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VEINS IN THE NORTHERN PART OF THE  
BOULDER BATHOLITH, MONTANA

by

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# VEINS IN THE NORTHERN PART OF THE BOULDER BATHOLITH, MONTANA

by

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## ABSTRACT

About 20 miles north of Butte and extending nearly to Helena, is an area of 350 square miles containing hundreds of veins and altered zones. The bedrock of the area is 1) late Cretaceous volcanic rocks, forerunners of the Boulder batholith, 2) the Boulder batholith of late Cretaceous to early Tertiary age and 3) two groups of Tertiary volcanic rocks lying on the eroded batholith. The veins are post-batholith and pre-Tertiary in age.

The veins are largely either quartz-sulfide veins of mesothermal type or chalcedony veins of epithermal type. The relations of these two types of veins have been the subject of conflicting ideas for 60 years. Three workers have proposed three different genetic classifications. This report shows that the quartz veins and the chalcedony veins are closely related parts of a strongly zoned hypogene vein system.

Strong zonal patterns were established using the grain size of quartz (or pyrite vs. carbonate in one district) as well as features of the altered rocks. The scale of the zoning ranges from single veins through groups of veins or mining districts to the entire mineralized area. Single veins are zoned around a core of coarse-grained

quartz; the quartz outward from the core becoming progressively finer-grained. The cores are zoned around eight major centers and several lesser ones. The centers and their nearby related veins are assigned to central, intermediate, and peripheral zones. Nearly all of the veins around the edge of the mineralized area are chalcedony.

Envelopes of altered rocks consist of seven major bands representing three major groups of constituents, aluminum silicates, iron-bearing minerals, and silica. Plagioclase altered successively to montmorillonite, kaolinite, and sericite; potassium feldspar altered to sericite (aluminum silicate group). Biotite released iron which formed successively, iron oxides, iron-bearing carbonate, and pyrite (iron-bearing minerals). Excess silica formed silicified bands. Constituents for which no stable phase occurs were largely leached from the rocks.

A model has been constructed showing the arrangement of zoned veins and altered rocks in which the minerals produced by alteration are arranged in bands on each side of the vein, similar to the Butte pattern. Along strike from the cores, the inner bands thin and pinch out against the vein so that the vein becomes enclosed successively in the next outer bands. The sequence of alteration minerals along the veins is sericite, kaolinite, and montmorillonite for the aluminum silicates; and pyrite, carbonate, and iron oxides for the iron-bearing minerals.

Alteration is thought to be controlled by reactions between wallrock minerals and the pore solution. In the aluminum silicate reactions,  $H^+$  was added to the rock and  $Na^+$  and  $Ca^{++}$  were removed.



Carbon and sulfur from the vein were added to iron of the wallrock to produce pyrite and iron carbonate. Carbon, sulfur, and hydrogen moved into the wallrock, while  $\text{Ca}^{++}$ ,  $\text{Na}^+$ , and some  $\text{SiO}_2$  moved toward the vein along concentration or activity gradients.

Temperatures during mineralization ranged from below  $200^\circ\text{C}$ . to about  $350^\circ\text{C}$ .

## INTRODUCTION

The Boulder batholith contains two large mineralized areas within it and several small districts around its borders. The Butte district, the most well known of the two main areas, is in the southwest part of the batholith. A second and larger mineralized area contains several districts and includes much of the northern part of the batholith and adjacent areas. This area extends southward about 17 miles from the north edge of the batholith and is about 20 miles from east to west (fig. 1). About 20 miles separates the northern

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Figure 1. Index map of the mineralized area in the Boulder batholith.

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mineralized area from the one at Butte. The northern mineralized area is generally not well known, and is the subject of this report.

Older work on the origin of the deposits in this area was done by Knopf in 1913 and Billingsley and Grimes in 1918. These writers proposed close genetic relations (in the sense of time, space and origin of materials) between the deposits and the intrusive rocks.

Their hypotheses were based on the assumption that, since quartz, tourmaline, and pyrite were the latest minerals to crystallize from the magma of the batholith and they are abundant in the veins, the veins and rocks must be very closely related. The main objections to this generalized type of hypothesis are that:

