

Wall-Rock Control of Certain Pitchblende Deposits in Golden Gate Canyon, Jefferson County Colorado

GEOLOGICAL SURVEY BULLETIN 1030-G

*This report concerns work done on behalf
of the U. S. Atomic Energy Commission
and is published with the permission of
the Commission*



Wall-Rock Control of Certain Pitchblende Deposits in Golden Gate Canyon, Jefferson County Colorado

By JOHN W. ADAMS *and* FREDERICK STUGARD, JR.

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

G E O L O G I C A L S U R V E Y B U L L E T I N 1 0 3 0 - G

*This report concerns work done on behalf
of the U. S. Atomic Energy Commission
and is published with the permission of
the Commission*



UNITED STATES DEPARTMENT OF THE INTERIOR

Fred A. Seaton, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

CONTENTS

	Page
Abstract.....	187
Introduction.....	187
Geology.....	190
Petrography of the wall rocks.....	191
Hornblende gneiss.....	191
Quartz-biotite gneiss.....	191
Breccia reefs.....	194
Ore deposits.....	195
Union Pacific deposit.....	195
Mineralogy of the ore.....	195
Ore minerals.....	195
Gangue minerals.....	199
Paragenetic history.....	200
Wall-rock control at the Union Pacific deposit.....	202
Buckman adit deposit.....	205
Discussion of pitchblende deposition.....	206
Conclusions.....	207
Literature cited.....	208

ILLUSTRATIONS

	Page
PLATE 11. Geologic map and section of the Union Pacific deposit, Jefferson County, Colo.....	In pocket
12. A, Photomicrograph of thin section of ore from Union Pacific deposit; B, Photomicrograph of polished section.....	Faces 198
13. Photomicrographs of polished sections.....	Faces 199
FIGURE 45. Index map of central Colorado showing location of Golden Gate Canyon and Ralston Creek areas.....	188
46. Geologic sketch map showing distribution of uranium oc- currences in the Golden Gate Canyon area, Jefferson County, Colo.....	189
47. Camera lucida drawing of ore showing localization of tennan- tite by earlier pyrite.....	198
48. Chemical changes during alteration of gneiss.....	201
49. Paragenesis of the minerals at the Union Pacific deposit.....	203
50. Geologic map of adit, Buckman deposit.....	205

TABLES

	Page
TABLE 1. Rock analyses, Union Pacific deposit, Jefferson County, Colo-----	192
2. Spectrographic and uranium analyses of rocks and ore, Golden Gate Canyon area-----	193

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

WALL-ROCK CONTROL OF CERTAIN PITCHBLENDE DEPOSITS IN GOLDEN GATE CANYON, JEFFERSON COUNTY, COLORADO

By JOHN W. ADAMS and FREDERICK STUGARD, JR.

ABSTRACT

Carbonate veins cutting metamorphic rocks of Precambrian age in the Golden Gate Canyon area, Colorado, contain pitchblende and base-metal minerals. The veins occupy extensive faults considered to be of Laramide (earliest Tertiary) age, but normally contain pitchblende only where they cut hornblende gneiss. At the Union Pacific deposit, which was studied in detail, pitchblende, hematite, and some ankerite formed before the sulfide minerals, except possibly for minor earlier pyrite. Base-metal minerals and the bulk of the ankerite vein filling were deposited after the pitchblende. Chemical analyses show a high ferrous iron content in the hornblende gneiss in contrast to low ferrous iron in the adjacent biotite gneiss. It is thought that ferrous iron released by alteration of hornblende was partly oxidized to hematite by the ore-bearing solutions and, contemporaneously, uranium was reduced and deposited as pitchblende.

In other veins that are not in hornblende gneiss, biotite or iron sulfide may have been similarly effective in precipitating pitchblende. Apparently both the ferrous ion and the sulfide ion can serve as reducing agents and control pitchblende deposition. Conditions that seem favorable for uranium deposition include those where uranium-bearing solutions had access to rocks rich in ferrous iron or preexisting sulfide minerals.

INTRODUCTION

Pitchblende and secondary uranium minerals are found in vein deposits in northern Jefferson County, Colo. The deposits, which were recently discovered, occur in or near Laramide fault zones that cut gneiss, schist, and pegmatite of Precambrian age. They have been found in two areas about 6 miles apart (fig. 45); the northern or Ralston Creek area contains the Schwartzwalder (Ralston Creek) mine now being actively worked, the North Star mine, the Nigger Shaft, and several other more recently discovered deposits. Eight occurrences of uranium minerals are known in the southern or Golden Gate Canyon area and include the Union Pacific, Buckman, and Ladwig deposits. Pitchblende is the most abundant uranium mineral

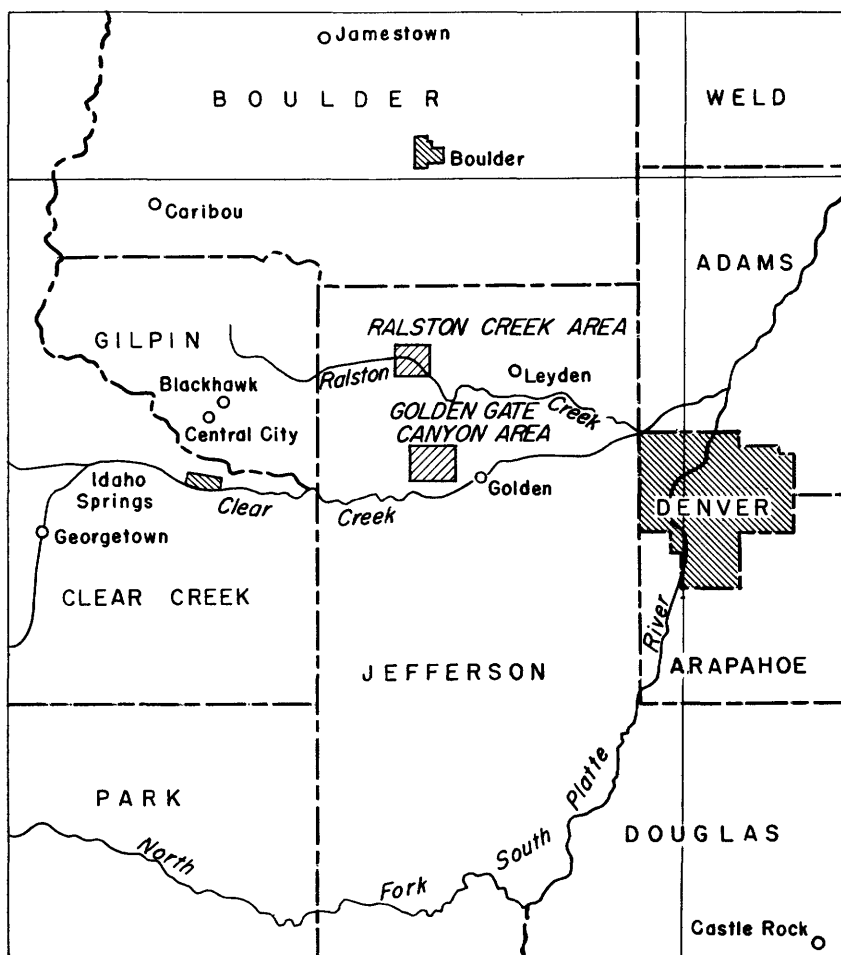
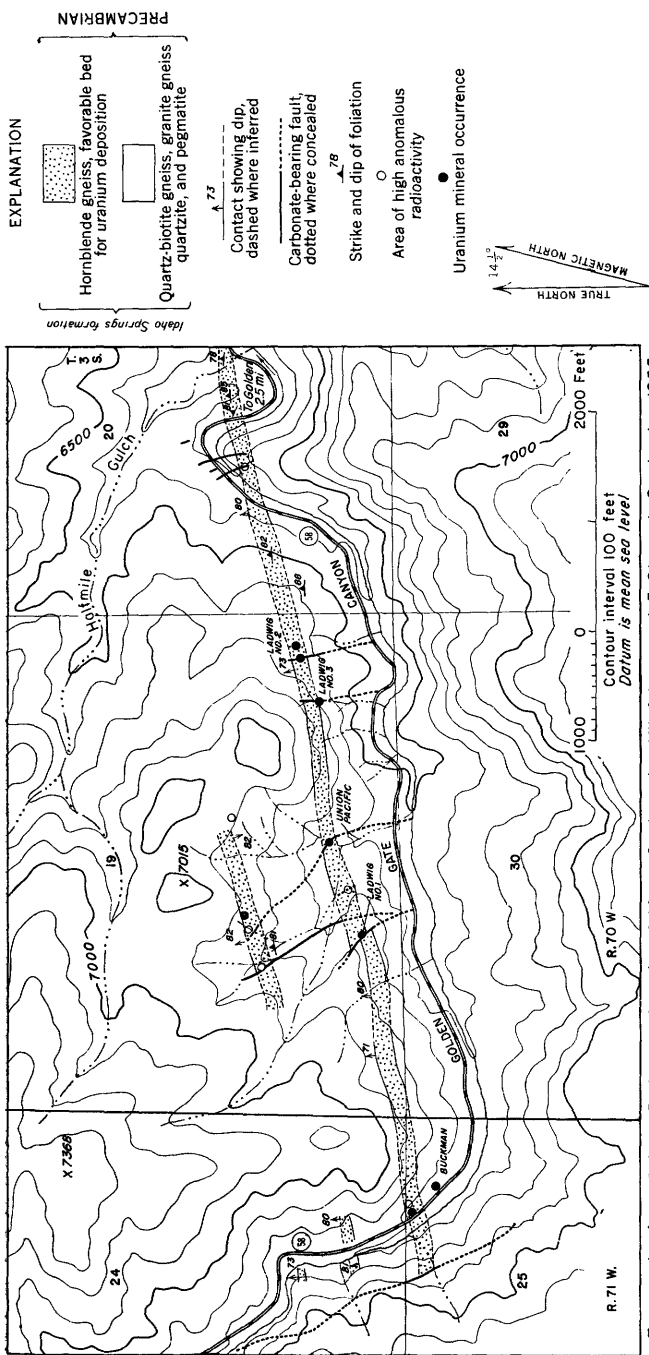


