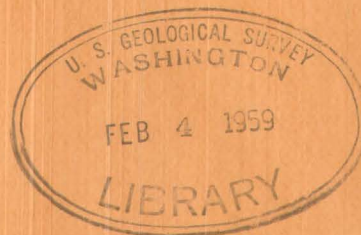


* (200)
T6 Tr
Nr. 430

Unclassified.

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

By John W. ^{Wagstaff} Adams, ^{9/15} and Frederick Stugard, Jr., ¹⁹¹⁹



Trace Elements Investigations Report 430

UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Geology and Mineralogy

This document consists of 34 pages,
plus 1 figure.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WALL-ROCK CONTROL OF CERTAIN PITCHBLEND E DEPOSITS,
IN GOLDEN GATE CANYON,
JEFFERSON COUNTY, COLORADO*

By

John W. Adams and Frederick Stugard, Jr.

December 1954

Trace Elements Investigations Report 430

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

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

USGS-TEI-430

GEOLOGY AND MINERALOGY

<u>Distribution (Series A)</u>	<u>No. of copies</u>
Argonne National Laboratory	1
Atomic Energy Commission, Washington	2
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Butte	1
Division of Raw Materials, Casper	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Hot Springs	1
Division of Raw Materials, Ishpeming	1
Division of Raw Materials, Phoenix	1
Division of Raw Materials, Richfield	1
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, Washington	3
Exploration Division, Grand Junction Operations Office	1
Grand Junction Operations Office	1
Technical Information Service, Oak Ridge	6
Tennessee Valley Authority, Wilson Dam	1
U. S. Geological Survey:	
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington	1
Geophysics Branch, Washington	1
Mineral Deposits Branch, Washington	2
E. H. Bailey, Menlo Park	1
A. L. Brokaw, Grand Junction	1
N. M. Denson, Denver	1
C. E. Dutton, Madison	1
W. L. Emerick, Plant City	1
C. B. Read, Albuquerque	1
M. R. Klepper, Spokane	1
A. H. Koschmann, Denver	2
R. A. Laurence, Knoxville	1
J. D. Love, Laramie	1
L. R. Page, Washington	1
P. C. Patton, Denver	2
J. F. Powers, Salt Lake City	1
Q. D. Singewald, Beltsville	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver	2
TEPCO, RPS, Washington, (Including master)	3
	<u>51</u>

CONTENTS

	Page
Abstract	5
Introduction	5
Geology	7
Petrography of the wall rocks	9
Hornblende gneiss	9
Quartz-biotite gneiss	10
Breccia reefs	13
Ore deposits	15
Union Pacific prospect	15
Mineralogy of the ore	15
Ore minerals	15
Gangue minerals	20
Paragenetic history	23
Wall-rock control at the Union Pacific prospect	27
Buckman adit	28
Discussion of pitchblende deposition	31
Conclusions	32
Literature cited	33
Unpublished reports	34

ILLUSTRATIONS

Figure 1. Index map of central Colorado showing location of Golden Gate Canyon and Ralston Creek areas	6
2. Geologic sketch map showing distribution of uranium occurrences in the Golden Gate Canyon area, Jefferson County, Colorado	8
3. Geologic map and section of the Union Pacific prospect, Jefferson County, Colorado	In envelope
4. Photomicrograph of thin section of ore from Union Pacific prospect, showing pitchblende (P) coating orthoclase (O) crystals developed on altered wall rock (WR). Plain light, X 80	17
5. Photomicrograph of polished section, showing typical pitchblende (P) - ankerite (A) intergrowth, with tennantite (T) and chalcopyrite (CP). X 1190	17
6. Photomicrograph of polished section, showing pitchblende (P) coating ankerite (A), both replaced by tennantite (T) and chalcopyrite (CP). X 580	18
7. Photomicrograph of polished section, showing replacement of ankerite crystal (A) by chalcopyrite (CP). Gray areas are pitchblende. X 580	18
8. Camera lucida drawing of ore, showing localization of tennantite by earlier pyrite.	21
9. Chemical changes during alteration of gneiss	24

Figure 10.	Paragenesis of the minerals at the Union Pacific prospect	Page 26
11.	Geologic map of adit, Buckman property, Jefferson County, Colorado	30

TABLES

Table 1.	Rock analyses, Union Pacific prospect, Jefferson County, Colorado	11
2.	Spectrographic and uranium analyses of rocks and ore, Golden Gate Canyon area, Jefferson County, Colorado	12

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 pre-Cambrian metamorphic rocks in Golden Gate Canyon contain pitchblende and base-metal sulfides. The veins occupy extensive faults of Laramide (?) age but normally contain pitchblende only where they cut hornblende gneiss. At the Union Pacific prospect, which was studied in detail, pitchblende, hematite, and some ankerite formed in advance of sulfides, except possibly for minor pyrite. Base-metal sulfides and the bulk of the ankerite-calcite 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 hypothesized 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, biotite or iron sulfides 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. It is suggested that conditions particularly favorable for uranium deposition are present where uranium-bearing solutions had access to rocks rich in ferrous iron or pre-existing sulfides.

INTRODUCTION

Pitchblende and secondary uranium minerals are found in vein deposits in northern Jefferson County, Colo. The deposits, which are of recent discovery, occur in or near Laramide fault zones that cut gneisses, schists, and pegmatites of pre-Cambrian age. They have been found in two areas about 6 miles apart (fig. 1); 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.