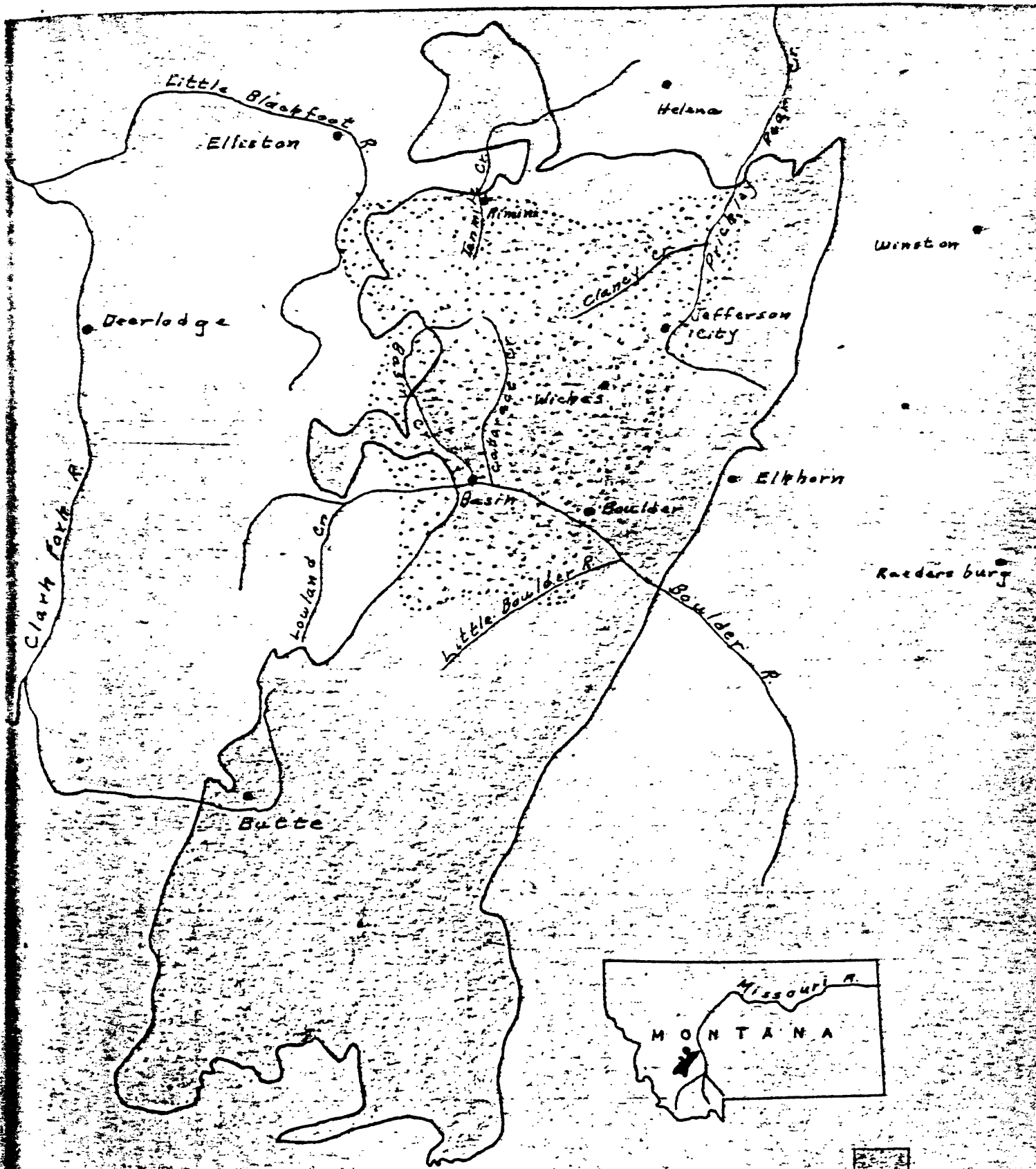




Fig. 1. Index map of the Boulder Batholith and Vicinity

 Boulder batholith  
 Mineralized area

0 10 20 Miles

1) It deals only with end members and leaves out the intermediate steps between intrusive rocks and the accumulated material in the veins. These steps have not been recognized in the field; especially the steps by which metals other than iron are accumulated and finally deposited.

2) Veins in the area appear to be xenothermal, mesothermal, and epithermal types and they appear to represent a considerable range in physical conditions of deposition.

One of the older works split the deposits into two groups of different ages, one group including the xenothermal and mesothermal veins and the other group including mostly epithermal veins. The writer noted that these two groups had many features in common and that the two groups seemed to change gradationally into each other. More knowledge of the veins was needed before genetic concepts of the origins and the method of accumulation of the metals could be formulated.

The results of the new work are the delineation of patterns of zoning of both veins and altered rock, and a model showing how the mesothermal types of veins grade into epithermal types. It cannot yet be shown just how the metals were collected from the magma, if indeed they were.

The study of the veins was greatly aided by work being done by other Geological Survey geologists in the area. By 1957 regional geologic mapping in and around the batholith had been completed over most of its northern part and over some outlying mining districts. This work served to define the larger mineralized area as an entity separate from the many outlying districts, and provided a large fund

of general geologic information useful in the study of the veins.

Field work devoted entirely to the study of veins in the mineralized area was done in 1958, 1959, and 1960 by the writer. Previously, he had mapped in the area and had studied aspects of the mineral deposits more directly related to mining.

## GEOLOGIC SETTING

### Resume of general geology

The most complete recent summaries of general geology of the region are given by Klepper, Weeks, and Ruppel (1957), Ruppel (1963), and Becraft, Pinckney, and Rosenblum (1963). The following resume is taken from these reports and other material in the files of the U. S. Geological Survey.

The long interval from late Precambrian to late Cretaceous was a time of stability that was followed by mountain building and igneous activity. In general it was an interval of deposition of shelf-type sediments broken by a few episodes of erosion or non-sedimentation.

In late Cretaceous time an episode of igneous and tectonic events started that reached a climax with the intrusion of the Boulder batholith. A series of volcanic rocks, the Elkhorn Mountain volcanics, accumulated to a thickness of probably over 10,000 feet. The batholith intruded well up into the upper part of the volcanic pile and hence may have reached within a few thousands of feet of the surface. The last igneous activity directly related to the batholith is indicated by a group of granites that were intruded as small plutons, flat-lying sheets and dikes of aplite, alaskite, and pegmatite.

A major period of mineralization followed the intrusion of the alaskite rocks and the cooling of the batholith. This is the period in which the veins at Butte and those in the northern part of the batholith

and adjacent areas were formed. Mineralization had probably completely ceased before the next sequence of rocks were laid down.

During the Eocene epoch, much of the batholith was uncovered by erosion, a mature topography was produced in the region, and the veins were oxidized and locally enriched. Erosion did not cut deeply into the batholith, and the present day surface is very near the roof. Erosion then gave way to renewed vulcanism.

In Oligocene time, and probably in the late Oligocene, (Smedes, 1962) renewed vulcanism deposited several thousand feet of quartz latitic tuff over the area, accompanied by the intrusion of many dikes and some small plutons of the same composition. The intrusive rocks cut and intrude along many veins; the tuff, where preserved in mineralized areas, overlies older oxidized vein outcrops and therefore establishes a minimum age for the period of major mineralization. A second period of mineralization followed the Oligocene vulcanism, but deposits of this age are of restricted extent and are not the subject of this report.

A series of rhyolite rocks, mainly lava flows, and some associated intrusive rocks overlie parts of the batholith and its roof rocks in the vicinity of Rimini and west of the area of figure 2. The time of their extrusion is not well established. Near Rimini they rest on a mature surface cut on batholithic or Cretaceous volcanic rocks. Near Champion Pass, about 12 miles west of Basin, they lie on quartz latite tuff (Smedes, 1960, p. B24), and have been partly dissected by Pleistocene glaciers. In one area southwest of Rimini these rhyolite contain low-grade disseminated deposits of gold, but no other mineralization has been linked to them.