FIGURE 45.—Index map of central Colorado showing location of Golden Gate Canyon and Ralston Creek areas.

in the deposits and is associated with copper minerals in a carbonate gangue with quartz and potash feldspar. Lead and zinc minerals are present in the ore but are not abundant.

A preliminary investigation of these deposits (Adams, and others, 1953) was made in 1952–53 as part of the study of uranium deposits undertaken by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission. During this study it was noted that most of the occurrences of uranium minerals and of high radioactivity anomalies in the Golden Gate Canyon area (fig. 46) were found where fault zones crossed a single bed of hornblende gneiss 100–150 feet thick. No significant radioactivity has been found along the same fault zones where they pass through other rocks.



As the preliminary data indicated "favorable" and "unfavorable" rock types, further investigations were made to establish, if possible, the reason for the apparent wall-rock control. Although the field and laboratory studies of this problem were concerned primarily with the Golden Gate Canyon area, notably the Union Pacific deposit, the results may be found applicable to uranium occurrences in other environments. For the present investigation, a map was made on a scale of 1 inch to 1,000 feet (fig. 46) to show the distribution of the known uranium occurrences in relation to the hornblende gneiss beds and breccia zones. A geologic map of the Ralston Buttes quadrangle (scale, 1:24,000), which includes the Golden Gate Canyon and Ralston Creek uranium areas, is now in preparation by the U. S. Geological Survey.

GEOLOGY

The rocks in the Golden Gate Canyon area include Precambrian hornblende gneiss, quartz-biotite gneiss, granite gneiss, quartzite, and pegmatite. Intrusive rocks of Tertiary age, such as are found in the Central City district (Phair, 1952), have not been recognized.

Hornblende gneiss and quartz-biotite gneiss are the rock types most closely associated with the uranium deposits. Both are similar in outcrop appearance and show distinct foliation that strikes about N. 80° E. and dips steeply north. These rocks are cut by several northwestward-trending faults characterized by carbonate-potash feldspar vein filling. The faults presumably are of Laramide age and are related to the highly siliceous breccia "reefs" or "dikes" of similar trend mapped by Lovering and Goddard (1950). One such fault on the west side of Golden Gate Canyon in secs. 24 and 25 (fig. 46) probably is a southern extension of the Hurricane Hill breccia reef, a structure that has been traced for almost 20 miles to the northwest (Lovering and Goddard, 1950, pl. 2). The relationship between the breccia reefs and the uranium deposits will be discussed in another section of this report.

The geology of an area including and extending north of Golden Gate Canyon has been mapped by Gabelman¹ on a scale of about 1 inch to 850 feet. As a result of his work, Gabelman believed the granite gneiss to be the marginal facies of a granitic intrusion lying south of Golden Gate Canyon and the other metamorphic rocks to represent the south limb of a large truncated synclinal fold. The other limb of the fold is believed to lie several miles to the north.

¹ Gabelman, J. W., 1948, The geology of the Golden Gate-Van Bibber Creek area, Jefferson County, Colo.: Unpublished thesis in files of Colo. School of Mines, Golden, Colo.

PETROGRAPHY OF THE WALL ROCKS

Field studies indicate that most of the uranium deposits in Golden Gate Canyon occur in hornblende gneiss in an area of predominant quartz-biotite gneiss; therefore these rocks were studied in detail by petrographic, spectrographic, and chemical methods. These two types of rocks are described below.

HORNBLENDE GNEISS

In the area studied, hornblende-plagioclase-quartz gneiss occurs in two main beds about 100 feet thick and in a few narrow layers in the adjoining quartz-biotite gneiss. The rock, which will be called hornblende gneiss, is fine grained and well foliated and in outcrop appears black or dark gray. Hand specimens show banding or layering of dark and light minerals, but these bands generally do not exceed a few millimeters in thickness. Biotite may be abundant along individual foliation planes, but it is a minor constituent of the rock. At the Union Pacific deposit, and presumably elsewhere, the rock contains small epidote-bearing lenses and a few narrow quartz stringers, neither sufficiently abundant to affect the bulk composition of the rock. The hornblende gneiss is uniform in composition as determined by examination of several thin sections; three typical modes are as follows:

	<i>Percent by volume</i>		
Hornblende.....	41	48	50
Plagioclase (andesine).....	42	35	37
Quartz.....	14	14	10
Opaque minerals.....	2	2	2
Others.....	1	1	1

Apatite is the most abundant nonopaque accessory mineral. Biotite, as previously noted, is common along some foliation planes and may be of secondary origin. Sphene, zircon, and garnet are less common than apatite. The opaque minerals as determined by polished-section methods and X-ray powder patterns are chiefly ilmenite and magnetite containing minor amounts of pyrite and chalcopyrite. The magnetite and ilmenite may be partly altered to hematite.

The results of chemical and spectrographic analyses of channel samples of the hornblende gneiss are given in tables 1 and 2.

QUARTZ-BIOTITE GNEISS

The term quartz-biotite gneiss is applied in this report to the bulk of the layered metamorphic rocks adjoining the hornblende gneiss beds in the Golden Gate Canyon area. They are, for the most part, lighter in color than the hornblende gneiss and tend to be more massive with fewer foliation planes per unit thickness. Although variable in mineral proportions, all are characterized by the presence

of biotite and the absence of hornblende. The fabric of the quartz-biotite gneiss layers commonly is granoblastic but may be locally gneissic. The following mode is typical of the granoblastic rock in the vicinity of the Union Pacific deposit:

	Percent by volume
Quartz.....	30
Plagioclase (albite-oligoclase).....	50
Biotite.....	20
Others.....	<1

Apatite is the most abundant accessory mineral in the rock represented by this mode, but, including zircon and opaque mineral grains, constitutes less than 1 percent of the total composition. Calcite, sphene, clinozoisite, and epidote have been noted in the thin sections.

In the less common gneissic beds, most of the biotite is restricted to thin bands separated and commonly crosscut by layers of quartz, plagioclase, and microcline. The laminated rock apparently was derived from the injection of silicic igneous material into the granoblastic quartz-plagioclase-biotite gneiss. Thin and polished sections show that the biotite rocks contain about one-third as much opaque material as the hornblende rocks and that most of this is magnetite or magnetite-hematite intergrowths. The results of the spectrographic and chemical analyses of a composite sample representing 100 feet of the biotite gneiss at the Union Pacific deposit are given in tables 1 and 2.

