other uranium occurrences noted in the stoped ground above the 177-foot level also form steeply plunging shoots, which are arranged en échelon. The shoot found on the 228-foot level has not been defined; where exposed in the drift, it has a length of 40 feet and possibly as much as 65 feet.

Within the shoots, the pitchblende occurs as small pods, lenses, and seams that are separated by inch-thin pitchblende-bearing seams generally too small to be extracted profitably. A podlike body of high-grade pitchblende ore, extracted from the underhand stope on the 177-foot level, plunged 20° NW. and measured 10 feet in length and an average of 1 foot in height and width. This body occurred at the junction of two closely spaced pitchblende-bearing seams. A similar pod of high-grade ore, likewise formed at the junction of two seams, was a foot thick, 3 feet high, and about 5 feet long, and was mined from the 228-foot level, 75 feet northwest of the shaft. Immediately southeast of this body, the two seams are from 12 to 15 inches apart; the rock between the seams contains irregular, discontinuous pitchblende-bearing seams, generally less than half an inch thick, the whole constituting minable ore.

CLAIRE MARIE MINE (7)

The Claire Marie mine is on the north slope of Nigger Hill about 280 feet southwesterly from the Two Sisters shaft (pl. 1B). The mine workings consist of a 255-foot shaft, which is inclined on the average 75° SE., and levels at depths of 125 and 206 feet. The workings connect to those from the Two Sister mine through a filled stope on the Claire Marie vein. So far as known, little mining was done from the Claire Marie shaft, and the value of the shipments probably was small. A shipment of concentrates (about 3 tons) contained 5.125 ounces gold, 10.9 ounces silver, 25.55 percent lead, and 10.7 percent zinc. The gross value of this shipment was $114.40 per ton, based on a gold price of $19. The mine was worked principally during the 1890's. It was reopened in 1928 by the Claire Marie Mining Company for examination and sampling, but no ore was shipped at this time. The shaft was sunk on the Claire Marie vein, which trends about N. 70° E. and dips an average of 75° SE. According to a private company report by Horace F. Lunt, prepared in 1928, the vein is weak where exposed on both the 125- and 206-foot levels and nowhere is sufficiently thick to mine profitably. On the 206-foot level, the vein contains a small body of galena, pyrite, and sphalerite that is generally less than 6 inches thick and carries varying, but generally small, quantities of gold and silver. Minable ore might be found below the 206-foot level, because the ore mined in the stope northeast of the shaft appears to rake to the southwest.

A small quantity of radioactive material, probably metatorbernite, was found on the dump. Some of the uranium mineral forms coatings on wood fragments.

RARA AVIS MINE

The Rara Avis mine, as used in this report, includes the workings from the shaft on the J. P. Whitney claim (33), situated on the north slope near the top of the hill between Eureka and Prosser Gulches, and the adit on the Rara Avis millsite (34), on the south side of Eureka Gulch (fig. 2). Both the dump at the shaft and the dump at the portal of the adit contain appreciable quantities of pitchblende-bearing rock.

The J. P. Whitney shaft, now inaccessible, is nearly vertical and is reported to be 589 feet deep. Six levels about 100 feet apart vertically connect with the shaft and consist of a total of 1,190 feet of drifts. The shaft collar is at an altitude of about 9,102 feet. At an altitude of about 8,800 feet the adit bears S. 25° W. and connects with the workings from the shaft on the 300-foot level. The portal is caved and accordingly the adit is partly filled with water. There are no known records of production.

At the surface the vein intersected by the J. P. Whitney shaft, where observed, trends N. 75°–85° E. and dips 84° SE. At the shaft collar the vein is about a foot wide. Presumably this was the principal vein worked underground. The ore consists predominantly of galena and sphalerite. The pitchblende has a colloform structure and is earlier in age than sphalerate, galena, chalcopyrite, and at least part of the pyrite.

Pitchblende-bearing material is present at three places on the shaft dump and at two places on the adit portal dump. According to Henry DeLinde (oral communication) pitchblende was reported from the third level below the adit, presumably the 600-foot level. It is possible, however, that more than one pitchblende body was found in the underground workings. Selected grab samples from the dumps assayed as much as 8.9 percent equivalent uranium and as much as 5.92 percent chemical uranium (table 1). The analyses indicate that there has been some leaching of uranium since the material was placed on the dumps; the equivalent-uranium content is thought to be indicative of the grade of ore mined underground.

