The Geology and Mineralogy of the W. Wilson Mine Near Clancey, Jefferson County, Montana

By D. Y. Meschter

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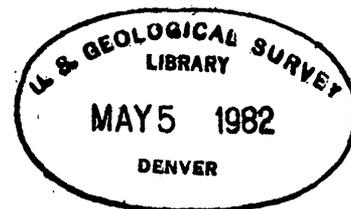plus 2 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE GEOLOGY AND MINERALOGY OF THE W. WILSON MINE

NEAR CLANCEY, JEFFERSON COUNTY, MONTANA*

By

D. Y. Meschter

March 1953

Trace Elements Investigations Report 256

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THE GEOLOGY AND MINERALOGY OF THE W. WILSON MINE

NEAR CLANCEY, JEFFERSON COUNTY, MONTANA

by

D. Y. Meschter

ABSTRACT

The W. Wilson mine, near Clancey, Mont., explores a siliceous vein in quartz monzonite of the Boulder batholith. The vein is a composite structure that consists of several closely spaced veinlets of quartz and chalcedony separated by silicified quartz monzonite. The vein has been recurrently brecciated and silicified. Typically, the quartz monzonite has been hydrothermally altered in zones of decreasing intensity outward from the vein. Pitchblende was deposited in and along the vein during one stage of the silicification that is characterized by fine-grained disseminated pyrite in black chalcedony. Subsequently most of the pitchblende was oxidized and hydrated to form a series of brightly colored secondary uranium minerals that exhibit a zonal relationship. Most of the known uranium minerals are localized in two small elongate ore bodies.

INTRODUCTION

Uranium minerals were first recognized in the Boulder batholith early in 1949 at the Silver Bell prospect (now the Free Enterprise mine) near Boulder. Late in 1949 Wayne Hinman of Clancey detected uranium minerals on the Haynes Homestead and located the W. Wilson claim and other claims in the vicinity (fig. 1). Subsequently numerous radioactivity anomalies have been detected in siliceous veins and base-metal deposits in the Boulder batholith.
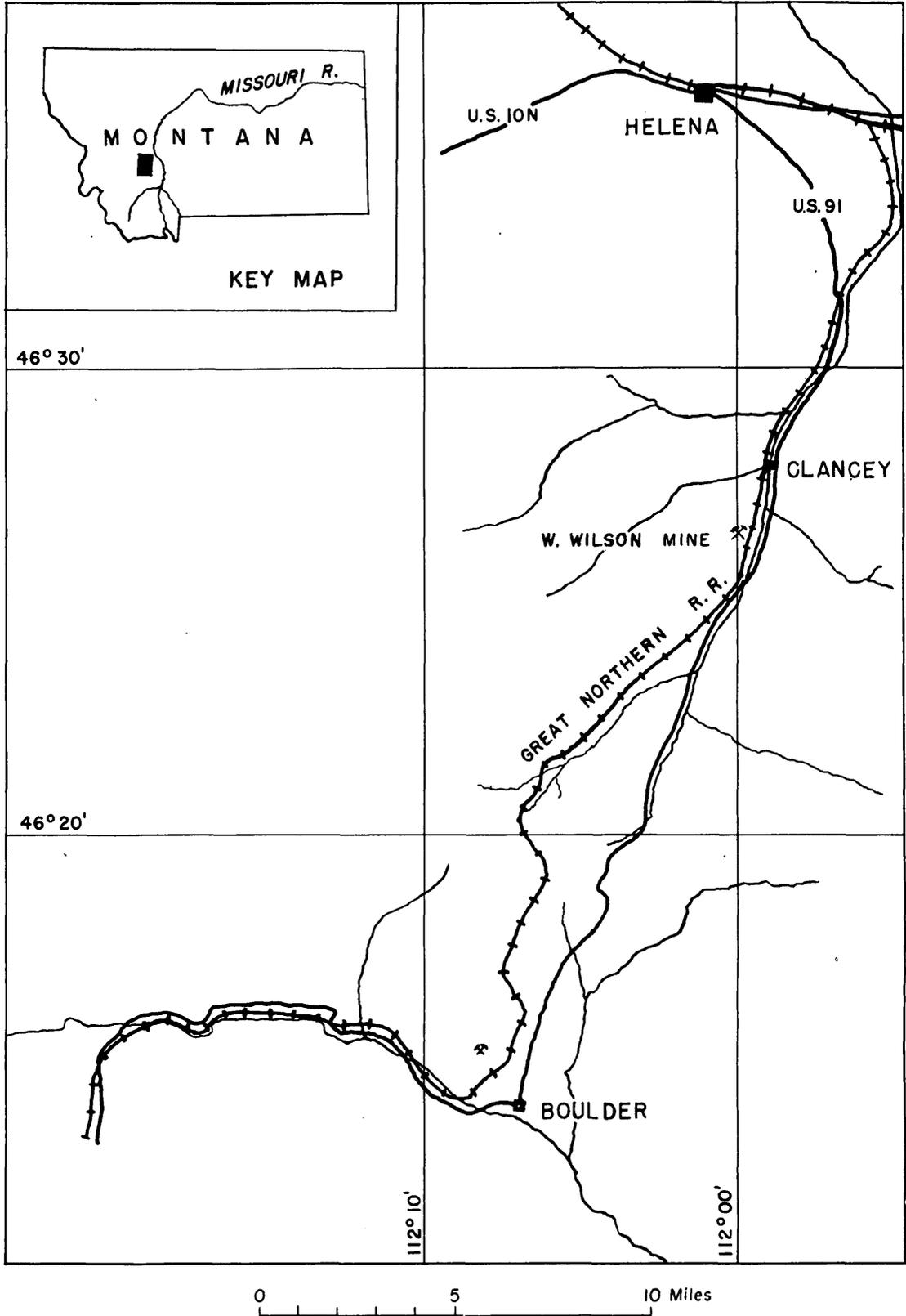
Figure I. — Index map showing location of W. Wilson Mine
near Clancey, Jefferson County, Montana.