TABLE 1.—*Rock analyses, Union Pacific deposit, Jefferson County, Colo.*

[Lucille M. Kehl, analyst]

Field no.	Description of rock					SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	
JWA-64-53...	Biotite gneiss.....					68.92	14.55	1.95	2.89	1.50	2.25	
JWA-77-53...	Hornblende gneiss. Composite sample representing 25.8-foot chip channel. East side of fault zone.					54.86	14.65	4.66	7.99	3.40	6.67	
JWA-82-53...	Hornblende gneiss. Chip channel across 11.4 feet of gneiss 130 feet west of fault zone.					55.78	13.82	4.85	8.55	2.84	6.34	
JWA-73-53...	Altered hornblende gneiss. Chip channel across 5 feet of altered rock underlying JWA-77-53.					51.70	18.06	12.36	.16	1.15	2.41	
JWA-3-54...	Breccia "reef" material. Composite sample of fresh rock from mine dump.					32.87	9.10	.45	10.57	5.60	12.03	

Field no.	Na ₂ O	K ₂ O	H ₂ O—	H ₂ O+	TiO ₂	CO ₂	P ₂ O ₅	S	MnO	Total	Less O for S	Adjusted total
JWA-64-53...	3.87	2.52	0.10	0.72	0.45	0.09	0.13	0.02	0.08	100.04	0.01	100.03
JWA-77-53...	3.28	.79	.30	1.35	1.41	.05	.31	.02	.22	99.96	.01	99.95
JWA-82-53...	3.32	.67	.27	1.33	1.58	.04	.41	.01	.24	100.05	-----	-----
JWA-73-53...	2.46	3.30	1.93	3.74	1.72	.17	.25	.01	.28	99.70	-----	-----
JWA-3-54...	.21	7.13	.15	.23	.81	20.58	.36	-----	.29	100.38	-----	-----

TABLE 2.—Spectrographic and uranium analyses of rocks and ore, Golden Gate Canyon area, Jefferson County, Colo.¹

[A single asterisk (*) indicates spectrographic analysis by G. W. Boyes, Jr. A double asterisk (**) indicates spectrographic analysis by R. G. Havens]

Field no.	Description of sample	eU	U	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ag	As	Ba	Be	Bi
JWA-84-53	*Biotite gneiss. Composite of chip samples at 3-foot intervals for 100 feet. ³	0.002	-----	XX.0	XX.0	X.0	0.X	0.0X+	X.0-	X.0-	X.0-	0	0	0.0X+	0	0	0
JWA-82-53	*Horriblende gneiss. Channel sample across 11.4 feet. ³	4.001	-----	XX	XX	X+	X+	X+	X+	X+	X-	X+	0	0.X-	0	0	0
JWA-73-53	*Altered horriblende gneiss. ³	2.000	-----	XX	XX	X+	X+	X+	X+	X+	X-	X	0	0.X	0.00X+	0	0.00X-
JWA-3-54	*Dycedra reef material, 5-pound dump sample from Union Pacific deposit. ³	-----	-----	X+	-----	X	X-	0X+	X	X-	X	X	Tr.	0	0.00X+	Tr.	0.00X-
JWA-90-53	**Hurricane Hill reef; 12-foot channel deposit. ³	5.009	0.004	XX	X+	X+	X	X-	X	X-	X-	X+	0	0	0.X	0.00X-	0
JWA-92-53	**Bentonite west of Union Pacific reef; 750 feet NW of Union Pacific deposit; 3-foot channel sample. ³	5.006	0.001	XX	X+	X	X	X-	X	X-	X-	X+	0	0	0.X+	0	0
JWA-94-53	**Reef 700 feet NW of Union Pacific deposit; 40-inch channel sample. ³	5.004	0.001	XX	X+	X+	X-	0X+	X+	X+	X+	X+	0	0	0.X-	0	0
UP- 4-52	*Pitchblende-bearing ore from Union Pacific deposit. ³	-----	-----	-----	X	X	X	X	X+	X+	X	X	0.X-	X+	X-	0	X+

Field no.	Co	Cr	Cu	Ga	La	Mo	Nb	Ni	Pb	Sb	Sc	Sr	U	V	Y	Yb	Zn	Zr
JWA-84-53	0.00X-	0.00X-	0.00X	Tr.	Tr.	0	0	0.000X+	0.00X-	0	0.00X-	0.0X-	0	0.00X	0.00X	0.000X	0	0.0X-
JWA-82-53	0.0X	0.00X+	0.00X+	0.0X-	0	0	0	Tr.	0	0	0.0X	0.0X-	0	0.00X+	0.00X	0.000X	0	0.0X-
JWA-73-53	0.0X	0.00X+	0.00X	0.0X-	0	Tr.	0	0.00X+	0.0X	0	0.0X	0.0X-	0	0.0X	0.00X	0.000X	0	0.0X-
JWA-3-54	0.0X	0.0X	0.0X	Tr.	0	0	0	0.00X+	0.0X	0	0.0X	0.0X-	0	0.00X+	0.00X	0.000X	0	0.0X-
JWA-90-53	0.0X	0.00X-	0.00X	0.00X+	0	0	0.00X-	0.00X	0.0X	0	0.0X	0.0X-	0	0.00X+	0.00X	0.000X	0	0.0X-
JWA-92-53	0.00X+	0.00X	0.00X	0.00X+	0.00X	0	0.00X	0.00X	0.0X	0	0.0X	0.0X-	0	0.00X	0.00X	0.000X	0	0.0X-
JWA-94-53	0.00X+	0.00X	0.00X	0.00X+	0.00X	0	Tr.	0.00X	0.0X	0	0.00X	0.0X-	0	0.0X	0.00X	0.000X	0	0.0X-
UP- 4-52	-----	0.00X+	X	0	0	0X	0	0.000X	X-	X	0.000X	0.0X-	X+	0.00X+	0.0X	0.00X+	X	X-

¹ The concentrations are reported as elements, not as oxides or compounds.

The following classification is used for the spectrographic data, in percent:

X+ = 10

X = 0.46-1.0

X- = 0.215-464

X = 5.04-10

X = 2.0-4.64

X- = 1.0-2.15

Tr. = Near threshold amount.

² Analysts: J. W. Patton, J. P. McCurk, and Wayne Mountjoy.³ Other elements looked for but not found: F, Au, B, Cd, Ca, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Ta, Th, Ti, Tl, U, W.⁴ Analyst: J. W. Patton.⁵ Analyst: S. P. Farnham.⁶ Analysts: Jesse Meadows, J. P. Schuch.

BRECCIA REEFS

The composition and character of the breccia reefs are of special interest because the uranium deposits are believed to be genetically related to them. The major reefs are presumably the southern extensions of structures along which faulting and silicification took place during the Laramide orogeny (Lovering and Goddard, 1950, p. 216-217). There is, however, a marked difference between the composition and appearance of the reefs to the north as compared with their presumed southern extensions. The northern reefs are highly siliceous and ferruginous and form resistant wall-like outcrops composed chiefly of iron-stained quartz. The southern reefs are not siliceous but consist of carbonate-potash feldspar as a fine-grained groundmass enclosing rock fragments that have been replaced in varying degrees by these minerals. Because of its carbonate content, the reef material is subject to more rapid chemical weathering than the country rocks, and good outcrops are uncommon. Typical exposures are reddish brown, and breccia fragments stand out in relief above the groundmass; the color is the result of the oxidation of iron from ankerite. Where unweathered, the rock is almost white and is compact and tough.

The chemical and spectrographic analyses of reef material (tables 1 and 2) show that it contains abundant potash. Part of this potash can be attributed to the included wall-rock fragments, but much presumably has been introduced. The reef material from the shaft at the Union Pacific deposit contains many fragments of the enclosing hornblende gneiss. These fragments retain the fabric of the gneiss, but of the original mineral components only quartz remains. The hornblende has been converted to an extremely fine grained material, presumably carbonate, and the plagioclase is replaced by potash feldspar, possibly by a base-exchange reaction.

The fine-grained groundmass of the reef material is probably composed of a carbonate having the approximate composition of ankerite, and an orthoclase-type feldspar. These two minerals, followed by later calcite, apparently are the products of a widespread introduction of hydrothermal solutions into not only the major faults but also the many presumably contemporaneous smaller subparallel fractures.