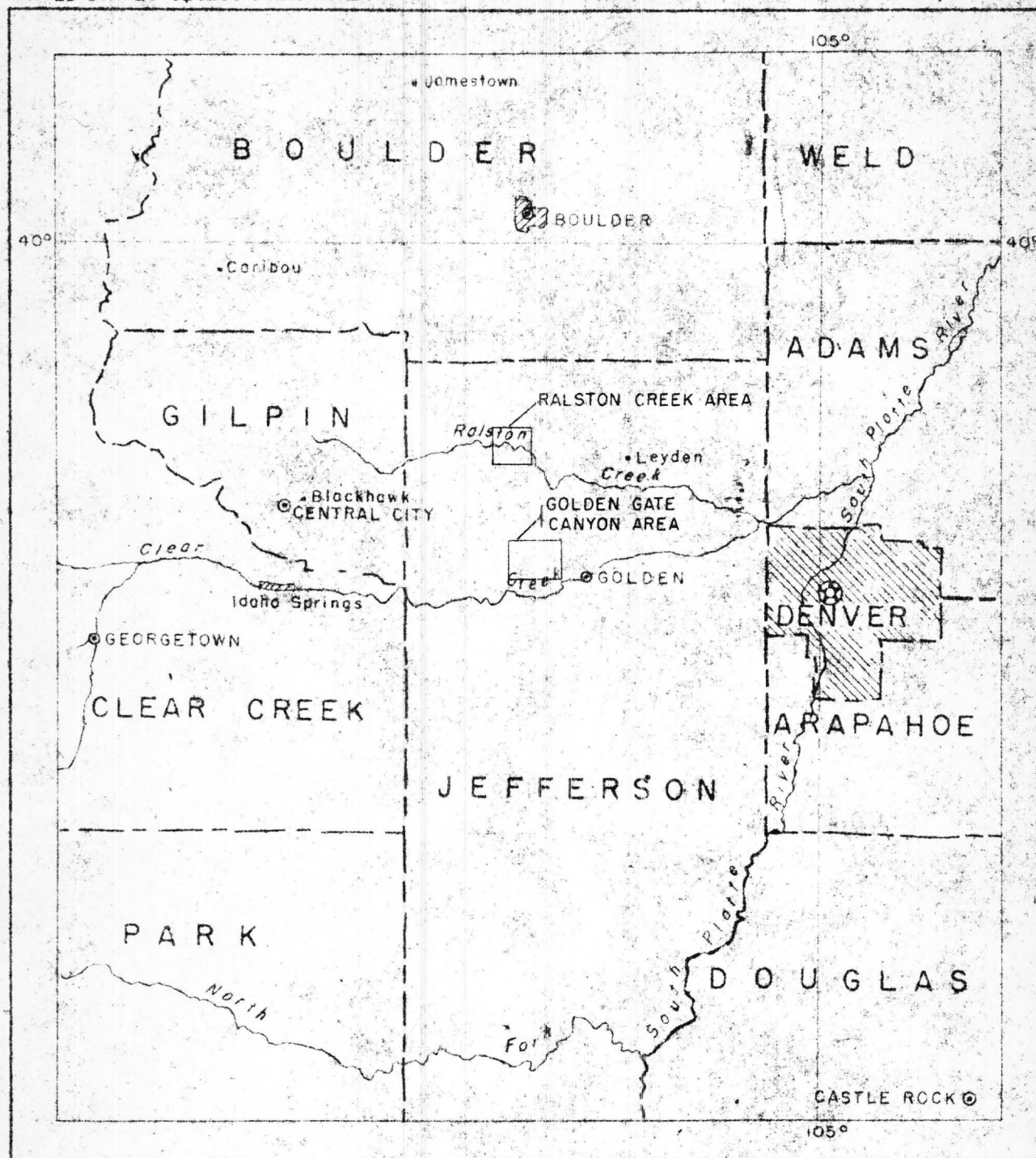


FIGURE 1—INDEX MAP OF CENTRAL COLORADO SHOWING LOCATION OF
GOLDEN GATE CANYON AND RALSTON CREEK AREAS.

10 5 0 10 Miles

Eight occurrences of uranium minerals are known in the southern, or Golden Gate Canyon area, and include the Union Pacific, Buckman, and Ladwig properties. Pitchblende is the most abundant uranium mineral in the deposits, and is associated with copper minerals in a gangue of carbonates, 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 during 1952-1953 as part of the study of uranium deposits undertaken by the U. S. Geological Survey on behalf of the Division of Raw Materials 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. 2) were found where fault zones crossed a single bed of hornblende gneiss, 100 to 150 feet thick. Conversely, no significant radioactivity has been found along the same fault zones where they pass through other rocks.

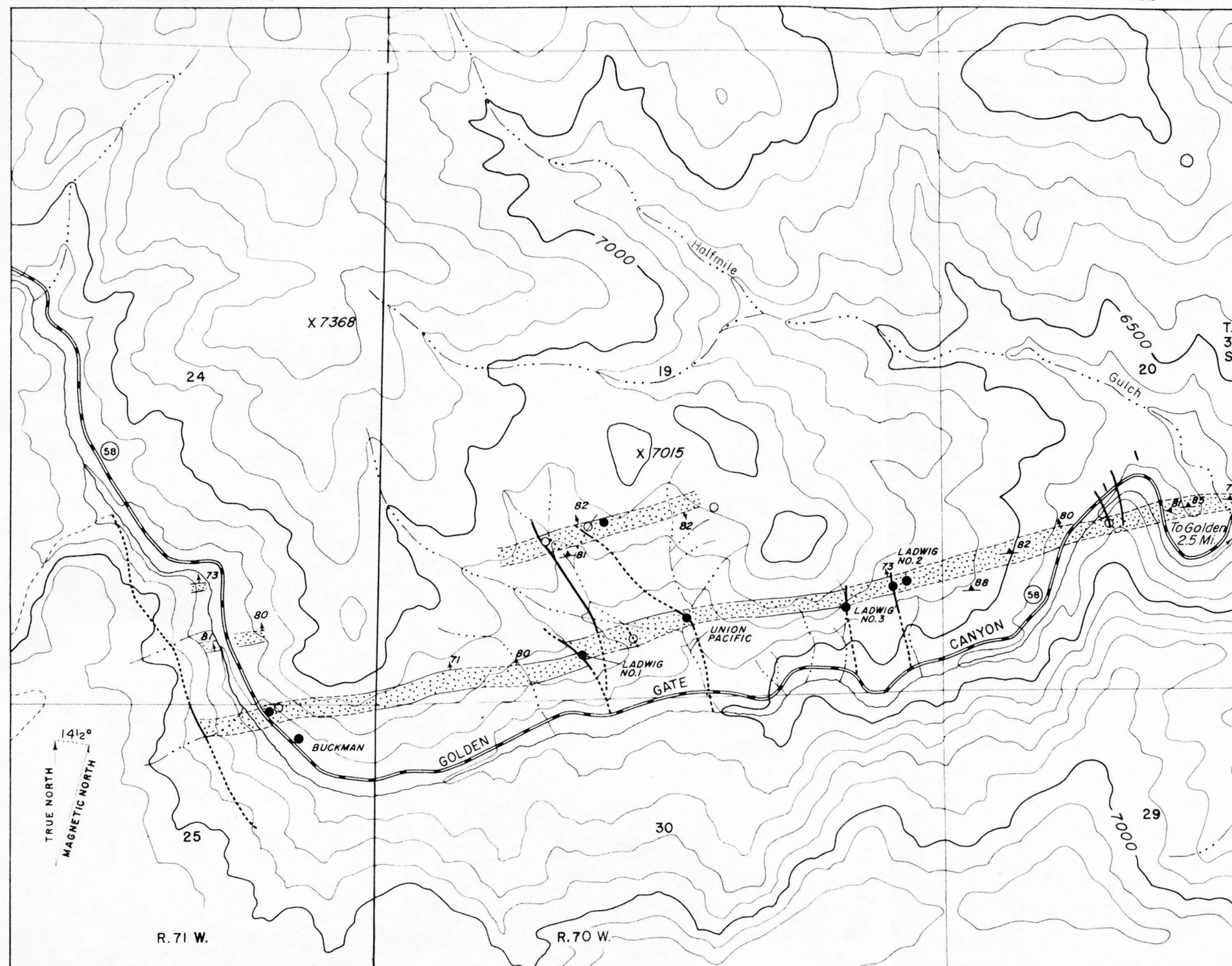
As the preliminary data indicated the existence of "favorable" and "unfavorable" rock types, further investigations were made to establish, if possible, the reason for the apparent wall-rock control. Although the field and laboratory studies of this problem were concerned primarily with the Golden Gate Canyon deposits, notably that at the Union Pacific prospect, 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. 2) to show the distribution of the known uranium occurrences in relation to the hornblende gneiss beds and breccia reefs.