GPO 830284

The Boulder batholith in west-central Montana consists principally of quartz-monzonite; it has a total exposure of about 1,100 square miles, extending about 60 miles in a southerly direction from the vicinity of Helena to that of Butte, and averages about 18 miles in width. Lode deposits in and near the batholith have yielded important quantities of copper, gold, silver, lead, zinc, and manganese ore.

The geology of part of the known uranium-bearing area of the batholith was mapped by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission during 1950-52 as part of a comprehensive investigation of the geology and ore deposits of the Boulder batholith. Detailed studies of known radioactive deposits and reconnaissance for additional occurrences have been made by both the Geological Survey and the Atomic Energy Commission.

Location

The W. Wilson mine is on one of a number of unpatented claims in the low hills west of Prickly Pear Valley, about 15 miles south of Helena. The valley is traversed by U. S. Highway No. 91 and a branch line of the Great Northern Railroad, both connecting the cities of Butte and Helena. The W. Wilson mine is reached by about a mile of ungraded dirt road that turns west from the highway at Alhambra.

Topography

The area in the vicinity of the W. Wilson mine is characterized by low rolling hills with a relief of a few hundred feet. Rounded hills or

ridges and valleys lead back from the Prickly Pear Valley with elevations

increasing away from the main valley so that the highest hills about two

miles away attain an elevation of a thousand or more feet above the valley

floor. Siliceous veins, with which many of the known radioactive deposits

are associated, typically crop out rather conspicuously and can be traced

for distances of as much as a thousand feet. The veins range from less

than a foot up to a few tens of feet in width. Some of the wider veins

form ledges or "reefs" that are as much as 10 feet high. The vein on

which the W. Wilson claim is located is exposed along the crest of a low

ridge.

Exploration and development

Preliminary exploration on the W. Wilson claim consisted of test

pitting the surface exposure of the vein (fig. 2). In late 1950 and early

1951, the Newmont Mining Company explored the deposit by driving 685 feet

of drift and crosscut and 70 feet of raise through an adit. Since that

time other lessees have extended the main drift, completed three short

crosscuts from this drift, extended the Newmont raise an additional 40

feet to the surface, and driven two intermediate levels from this raise

(fig. 3). One other raise to the surface has also been completed. Ore

has been mined from surface trenches and from the two intermediate levels

driven from the Newmont raise.

Previous work

Previous geologic reports on the Clancey area by Knopf (1913, pp.

120-128) and Pardee and Schrader (1933, pp. 285-299) provide valuable

information on regional geology and details on some of the metalliferous

deposits. Detailed investigations of the geology and radioactive deposits

in and near the Haynes property were made previously (Thurlow and Reyner,

1951, and Roberts and Gude, 1951), and a study of rock alteration in the

W. Wilson adit was made by Kerr and others (1951, pp. 58-68) before the

adit was completed.

Past Production

Pardee and Schrader (1933, p. 286) list the value of production from

the Clancey area at about $3,500,000 in silver, lead, gold, and copper.

More recently, silver has been mined from the district and gold has been

dredged from gravels along Prickly Pear Creek south of Clancey. The first

shipment of uranium ore from the W. Wilson mine was made late in 1951;

additional shipments were made in 1952. The ore ranged in grade from about

0.3 percent U_3O_8 to 1.1 percent U_3O_8.

Field work, laboratory work, and acknowledgments

The present investigation was undertaken at the suggestion of L. R.

Page and was done under the field supervision of M. R. Klepper, both of

the U. S. Geological Survey. The W. Wilson mine was selected for investi-

gation because of the variety of uranium minerals present, and because the

underground workings afforded an opportunity to study in detail a uranium-

bearing vein and its relations to structural features and alteration

phenomena. The principal objectives of the study were to determine: (1)

the mineralogy and paragenesis of the W. Wilson deposit; (2) the type of

wall-rock alteration and its relation, if any, to the occurrence of primary
uranium minerals; and (3) the effect of weathering and oxidation on a
uranium deposit.

The field work occupied the last part of August 1951, and consisted
of mapping the geology of the mine and the surface exposures of the de-
posit and collecting specimens of minerals, wall rock, and vein material.
The specimens and selected thin sections were studied in the laboratory
at Washington University, St. Louis Mo. The mine was revisited during
the summer of 1952 and the underground maps were brought up to date.
G. E. Becraft assisted with the underground mapping. The chemical
formulas for the uranium-bearing minerals are those used by the U. S.
Geological Survey (Frondel and Fleischer, 1952).

REGIONAL GEOLOGY

The Boulder batholith, composed chiefly of quartz monzonite, is
intruded into a thick unit of andesites and latites of probable late
Cretaceous age, and is cut locally and in part overlain by rhyolite and
dacite (Knopf, 1913, pp. 96, 102-103) of probable mid-Tertiary age. The
quartz monzonite also is intruded by silicic igneous rocks including
aplite, alaskite, alaskite-porphyry, and pegmatite, most of which occur
as dikes or gently-dipping sheets; a few are large and irregularly-shaped
masses. At many localities the rocks of the batholith are severely
fractured and faulted. Mineralized veins are widely distributed through-
out the intrusive and associated rocks, and the individual vein deposits
represent many types of mineralization.

The country rock in the vicinity of the W. Wilson mine is chiefly

quartz monzonite cut by a few thin dikes of aplite and a few moderately

thick sheets of alaskitic rocks. The rocks are locally fractured and

faulted, but faults rarely can be recognized at the surface. Siliceous

veins, most of which are nearly vertical and trend either about N. 60° E.

or easterly, are common in the vicinity of Clancey. The veins are com-

posite structures consisting of from one to five or more closely-spaced

siliceous veinlets commonly one to two inches thick, but at places more

than a foot thick; each veinlet is bordered by silicified quartz monzonite.