It was formerly thought (Adams, and others, 1953, p. 8) that the copper and uranium minerals found along the reefs were introduced late in the period of carbonate deposition. The study of the Union Pacific deposit now makes it appear more likely that the principal ore minerals were introduced early in the hydrothermal process and that the bulk of the fault-filling occurred after ore deposition.

The scope of this investigation did not permit more than a limited study of the reefs, but it is apparent that a better understanding of these structures would be of material aid in the search for additional uranium deposits. If the carbonate-potash feldspar reefs are extensions of the siliceous reefs, a significant temperature-zoning pattern might be established to delineate areas favorable for uranium deposition.

ORE DEPOSITS

Except for some recently discovered occurrences in the Ralston Creek area, the known uranium vein deposits in northern Jefferson County have been described by Adams and others (1953). For this reason mention will be made of the geology of only those deposits reexamined for the purposes of this investigation; namely, the Union Pacific and Buckman adit deposits.

UNION PACIFIC DEPOSIT

At the Union Pacific deposit (pl. 11), pitchblende and base-metal minerals occur along the hanging wall of a carbonate-potash feldspar reef which cuts hornblende gneiss. The pitchblende-bearing rock exposed in the mine workings is less than half a foot thick but may contain as much as 5 percent uranium. Only the leached oxidized exposure of the vein is now accessible because the shaft is filled with water. So far as is known, the ore is confined to the hornblende gneiss, which at the deposit forms a steeply dipping bed about 100 feet thick. Quartz-biotite gneiss lies above and below the hornblende-gneiss unit.

MINERALOGY OF THE ORE

The ore mineral assemblage at the Union Pacific deposit may be representative of the uranium deposits in the two areas. Whether the mineralogy of an individual deposit is simple or complex, the association of pitchblende with copper sulfide and arsenide minerals is persistent. The ore minerals are also characterized by a fine-grained texture in which individual mineral grains commonly are less than a millimeter in diameter and may require polished-section techniques for identification and study.

ORE MINERALS

Pitchblende.—Pitchblende is the only uranium mineral that has been found at the deposit. In polished section it shows a uniform high reflectivity and gray color somewhat lighter than tennantite with which it is commonly associated. The pitchblende is seldom recognizable to the unaided eye unless it is present in the form of

films which may be several millimeters thick and occupy fractures in iron-stained altered gneiss. These pitchblende films commonly include minute euhedral crystals of carbonate and may coat crystals of potash feldspar (pl. 12A) that have grown from the walls of fractures. Ore showing pitchblende films contains only sparse sulfides and probably formed in the outer edge of the ore zone. In a more common type of ore, the pitchblende, which is not discernible without the use of the ore microscope, occurs in colloform masses that commonly are less than 0.1 millimeter in diameter and densely coat crystals of ankerite of comparable dimensions (pl. 12B). The pitchblende-ankerite veinlets are irregularly distributed through intensely altered wall rock and are replaced in varying degrees by later sulfide minerals (pl. 13A). This second type of ore probably formed in the fractured wall rock near the central channelway, but this could not be confirmed because of the present inaccessibility of the pitchblende-bearing area in the Union Pacific shaft.

Hematite.—Finely dispersed hematite gives the hydrothermally altered rocks of the deposit a characteristic brick-red color. It appears to be most abundant in the altered feldspar and was formed from iron progressively released first from the hornblende and later from chlorite. Like pitchblende, hematite was deposited on some of the vein orthoclase crystals. This hematite formed aggregates of transparent bright-red crystals. Platy intergrowths of hematite and pyrite replace hornblende or the opaque minerals of the gneiss. These intergrowths are the centers for deposition of late copper minerals.

Tennantite.—Tennantite, probably the most abundant copper mineral in the deposit, occurs in discontinuous veinlets that rarely exceed 1 millimeter in width. In polished section the tennantite is light gray and gives a red powder when scratched. The mineral probably is in the tennantite end of the tetrahedrite series because of the 4:1 arsenic to antimony ratio in a typical specimen of the ore. As no other arsenic-antimony minerals are known in the ore, the ratio is assumed to apply to the tennantite. The identification was confirmed by X-ray powder pattern.

Chalcopyrite.—Chalcopyrite, which is next to tennantite in abundance, replaces the earlier pitchblende-carbonate veinlets. The textural relationship observed in polished sections indicates that chalcopyrite was deposited both before and after tennantite. The early chalcopyrite is found in fine-grained intergrowth with bornite, covellite, galena, sphalerite, and emplectite(?). These intergrowths appear as isolated patches engulfed by tennantite. The late chalcopyrite commonly occurs as rims or as isolated grains along the margins of tennantite areas. Where the rim structure is formed,

chalcopyrite has apparently invaded existing interfaces between tennantite and pitchblende. Shrinkage of the pitchblende and formation of concentric and radial cracks may have afforded channels through which the chalcopyrite could migrate and replace the carbonate gangue of the early pitchblende veinlets. Plate 13B shows a relatively large carbonate crystal almost completely replaced by chalcopyrite.

Bornite, chalcocite, and covellite.—Bornite, chalcocite, and covellite are the three most abundant minerals of the early sulfide assemblage. Except for the presumably supergene replacement of much of the bornite and chalcocite by covellite, the relationship is problematical. The bornite commonly contains blades of chalcopyrite in a textural pattern that has been ascribed to exsolution (Edwards, 1947, fig. 79); the chalcopyrite of these intergrowths does not extend beyond the grain boundaries of the bornite.

Sphalerite.—Sphalerite is sparse in the ore, appearing as irregular grains that have a brown, mottled, nonmetallic appearance with crossed nicols. The largest sphalerite grain seen in polished specimens of the ore was approximately 0.3 millimeter in maximum dimension. Sphalerite probably was one of the early suite of sulfide minerals, more abundant before replacement by tennantite and late chalcopyrite.

Galena.—Galena is commonly associated with sphalerite but is the less abundant of the two minerals. Like sphalerite it is considered one of the early-formed minerals.

Emplectite.—Emplectite (CuBiS_2) was tentatively identified in the ore. The mineral occurs intergrown with chalcopyrite in irregular patches in tennantite. The emplectite(?)—chalcopyrite intergrowths are extremely fine grained and, without high magnification, appear as a single mineral resembling chalcopyrite but of a somewhat paler color. Under high magnification, the chalcopyrite is seen to be intergrown with a mineral that is pale cream-yellow and shows brownish-green and violet interference colors. The mineral has a hardness about that of chalcopyrite and stains brown with HNO_3 .

Material removed from the pale yellow areas gave a microchemical reaction for bismuth. The powder tested unavoidably included some of the surrounding tennantite, but when tennantite apparently free of these minerals is similarly tested it reacts for antimony rather than bismuth. Spectrographic analysis of ore from the deposit indicates that bismuth is present in the same relative abundance as arsenic (table 2). As little emplectite(?) was found in the polished sections studied, it is probable that some bismuth may be contained in the tennantite.

Pyrite.—Pyrite is not abundant in the ore, and where present is found in minute grains intergrown with hematite. These intergrowths