A geologic map of the Ralston Buttes quadrangle (1:24,000), which includes both 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 pre-Cambrian 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.



Topography from Ralston Buttes quadrangle, 1948.

Geology by J.W. Adams and F. Stugard, September 1953.

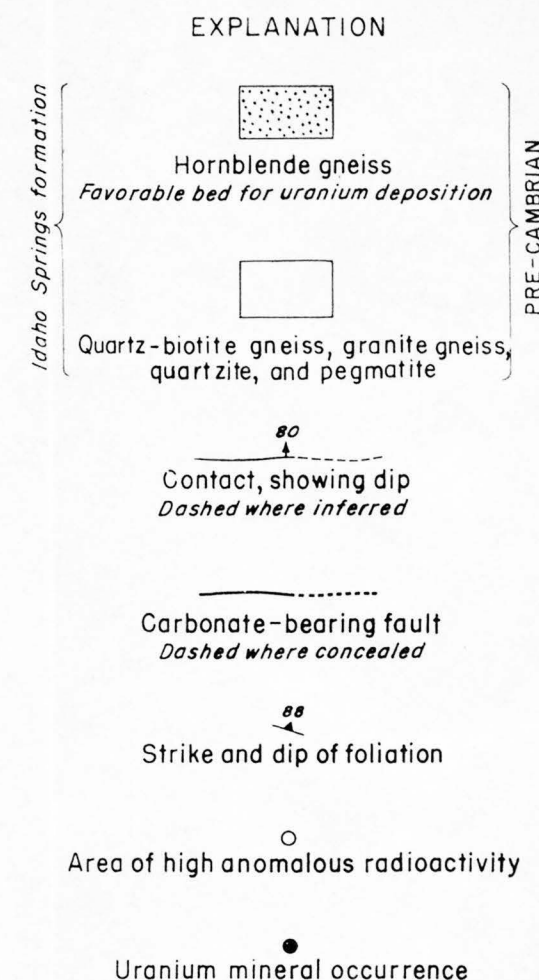


FIGURE 2 - GEOLOGIC SKETCH MAP SHOWING DISTRIBUTION OF URANIUM OCCURRENCES
IN THE GOLDEN GATE CANYON AREA, JEFFERSON COUNTY, COLORADO.

1000 0 1000 2000 3000 Feet

Contour interval 100 feet
Datum is mean sea level.

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 approximately N. 80° E. and dips steeply north. These rocks are cut by a number of northwesterly-trending faults characterized by carbonate-potash feldspar vein filling. The faults presumably are of Laramide age and 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 sections 24 and 25 (fig. 2) is believed to be a southern extension of the Hurricane Hill breccia reef, a structure that has been traced for almost twenty miles to the northwest (Lovering and Goddard, 1950, pl. 2). The relationship between the breccia reefs and the uranium deposits will be discussed further in this paper.

The geology of an area including and extending north of Golden Gate Canyon has been mapped by Gabelman (1948) on a scale of approximately 1 inch equals 850 feet. As a result of his work, Gabelman believed the granite gneiss to be the marginal facies of a granitic intrusive lying south of Golden Gate Canyon and that the other metamorphic rocks 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 (Gabelman, 1948, p. 116).

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. The two 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 for convenience 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 is a minor constituent of the rock. At the Union Pacific prospect, and presumably elsewhere, the rock contains small epidote-bearing lenses and a few narrow quartz stringers, neither sufficiently abundant materially to

affect the bulk composition of the rock. The hornblende gneiss is rather uniform in composition as determined by examination of a number of thin sections; three typical modes are as follows:

	volume percent		
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 non-opaque 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 with very minor amounts of pyrite and chalcopyrite. The magnetite and ilmenite may be partially 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 paper 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. Some of the rocks have a granoblastic fabric; these alternate with those that are markedly gneissic. The following mode is considered typical of the granoblastic rock in the vicinity of the Union Pacific prospect:

Table 1. Rock analyses, Union Pacific prospect, Jefferson County, Colorado.

(All analyses by U. S. Geological Survey Denver Rock Analysis Laboratory; analyst: Lucille M. Kehl)

Field number	Description of rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	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	Biotite gneiss.	68.92	14.55	1.95	2.89	1.50	2.25	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	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	3.28	0.79	.30	1.35	1.41	.05	.31	.02	.22	99.96	.01	99.95
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	3.32	.67	.27	1.33	1.58	.04	.41	.01	.24	100.05		
JWA-73-53	Altered hornblende gneiss. Chip channel across 5 feet of altered rock underlying JWA-77-53.	51.70	18.06	12.36	0.16	1.15	2.41	2.46	3.30	1.93	3.74	1.72	.17	.25	.01	.28	99.70		
JWA- 3-54	Breccia reef material. Composite sample of fresh rock from mine dump.	32.87	9.10	0.45	10.57	5.60	12.03	.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, Colorado 1/.
(All analyses by Trace Elements Section, Denver Laboratory, U. S. Geological Survey)