The vein silica and silicified wall rock are resistant and typically form

a long, linear outcrop that protrudes at least a few inches above the

surface. Where outcrops are lacking, angular fragments of siliceous

float indicate the position of the vein. The veinlets are made up of

finely crystalline quartz and chalcedony. The chalcedony is typically

dark gray to nearly black although some of it is light to dark gray or

tan; the quartz is white to gray or tan. Quartz and chalcedony in most

places in the veins are intimately associated.

Uranium minerals have been deposited in and adjacent to some of the

veins, and in some places--as at the W. Wilson mine--form ore bodies com-

posed of both pitchblende and brightly colored supergene uranium minerals.

At places fractures lined with hyalite and aragonite cut both quartz

monzonite and the siliceous veins.

Each of the veins in the area is bordered by altered country rock.

The alteration zones, so far as known, are symmetrical and several times

thicker than the veins.

GEOLOGY OF THE W. WILSON MINE

Petrography

The principal rock in the W. Wilson mine area is a gray, equigranular, medium-grained quartz monzonite. A typical specimen of the rock has the following approximate modal composition: plagioclase--50 percent, ortho-clase--25 percent, quartz--15 percent, biotite--5 percent, and hornblende--2-3 percent. The accessory minerals are magnetite, apatite, sphene and zircon.

The plagioclase (An_{30-35}) occurs as anhedral to subhedral crystals, many of which enclose minute flakes of biotite and a few of which enclose tiny prisms of hornblende and apatite. The orthoclase is anhedral to euhedral and tends to form phenocrysts. In several specimens of slightly altered quartz monzonite, some of the feldspar has a small 2V and the glassy appearance characteristic of sanidine. The quartz is anhedral; the biotite froms subhedral basal plates; and the hornblende forms euhedral to subhedral plates with well formed prism faces.

The only other rock in the W. Wilson mine area is an aplite dikelet a few inches thick that cuts quartz monzonite about 125 feet west of the intersection of the adit with the vein. It strikes N. 30° W. and dips to the east. The aplite is light-colored in tints of gray and yellow, has a fine-grained sugary texture, and consists of about 45 percent each of quartz and orthoclase, including some microcline, and 10 percent of oligoclase. The age relationship of the vein and the dikelet could not

be determined because the rocks are shattered and discolored at their intersection. Similar veins in the vicinity are known to be younger than the aplite dikes.

Alteration

The quartz monzonite adjacent to the W. Wilson vein and the veinlets comprising the vein have been hydrothermally altered to kaolin and sericite accompanied near the vein by silicification. The alteration typically is arranged in poorly defined gradational zones of decreasing intensity outward from the vein. Silicification characterizes the innermost zone immediately adjacent to the vein. Sericitization characterizes an intermediate zone, beyond which lies a zone of kaolinization. The outermost zone is very poorly defined and is characterized by very low intensity alteration, possibly the result of weathering, in which some of the biotite and hornblende have been slightly oxidized and the plagioclase slightly kaolinized.

In addition to the broad, general zones of alteration around the main vein, the individual veinlets that together make up the main vein, and even the small silica veinlets that cut moderately or slightly altered quartz monzonite some distance from the vein, are bordered by a narrow zone of alteration slightly more intense than the alteration in the surrounding rock. For example, some small isolated veinlets observed in the zone of kaolinization were noted to be bordered by a very thin zone of silicification and possibly sericitization. Where several veinlets occur close to each other, as in the case of the several small veinlets that make up the main vein structure, the alteration effects of any one individual veinlet are obscured by the combined effects of the several veinlets.

The most widespread alteration zone surrounding the main vein structure is the outermost--a zone in which some of the mafic minerals have been slightly oxidized; some of the iron has been removed from them and redistributed as iron oxides along fractures. Hornblende seems to have been the most susceptible to change, having been altered to iron oxides and silica. Biotite altered first to a colorless white mica through the loss of iron and then, in some places, to kaolin or sericite. No chlorite was observed. Slight kaolinization of plagioclase also has taken place in the outer zone, the alteration having begun with the corrosion of the edges of the plagioclase crystals.

The most conspicuous effect of alteration in the outer zone is a whitening of the rock as a result of the loss of iron from biotite and hornblende. As a result of kaolinization, the normally gray plagioclase crystals are white; the potash feldspar is unaffected. Where kaolinization and sericitization are more intense, the rock has a chalky appearance, and the fine-grained kaolin and sericite readily rubs onto the hands or clothes.

The zone of next higher intensity of alteration is characterized by more complete kaolinization of plagioclase. In this zone, the plagioclase has been almost completely replaced although the potash feldspar is not noticeably altered.

The zone of kaolinization grades into the zone of sericitization, in which sericite has typically replaced much of kaolin. In a few places plagioclase appears to have been altered directly to sericite. A little of the orthoclase has not been altered, but in most specimens it is almost completely kaolinized or at least partially sericitized.

Silicification, the most intense type of alteration, is a character-

istic feature within and immediately adjacent to the vein. It is also

present at some distance from the vein at those places where several

veinlets occur close together. Not all veinlets, however, are bordered

by a recognizable zone of silicification. The zone of silicification on

each side of the vein is commonly a foot or two wide, and in places is as

much as three or four feet wide. In thin section silica is seen to have

replaced sericite and kaolin, and less commonly unaltered feldspars.

Kaolin and sericite have replaced feldspar crystals beginning at the edges

of the crystals and along cleavage planes. Sericite is generally elongate

parallel to cleavage planes in the feldspar and has a matted appearance.

Where sericite has been replaced by silica, the quartz retains the orien-

tation and matted appearance of the sericite. Minor amounts of silica

have also been added to the wall rock by the formation of veinlets 0.1 mm

or less wide of microcrystalline quartz.

Although most of the rock adjacent to the vein has been completely

silicified, generally it retains the granitoid texture of the original

quartz monzonite. The primary quartz of the rock is unchanged and retains

its characteristic glassy appearance. Silicified minerals, however, have

a dull, flat white appearance.