Following the extrusion of rhyolite the history of the region was characterized by uplift; erosion and glaciation produced a dissected upland surface, partly mantled by ground moraine. Many valleys in the western part of the mineralized area contain moraines, outwash gravels, and other Quaternary deposits.

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## Mineralized area

The mineralized area in the northern part of the batholith, outlined on figure 2, is roughly circular, about 20 miles across, and

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Figure 2. Geology of the mineralized area.

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comprises about 350 square miles. Within it are hundreds of veins and altered zones, several mineralized or altered breccia pipes, disseminated gold deposits, and various other deposits. The mining districts of older reports within the mineralized area are small areas in which the veins are more closely spaced than elsewhere and which contain one or more centers of mineralization. Areas between some of these poorly defined mining districts contain strikingly fewer veins.

The north border of the mineralized area, not completely shown on the map, is situated a short distance beyond the north edge of the map-area. The northwest border of the mineralized area is rather poorly defined; veins are widely scattered from Rimini to the valley of the Little Blackfoot River.

## Host rocks

The wall rocks of the veins are andesite and quartz latite of the Elkhorn Mountains volcanics and rocks of the Boulder batholith. They are briefly described here. More complex descriptions are available in publications of the U. S. Geological Survey, Bulletin 1151 and Professional Papers 292 and 428.

The Elkhorn Mountains volcanics are the oldest rocks exposed in the mineralized area. These rocks form the roof of the batholith along its west side and a large roof remnant near Wickes. Many smaller remnants of the roof rocks are in the drainage area of Cataract and Basin Creeks. The volcanic rocks have been deformed into broad open folds, the flanks of which rarely dip more than 35 degrees. East of the mineralized area, the rocks have been divided into three members (Klepper, Weeks, and Ruppel, 1957, p. 32) that have an aggregate thickness probably in excess of 10,000 feet. However, in the map area, the lower unit, largely andesitic tuff, is missing and apparently was stopped out by the batholith, but the middle unit (largely quartz latitic welded tuff) and the upper unit (largely reworked andesitic fragmental rocks) are present and form the preserved part of the roof.

## Rocks of the Boulder batholith

The Boulder batholith is about 60 miles long in a northeast-southwest direction and about 25 miles wide. Most of the mineralized area is underlain by rocks of the batholith which together with a lesser amount of Elkhorn Mountains volcanic rocks are the country rocks of nearly all of the deposits considered in this report.

A large part of the batholith, in and near the mineralized area, probably comprises a large pluton of quartz monzonite or granodiorite that is cut by late magmatic leucogranite intrusives. The northern part of the pluton consists of several varieties, most of which are similar chemically and mineralogically, but differ in grain size, color, and fabric. Such texturally defined bodies grade imperceptibly into each other, and probably represent different parts of the same magma. A few other bodies of this same composition are roughly circular in outline, suggesting that they may be slightly later plutons that were intruded into a higher consolidated part of the magma.

No relationship was found between the mineral deposits and the different textural varieties of the batholith. Rather it seems that the textural varieties are related to the roof of the batholith and the veins were derived from some more deeply seated source. For this reason the textural varieties are not shown on the geologic map (fig. 2).

The late granites of the batholith, referred to as alaskite, are leucocratic pinkish-buff rocks with little, if any, mafic minerals and a high proportion of quartz. Within most bodies, regardless of size, their texture ranges from fine aplites to pegmatite in which quartz and feldspar crystals are commonly over one inch across. The greatest concentration of these rocks occurs in a belt about 7 miles wide that trends northeasterly, parallel to the long axis of the batholith. Most dikes and numerous joints and veins within the alaskite belt also trend northeast, so that this trend seems to be a reflection of some fundamental structure within the batholith. The position of the batholith in the upper unit in the area of the large roof remnant west of Wickes indicates that the batholith may have reached to shallow depths and hence that the veins were likewise deposited under a thin cover.

### Nature of vein exposures

The Tertiary and Quaternary deposits shown on the map (fig. 2) indicate the amount of cover and, therefore, the density of data that was obtained. In the western part of the mineralized area, vein outcrops are almost non-existent; in these areas, nearly all of the veins are known only from artificial exposures. Even where covering deposits are absent the area is covered by thick forest litter that obscures the veins and altered zones. In the eastern part of the area covering deposits are less abundant and forest litter is thin to absent, so that many veins can be followed in almost continuous outcrop for their entire length.

## MINERAL DEPOSITS

### Age of deposits

The deposits in the area belong to at least two, and possibly three, periods of mineralization and are dated primarily on the basis of their relation to surrounding rocks, and secondarily on the basis of mineralogical similarity. All the deposits are considered to be of Tertiary age since they are younger than the batholith which is probably very late Cretaceous. Because direct evidence was found for only two periods of mineralization, the deposits are grouped into older and younger Tertiary deposits, with the reservation that the younger group may include two periods of mineralization.

### Older Tertiary deposits

Nearly all the deposits in the area belong to an early Tertiary period of mineralization. Minimum age relations can be established for only a few deposits, others are put into this group because of strong similarities of structure, alteration, vein minerals suites, and sequence of events. These characteristics differ from place to place, but the differences are gradational and fit a zonal pattern. Therefore, all of these deposits are considered to have originated in the same manner and at the same time. Deposits of the older Tertiary group were oxidized during early Tertiary time and their gossans on the west side of Alta Mountain (73), are overlain by quartz latite tuff of late Oligocene age. Many of them have also been intruded by dikes associated with this early Oligocene tuff. Their age relations are therefore established as post youngest batholith rocks and pre-late Oligocene volcanic rocks.