Field number	Description of sample	eU (percent)	U	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ag	As	Ba	Be	Bi	Co	Cr	Cu	Ga	La	Mo	Nb	Ni	Pb	Sb	Sc	Sr	U	V	Y	Yb	Zn	Zr
JWA-64-53	Biotite gneiss. Composite of chip samples at 3-foot intervals for 100 feet.* <u>2/</u>	0.002 <u>2/</u>	---	xx.o	xx.o	x.o	o.x	o.oX+	x.o-	x.o-	x.o-	x.o-	0	0	o.oX+	0	0	o.oX-	o.oX-	o.oX	Tr.	Tr.	0	0	o.oX+	o.oX-	0	o.oX-	o.oX-	0	o.oX	o.oX	o.oX	0	o.oX-
JWA-82-53	Hornblende gneiss. Channel sample across 11.4 feet.* <u>2/</u>	.001 <u>4/</u>	---	xx.	xx.	x.+	.x+	.x	x.+	x.+	x.-	.x+	0	0	.oX-	0	0	.oX-	.oX	.oX+	.oX-	0	0	0	Tr.	0	0	.oX	.oX-	0	.oX+	.oX	.oX	0	.oX-
JWA-73-53	Altered hornblende gneiss. <u>2/</u>	.000 <u>2/</u>	---	xx.	xx.	x.+	.x+	.x	.x+	.x+	x.-	x.	0	0	.oX	.oX+	0	.oX	.oX+	.oX	.oX-	0	Tr.	0	.oX+	Tr.	0	.oX	.oX-	0	.oX	.oX	.oX	0	.oX-
JWA- 3-54	Breccia reef material; 5-pound dump sample from Union Pacific prospect.* <u>2/</u>	---	---	x.+	x.	x.	.x-	.oX+	x.	x.-	.x	x.	Tr.	0	.oX+	Tr.	.oX-	.oX-	.oX-	.oX	Tr.	0	.oX+	0	.oX-	.oX	0	.oX-	.oX-	0	.oX+	.oX	.oX	0	.oX
JWA-90-53	Hurricane Hill reef; 12-foot channel sample west of Buckman adit.** <u>2/</u>	.009 <u>5/</u>	.004 <u>6/</u>	xx.	x.+	x.+	.x	.x-	x.	x.-	.x-	x.+	0	0	.oX-	.oX-	0	.oX-	.oX-	.oX	.oX+	0	0	.oX-	.oX-	.oX-	0	.oX	.oX-	0	.oX+	.oX-	.oX-	0	.oX
JWA-92-53	Reef 750 feet WNW of Union Pacific prospect; 3-foot channel sample.** <u>2/</u>	.006 <u>5/</u>	.001 <u>6/</u>	xx.	x.+	x.	.x	.x-	x.	x.-	.x-	x.+	0	0	.oX+	0	0	.oX+	.oX	.oX	.oX+	.oX	0	.oX	.oX-	.oX-	0	.oX-	.oX+	0	.oX	.oX	.oX	0	.oX-
JWA-94-53	Reef 700 feet northwest of Union Pacific prospect; 40-inch channel sample.** <u>2/</u>	.004 <u>5/</u>	.001 <u>6/</u>	xx.	x.+	x.+	.x-	.oX+	x.+	.x-	x.-	x.+	0	0	.oX-	0	0	.oX+	.oX	.oX-	.oX+	.oX	0	Tr.	.oX-	.oX-	0	.oX-	.oX-	0	.oX-	.oX+	.oX+	0	.oX-
UP-4-52	Pitchblende-bearing ore from Union Pacific prospect.* <u>2/</u>	---	---	---	x.	x.	.x	.x	x.+	x.+	.x	x.	.oX-	.x+	.x-	0	.x+	---	.oX+	x.	0	0	.oX	0	.oX	.x-	.x	.oX	.oX-	x.+	.oX+	.oX-	.oX	.x	.x-

* Spectrographer: G. W. Boyes, Jr.

** Spectrographer: R. G. Havens.

1/ Note that the concentrations are reported as elements, not as oxides or compounds.

xx. = anything above 10%
x. = 1.0 to 9.99%
Example of plus-and-minus notation: .x+ = 0.464 to 1.0%
.x = .215 to .464%
.x- = .10 to .215%

2/ Analysts: J. W. Patton, J. McGurk, and Wayne Mountjoy.

5/ Analyst: S. P. Furman.

Other symbols used:

--- = not looked for
0 = looked for but not detected
tr = near threshold amount of element

6/ Analysts: Jesse Meadows, J. P. Schuch.

3/ Other elements looked for but not found: P, Au, B, Cd, Ce, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Nd, Os, Pd, Pt, Re, Rh, Ru, Sn, Sm, Ta, Th, Tl, Te, W.

4/ Analyst: J. W. Patton.

	volume percent
Quartz	30
Plagioclase (Albite- oligoclase)	50
Biotite	20
Others	less than 1

Apatite is the most abundant accessory mineral in the rock represented by this mode, but together with 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 do the hornblende rocks, and that most of this magnetite or magnetite-hematite intergrowths.

Results of spectrographic and chemical analyses of a composite sample representing 100 feet of the biotite gneiss at the Union Pacific prospect are given in tables 1 and 2.

Breccia reefs

The composition and character of the breccia reefs are of special interest because the uranium deposits are believed genetically related to them.

The major reefs are presumably the southern extensions of structures along which faulting and silicification took place during the Laramide revolution. (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 dominantly of iron-stained quartz. By contrast, the southern reefs are not siliceous but consist of carbonates and potash feldspar as a fine-grained ground-mass 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 largely the result of the oxidation of iron from ankerite. Where fresh, the rock is almost white and is extremely 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 has undoubtedly been introduced. The reef material from the shaft at the Union Pacific prospect contains many fragments of the enclosing hornblende gneiss. These fragments still 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 believed to be composed of a carbonate having the approximate composition of ankerite, together with an orthoclase-type feldspar. These two minerals, followed by later calcite, appear to have been the products of a very widespread introduction of hydrothermal solutions into not only the major faults but also the many presumably contemporaneous smaller subparallel breaks.

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 is post-ore in age.

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 actually 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 very recently discovered occurrences in the Ralston Creek area, the known uranium vein deposits in northern Jefferson County have been described in U. S. Geological Survey Circular 320 (Adams, and others, 1953). For this reason mention will be made of the geology of only those deposits re-examined for the purposes of this investigation, namely the Union Pacific prospect and Buckman adit.

Union Pacific prospect

At the Union Pacific prospect (fig. 3), pitchblende and base-metal minerals occur along the hanging-wall of a carbonate-potash feldspar reef cutting 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 surface 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 considered representative of the uranium deposits in the two areas. The mineralogy of an individual deposit may be simpler or more complex, but the association of pitchblende with copper sulfides and arsenides 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 so 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 its common associate tennantite. 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 carbonates and may coat crystals of potash feldspar (fig. 4) 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 discernable without the use of the ore microscope, occurs in colloform masses that commonly are less than 0.1 mm in diameter and densely coat crystals of ankerite of comparable dimensions. (fig. 5). The pitchblende-ankerite veinlets are irregularly distributed through intensely altered wall rock and are replaced in varying degrees, by later sulfides (fig. 6). This second type of ore is believed to have formed in the fractured wall rock close to 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. --Hematite, in a finely dispersed state, is abundant in the hydrothermally altered rocks of the deposit and gives them a characteristic brick-red color. It appears to be most abundant in the altered feldspars 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. Hematite is also present as platy intergrowths with pyrite that 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 mm in width. In polished section it 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 to 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.