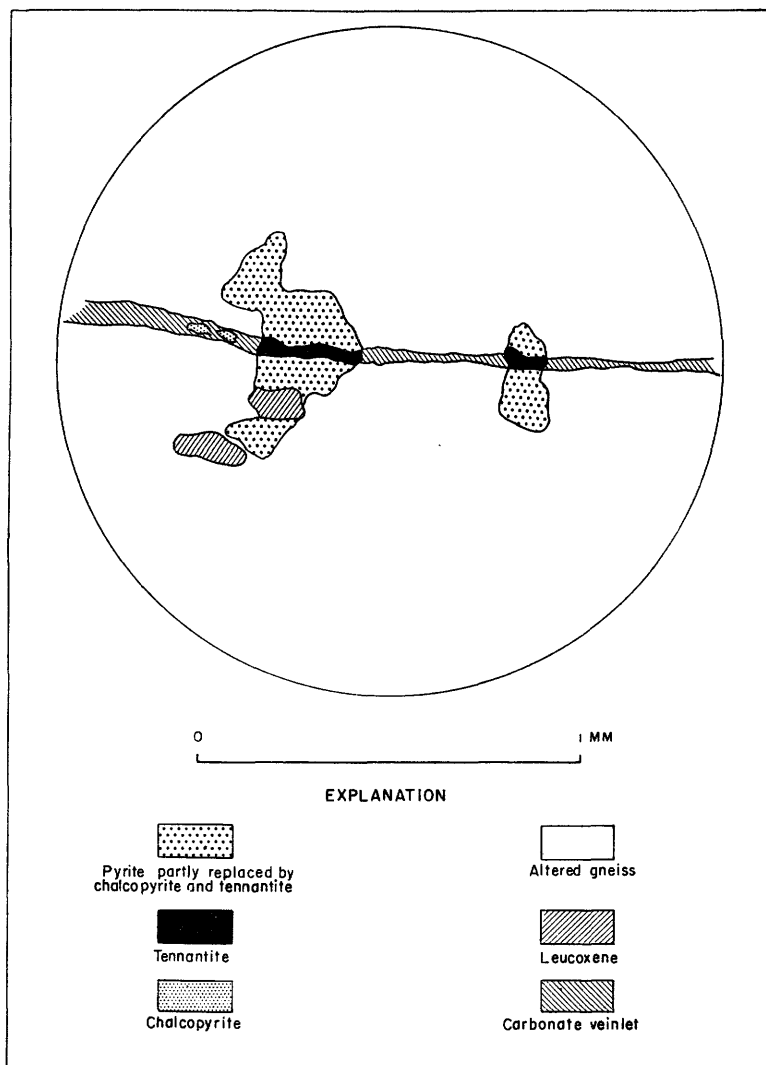
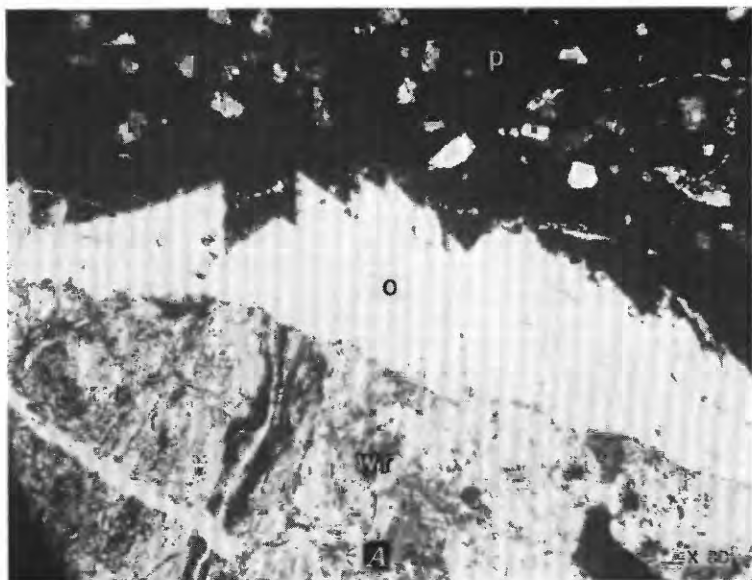
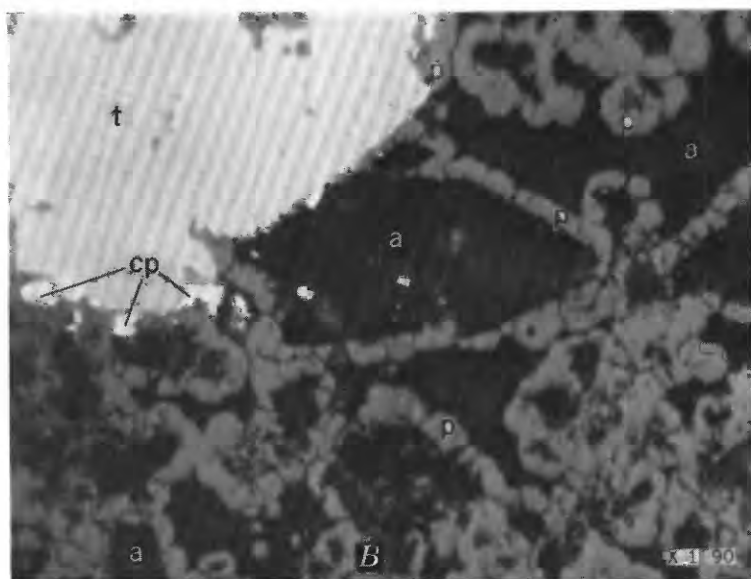


FIGURE 47.—Camera lucida drawing of ore showing localization of tennantite by earlier pyrite.

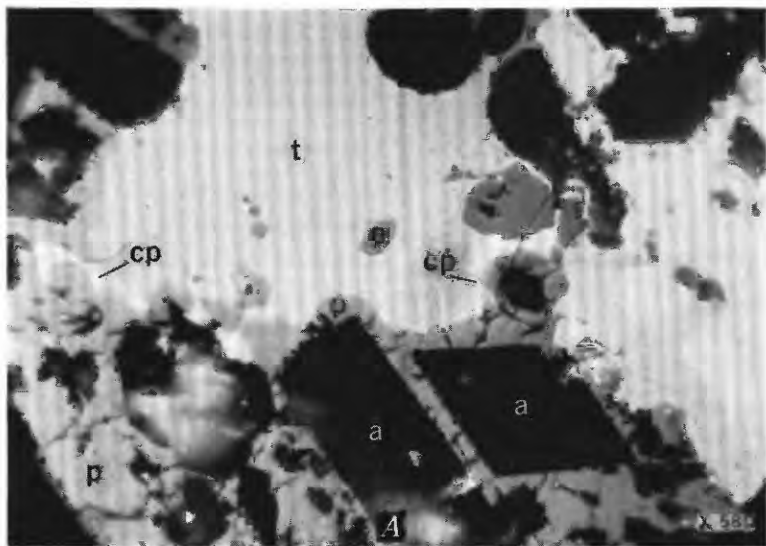
probably are relics of some of the original iron-bearing minerals of the hornblende gneiss. The shape of many of these intergrowths suggests that they were originally hornblende, but others may represent ilmenite or magnetite grains; these are commonly associated with leucoxene. The pyritization was probably an early reaction between the host rock and the first solutions introduced into the fault zone. Where the pyrite-hematite grains are transected by veinlets containing copper minerals, replacement of the pyrite is discernible



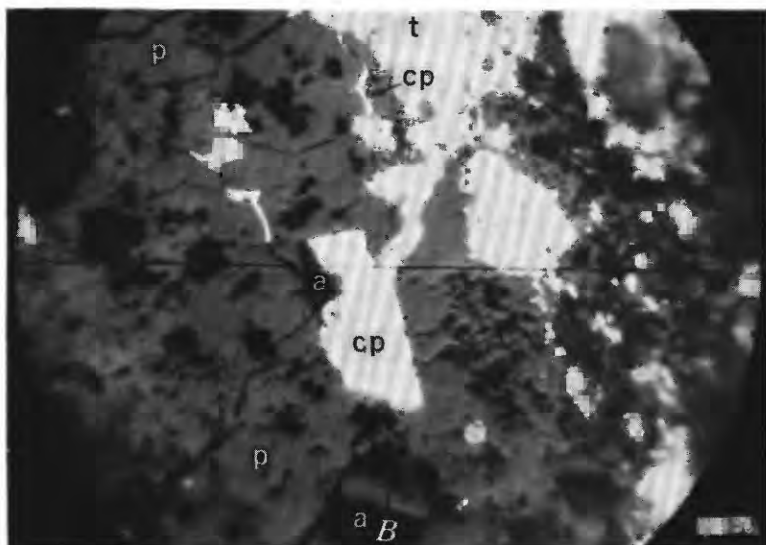
A. PHOTOMICROGRAPH OF THIN SECTION OF ORE FROM UNION PACIFIC DEPOSIT
Shows pitchblende (*p*) coating orthoclase (*o*) crystals formed on altered wall rock (*wr*). Plain light, $\times 80$.



B. PHOTOMICROGRAPH OF POLISHED SECTION
Shows typical pitchblende (*p*) ankerite (*a*) intergrowth, containing tennantite (*t*) and chalcopyrite (*cp*). $\times 190$.



A. Shows pitchblende (*p*) coating ankerite (*a*), both replaced by tennantite (*t*) and chalcopyrite (*cp*). $\times 580$.



B. Shows replacement of ankerite crystal (*a*) by chalcopyrite (*cp*) marginal to tennantite (*t*). Gray areas are pitchblende (*p*). $\times 580$.