R. H. D. CLAIM

The R. H. D. claim adjoins the Two Sisters claim on the east; the west end line is just west of the R. H. D. shaft (9), and east of the St. Anthony shaft (pl. 1B). The principal mine openings on the claim are the R. H. D. shaft and McKay shaft (10), 70 feet to the east. The R. H. D. shaft, inaccessible in September 1953, is a nearly vertical shaft that extends downward into an open stope (Van McKay, oral communication). At a vertical depth of about 100 feet a drift extends eastward beneath the workings from the McKay shaft.

The McKay shaft, vertical to a depth of 23 feet, then inclined 80° N., is 42 feet deep; a 117-foot drift extends eastward from the bottom of the shaft a distance of 105 feet and connects to the west with a stope from the R. H. D. shaft workings (fig. 2). In September 1953 the connection was closed by a cave in the drift. The bottom of an old shaft was entered 100 feet east of the McKay shaft; this opening has been timbered and its exact location could not be determined.

West of the McKay shaft the R. H. D. vein trends northwestward, and east of the shaft it trends slightly north of east (pl. 1B); the vein dips 60°–80° N. In the McKay shaft workings the vein is curved and has many irregular branches and splits, as shown on figure 2. Whereas the main vein trends roughly eastward, the subsidiary veins branch to the northeast or to the southwest; many branches roll into the foliation of the wall rocks and die out within a few feet from the main vein. Horses between splits in the vein typically are sheared and altered and at places are brecciated.

The main vein consists largely of white clay gouge, at places associated with some breccia, and sparse white quartz; near the shaft the vein contains as much as 2 inches of gray, fine-grained quartz.

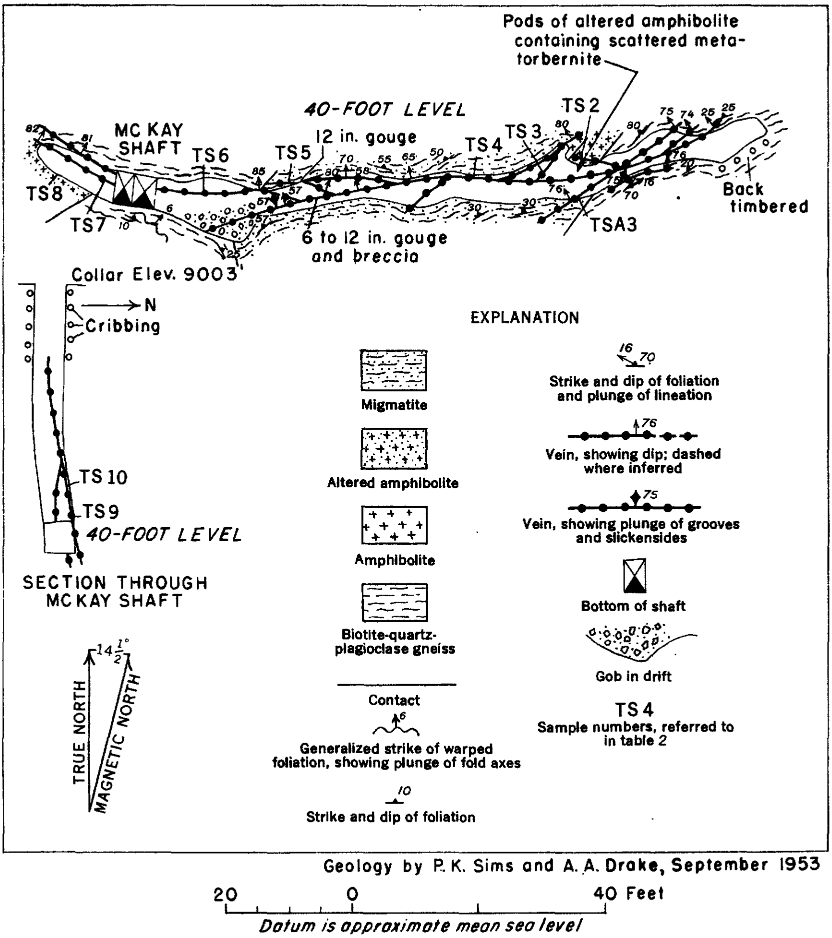

FIGURE 2.—Geologic map and section of McKay shaft, R. H. D. claim, Gilpin County, Colo.