Alteration to a montmorillonite-type clay _/ was noted at two

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_/ The clay was determined to be montmorillonite by the use of benzedine
solution; when applied to the white clay the solution stains it a distinct
and beautiful blue color which fades upon drying. This reaction, according
to Bosazza (1946, pp. 107-114; 1944, pp. 235-241) is indicative of the

montmorillonite and illite type clays. Examination of the clay microscopically reveals that it has the low refractive indices ascribed to montmorillonite.

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places--in the drift at the place where cross section D-D' was drawn and at

the foot of the raise to the east (fig. 3). In both places the wall rock

outside of the silicified zone is not intensely altered but contains un-

altered or slightly altered orthoclase in association with plagioclase that

is almost completely altered to kaolin and sericite. The montmorillonite

occurs as irregular, well-defined blebs, typically less than 1 mm in

largest dimension, located within or adjacent to kaolin or sericite or in

the interstices between quartz and orthoclase crystals. Some of the mont-

morillonite observed in hand specimens occurs as elongate masses of fine-

grained clay that fills small fractures.

The distribution of the zones of alteration, where they could be

defined, is shown in figures 2 and 3. The limits are approximate because

of the gradation between the zones. The alteration appears to be more

extensive in the area where primary uranium minerals occur. The montmo-

rillonite-type clays are found directly beneath the ore bodies.

The alteration at the W. Wilson mine resembles that at Butte, Mont.,

where the alteration of quartz monzonite of the Boulder batholith adjacent

to copper veins has a distinct zonal pattern; the zones, from outermost to

innermost are characterized by montmorillonite, kaolin, sericite, and

silica (Sales and Meyer, 1946, pp. 9-33). Sales and Meyer believe that

the alteration at Butte was caused by the vein-filling solutions, and that

the zones are due, not primarily to changes in the mineralizing solutions,

but to changes in physiochemical environment in the wall rock encountered by the solutions as they migrated away from the vein and progressively replaced earlier-formed alteration minerals. The alteration at the W. Wilson mine is probably the result of a similar process, even though the montmorillonite zone at the W. Wilson mine is either very indistinct or lacking. There is, however, a possibility that the montmorillonite in the W. Wilson mine is related directly to the overlying ore bodies and that its occurrence is due in part to physiochemical reactions resulting specifically from the deposition of radioactive substances. Everhart (1951) notes in regard to lode deposits containing radioactive minerals that in general:

> "The wall rock has been altered in part to clays with high base exchange properties (montmorillonite) as well as kaolinite, and may have been affected by chloritization, sericitization, or silicification, or by all three processes."

At the Boulder Hot Springs, which issue from the quartz monzonite of the Boulder batholith a few miles south of Boulder, Weed (1900, pp. 233-255) observed the actual processes of vein formation and associated alteration going on due to hot-spring activity. The alteration there is similar to that at the W. Wilson mine and includes kaolinization, sericitization, and silicification. The vein structure formed at the springs is described by Weed as "netted" and the vein silica as chalcedonic. There seemed to be no doubt that the vein formation and wall rock alteration observed by Weed was due entirely to the hot waters that issued from the springs.

The alteration at the W. Wilson mine is intimately related to the siliceous veins, as it is at both Butte and Boulder Hot Springs, and presumably was caused by the same solutions that deposited the quartz and chalcedony of the veins. The alteration, in addition to having symetrical arrangement around the W. Wilson vein, also has a rough quantitative relationship, the wider zones of alteration having been formed around the thickest portions of the veins.

The known uranium-bearing ore bodies occur in an along the vein at places where the vein is relatively thick and the zones of alteration are wide. No particular feature of the alteration, however, can be attributed specifically to the uranium mineralization except perhaps the local alteration of some material to montmorillonite.

Vein structure

The W. Wilson vein is exposed for a length of over 500 feet in the main drift and is continuous in both directions beyond the ends of the drift; it pinches out in one place near the west end for an interval of about 15 feet. Figure 3, a map and cross sections of the underground workings, shows the vein, related structural features, and the alteration zones.

The main vein is a composite structure consisting of from one to five closely spaced veinlets of quartz and chalcedony surrounded by a zone of silicified quartz monzonite. Individual veinlets locally are as much as 3 feet thick but average only about 0.3 foot thick. The vein structure might be described as "netted", for the individual veinlets, although roughly

parallel to the vein structure in both strike and dip, in detail interlace

in a slightly sinuous anastomosing pattern that resembles crude netting.

Where the vein is composed of four or five veinlets it may be more

than eight feet wide, but in the places where it is composed of only one

or two veinlets it is only a foot or two wide. The combined width of the

vein and the alteration zones ranges from 25 to 50 feet. Where the adit first

intersects it, the vein consists of only two or three veinlets, each less

than 0.2 foot thick in a total thickness of about 6 feet. At cross section

B-B' (fig. 3) the vein is about 10 feet thick and is composed of five

prominent veinlets and several inconspicuous veinlets each less than 0.1

foot thick. Silica is most abundant near the location of cross section

C-C' (fig. 3). Here the vein is a single unit about 3 feet thick composed

chiefly of dark-gray to black chalcedony. Both east and west of this point

the total amount of silica in the vein decreases. Dark-gray to black

chalcedony is found throughout most of the vein, but white or light-gray

quartz is the more abundant form of silica at many places. At some ex-

posures the vein is somewhat banded due to recurrent fracturing and depo-

sition of black chalcedony and white to gray finely crystalline quartz.

The dark-gray or black color of the chalcedony is due to minute inclusions

of pyrite, chalcopyrite, and possibly arsenopyrite _/. Small lenses as

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_/ The identification of the sulfide minerals was made by grinding a
sample of the black chalcedony to about 250 mesh, leaching the powder with
acid, and analyzing the residual liquor. The analysis indicated the presence
of large amounts of sulfur and iron, and small amounts of copper. In-
spection of leached grains of 250-mesh size showed that nearly all of them
still contained minute inclusions of sulfide minerals that had not been
attacked by the acid because of the protective surrounding mass of silica.