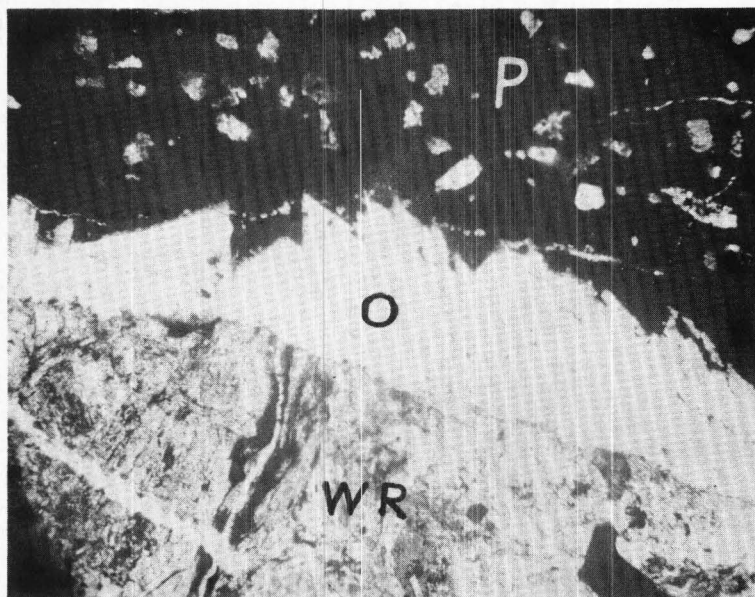


Figure 4. -- Photomicrograph of thin section of ore from Union Pacific prospect, showing pitchblende (P) coating orthoclase (O) crystals developed on altered wall rocks (WR). Plain light. X 80.

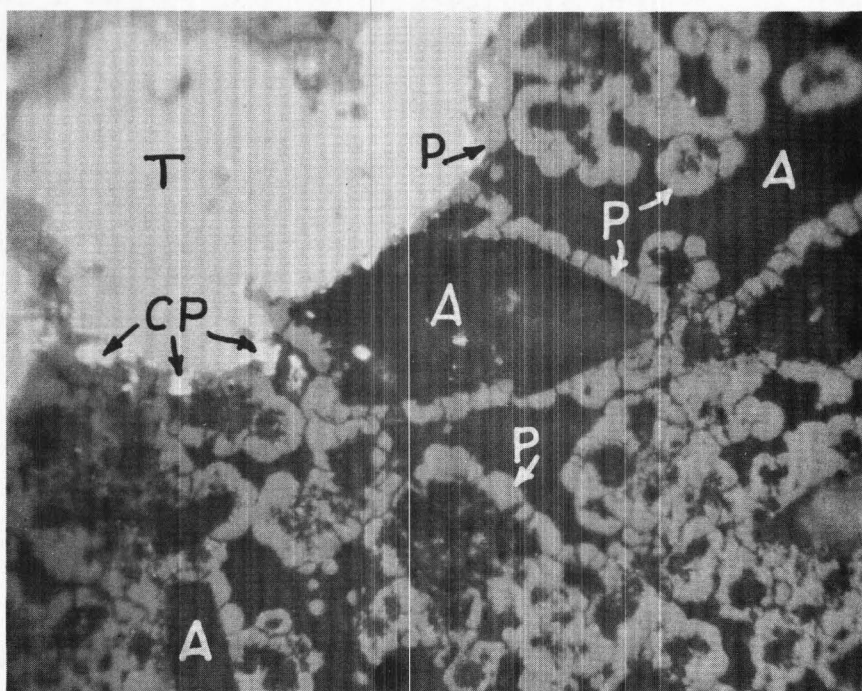


Figure 5. -- Photomicrograph of polished section, showing typical pitchblende (P) - ankerite (A) intergrowth, with tennantite (T) and chalcopyrite (CP). X 1190.

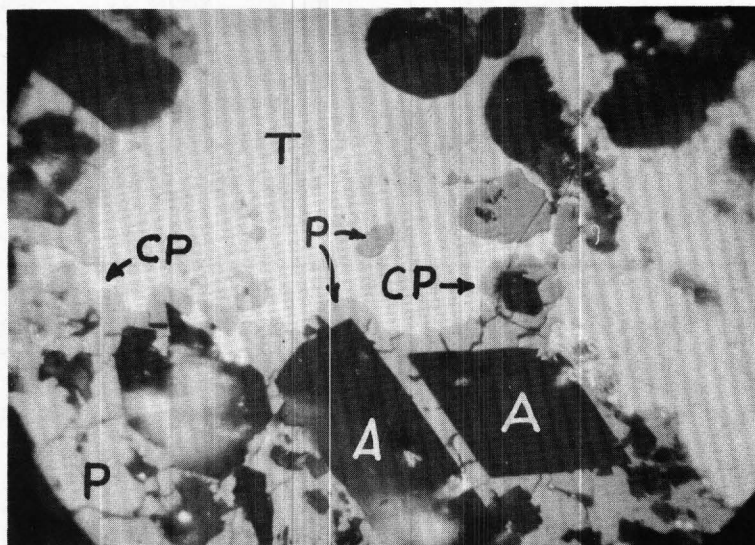


Figure 6. -- Photomicrograph of polished section, showing pitchblende (P) coating ankerite (A), both replaced by tennantite (T) and chalcopyrite (CP). X 580.

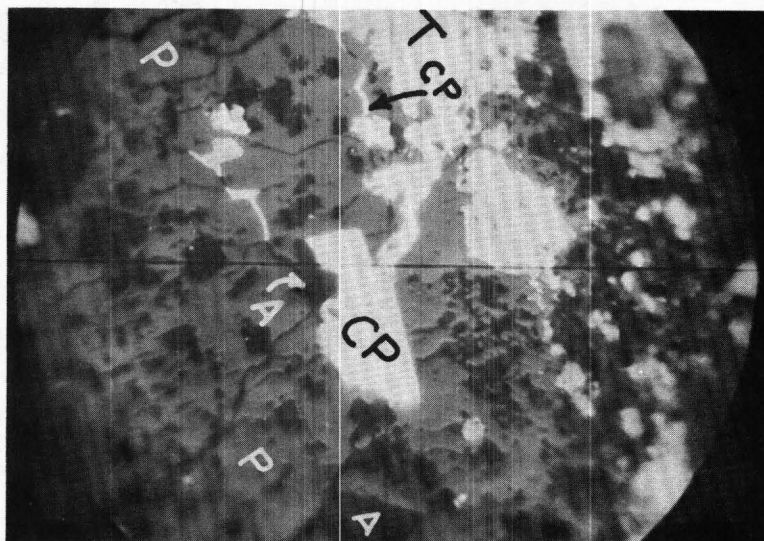


Figure 7. -- Photomicrograph of polished section, showing replacement of ankerite crystal (A) by chalcopyrite (CP). Gray areas are pitchblende (P). X 580

Chalcopyrite. --Chalcopyrite is next to tennantite in abundance, the two minerals making up much of the ore mineral assemblage, and it replaces the earlier pitchblende-carbonate veinlets. Textural relationships observed in polished sections suggest 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 rims tennantite or occurs as isolated grains along the margins of tennantite areas. Where the rim structure is developed, chalcopyrite has apparently invaded pre-existing interfaces between tennantite and pitchblende. Shrinkage of the pitchblende with development of concentric and radial cracks may have afforded routes through which the chalcopyrite could migrate and replace the carbonate gangue of the early pitchblende veinlets. Figure 7 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, relationships are 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, non-metallic appearance with crossed nicols. The largest sphalerite grain seen in polished specimens of the ore was approximately 0.3 mm in maximum dimension. Sphalerite probably was one of the early suite of sulfide minerals, more abundant prior to 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 to be one of the early-formed sulfides.