The vein ranges in thickness from less than an inch to a maximum of about 12 inches. The subsidiary veins generally are less than 6 inches thick, and many are less than an inch thick. The vein is reported to contain local pockets of galena surrounded by cerussite, but sulfides were not observed by the writers. Van McKay (oral communication) reports that a small shoot containing free gold is present east of the McKay shaft.

The wall rocks consist predominantly of biotite-quartz-plagioclase gneiss, locally garnetiferous, which at places contains interlayers of granite pegmatite and pods of amphibolite. Most of the biotite-quartz-plagioclase gneiss and nearly all of the amphibolite have been intensely altered. The amphibolite has been altered to biotite and subsequently to a soft, green clay that when wet resembles olive-green soap. (See p. 17.) The biotite-quartz-plagioclase gneiss and associated pegmatite layers trend northeastward and on the average dip moderately northwestward. The amphibolite occurs within the gneiss in podlike bodies that are as much as 7 feet in diameter and which plunge gently northeastward. Most of the amphibolite bodies are too small to be shown on figure 2.

Abnormal radioactivity is widespread on the 40-foot level and in the lower part of the McKay shaft; uranium analyses are given in table 2. The radioactivity is caused by metatorbernite, except for sample TS7, which possibly contains kasolite.

Metatorbernite occurs sporadically along the R. H. D. vein and subsidiary branching veins but generally is not abundant; an exception is the hanging-wall vein in the lower part of the McKay shaft (fig. 2), where a vein, one inch wide, contains 0.19 percent chemical uranium. Substantial quantities of metatorbernite occur in altered amphibolite adjacent to the main vein or subsidiary veins. The metatorbernite primarily is concentrated in the margins of the altered biotitic amphibolite pods, but it is also disseminated through the green clay. A selected sample (TS2, table 2) of metatorbernite-bearing clay from a pod 68 feet east of the McKay shaft contains 0.24 percent chemical uranium. Other adjacent pods contain comparable, but generally somewhat smaller quantities of uranium. Small bodies of altered amphibolite near the shaft (samples TS8 and TS9) from a horse between two veins contain respectively 0.004 and 0.018 percent equivalent uranium (table 2).

TABLE 2.—*Uranium analyses from McKay shaft workings, R. H. D. claim*

[All locations are east of the shaft except those marked with *; these are west of the shaft. Analyses by Denver laboratory of the U. S. Geological Survey]

Field no.	Type of sample	Width (inches)	Material	Location (feet)	Equivalent uranium (percent)	Chemical uranium (percent)
TS2	Grab		Intensely altered amphibolite	68	0.18	0.24
TS3	Chip	6	Shear zone	62	.12	.14
TS4	Grab		Vein	52	.025	.025
TS5	Chip	8	do	20	.006	.003
TS6	do	12	do	7	.036	.033
TS7	Grab		Hydrous iron oxides	*2	.031	.034
TS8	do		Intensely altered amphibolite	*10	.004	
TS9	do		do	*2	.018	.011
TS10	Chip	1	Hanging-wall vein	At shaft	.15	.19
TSA3	do	4	Intensely altered amphibolite	69	.053	.062

Abnormal radioactivity extends to within 25 feet of the surface in the McKay shaft; above that altitude the vein is not radioactive and presumably the uranium, if ever present, has been leached. The radioactive material can be expected to extend to lower depths but possibly will not be found below the lower limit of the zone of oxidation.

TWO SISTERS MINE (8)

The Two Sisters shaft, on the north slope of Nigger Hill (pl. 1B), is the largest mine in the Nigger Hill area but like most others in the region has been closed for many years. In 1954, the Two Sisters shaft was caved at the collar and the mine was inaccessible. The mine workings, according to a private company report by Daniel Munday, consist principally of a 700-foot shaft, which is inclined about 75° SE., and three levels at depths of 100, 150, and 300 feet. Extensive stoping was done northeast of the shaft on the Two Sisters vein (?) from the 100-foot level to the surface, and gold ore valued at nearly $100,000 was extracted. West of the shaft, some stoping was done on the Claire Marie vein between the 100- and 150-foot levels, and Munday reports that ore valued at about $35,000 was removed. Apparently little, if any, stoping was done on the 300-foot level. West of the shaft on the 100-foot level, the workings on the eastward-trending Two Sisters vein connect to the workings on the northeast-trending Claire Marie vein through a crosscut about 60 feet long. According to the company report the drift to the west on the 100-foot level is 750 feet long, but it is probable that this drift is much shorter. On the 150-foot level the drift extends 70 feet to the east and 95 feet to the west; on the 350-foot level the drift extends 190 feet to the east and 75 feet to the west. Munday reported good showings of lead ore in the east drift, 300-foot level.