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much as 5 mm thick and 20 to 25 mm long of fine-grained pyrite with sparse

chalcopyrite and arsenopyrite(?) occur locally in the chalcedony. Rarely,

small amounts of sulfide minerals were also deposited in the wall rock

adjacent to the chalcedonic veinlets. The surfaces of weathered fragments

of chalcedony are typically stained red to red-brown by iron oxides formed

by the oxidation of the pyritic inclusions. Malachite, probably derived

from the copper contained in the chalcedony, was noted to occur at just

one place - in the drift just west of the main raise as shown on figure

3 - as a thin encrustation on rock fracture surfaces. The content of

sulfide minerals in the chalcedony is estimated locally to be as much as

5 percent.

Short crosscuts, which have been driven into the walls of the vein

at several places, have exposed several discontinuous silica veinlets,

most of which parallel the main vein. The veinlets are commonly less than

0.1 foot thick and are composed mostly of white to tan or light-gray

finely-crystalline quartz and sparse chalcedony. One veinlet, about 0.2

foot thick in the wall north of the vein contained clear coarsely-

crystalline quartz.

Microscopic study of the vein material shows that there were at

least three, and perhaps four, periods of deposition of silica and at

least two stages of brecciation during vein formation. The earliest

quartz consists of relatively large anhedra that occur in and along the

edges of some veinlets. This quartz may represent either early vein

filling or relict crystals from the quartz monzonite. Some quartz of

this type shows strain shadows, and some of it has distinct anomalous

biaxial properties with a 2V of approximately 5 degrees. If this early

quartz represents relic crystals from the wall rock, its deformation was

probably caused by pre-vein faulting; if this quartz is a vein filling,

the strain was probably caused by early-vein faulting. The later vein

quartz, although somewhat brecciated, is not deformed.

The earliest quartz, the relatively large anhedra, was cemented by

clear microcrystalline quartz. Subsequently these two types of quartz

were brecciated and recemented by the distinctive dark-gray to black

chalcedony. In many veinlets deposition of chalcedony was preceded by

deposition of clear microcrystalline quartz, which crystallized at the

edge of the vein openings. The dark-colored chalcedony was deposited in

the center of these veinlets and also in veinlets without microcrystalline

quartz.

The deposition of chalcedony was followed, apparently without signifi-

cant brecciation, by the introduction of small quantities of clear micro-

crystalline quartz in tiny veinlets cross-cutting all the earlier types

of silica. The relations of all the types of silica are shown in figure 4.

A post-vein fault crosses and displaces the vein near the east end of

the workings (fig. 3), and other faults parallel the vein and have brecci-

ated the vein silica. The fault that displaces the vein near the east end

of the drift has gently plunging slickensides on a steeply dipping fault

face and an apparent horizontal displacement of approximately 30 feet.

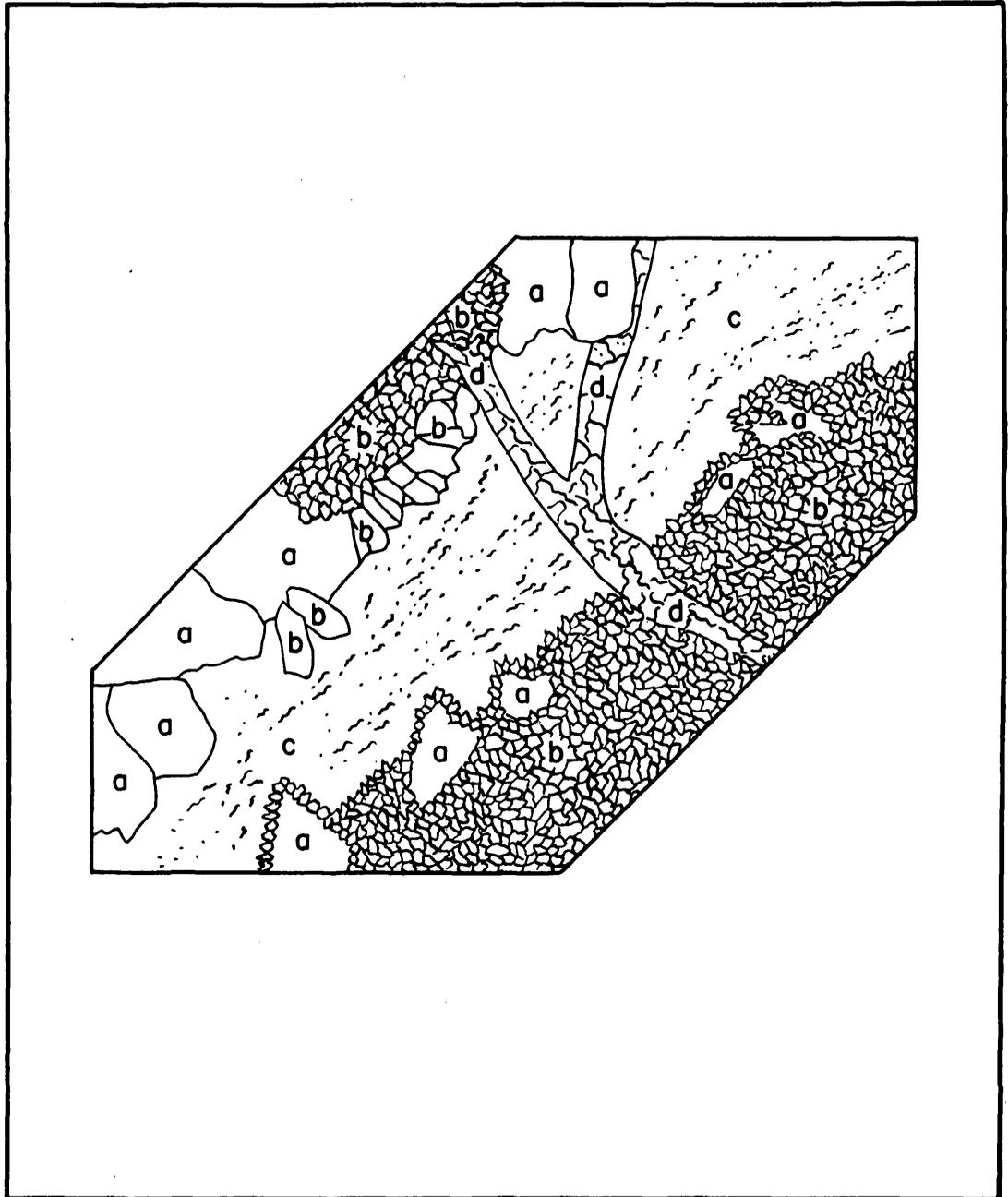Another fault exposed for about 200 feet along the north side of the vein