Weed (1898) considered some veins of this group to be of Recent hot spring origin, and Knopf (1913, p.103) considered others to belong to the Younger Tertiary deposits. Weed noted that hot springs issued from a small group of chalcedony veins  $2\frac{1}{2}$  miles south of Boulder, and he concluded that spring waters were altering quartz monzonite and had deposited the veins. He extended this hypothesis to account for the chalcedony veins northwest of Boulder. This writer examined the springs and found that while some springs issue from veins and altered

rock, others issue from fissures in unaltered rock, and that the springs are not presently depositing silica. From this it is concluded that the chalcedony veins are not related to Recent hot springs such as the ones near Boulder.

Knopf (1913,p.103) considered that the silver-bearing veins in the Clancy district, and probably the chalcedony veins also, to be younger than the episode of Oligocene vulcanism. He noted that a quartz latite dike associated with the volcanic rocks was altered where exposed near a vein in the workings of the King Solomon mine (34). He concluded that the solutions that had deposited the vein and altered the adjacent quartz monzonite had also altered the dike. He therefore concluded that this vein and similar veins around Clancy were younger than the Oligocene vulcanism.

The exposures seen by Knopf are now inaccessible, but similar rocks were found on the mine dump indicating that Knopf's evidence should now be inconclusive. The part of the dump containing rock from the dike also contains quartz monzonite altered only to montmorillonite, whereas the altered fragments from the dike contain kaolinite. The writer has observed many similar dikes altered to kaolinite that occur away from veins. In contrast, a vein similar to that in the King Solomon (34) mine, the Boulder vein (116)(Ruppel 1963, p. 51) and a chalcedony vein at the Mineral Hill mine (figure 4), are cut by quartz latite dikes. Therefore, the writer concludes that all of the veins in the mineralized area belong to the older Tertiary period of mineralization.



### Younger Tertiary deposits

Deposits in the area belonging to the mid-Tertiary period of mineralization consists of a mineralized breccia pipe at the Montana Tunnels group of claims near Wickes (61), disseminated gold deposits in rhyolite southwest of Rimini (Pauper's Dream and Porphyry Dike mines), several silicified quartz latite dikes, and pods and veinlets of barite deposited in quartz latite, in older rocks, or in reopened older veins. Deposits of these materials are found in both types of Tertiary volcanic rocks that overlie the batholith, and their age is therefore established as post-early Oligocene. However, a minimum age cannot be established for these deposits. The disseminated gold deposits near Rimini are in rhyolite that appears to be younger than the early Tertiary quartz latite, but a more exact age for the rhyolite has not been established. The rest of the deposits of the younger group are in quartz latite. They may be products of a period of mineralization related to the quartz latite vulcanism, or they may be as young as the gold deposits in the rhyolite.

The younger Tertiary group of deposits of this paper corresponds to the younger deposits of Knopf's classification, (Knopf, 1913, pp. 43-60) but most of the deposits included by Knopf in his younger groups, i.e., the veins in the area around Clancy, are considered by the writer to belong to the older Tertiary group.

## GEOLOGY OF THE OLDER DEPOSITS

### Distribution

As can be seen from figure 2, the veins are by no means evenly distributed throughout the mineralized area. The area of greatest concentration of veins is the district around Clancy; this extends southwestward into the Wickes district. Near the southern end of the mineralized area, a district extending roughly from Boulder to Basin contains another great concentration of veins. In several places in these two areas, the veins are so closely spaced, only the larger ones could be shown on the map. An area about 3 miles wide and nearly barren of veins separates these two areas between Amazon and Spring Creek. A third belt, involving fewer veins, extends from Basin northward to Rimini. Elsewhere in the central and northwest parts of the mineralized area the known veins are more widely spaced. This may be in part due to poor exposures; these are areas of either heavy timber or ground moraines or both.

Within the belts of veins, the veins have a tendency to be clustered in groups, as northwest of Boulder, the area extending from the Three Brothers to the south of Uncle Sam Gulch, or as on the west side of Red Mountain south of Rimini. In general, it appears that in several of the vein groups, one or two veins were the site of most intense mineralization, and veins farther from them were progressively less intensely mineralized. These main veins often are centers around which the minerals in the other veins are arranged in a zonal pattern.

## Structure

Veins in the mineralized area are along regional structural trends and some of these trends are more dominant than others in some areas. The structural trends are indicated by joints, faults, veins, dikes, and stream courses. The locus and trend of these structural elements are thought to be controlled by joints, mostly as sheeted zones in the batholith. Directions of the dominant trends are east ( $\pm 20^\circ$ ), about N.  $65^\circ$  E., and nearly north. Most veins, dikes, and faults follow the east and northeast trends; many post-vein faults follow the northerly trend. Foliation in the batholith is weak and is very poorly known.

### Sheeted zone veins

Veins with the simplest internal structure consist of parallel bands of vein minerals deposited along the joints of a sheeted zone. Many entire veins are of this type, and many of the more structurally complicated veins, if followed along strike to where they thin and start to die out, become simpler in internal structure until they are merely mineralized sheeted zones. The veins in sheeted zones have formed by replacement of the wall rocks between the joints. Open-space type of crustification has not been found in the sheeted zones. Replacement of altered wall rock by vein minerals has usually proceeded two or three inches outward from the controlling joints. In the sheeted zones, joints are usually only a few inches apart and many vein bands merged into each other as adjacent bands become wider by replacement of the wall rock. The end result is a banded vein that contains ghosts of former wall rock bands. Such veins are commonly several feet wide and look massive, except for a faint striped appearance due to thin zones in which the wall rock minerals have not been completely replaced.

Any single band is a long thin lens that thins to a film at its edges. The bands are closely arranged in an en-echelon pattern in which the strike of the bands and the strike of the vein is nearly the same, so that a strong overlap exists between the lenses. Any single band may be only a few tens of feet long and a few inches wide, but

the vein may be several feet wide and continuous for a mile or more.

The sheeted zone type of veins are by far the most common type throughout the area. In many places the wall rock bands between bands of vein minerals have been sheared.