PHOTOMICROGRAPHS OF POLISHED SECTIONS

(fig. 47), and no additional pyrite appears to have been deposited until the end of hydrothermal activity.

Very small grains of pyrite, probably deposited after the bulk of the ore minerals, are found throughout the main mass of the ankeritic breccia filling. These pyrite grains surround small calcite-filled cavities and fractures and probably represent the final stage of metallization. Deposition of pyrite rather than chalcopyrite, and calcite rather than ankerite, indicates that the solutions had become impoverished in copper and iron.

GANGUE MINERALS

Only a few gangue minerals of hydrothermal origin have been recognized in the ore. These include the carbonate minerals, ankerite and calcite, potash feldspar, chlorite, and minor sericite. Although quartz is a common constituent in the ore, and to a lesser degree in the carbonate vein filling, the rounded or fragmental grains are presumably derived from the wall rocks. Some vein quartz, however, has been noted in the Ralston Creek deposits.

Carbonate minerals.—A carbonate mineral close to ankerite in composition is common in the ore and breccia and for the most part was introduced after the ore minerals. Together with potash feldspar and pitchblende, ankerite makes up the early pitchblende-bearing veinlets. Little gangue was deposited with the copper minerals, and replacement of earlier carbonate minerals by chalcopyrite and tennantite is common. After deposition of the copper minerals, ankerite was formed abundantly until the reef filling was nearly complete. Then minor amounts of calcite were deposited. The ankerite was identified by X-ray powder pattern and is readily distinguished from calcite by staining with potassium ferrocyanide. Hydrothermal alteration of the hornblende in the wall rocks has produced an extremely fine grained white aggregate believed to be largely carbonate minerals.

Potash feldspar.—Potash feldspar is a characteristic mineral of the breccia and the associated pitchblende deposits. The exact nature of the feldspar has not as yet been determined, but it is presumably a variety of orthoclase, possibly adularia. Some grains, however, show an optic angle ($2V$) estimated to be between 20° and 30° so that an unusual type of feldspar may be present. Birefringence of the mineral is very low. The widespread distribution of potash feldspar in the altered wall rock and breccia filling is strikingly shown by staining rock slices or uncovered thin sections with sodium cobaltinitrite solution (Gabriel and Cox, 1929) and is further confirmed by the potash content of these rocks (table 1).

The orthoclase occurs both as replacements of anhedral plagioclase grains in the hornblende gneiss and as small crystals formed on fragments of brecciated gneiss. The crystals surrounding the breccia fragments are clear and transparent by comparison with the cloudy orthoclase (pl. 12A) formed by replacement. No euhedral orthoclase crystals have been recognized in the main mass of the carbonate vein filling, but the rock contains innumerable fragments of altered gneiss in which orthoclase is abundant. The observed relationship of orthoclase in the deposit leads to the conclusion that potash was introduced during the early stage of hydrothermal activity.

Chlorite.—A green mineral presumed to be a member of the chlorite group forms very fine grained aggregates in the ore and is relatively abundant below the zone of oxidation in the altered gneiss of the hanging wall. In a specimen of this gneiss containing pitchblende, the chlorite is confined to the pitchblende-coated gneiss fragments that have been isolated by carbonate veinlets. The chlorite and associated sericite are evidently products of a propylitization-type of rock alteration that preceded the introduction of uranium. Gneiss fragments in the carbonate breccia underlying the chlorite-bearing gneiss contain no chlorite, and it is assumed that the minerals of the earlier propylitization were largely destroyed by chemical action of concentrated carbonate-bearing solutions.

PARAGENETIC HISTORY

Studies of thin and polished sections of the rocks and ores indicate that a complex series of events was effective in the formation of the deposits.

Formation of the major faults and many other subsidiary fractures, such as that at the Union Pacific deposit, presumably took place during early Tertiary time. Open parts of these structures then became channelways for the migration of alkalic solutions of unknown source but of sufficient volume to deposit carbonate throughout fault zones miles long and from 1 to 20 feet wide. The effect of these solutions in regard to the ore deposition and wall-rock alteration will be considered here.

The first process in the formation of the ore is thought to have been propylitization of the hornblende gneiss. This resulted in the partial conversion of hornblende to chlorite and some sericitization of plagioclase. The sulfide ion concentration of the solutions was probably low as only a very little pyrite was formed from the breakdown of the iron-bearing minerals, thus permitting any excess iron to deposit as hematite.

The extent of the original propylitization is indicated by the outcropping zone of bleached gneiss, 2-5 feet thick, lying above the

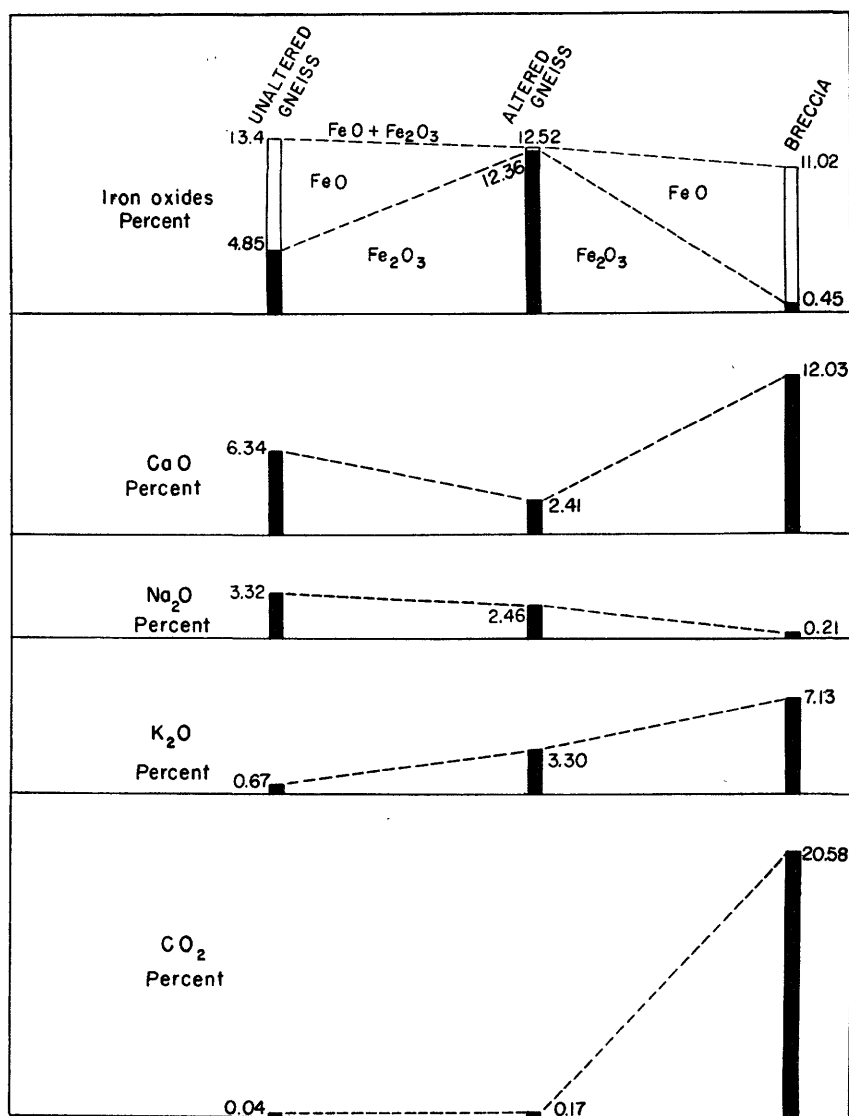


FIGURE 48.—Chemical changes during alteration of gneiss.

central carbonate breccia filling; the footwall bleached zone is not as well exposed but is probably of comparable width.

Following, or perhaps during, propylitization, solutions were introduced that raised the potash content of the gneiss from less than 1 to more than 3 percent (fig. 48). The added potash is in part contained in small clear crystals of orthoclase that line fractures in the rock, but as much or more of the potash may be replacing the soda of the original plagioclase. This alteration of the plagioclase is shown

by the distribution of potassium as indicated by staining and also by the decreased soda content of the gneiss after alteration (fig. 48). The replacement of plagioclase by potash feldspar has been described by Fenner (1936) and Steiner (1953) as a process of rock alteration resulting from hot-spring activity.