FIGURE 4.-SKETCH SHOWING QUARTZ-CHALCEDONY RELATIONS IN
VEINS.

a,early quartz anhedra; b,early microcrystalline quartz; c,pyritic chalcedony;
d, late microcrystalline quartz veinlet. Magnification about 40X as viewed
through microscope.

from the east to central part of the drift does not cross the vein, but it does displace an aplite dikelet. The observed faults are filled with gouge and are relatively impervious.

Gently-dipping fractures and joints in the altered quartz monzonite are common in the underground workings and some cut the vein. There is no apparent movement along most of these, but a few slightly displace older fractures. The gently-dipping fractures commonly are lined with dark red hematite and coarse anhedra of quartz that have a crude parting parallel to the plane of the fractures. A few of the joints have encrustations of hyalite and aragonite and have been mapped as hyalite-aragonite veins.

Occurrence of uranium minerals

Two lens-like ore bodies that contain primary and secondary uranium minerals are exposed at the surface just to the east of the main raise (fig. 2). Most of the uranium minerals are confined to these bodies, but a few secondary uranium minerals are sparsely distributed outside of the ore bodies proper. Each of the ore bodies is about 25 feet long and from less than 1 foot to 5 feet in thickeness; they are separated laterally by about 10 feet of altered and silicified quartz monzonite. The west ore body extends to a maximum depth of about 12 feet; the east ore body forms a long vertical shoot extending downward about 60 feet and is exposed in the lower of the two intermediate levels (fig. 3, sec. E-E'). Neither of the ore bodies extends down to the adit level, which is about 105 feet below the outcrop of the east ore body.

The ore bodies are characterized by sparse pitchblende and by relatively abundant yellow and orange secondary uranium minerals. Green metatorbernite-metazeunerite and yellow autunite occur chiefly outside the ore bodies in a halo representing the migration of a portion of the uranium.

The veinlets, as shown in cross-section E-E' (fig. 3), diverge upward from the adit level resulting in a general widening of the vein and of the zones of alteration in the area around the ore bodies. A thick vein of black chalcedony near cross-section C-C' (fig. 3) appears to form a long lens raking downward either vertically or steeply to the east. In contrast to a typical thickness of the chalcedony veinlets, a few tenths of a foot, the vein near C-C' is about 3 feet thick. Above this and slightly to the west in the lower intermediate level the chalcedony vein is about a foot thick. Above the lower intermediate level the chalcedony vein splits, diverging upward, and in the upper intermediate level the chalcedony is 0.5 foot or more thick in each of several veinlets.

The east ore body in particular is spatially related to the black or dark gray chalcedony. Between the upper intermediate level and the surface it lies between two prominent chalcedony veinlets, and in the lower intermediate level it lies along both sides of a chalcedony veinlet. It is crossed at a low angle by another veinlet between the two intermediate levels. The ore body projected down to the adit level, however, would be somewhat to the west of the thick chalcedony veinlet near section C-C'. It is apparent, considering the W. Wilson vein as a whole (figs. 2 and 3),

that the ore bodies and thick chalcedony occur at about the same place and that at this place the band of alteration is wider than elsewhere. Meta-torbernite-metazeunerite and autunite were observed at several other places along the 450 feet of vein that was mapped (fig. 2), but no evidence of primary uranium mineralization was noted at these places.

MINERALOGY OF THE W. WILSON MINE

Primary minerals

The only primary uranium mineral recognized in the deposit is pitch-blende. It occurs within the ore bodies near the surface as small pods up to 10 mm across, as disseminated grains, and as minute streaks or veinlets that are invariably surrounded or enclosed by rims of yellow and orange secondary uranium minerals derived from the oxidation and hydration of the pitchblende. The larger masses of pitchblende contain inclusions of foreign material which in thin section were determined to be (1) euhedral crystals and granular masses of fine-grained pyrite, (2) breccia fragments of quartz vein material, and (3) an amorphous material with properties similar to those of collophane.

The pitchblende is minutely colloform in habit and is somewhat banded. The bands are gently curving. Replacement by secondary minerals has progressed preferentially along some of the bands and relict banding can be seen in some of the secondary minerals. Some authors have in-terpreted colloform banding similar to this as being the result of deposition from a colloid. Pods of secondary minerals that have shapes

and banding similar to colloform pitchblende are believed to represent completely replaced masses of the primary mineral.

The mineral believed to be collophane occurs as minute anhedral masses in pitchblende or closely associated with pitchblende. The mineral is amorphous with a refractive index of 1.59 ($\pm$ .02), is colloform in habit, and is brownish to colorless in thin section.

Secondary minerals

The secondary uranium minerals in general are brightly colored in shades of yellow, orange, and green, and take the form of irregular veinlets, encrustations on fractures, rims around pitchblende, and rims around fragments of nonradioactive minerals. Some ore that contains abundant secondary uranium minerals bears a strong resemblance to some types of pisolitic bauxite but is more brightly colored.