The St. Anthony shaft on the Two Sisters claim is near the east end line (pl. 1B) and apparently was sunk on the R. H. D. vein. According to the report by Munday, the St. Anthony shaft is 230 feet deep and drifts were driven from it at depths of 50 and 100 feet. At the 50-foot level the drift extends 60 feet southeastward and 35 feet northwestward; from the east drift the vein was stoped nearly to the surface. At the 100-foot level the drift extends 125 feet to the east and 40 feet to the west. According to Munday the westward drift on the 100-foot level crossed the Claire Marie vein 40 feet northwest of the shaft. If this is true, the Claire Marie vein must intersect the Two Sisters vein near the collar of the Two Sisters shaft; possibly the shallow pits that are alined northeasterly between the Two Sisters and St. Anthony dumps were dug on the Claire Marie vein (pl. 1B) north of its intersection with the Two Sisters vein.

The Two Sisters shaft was sunk at the approximate junction of the northeastward-trending Claire Marie vein and the eastward-trending Two Sisters vein. The Two Sisters vein was prospected to shallow depths in the pits west of the Two Sisters shaft, south of the road (pl. 1A). East of the Two Sisters shaft the Two Sisters vein (?) was mined in "grass root" stopes. In these workings the vein makes a very flat S-shaped bend, changing in strike from N. 86° E. to N. 70° E. and back to N. 86° E. This dip ranges from 68° to 75° SE. Probably the vein joins with the R. H. D. vein in the vicinity of the McKay shaft, but this cannot be proved (pl. 1B). In the open stope 160 feet east of the Two Sisters shaft the vein trends N. 70° E. and dips 75° S. where the stope is from 3 to 4 feet wide, but is from 5 to 6 feet wide where the trend is N. 86° E. and the dip is 68° S.

Bastin and Hill (1917, pl. 4) classified the Two Sisters vein as a gold-silver vein of the galena-sphalerite type. So far as known galena and sphalerite are the predominant metallic minerals, with smaller quantities of pyrite. Free gold is present, at least in the near-surface part of the vein.

Substantial quantities of metatorbernite and kasolite are present on the Two Sisters mine dump; no pitchblende was found. Most of the uranium-bearing material is near the toe of the dump, near the shaft on the west side, and on the east side of the lobe that extends east from the shaft (pl. 1B). The dump contains a minimum of 3.5 tons of material of ore grade.

The metatorbernite occurs primarily in a distinctive, green altered biotite-quartz-plagioclase gneiss, but also is present in smaller quantities in other rock types. Although most of the metatorbernite is disseminated through the altered gneiss, it also is present along fractures in the rock. A description of the relation of the uranium mineral to the host rock has been given on pages 17–18. Analyses of selected pieces of metatorbernite-bearing altered biotite-quartz-plagioclase gneiss (N44, N44–A, N44–C, table 1) indicate a range from 1.42 to 6.11 percent chemical uranium. The equivalent-uranium content of the samples is from 8 to 25 percent less than the chemical uranium.

Kasolite is much less abundant than metatorbernite; most of it is in the west side of the dump near the shaft. The kasolite occurs in vugs within hydrous iron-rich vein material that resembles gossan and to a lesser extent as coatings on fractures in altered vein material. An analysis of a selected kasolite-bearing specimen (N44–B, table 1) of the most radioactive material indicated 2.6 percent equivalent uranium and 3.05 percent chemical uranium.

Because the mine is inaccessible, an evaluation of the uranium deposit must be based entirely upon the known geology of the region. It is probable that the biotite-quartz-plagioclase gneiss that is the principal host rock for the metatorbernite constitutes less than 5 percent of the wall rocks in the mine. It also is likely that the uranium is mainly confined to the upper part of the mine, within the zone of oxidation; the depth of this zone is unknown. To judge from the high proportion of altered rocks on the dump, it is quite possible, however, that the oxidized zone extends to the 150-foot level.

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