### Fracture zone veins

Many veins are along the zones of anastomosing fractures. In these zones each little fracture may contain a veinlet and the entire vein consists of a network of intersecting veinlets. In most such veins the wall rock between veinlets has been replaced to a large degree, especially in the central part of the vein, and the veins tend to be either massive or of very complex internal structure. Veins of this type are common throughout the mineralized area and in places they are 100 feet wide.

### Breccia zone veins

The initial structure of some veins may have been a fault with open breccias, but replacement has been so thorough in many of these that the initial breccia texture has been destroyed or greatly obscured. Where the breccia filling is chalcedony, the crustification tends to be well defined, but where the filling consists of crystals of quartz or sulfide minerals, the crustification is imperfect. Usually brecciation continued throughout the time of vein deposition so that all minerals from the earliest to the latest were broken.

## Mineral assemblages

More than 50 primary minerals are known from the veins and altered zones but only about 10 occur in major amounts. One of them, quartz, is ubiquitous and another one, pyrite, is nearly so. The rest of the minerals, while locally abundant, make up only a small part of the total amount of material in any of the veins. No vein is composed of a single mineral species, in spite of the fact that only a few minerals comprise nearly all of the veins. Rather, the veins are formed of groups of minerals, each group, or mineral assemblage, consists of two to four minerals that are closely associated in both space and time. Individual bands in a vein, and some entire veins, consist of only one assemblage, but many veins contain more than one assemblage. Earlier assemblages tend to be cut and replaced by later assemblages, and in many places several assemblages are well mixed.

The minerals of an assemblage are much more closely related to each other in time of deposition than to minerals of other assemblages. Veinlets of one assemblage crosscutting another assemblage are fairly common, but within an assemblage such relationships exist only on a minor scale and can be seen much less frequently than textural evidence of time relations between assemblages. The minerals of an assemblage are therefore considered to be contemporaneous or nearly so because of a general lack of relations that strongly or consistently indicate different time of deposition, and because grain boundary



relations are not inconsistent with contemporaneous deposition.

The mineral assemblages are listed below in their order of deposition from oldest to youngest; they are:

1. quartz and tourmaline + pyrite
2. pyrite with minor quartz
3. galena and sphalerite with minor quartz and pyrite
4. arsenopyrite and quartz
5. quartz and pyrite, with or without chalcopyrite, or carbonate minerals.

In addition to the five assemblages listed above, an assemblage of quartz and molybdenite occurs in small amounts in several places in the area. It is older than the pyrite-quartz assemblage, but its relation to tourmaline is not known.

### Quartz-tourmaline assemblage

The assemblage of quartz and tourmaline, often associated with pyrite, is the oldest in the veins. It is consistently cut by veinlets of all other assemblages, but reverse relations have not been found. The quartz and tourmaline are intimately intergrown and are considered to have been deposited together, typically as fine needles of tourmaline randomly oriented in a matrix of quartz. Veins with large amounts of the quartz-tourmaline assemblage occur most abundantly in the Rimini mining district in an area extending from the Little Blackfoot River to Red Mountain. Elsewhere the quartz-tourmaline assemblage is much less abundant and no where are the veins as wide.

Many smaller veins occur along a 4 or 5-mile stretch of the valley of Cataract Creek above the mouth of Big Limber Gulch. In the Wickes district, the Minah (65) and Alta (76) veins contain some tourmaline. The areas around both Boulder and Clancy are notably lacking in the quartz-tourmaline assemblage. In general, the quartz-tourmaline assemblage diminishes greatly in amount with distance from the Rimini district.

All veins of the quartz-tourmaline assemblage show a uniform banding parallel to closely spaced joints. In the more massive veins the interleaved and altered quartz monzonite has been almost completely replaced by quartz and tourmaline, but as the veins die out along strike, some of the bands become thinner and the vein contains interleaved bands of altered quartz monzonite, and the original joint is



often preserved in the center of the band. The edges of the band are irregular and many crystals, or radiating clusters of crystals, project into the wall rock from the original joint. They thus appear to have grown outward from the joint into the wall rock. Vugs or other criteria of open-space filling were not found.

### Pyrite-quartz assemblage

The pyrite-quartz assemblage consists of coarse-grained pyrite and a little milky quartz intergrown into compact masses. The pyrite crystals are anhedral to subhedral and from one-fourth inch to 2 inches across. They have grown largely by replacement of wall rock as indicated by numerous inclusions of wall rock minerals, especially sericite.

### Galena-sphalerite assemblage

The galena-sphalerite assemblage consists of galena and sphalerite and with or without minor amounts of pyrite and quartz. Galena and sphalerite are so closely associated that no lead ore is free of zinc, nor is zinc ore free of lead, although some large pieces of one may contain little of the other. This is a result of a tendency for grains of each mineral to occur in clusters. In most places both species are usually present in roughly equal amounts.

The galena-sphalerite assemblage is the "ore" assemblage of the area. The galena is apparently argentiferous; rarely are silver-bearing minerals seen in this assemblage although much lead ore is high in silver. Bulk analyses of galena indicates as much as 75 ounces of silver per ton; polished sections prepared from the same specimens contain no silver minerals, except rare and very small specs of tetrahedrite.

### Arsenopyrite-quartz assemblage

Arsenopyrite and quartz constitute a distinctive assemblage in the veins. The arsenopyrite has a strong tendency to be in long euhedral prisms intergrown with subhedral quartz prisms. Minerals of this assemblage typically and completely fill open spaces along fractures or in breccias but in many places the arsenopyrite-quartz assemblage has replaced older assemblages.

The arsenopyrite-quartz assemblage is much less common throughout the area than some of the other assemblages, and in only a few places does it constitute a large part of the veins. Arsenopyrite is most abundant in the Rimini district and parts of the Elliston district, where some veins contain so much arsenopyrite that they could not be mined because of high-treatment charges imposed on arsenical ore at the smelters. In other districts, arsenopyrite is abundant only in a few veins.