The precipitation of uranium followed potassic alteration and coincided with the beginning of a carbonate phase. This is shown by the deposition of pitchblende on orthoclase crystals and its intergrowth with ankerite. The reduction of U^{+6} ions to U^{+4} by the Fe^{+2} ions released by the breakdown of (1) hornblende and (2) chlorite probably caused the precipitation of uranium. Gruner (1952) has experimentally produced pitchblende and hematite by reduction of U^{+6} by Fe^{+2} ; hematite formed only when the pitchblende was synthesized in an H_2S -free environment. In the ore deposit, pitchblende and hematite (later ankerite) were deposited at essentially the same time and before the formation of the sulfide minerals with the exception of the very minor pyrite formed during propylitization.

After depletion of the available uranium, several simple copper sulfide minerals, sphalerite, galena, and emplectite(?) were deposited in an intricate network of fractures that only in part follow the original pitchblende-bearing veinlets. Deposition of these sulfide minerals was followed by tennantite replacement. It is questionable whether this replacement was part of a continuous period of sulfide deposition or whether a "rest interval" took place. Polished-section relationships favor discontinuity with a new wave of solution containing arsenic and antimony in addition to copper and iron migrating along the margins of preexisting veinlets. On the depletion of the arsenic and antimony, sufficient copper remained so that chalcopyrite again formed locally throughout the tennantite and along grain boundaries of tennantite and other minerals. With the deposition of chalcopyrite the sulfide mineralization waned, and a vigorous carbonate phase began which was to continue until the close of hypogene activity. The bulk of the carbonate deposited was extremely fine grained ankerite, succeeded at the last by somewhat coarser grained calcite. The calcite, which is sparse, forms veinlets and fills cavities in the ankerite. Minute pyrite crystals that formed along the edges of the calcite-filled openings indicate that a very weak sulfide phase marked the transition between the two carbonate minerals. Figure 49 is a graphic representation of the paragenesis of the deposit.

WALL-ROCK CONTROL AT THE UNION PACIFIC DEPOSIT

The ore occurrence at the Union Pacific deposit is, so far as is known, confined to hornblende gneiss wall rocks. This localization, repeated

Minerals	Propylitization stage	Vein stage	
Pyrite	—		—
Chlorite	—		
Leucocene	—		
Ankerite	? — — — — —	— — — — —	
Potash feldspar	? — — — — —		
Pitchblende		— — — — —	
Hematite	? — — — — —		
Chalcopyrite			— — — — —
Bornite			— — — — —
Chalcocite			— — — — —
Sphalerite			— — — — —
Galena			— — — — —
Emplectite(?)			— — — — —
Tennantite			— — — — —
Calcite			— — — — —
Covellite	Presumably supergene		
Malachite	Supergene		
Azurite	Supergene		

FIGURE 49.—Paragenesis of the minerals at the Union Pacific deposit.

at several other uranium occurrences in the area, seems to be a result of the composition and texture of the wall rock.

As discussed under "Paragenetic history," the deposition of uranium probably was effected by the oxidation of ferrous to ferric iron. Analyses of the two rock types (table 1) show that the hornblende gneiss contains almost four times as much ferrous iron as the biotite gneiss. Field observations and thin section studies indicate that the hornblende gneiss was readily altered by the solutions introduced along the fault, and that hornblende, the dominant iron-bearing mineral of the rock, was especially subject to attack. The writers believe that the release and subsequent reprecipitation of iron from hornblende provided an effective mechanism for uranium deposition.

The nature of the iron-bearing mineral probably was of little consequence, providing it was reactive and present in sufficient quantity. Thus a rock rich in biotite might be just as effective a precipitant as

one containing its iron equivalent as hornblende. In the Joachimsthal District, Czechoslovakia, pitchblende has been observed to be more abundant where the wall rocks of the veins were rich in biotite (Everhart and Wright, 1953).

A direct comparison of the iron content of rocks as a measure of their effectiveness in uranium deposition should be qualified by a consideration of the availability of the iron-bearing mineral to contact with the vein fluids. This availability will be a function of (1) the degree to which the rock is shattered and hence its surface area, (2) the relative solubility of the other mineral components, and (3) the texture of the rock.

No opportunity was afforded to compare the shattering of the two rock units at the deposit as the biotite gneiss is not well exposed in the vicinity of the fault zone. Comparison may be made, however, between the rocks in regard to their relative solubility and texture.

The persistence of quartz in highly altered hornblende gneiss indicates that quartz was not readily attacked by the hydrothermal solutions. Modal analyses show that the biotite gneiss contains from two to three times as much quartz as the hornblende gneiss, and hence, in spite of a somewhat higher plagioclase content, the biotite gneiss should be the more resistant of the two rocks.

While the rocks classed as biotite gneiss in this report contain layers that are markedly gneissic, they are for the most part granoblastic. In contrast, the hornblende gneiss is uniformly foliated and contains closely spaced layers of light and dark minerals. It would seem reasonable that where vulnerable minerals are aligned in almost continuous planes, as in the hornblende gneiss, they would be more accessible to the invading solutions than where randomly distributed throughout the rock.

The relative abundance of metallic minerals, chiefly ilmenite, in the hornblende gneiss was first considered by the writers as a possible factor in the localization of uranium. Ilmenite, and some magnetite and hematite, constitutes about 2 percent of the unweathered gneiss but is not found in the altered gneiss of the ore zone. Instead, the ore contains intergrowths of pyrite and hematite, and white opaque grains of leucoxene. Many of these probably were derived from the ilmenite, although some of the pyrite-hematite intergrowths may represent earlier hornblende. As ilmenite contains ferrous iron, its oxidation to hematite would favor uranium deposition, but probably 10 times as much ferrous iron was available from the more abundant hornblende. Although the ilmenite probably was of negligible importance in the deposition of uranium, the pyrite-hematite intergrowths were to some extent effective in precipitating copper.

BUCKMAN ADIT DEPOSIT

The occurrence of pitchblende and secondary uranium minerals at the Buckman adit deposit (fig. 46) differs from others in the Golden Gate Canyon area in that it is not in hornblende gneiss and is not known to be closely associated with a carbonate-potash feldspar reef. Instead, the uranium minerals occur in narrow shears that cut biotite gneiss, pegmatite, and a discontinuous sulfide-bearing quartz vein. The pitchblende is most abundant where a fault sheared the quartz vein and it is only sparsely present in the adjoining gneiss. The locality is about 300 feet east of a wide carbonate-potash feldspar-bearing structure that is presumed to be the southern extension of the Hurricane Hill reef.

This apparently anomalous occurrence is probably the result of the interaction of uranium-bearing solutions with the sulfide-bearing quartz vein, the vein supplying both the structural and chemical control for ore deposition.

Movement along small faults sheared the gneissic rocks to some extent, whereas the vein was shattered into a breccia of angular quartz fragments in which sulfide grains were embedded. This zone of brecciated quartz, by reason of its greater permeability, provided a favored channelway for the uranium-bearing solutions.

The quartz vein is exposed in the adit as two major segments about 20 feet long (fig. 50) and small intervening stringers or lenses all roughly concordant to the enclosing biotite gneiss. Pyrite, chalcopryrite, and molybdenite occur sparsely in the central part of the

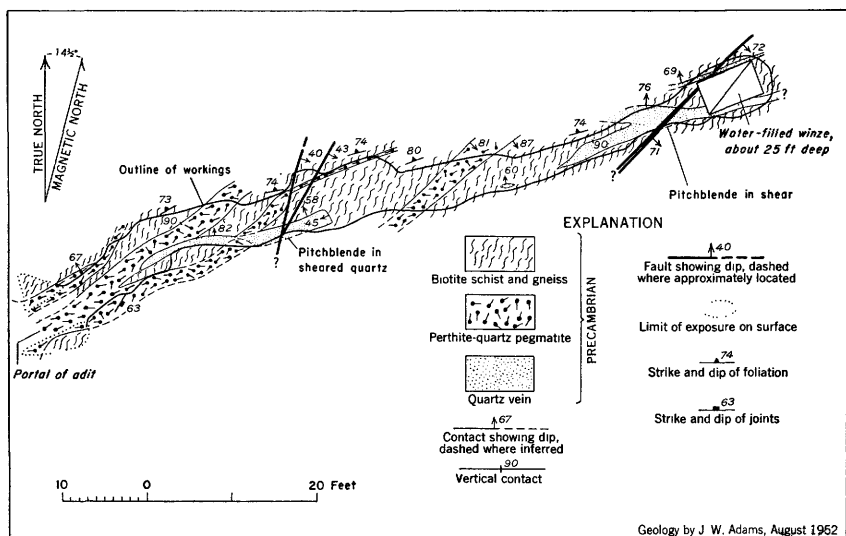


FIGURE 50.—Geologic map of adit, Buckman deposit, Jefferson County, Colo.

quartz bodies but are relatively abundant along their margins in selvage zones containing biotite and magnetite. Some of the sulfide minerals adjoin magnetite grains from which they may have been derived in part. Hematite and an iron-bearing carbonate replace some of the sulfide grains. The pyrite, chalcopyrite, and molybdenite probably represent a period of mineralization unrelated to the uranium-bearing veins, and possibly of Precambrian age.