Most of the secondary minerals occur as microcrystalline to amorphous masses, and the identification of individual minerals is therefore difficult. Identification of minerals is further complicated by the tendency of secondary minerals to be intimately intergrown. This feature is especially characteristic of gummite, which almost invariably is intergrown with uranophane and phosphuranylite.

Of the secondary uranium minerals present in the deposit, meta-torbernite-metazeunerite, autunite, uranophane, and gummite were identified by conventional megascopic and microscopic techniques. Uranocircite and phosphuranylite were positively identified by X-ray and spectroscopic analyses made by the U. S. Geological Survey's Geochemistry and Petrology

laboratory in Washington, D. C. Roberts and Gude (1951, p. 24) reported that the uranium carbonate minerals voglite and rutherfordine occurred in direct association with pitchblende in ore from the W. Wilson deposit. Voglite was not recognized in the suite used for the present study, while rutherfordine is now considered a dubious mineral usually being found to be a mixture of uranophane and calcite.

Metatorbernite and metazeunerite

Metatorbernite ($Cu (UO_2)_2 (PO_4)_2. 8H_2O$) and metazeunerite ($Cu (UO_2)_2 (AsO_4)_2 .8H_2O$) are the most widely distributed uranium minerals in and adjacent to the W. Wilson vein. They are not abundant within the ore bodies but are conspicuous peripheral to them, chiefly in the surface pits northeast and southwest of the ore bodies and in underground workings beneath the ore bodies. All observed occurrences have been within 10 feet of the vein. Consequently, it is thought that these two minerals may have some value as a guide in exploration.

These two minerals are similar in physical properties and can be told apart only by optical properties. Both metatorbernite and metazeunerite form nearly perfect crystals that are thin plates with a square or rectangular outline up to 0.3 mm in largest dimension. They are typically deposited along fractures as individual crystals or clusters of crystals. Megascopically both minerals are bright green; microscopically both are a lighter green and exhibit blue interference colors and weak pleochroism. The two minerals are distinguished from each other by their optic sign. Metatorbernite is uniaxial positive in white light and metazeunerite is

uniaxial negative. Both are tetragonal, ditetrangonal-dipyramidal
(Palache, Berman, Frondel, 1951, pp. 991-993).

The two minerals, despite their similar crystallographic structure
and chemical composition, do not appear to form a completely isomorphous
series; according to Dana (1892, pp. 856-857) there is a limited isomor-
phism with the phosphorous in torbernite being replaced by arsenic to the
extent of 3.24 percent. A later reference (Palache, Berman, Frondel,
1951, p. 993) states, "(PO_4) doubtless can substitute for (AsO_4) but
analytical evidence of this in natural material is lacking". There are
no data on replacement in metatorbernite.

Autunite

Most of the autunite (Ca (UO_2)$_2$ (PO_4)$_2$ .10.12H_2O) occurs in the
peripheral part of the ore bodies; some of it occurs in the meta-
torbernite-metazeunerite halo. It occurs as yellow micaceous masses and
is identified on the basis of color, crystal habit, and a bright yellow-
green fluorescence similar to hyalite. Autunite is difficult to
distinguish from uranocircite.

Uranocircite

Uranocircite (Ba (UO_2)$_2$ (PO_4)$_2$ .8H_2O) is the barium equivalent of
autunite. It resembles and occurs with the autunite in the peripheral
part of the ore bodies. It is yellow-green, soft, micaceous, and
fluoresces bright yellow-green. Positive identification of this mineral

required X-ray and spectroscopic analysis; a report from the Geochemistry
and Petrology laboratory at Washington indicates that a specimen submitted
for identification contains both calcium and barium, suggesting that it
is either a mixture of autunite and uranocircite or a single mineral
species intermediate between the two.

Uranophane

Uranophane ($Ca (UO_2)_2 Si_2O_7 \cdot 6H_2O$) appears to be the most abundant
secondary uranium mineral in the ore bodies. It occurs throughout the ore
bodies, in some places as minute veinlets and encrustations free from
other minerals, but more commonly as encrustations and alteration rims
intimately intergrown with gummite and phosphuranylite. It is typically
associated with some other uranium mineral, even where it is not obviously
intergrown. A commonly associated mineral is gummite. In one specimen a
mass of uranophane is bordered on one side by gummite and on the other by
a discontinuous streak of pitchblende. Uranophane in some places occurs
as veinlets less than 0.1 mm wide that crosscut fractured quartz crystals,
breccia fragments, and pitchblende.

Uranophane varies in color from yellow through yellow-green to green,
the darker color appearing to be the result of greater thickness of the
mineral. In thin section it is yellow and tends to be crystalline. It is
identified on the basis of refractive indices, biaxial negative inter-
ference figure, and bright gray-blue abnormal interference colors.

Phosphuranylite

Phosphuranylite (Ca_3 $(UO_2)_5$ $(PO_4)_4$ $(OH)_4 \cdot 2H_2O$?) has been observed only
in close association with pitchblende. It occurs either as part of en-
closing rims of second minerals around pitchblende or in pea-sized pods
that seem to represent complete replacement of pitchblende in place. In
every occurrence it is intermixed with other uranium minerals and is
difficult to distinguish from uranophane. It was identified by the
Geochemistry and Petrology laboratory.

Gummite

Gummite (Frondel and Fleischer, 1952, p. 5), like phosphuranylite,
occurs only in close association with pitchblende. It is a mixture of
uranium compounds and appears to be one of the earliest products formed
in the alteration of pitchblende. The substance is cryptocrystalline. It
was identified by the Geochemistry and Petrology laboratory of the U. S.
Geological Survey on the basis of yellow-orange to orange color,
cryptocrystalline form, and mineralogic association.