Emplectite. --Emplectite (Cu BiS_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. With high magnification, the chalcopryite 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 approximately that of chalcopryite 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 very 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 it is largely in minute grains intergrown with hematite. These intergrowths are believed to be relics of some of the original iron-bearing minerals of the hornblende gneiss. The shape of many of these intergrowths suggest that they were originally hornblende, but others probably 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 discernable (fig. 8), and no additional pyrite appears to have been deposited until the very close 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 rim small calcite-filled cavities and fractures and apparently represent the final stage of metallization. Deposition of pyrite rather than chalcopryite, 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 carbonates ankerite and calcite, potash feldspar, chlorite, and minor sericite. Although quartz is common in the ore, and to a lesser degree in the carbonate vein filling, the rounded or fragmental grains are presumably all derived from the wall rocks. Some vein quartz, however, has been noted in the Ralston Creek deposits.

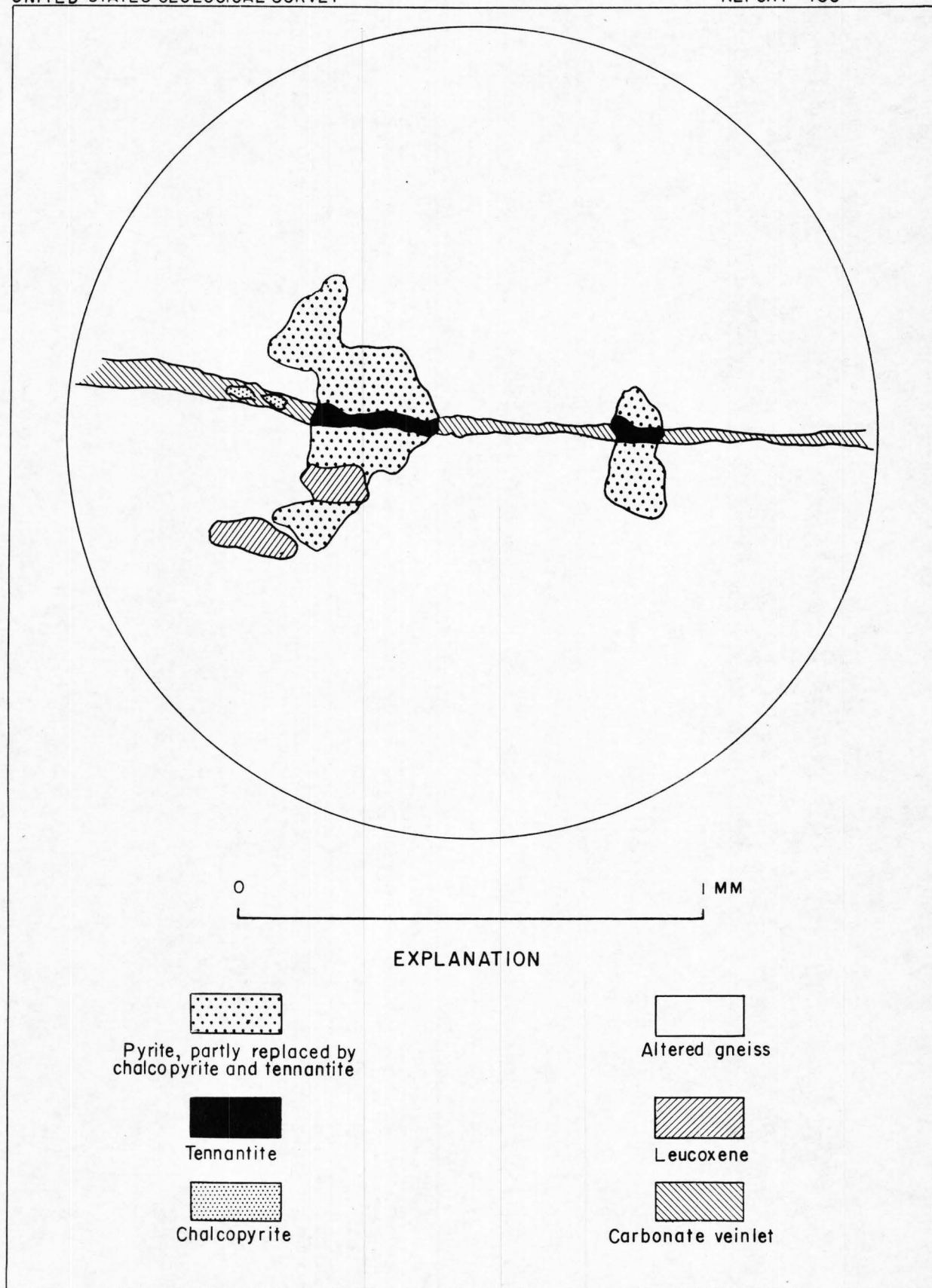


FIGURE 8 — CAMERA LUCIDA DRAWING OF ORE, SHOWING LOCALIZATION
OF TENNANTITE BY EARLIER PYRITE

Carbonates. --A carbonate mineral close to ankerite in composition is common in the ore and breccia reefs 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 carbonates 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 reefs 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 developed on fragments of brecciated gneiss. The crystals rimming the breccia fragments are clear and transparent by comparison with the cloudy orthoclase (fig. 4) 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. These observed relations of orthoclase in the deposit lead to the conclusion that potash was introduced largely 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 largely 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 or 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 effects of the earlier propylitization were largely destroyed when the rock fragments were subjected to severe attack by carbonate-bearing solutions.

Paragenetic history

Studies of thin and polished sections of the rocks and ores indicate that a rather complicated series of events were effective in the formation of the deposits.