### Quartz-pyrite-chalcopyrite assemblage

Probably more than eight-tenths of all vein material in the area is represented by an assemblage of quartz-pyrite-chalcopyrite and primary carbonate minerals and is the most widespread assemblage in the area. As well as pyrite and chalcopyrite, the assemblage contains iron-bearing carbonate, dolomite, calcite, hematite, magnetite, bornite, enargite, tetrahedrite, and pitchblende. The proportions of the minerals in the assemblage range considerably from place to place, but the assemblage is usually about nine-tenths quartz; pyrite commonly makes up several percent, and chalcopyrite only a few percent or less. In some places the carbonate minerals are the dominant minerals of the assemblage.

The quartz of this assemblage shows more varieties than any other mineral, and a classification of the veins is based largely on the habit of quartz. The quartz ranges in grain size from crystals 4 inches across through microcrystalline quartz to the cryptocrystalline varieties of jasper and chalcedony. The color of the more coarse-grained varieties (about one-fourth millimeter or larger) is usually milky white, but nearly clear or cloudy white varieties are present in small amounts everywhere, and they are the dominant variety. The clear or cloudy quartz grew in open space but the milky quartz grew either by replacement, or if it grew in open spaces, these were completely filled with a compact mass of quartz crystals, all of which now appear milky because of the abundant fluid inclusions. Many

crystals are zoned with inclusions. As the grain size of the quartz decreases below about 1 millimeter, the quartz crystals become increasingly anhedral and the finer-grained varieties form a mosaic of nearly equidimensional grains. The finest-grained varieties of quartz, both jasper and chalcedony, are commonly gray when fresh, but the color ranges from white through buff to black. The gray and black shades are due to fine intermixed pyrite and possibly other sulfide minerals, as shown in a detailed study by Bieler and Wright (1960, pp. 366-371). Weathered outcrops of the fine-grained varieties are commonly brown or red from the oxidation products of pyrite.

Iron, calcium, and magnesium carbonate minerals are fairly commonly associated with jasper and chalcedony and much less so with the coarser grained prismatic quartz. In some areas, the presence of manganese-bearing carbonates are indicated by gossans containing several percent of manganese oxides. Rhodochrosite is rare.

Pyrite in amounts generally less than about 10 percent is common in the quartz-pyrite-chalcopyrite mineral assemblage. Since pyrite is nearly ubiquitous in both space and time in the veins, that which belongs to this assemblage is often difficult to distinguish from other pyrite. The criteria used are: (1) intimate association, including segmented veins; (2) lack of consistent crosscutting or other relations that indicate pyrite is either older or younger than the quartz; and (3) absence of other pyrite in a vein or band of a vein.

Chalcopyrite is common in the quartz-pyrite-chalcopyrite assemblage, but it usually occurs in small amounts. The amount of chalcopyrite ranges from a maximum of several percent to a trace.



In many veins, especially those composed predominately of jasper or chalcedony, the presence of copper-bearing minerals is often indicated by traces of malachite. Copper, mostly as chalcopryite, is most abundant in the veins on the east side of Alta Mountain and near the villages of Wichea and Corbin. The only other places where copper occurs in more than minor amounts are the Crystal mine (100) and Gray Eagle mine (129).

The distribution pattern of the quartz-pyrite-chalcopryite assemblage is the same as that of the veins shown on figure 2. It is the most widespread of all the assemblages, and is found in almost all veins that contain any one of the other assemblages. It is the only assemblage in many veins, especially in the vicinities of Boulder and Clancy.

## Older classifications

Two markedly different classification schemes of the mineral deposits in the area have been proposed by Knopf (1913, pp. 42-61) and by Billingsley and Grimes (1918, pp. 284-361). These are discussed in detail below because both of them contain weak points that make them inadequate to handle the great amount of new data. Knopf's system is more like the one used in this paper.

Knopf (1913, pp. 42-61) divided the deposits in the area into two groups on the basis of (1) suspected age and (2) mineralogy and metal content. Representatives of his older group in the area are veins characterized by abundant tourmaline and further subdivided into silver-lead and silver-copper veins. He recognized that the amount of tourmaline had a considerable range and that tourmaline was absent in some veins of this group. He considered that the veins had a close genetic relation to the batholith because of their content of tourmaline. Their age was established as older than the quartz latite (Knopf's dacite) because some of them are cut by quartz latite dikes.

Knopf's younger group of deposits (1913, p. 54-59) included the gold deposits disseminated in rhyolite near Rimini, epithermal deposits at Marysville and Lowland Creek beyond the map-area, the mineralized breccia at the Montana Tunnels prospect (61) near Wickes, the silver-bearing veins near Glancy, and a large group of nearly barren chalcedony

veins. These were all considered to be younger than the quartz latite. The deposits in Lowland Creek and at the Montana Tunnels (61) are in quartz latite, and the gold deposits at Rimini are in rhyolite. All of these can therefore be considered clearly younger than the older Tertiary veins that are cut by quartz latite dikes. The silver-bearing veins near Clancy and the chalcedony veins, however, are considered by the present writer to be part of the older deposits.

Billingsley and Grimes (1918) classified the ore deposits of the entire Boulder batholith region. Their paper presents much interpretation, but very little descriptive material. Their approach was to relate the deposits to the igneous rock from which they thought the ores were derived. They relate 14 groups of deposits to three periods of igneous activity involving six igneous phases. The igneous periods are: (1) andesite (Elk Horn Mountains volcanics); (2) granite (Boulder batholith and other ~~nearby~~ plutonic bodies); and (3) rhyolite (quartz latite and rhyolite ~~volcanic~~ episodes). In the classification of Billingsley and Grimes, all the older deposits of Knopf (1913, pp. 41-54) are placed in an aplite phase / of the granite period. The silver-bearing veins

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/Aplite of Billingsley and Grimes (1913) is alaskite of this paper.

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near Clancy were also included, whereas Knopf had considered them to belong to the younger period of mineralization. Billingsley and Grimes believe the veins were derived from the last residue of aplite bodies which differentiated ~~from~~ the rest of the batholith in essentially the place they now occupy. Furthermore, the aplite bodies were thought to be most

abundant in the very upper part of the batholith. They believed that the ore-bearing part of all the veins was restricted to a zone within 1,000 feet vertically from the roof of the batholith, and that the batholith below this depth contained only barren "roots" of veins. Partly as a result of this interpretation, very little mining exploration has been done in the area in the last 40 years.