The pitchblende-bearing breccia differs from the ore found at the Union Pacific deposit; copper minerals are sparse and carbonate minerals have not been noted. Pitchblende and hematite are the most abundant metallic minerals in the ore. Pitchblende, showing typical colloform structures, occurs as rims around the brecciated quartz fragments, many of which were later sheared and offset. Hematite is interstitial to the pitchblende-coated grains, replaces quartz and sulfide, and veins the pitchblende.

Chalcopyrite, pyrite, and covellite occur in small residual grains in the hematite. Minute grains of an unidentified mineral that may be tennantite are present in some quartz fragments and in the interstitial material. Whether any of these sulfides are relics of the original quartz-vein minerals has not been determined, but, in any event, only a little copper was introduced with the uranium.

Radial aggregates of uranophane crystals line cavities in the hematite and fill fractures in quartz grains; the fractures appear to have been enlarged by uranophane replacement of the quartz.

By comparison with the Union Pacific deposit, the occurrence at the Buckman adit deposit may represent only the first stages of the complete sequence of metallization possible from the solutions that invaded the faults. Mineral deposition did not progress far beyond the pitchblende-hematite stage, as shown by the relative paucity of copper minerals and the absence of the ankerite phase after ore deposition. This relatively brief "life cycle" probably resulted from an early choking-off of the narrow channelway by pitchblende and hematite.

Precipitation of the pitchblende is thought to have been effected by the iron-bearing minerals in and adjacent to the quartz vein. Pyrite, chalcopyrite, biotite, and magnetite were all available to the solutions moving up the pipelike channel afforded by the sheared vein and provided a source of ferrous iron which, through oxidation to hematite, could precipitate uranium.

DISCUSSION OF PITCHBLENDE DEPOSITION

Wall-rock control similar to that at the Union Pacific deposit was probably effective at all the pitchblende occurrences in the hornblende gneiss beds (fig. 46) in Golden Gate Canyon.

The formation of such pitchblende-hematite-carbonate deposits apparently requires an environment relatively free of sulfide ions so that Fe^{+2} can be oxidized to Fe^{+3} . In comparing the pitchblende deposits of the Theano Point area, Ontario, with that of the Caribou mine in Colorado, Wright (written communication, 1950) states:

The predominance of calcite gangue in the uranium-bearing veins of the Theano Point area and the virtual absence of sulfides suggest that the oxidizing action of carbon dioxide in the mineralizing solutions, and the small amount of sulfur which could act as a reducing agent may provide a partial explanation for the abundance of hematite adjacent to the vein. The almost complete absence of hematite in the wall rock of the Caribou occurrence, which is rather rich in sulfides and where the gangue is predominantly silica rather than calcium carbonate, is in agreement with this explanation.

In the Ralston Creek area (fig. 45) two of the known deposits, the Nigger Shaft and North Star, are associated with hornblende gneiss. The pitchblende deposit at the Schwartzwalder (Ralston Creek) mine, currently being worked, was not studied in detail during these investigations, but the writers believe that pitchblende localization may be related to the distribution of a tourmaline-garnet skarn-type rock that accompanies the more abundant quartz-muscovite schist or phyllite of the mine area. The skarn rock, severely bleached and altered in the ore zone, may have provided ferrous iron either from tourmaline or from primary sulfide minerals.

The role of early sulfide minerals in uranium deposition has not been established by this investigation, but these minerals are thought to have been contributory at the Buckman adit deposit and may have been important at the Copper King deposit in northern Colorado described by Sims and Phair (1952). At this deposit, pitchblende of Tertiary age occurs in a pyrite-sphalerite ore body genetically related to Precambrian granite. Gruner (1952) describes the synthesis of pitchblende by the reaction between iron sulfide and a solution of uranyl sulfate. In these experiments, performed at temperatures of about 200°C and under acidic conditions, oxidation of sulfur but not iron was detected. "Sooty" pitchblende is commonly associated with pyritic ore, such as that found at the Copper King deposit, and may be the result of a sulfur oxidation reaction. Where hematite has been coprecipitated with pitchblende, as at the Buckman adit deposit, iron oxidation and uranium reduction is indicated as the more probable process for uranium deposition.

CONCLUSIONS

The detailed study of the Union Pacific deposit indicates that the abundance and availability of oxidizable iron-bearing minerals in the wall rocks may determine whether uranium deposition will take

place. Hornblende has been shown to be an effective source of ferrous iron, but other minerals, such as biotite, may serve equally well.

Pitchblende, accompanied by hematite and minor early ankerite, was deposited in advance of all sulfide minerals except for possible minor amounts of pyrite at the Union Pacific deposit. During the period of sulfide mineralization, pitchblende was not deposited; and locally it was replaced. Evidence indicates that the requirements for uranium deposition were fully met only during the initial stage of mineralization where the sulfide ion concentration of the incoming solutions was low.

The studies made during this investigation lead to the conclusion that pitchblende-bearing veins of the carbonate type may be expected where ample ferrous iron is available in the wall rocks. The difference in the available ferrous iron of the hornblende gneiss and biotite gneiss beds is thought to have resulted in the localization pattern exhibited by the pitchblende occurrences in the Golden Gate Canyon area.

This conclusion may be of some value in prospecting for uranium in areas of comparable geologic environments; the nature of the ferrous iron-bearing mineral is probably unimportant so that no special significance should be placed on the presence of hornblende. Biotite, magnetite, tourmaline, and iron sulfide minerals may be equally effective where present in sufficient quantity. In a sulfide environment, conditions resulting in the oxidation of either iron or sulfur may precipitate pitchblende. This implies that conditions favorable for uranium deposition are presented where uranium-bearing solutions have access to sulfide-bearing rocks.

LITERATURE CITED

- Adams, J. W., Gude, A. J. 3d, and Beroni, E. P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colo.: U. S. Geol. Survey Circ. 320.
- Edwards, A. B., 1947, Textures of the ore minerals and their significance: Australasian Inst. Min. and Metallurgy, Melbourne, 185 p.
- Everhart, D. L., and Wright, R. J., 1953, The geologic character of typical pitchblende veins: Econ. Geology, v. 48, p. 77-96.
- Fenner, C. N., 1936, Borehole investigations in Yellowstone Park: Jour. Geology, v. 44, no. 2, pt. 2, p. 225-315.
- Gabriel, Alton, and Cox, E. P., 1929, A staining method for the quantitative determination of certain rock minerals: Am. Mineralogist, v. 14, no. 8, p. 290-292.
- Gruner, J. W., 1952, New data of synthesis of uranium minerals: U. S. Atomic Energy Comm. Tech. Inf. Service, RMO-983, Oak Ridge, Tenn.
- Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colo.: U. S. Geol. Survey Prof. Paper 223, 319 p.

- Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colo., and their bearing upon pitchblende deposition: U. S. Atomic Energy Comm. Tech. Inf. Service, TEI-247, Oak Ridge, Tenn.
- Sims, P. K., and Phair, George, 1952, Geology of the Copper King mine area, Prairie Divide, Larimer County, Colo.: U. S. Atomic Energy Comm. Tech. Inf. Service, TEI-311, pt. 1, Oak Ridge, Tenn.
- Steiner, A., 1953, Hydrothermal rock alteration at Wairakei, New Zealand: Econ. Geology, v. 48, no. 1, p. 1-13.