Development of the major faults, together with many other subsidiary breaks, such as that at the Union Pacific deposit, presumably took place during early Tertiary time. Open portions of these structures then became channelways for the migration of alkalic solutions of unknown source but of sufficient volume to deposit carbonate throughout crush zones miles long and a foot to twenty feet wide. Only the effect of these solutions in regard to the ore deposition will be considered here, as a study of the reefs themselves is outside the scope of this investigation.

The first process in the development 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 to 5 feet thick, lying above the central carbonate breccia filling; the foot wall bleached zone is not as well exposed but is believed to be of comparable width.

Following, or perhaps during propylitization, solutions were introduced that raised the potash content of the gneiss from less than one to more than three percent (fig. 9). The added potash is in part contained in small clear crystals of orthoclase that line fractures in the rock, but as much or more may be replacing

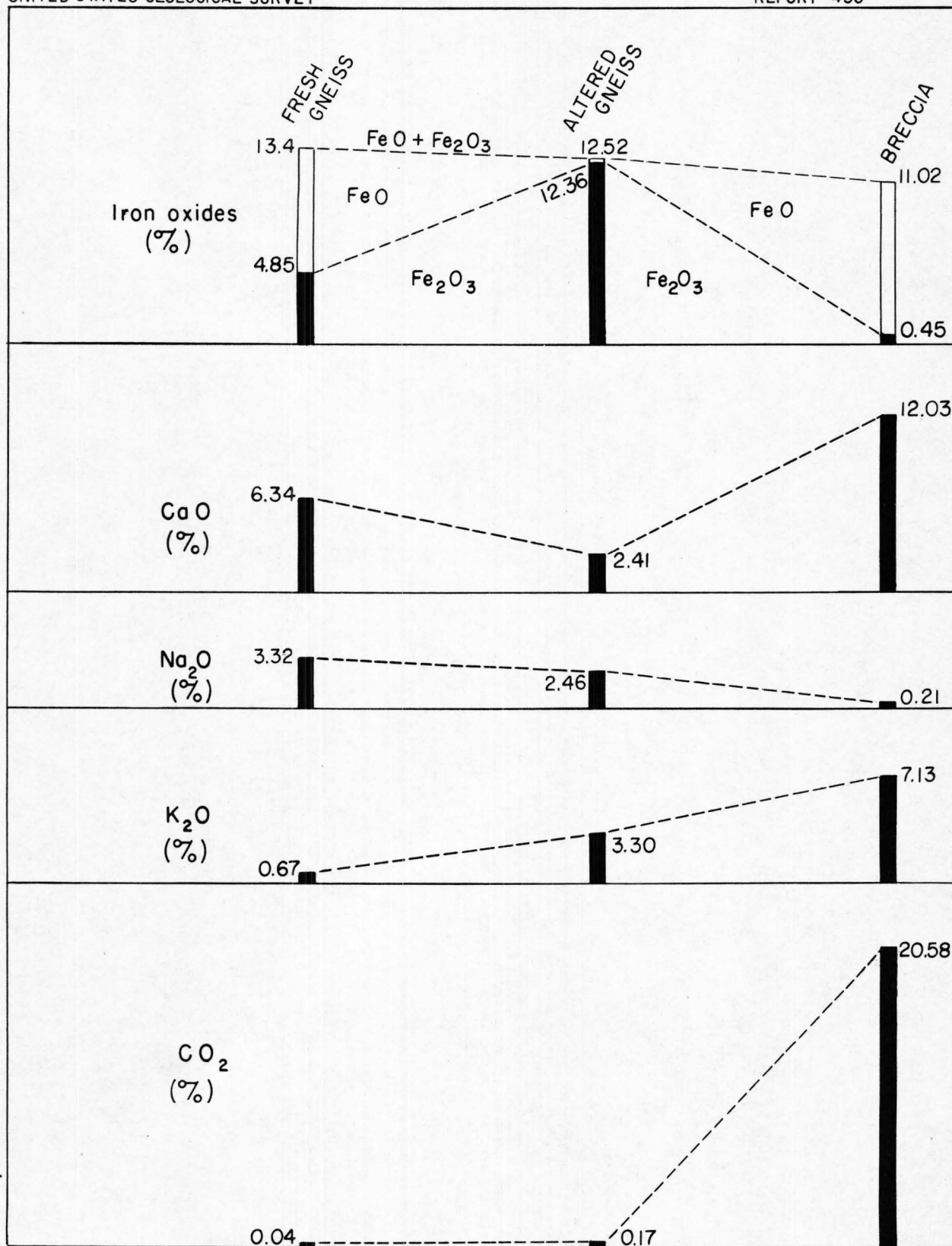


FIGURE 9 — CHEMICAL CHANGES DURING ALTERATION OF GNEISS

the soda of the original plagioclase. This alteration of the plagioclase is shown by the distribution of potassium as shown by staining, and also by the decreased soda content of the gneiss after alteration (fig. 9). 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 precipitation of uranium is thought to have been caused by the reduction of U^{+6} ions to U^{+4} by the Fe^{+2} ions released by the breakdown of (1) hornblende and (2) chlorite. 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 prior to the formation of all sulfides, with the exception of the very minor pyrite formed during propylitization.

After depletion of the available uranium, a number of simple copper sulfides, 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 sulphides 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 pre-existing 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 developed along the edges of the calcite-filled openings indicate that a very weak sulfide phase marked the transition point between the two carbonates.

Figure 10 shows a graphical representation of the paragenesis of the deposit.

DEPARTMENT OF THE INTERIOR
 UNITED STATES GEOLOGICAL SURVEY

 TRACE ELEMENTS INVESTIGATIONS
 REPORT 430

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

 FIGURE 10— PARAGENESIS OF THE MINERALS AT THE UNION PACIFIC
 PROSPECT

Wall-rock control at Union Pacific prospect

The ore deposit at the Union Pacific prospect is, so far as is known, confined to hornblende gneiss wall rocks. This localization, repeated at several other uranium occurrences in the area, appears to be largely the 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 involved (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. It is believed that the release and subsequent re-precipitation 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 (1) of the degree to which the rock is shattered and hence its surface area, (2) the relative solubility of the various mineral components, and (3) the texture of the rock.

No opportunity was afforded to compare the relative 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.

It has been previously mentioned that quartz grains in the hornblende gneiss show a high resistance to attack by the hydrothermal solutions. Modal analyses show that the biotite gneiss contains from two to three times as much quartz as does 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, with closely spaced layers of light and dark minerals. It would seem reasonable that where vulnerable minerals are aligned in more or less continuous planes, as in the hornblende gneiss, they would be far more accessible to the invading solutions than when 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, together with some magnetite and hematite, constitutes approximately two percent of the fresh 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 largely contains ferrous iron, its oxidation to hematite would favor uranium deposition, but probably ten 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

The occurrence of pitchblende and secondary uranium minerals at the Buckman adit (fig. 2) 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 shear cuts the quartz vein and 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 thought to be 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.