Billingsley and Grimes' genetic classification is based on three main arguments. They believed that (1) a close spatial relation exists between the aplite bodies and the veins, (2) the last vein minerals (tourmaline, quartz, and pyrite) to crystallize from the aplite magma were the first to be deposited in the veins, and thus the veins represent the last residue from the magma, and (3) the veins change in a short vertical interval (1,000 feet to 2,000 feet) from galena-rich at the top through sphalerite-rich near the lower part of the productive zone, and finally to a "root" consisting of pyrite and quartz with a minor amount of other minerals. The writer disagrees with most of the genetic concepts presented by Billingsley and Grimes, and the implications derived from these concepts wherever they may have been applied to the deposits of the area. The main points of their classification are discussed below.

If the veins are related to alaskite, a close spatial association of the two would be expected. The distribution of alaskites and veins is known much better now than previously, and can be seen from figure 2. The mineralized area and areas of many bodies of alaskite are not closely coincident. Veins extend far to the west of the alaskite belt into areas where few alaskite bodies have been found. Furthermore, several large complex plutons of alaskite are known outside the mineralized area, and these do not have veins associated with them.

The presence of quartz and small amounts of tourmaline and pyrite in both veins and alaskite is not conclusive proof that the veins are end products of magmatic differentiation. Pyrite is scattered throughout much of the batholith in accessory amounts. Tourmaline is fairly common in the alaskite in some areas, but is virtually absent in the same rock in other areas where veins are abundant. Tourmaline is most abundant in the veins near Rimini, and some of these veins consist of a solid mass of tourmaline with quartz and pyrite, but alaskite is sparse in this area. Conversely, the alaskite bodies in the vicinity of Clancy and Boulder contain about as much tourmaline as those elsewhere in the area, but the veins in these areas are almost devoid of tourmaline.

The vein "roots" of Billingsley and Grimes is the quartz-pyrite-chalcopyrite assemblage of this paper. This assemblage has greater extent in most veins than does the galena-sphalerite assemblage. It occurs at the ends, top, and bottom of ore bodies as well

as within them. Its distribution does not appear to be related to either depth below the roof of the batholith or the distribution of alaskite or tourmaline. Furthermore, it was deposited in the veins later than the galena and sphalerite.

Classification of veins containing  
the quartz-pyrite-chalcopyrite assemblage

As is shown in the description of the mineral assemblages, the veins, even though they are composite veins, are composed largely of the assemblage of quartz-pyrite-chalcopyrite. This assemblage is quite variable in appearance from place to place, and differences in it are easily discernible in large outcrops and hand specimens. The most striking difference is in the crystal habit and grain size of the minerals, especially quartz. Many veins consist largely of medium-grained to coarse-grained milky quartz, whereas many others consist largely of jasper and/or chalcedony. On this descriptive basis, then, the veins can be easily divided into two major groups representing end-member types: (1) those consisting largely of the coarser varieties of quartz are referred to simply as quartz veins, and (2) those consisting largely of jasper and/or chalcedony are referred to as chalcedony veins. Nevertheless, it should be kept in mind that these are end-member types. The veins exhibit a complete gradation from the one type to the other and many veins contain both types of material. These are referred to as veins of mixed type.

Weak points inherent in this classification are the following:

- (1) The terms quartz and chalcedony are used as convenient terms to refer to grain size differences, ignoring the fact that chalcedony and jasper are varieties of quartz.

(2) Much of the material referred to as chalcedony is actually very fine-grained quartz with intermixed and finely divided sulfide, carbonate, or iron oxide minerals. However, no term for such a mixture exists; most sulfides in the outcrops are oxidized, and the outcrops are therefore largely jasper. The entire vein can be easily considered as a vein of jasper, if one keeps in mind that some of the iron oxide is a supergene product.

(3) Textural evidence indicates that much of the silica of the jasper may have been deposited originally as a gel that crystallized first to a fibrous form and later recrystallized to nonfibrous quartz, yet the term chalcedony does not accurately describe material that may be largely jasper in the sense used here.

(4) The classification ignores the large amount of sulfide or other minerals in many veins, however, these minerals can be correlated, in a rough manner, with the main types of veins used here. For example, the quartz veins contain far greater amounts of sulfide minerals than the chalcedony veins. Other lesser differences in sulfide mineralogy can be correlated with the two major types of veins.

(5) The form of silica in about 10 percent or less of all the veins is neither all chalcedony (and/or jasper) nor quartz, but are mixtures of the two types arranged in a zoned and orderly manner. These veins represent an intermediate variety and are gradational into the end-member types.

The main advantage of the classification is that it is extremely simple and easy to use in the field. Every vein in an outcrop or



prospect, and even parts of a single vein, can be assigned directly on the basis of visible features. The older classifications, by contrast, were based on correlating veins with igneous intrusions or periods of time, and these correlations can be established for only a few deposits. In the classification used here, there is little doubt about the age group, or phase of igneous intrusion to which a vein belongs. Furthermore the classification permits such other features as differences of wall rock alteration, sulfide mineralogy, and temperature of deposition, to be arranged in an orderly manner.

### Quartz veins

The quartz veins consist dominantly of the coarser varieties of quartz of the quartz-pyrite-chalcopyrite assemblage. The carbonate minerals of the assemblage are rare in some quartz veins. The quartz veins also contain differing amounts of one or all of the other sulfide-bearing assemblages. In parts of some veins, the other assemblages are the dominant ones present, but entire veins of this sort are rare, except for small veins of quartz and tourmaline. Larger amounts of the quartz-tourmaline assemblage occurs only in the quartz veins, as far as is known. The quartz veins have poor outcrops, and they are known largely from mines and prospects or the dumps from these workings. The quartz veins include all of the older tourmaline lodes of Knopf (1913, pp. 43-54) and some of his younger deposits near Clancy (Knopf, 1913, p. 54). Within the area, they include all of the veins of the aplite phase of Billingsley and Grimes (1918, pp. 304-315).