Zoning of secondary uranium minerals

The secondary uranium minerals were formed in part by the direct
replacement of the pitchblende, in part by replacement of earlier secondary
minerals, and in part by solution of earlier uranium minerals and re-
deposition of uranium salts after migration in meteoric waters. The
distribution of the different secondary minerals in crude zones appears
to be a key to the internal structure of the ore bodies.

Pitchblende appears to have been altered directly to gummite and phosphuranylite. The gummite evidently formed by the oxidation of the pitchblende; the phosphuranylite formed by hydration and combination of the oxides of uranium with phosphorus that might have been derived from collophane(?) or from accessory apatite in the quartz monzonite. These two secondary minerals in direct association with pitchblende characterize an inner zone of alteration.

Uranophane, autunite, and uranocircite, which occur within the ore bodies but not necessarily near pitchblende, appear to represent a later stage of alteration. In some places uranophane appears to replace gummite and phosphuranylite in situ by the addition of silica; elsewhere it has been deposited from migrating solutions that leached uranium either from pitchblende or from gummite and phosphuranylite. Autunite and uranocircite do not have a direct association with pitchblende and probably were deposited from migrating solutions in much the same way as the uranophane.

The outermost zone of alteration is represented by metatorbernite and metazeunerite that were deposited by meteoric waters outside of the ore bodies. The copper and arsenic necessary to form these minerals were probably provided by the solution of sulfide minerals in the black chalcedony.

The perfection of crystallinity in the secondary minerals appears to be a function of the sequence of alteration and also of the mode of deposition. Gummite and phosphuranylite, characteristic of the earliest and innermost stage of alteration, are cryptocrystalline; uranophane, autunite, and uranocircite, characteristic of the intermediate stage, are

somewhat more crystalline, and metatorbernite and metazeunerite, charac-
teristic of the last and outermost stage, form nearly perfect crystals.
The minerals, such as gummite and phosphuranylite, that were formed by
replacement tend to be cryptocrystalline; the minerals, such as autunite,
uranocircite, and some of the uranophane, that were formed by deposition
from solution are distinctly crystalline. Crystallinity may also be a
function of the space available, as metatorbernite and metazeunerite, the
only secondary minerals to have been deposited in relatively large open
fractures, are nearly perfectly crystalline.

Paragenesis

At least three periods of silicification in the W. Wilson mine can be
recognized. The first period consists of clear microcrystalline quartz,
the second of black or dark gray chalcedony, and the third of clear
microcrystalline quartz.

Pyrite occurs in the chalcedony and appears to be contemporaneous with
it since the pyrite does not occur in either the earlier or later quartz
even where the quartz and chalcedony are in contact. The pyrite occurs as
fine grains distributed fairly uniformly through the chalcedony as if the
pyrite grains had just been formed when the chalcedony solidified.

The pitchblende in the deposit probably is related to the pyritic
stage of silicification as it is found only near veinlets of dark
chalcedony in the silicified zone of alteration. Although it has not been
definitely observed to occur with the chalcedony proper of the vein, it

has been noted to contain inclusions of pyrite and quartz breccia. The quartz breccia, composed of some microcrystalline quartz, is believed to have been formed between the periods of deposition of the first micro-crystalline quartz and the chalcedony, because there is no evidence of hydrothermal activity after the brecciation following the last micro-crystalline quartz. The pyrite inclusions occur as individual minute grains, as small masses of minute grains, and less commonly as crystalline euhedrons that display growth lines. The pitchblende typically forms rounded grains that exhibit banded colloform texture. It probably was deposited from a colloidal solution, and it appears to have solidified around and enclosed pyrite grains in the same manner as the chalcedony solidified around disseminated pyrite particles.

It appears that the sequence of deposition during the chalcedonic stage of vein formation was: crystallization of the slight marginal microcrystalline quartz along some of the chalcedony veinlets, pyrite, chalcedony, and lastly pitchblende. All the minerals formed so nearly at the same time as to be essentially contemporaneous.

Alteration of the pitchblende to secondary uranium minerals probably began shortly after the deposition of the pitchblende. The sequence of deposition of the secondary minerals was (1) gummite and phosphuranylite replacing pitchblende; (2) uranophane replacing phosphuranylite, gummite, and possibly pitchblende, by addition of silica; (3) uranophane deposited from uranium-bearing solutions; (4) autunite and uranocircite; and (5) metatorbernite and metazeunerite. The formation of all these minerals was a continuing process and their periods of deposition overlap. For example,

gummite was one of the earliest of the secondary minerals to form but may
at the present time be replacing pitchblende to a small extent. Meta-
torbernite and metazeunerite are the last-formed minerals in the deposit,
and are probably still being deposited.

Hyalite and aragonite were deposited after a period of post-vein
faulting. Their deposition was probably related to hot spring activity
such as is still continuing at Boulder Hot Springs and Alhambra Hot
Springs.

SUMMARY

The uranium minerals at the W. Wilson mine are intimately related to
a siliceous vein, which is one of many in the vicinity of Clancey. The
vein was emplaced along a zone of recurrent faulting. Silica was de-
posited from hydrothermal solutions that also altered the quartz monzonite
wall rock to silica, sericite, kaolin, and sparse montmorillonite. The
vein silica is brecciated and the vein itself is locally displaced.

One of the several stages of vein silica is characterized by fine-
grained disseminated pyrite, and it is believed that the pitchblende was
deposited during this stage. An important structural feature of the
deposit is a concentration of pyritic chalcedony that forms a long steeply
raking lens or "shoot" near and within which the pitchblende is localized.

The geologic history of the deposit may be briefly summarized as
follows:

1) Intrusion and solidification of quartz monzonite host rock.

2) Intrusion and solidification of aplite dikes.

3) Fracturing or faulting.

4) Silicification of vein structure by hydrothermal activity accompanied by wall rock alteration and primary uranium mineralization.

5) Oxidation and hydration of uranium continuing to the present.

6) Faulting accompanied by shearing and jointing.

7) Erosion and hot spring activity accompanied by deposition of hyalite and aragonite.

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