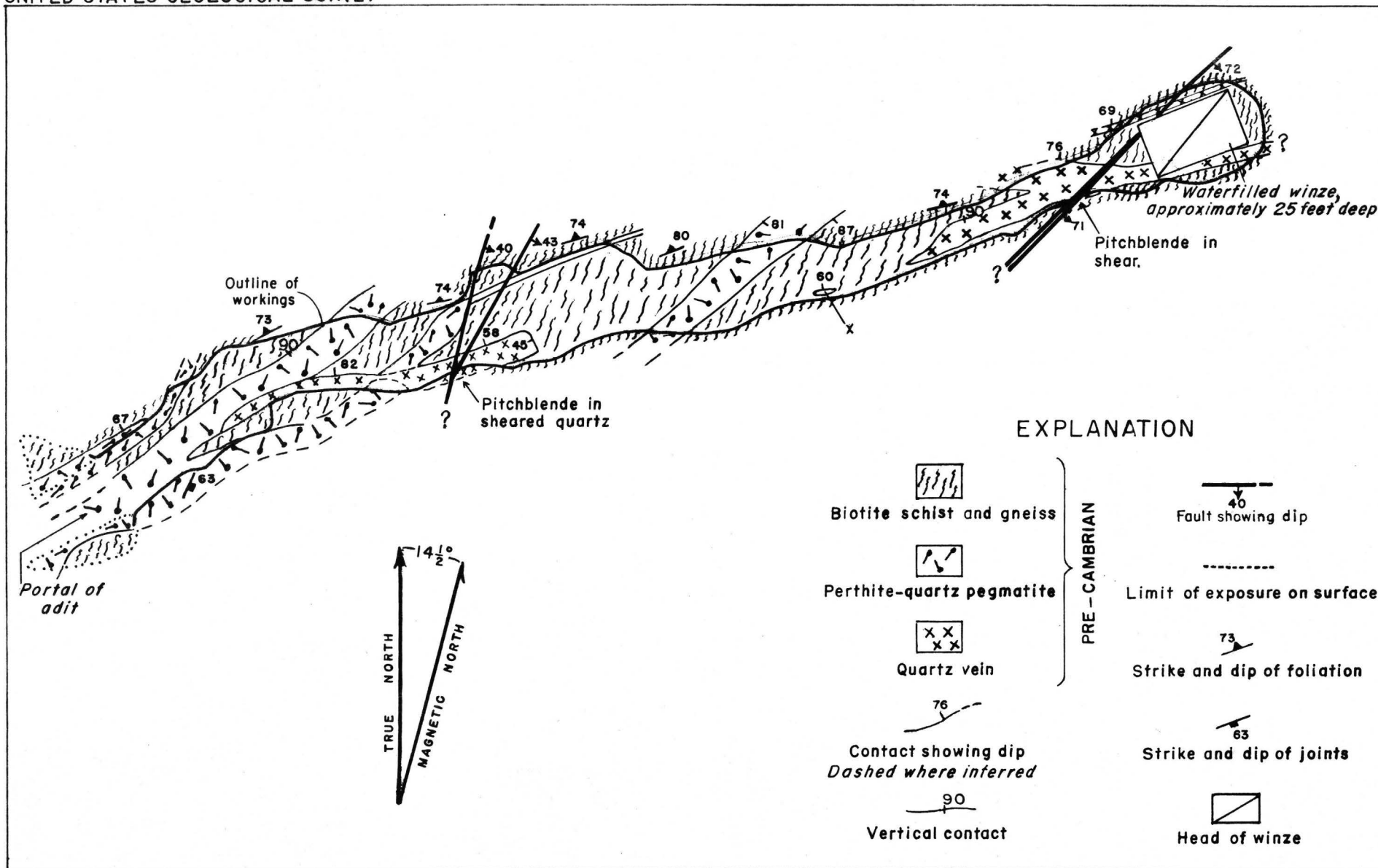
The quartz vein is exposed in the adit as two major segments about twenty feet long (fig. 11) and small intervening stringers or lenses all roughly concordant to the enclosing biotite gneiss. Pyrite, chalcopyrite, and molybdenite occur sparsely in the central part of the quartz bodies but are relatively abundant along their margins in selvage zones containing biotite and magnetite. Some of the sulfides 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 are believed to represent a period of mineralization unrelated to the uranium-bearing veins, and possibly of pre-Cambrian age.

The pitchblende-bearing breccia differs from the ore found at the Union Pacific deposit; copper minerals are sparse and carbonates 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 sulfides, 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 very 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 may be considered to represent only the first stages of the complete sequence of metallization possible from the solutions that



Geology by J.W. Adams, August 1952.

FIGURE 11—GEOLOGIC MAP OF ADIT, BUCKMAN PROPERTY, JEFFERSON COUNTY, COLORADO

invaded the faults. In short, 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 post-ore ankerite phase. 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 pipe-like 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 of the pitchblende occurrences in the hornblende gneiss beds (fig. 2) 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 (1950, p. 10-11) 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. 1) 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' observations suggest 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 sulfides.

The role of early sulfides in uranium deposition has not been established by this investigation, but they 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 pre-Cambrian granite. Gruner (1952, p. 17) describes the synthesis of pitchblende by the reaction between iron sulfides 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. The not-uncommon association of "sooty" pitchblende with pyritic ores, such as at the Copper King, may be the result of such a sulfur oxidation reaction. Where hematite has been co-precipitated with pitchblende, as at the Buckman adit deposit, iron oxidation and uranium reduction is suggested as the more probable mechanism 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 or not 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 sulfides 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. It would thus appear that the requirements for uranium deposition were fully met only during the initial stage of mineralization when 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 are expectable 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 sulfides may be equally effective when 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 particularly favorable for uranium deposition are presented where uranium-bearing solutions have access to sulfide-bearing rocks or veins.

LITERATURE CITED

- Adams, J. W., Gude, A. J., 3rd, and Beroni, E. P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: U. S. Geol. Survey Circ. 320.
- Edwards, A. B., 1947, Textures of the ore minerals and their significance: Australian Inst. Min. and Metal., 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, Part 1: U. S. Atomic Energy Comm. Tech. Inf. Service, RMO-983.
- Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Geol. Survey Prof. Paper 223, 319p.

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

UNPUBLISHED REPORTS

- Gabelman, J. W., 1948, The geology of the Golden Gate-Van Bibber Creek area, Jefferson County, Colorado: Unpublished thesis, Colorado School of Mines.
- Wright, H. D., 1950, Memorandum on the study of certain Colorado and Ontario uraninite deposits: U. S. Atomic Energy Comm. RMO-721.