Nearly all of the metals produced in the area have come from the quartz veins. Their value has been chiefly for their silver content, but they have yielded considerable lead and some gold and copper. They also contain considerable zinc, but the amount of zinc cannot be estimated from existing production data. Zinc-rich ore usually was not mined due to high treatment charges.

### Chalcedony veins

The chalcedony veins consist almost entirely of the quartz-pyrite-chalcopyrite assemblage. These veins are microcrystalline and cryptocrystalline quartz to the extent of about 95 percent or more. Larger quartz crystals are rare and are present only as tiny druzes lining small vugs. The chalcedony veins contain pyrite, carbonates, or iron oxides and some of them contain a little pitchblende. The chalcedony veins, in contrast to the quartz veins, have good outcrops for most of their length and in several places they form huge wall-like outcrops 30 or 40 feet high.

Production from the chalcedony veins is nil. Their outcrops are nearly barren and as a consequence, very little prospecting has been done along them. A small amount of uranium ore was produced in recent years from three chalcedony veins and the chalcedony end of one mixed vein.

### Veins of mixed type

Nearly all quartz veins contain stringers of very fine-grained quartz or chalcedony and in fact, a complete range exists from quartz veins with very little chalcedony to chalcedony veins containing a few crystals of coarse-grained quartz. Only those veins in which the lesser material occurs in more than minor amounts are considered here to be veins of the mixed type. Because the veins of mixed type are intermediate between the quartz and chalcedony end-member types, they best reveal the relations of these two major types. These relations are described in the following section. They are interpreted as a primary zonal pattern that can be recognized on all scales ranging from individual veins to the entire region.

## Quartz and chalcedony relations in veins of mixed type

The relations outlined above do not show that the quartz and chalcedony veins are of different ages, but rather they show that little basis exists on which to conclude the different ages for these two types of veins. The best place to see relations of quartz and chalcedony are in veins of the mixed group for in these veins both major types of vein material are present in large quantities. The conclusions reached from observations made along many of these veins are:

1. Quartz and most chalcedony in different segments along the vein are contemporaneous. During mineralization silica was deposited as quartz in one part of the vein and as chalcedony in other parts of the same vein.

2. With time, quartz deposition ceased and chalcedony was deposited in the quartz rich part of the vein.

3. The quartz rich part of the vein represents a core and is that part of the vein where mineralization was most intense in the sense that the most stable form of silica was deposited, sulfur and  $H^+$  were most abundant, and the envelope of altered rock is widest.

The relations supporting the first two conclusions are presented below. Those leading to the third conclusion are presented in later section.

### Arrangement of quartz and chalcedony

In nearly all of the mixed type of veins, quartz and chalcedony are arranged in a constant and systematic manner regardless of the relative amount of the two types. The general pattern in many veins is a core of quartz surrounded by chalcedony. Simple veins consist of one quartz lens with chalcedonic extensions; more complex veins may have more than one quartz lens that overlap each other or are strung out along strike. In most places, these cores are a composite lens built up of quartz bands. Both individual bands and the over-all lens of quartz thin in both directions along strike. As the quantity of quartz decreases along strike toward the ends of the lens, the relative amount of chalcedony increases, and individual bands change gradually from quartz to chalcedony, while the width of the bands or veins may remain constant. In general as the relative amount of quartz diminishes from the center of the core toward the ends of the quartz lens, the grain size of the quartz decreases and the vein changes gradually from a quartz type of vein to a chalcedony type of vein. In the core the quartz is nearly always milky and subhedral; the crystals are typically thoroughly intergrown into a compact mass. Toward the ends of the quartz lens, the crystals become so fine-grained that the quartz breaks with a rough hackly surface. The color changes from white quartz to gray chalcedony. Many veins, either simple or complex, have a sheath of chalcedony bordering the sides of the quartz lens in addition to the chalcedonic extensions of the quartz lens.

In some places where the chalcedonic ends of the quartz lenses could be traced through good exposures, the chalcedony was found to extend along the sides of the quartz lens, and to form a sheath around the quartz core, discontinuous or thin where the quartz lens is widest. The marginal chalcedony sheath is formed largely of silicified and otherwise altered wall rock; it is the same as the thoroughly silicified rock of many chalcedony veins, and it grades outward into unsilicified wall rock. It contains relics from the wall rock as grains of igneous quartz, small clots of clay or sericite, and pyrite disseminated through it is suggestive of the pyrite disseminated in the sericitic border zone of many veins. Where the chalcedony sheath is present, many crosscutting stringers of chalcedony extend inward through the quartz core, indicating that chalcedony deposition continued after quartz deposition had ceased.

The relation of quartz and chalcedony are best shown by examples. For this, two veins are described in order of increasing complexity of structure. They are the Mineral Hill (42) vein and the veins at localities 170 and 176.

The vein that outcrops on the Mineral Hill (42) claim (fig. 3)

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Figure 3. Geology of the Mineral Hill vein.

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has three short quartz cores and long chalcedony ends. The core east of the shaft contains the milky quartz crystals up to  $3 \times 7$  mm., and some of the bordering sericitic rock has been replaced by milky quartz veins. The milky quartz in the two quartz cores to the west is all

fine-grained. These cores also contain a noteworthy amount of chalcedony and exhibit chalcedonic ends. Both ends of the vein are composed of chalcedony and the quartz cores grade into the chalcedony ends of the vein.

Another vein that illustrates the relations rather well, even though it is of much more complex structure, trends northeastward through secs. 33 and 34, T.6N., R.4W. This vein consists of four mineralized segments separated along strike by stretches of altered rock. The two eastern segments (176) are shown in figure 4. The

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✓ Figure 4. Relation of chalcedony and quartz.

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easternmost of these is entirely chalcedony. The other segment, containing both quartz and chalcedony, is roughly lens shape, about 600 feet long, and very well exposed. The southwestern end tapers to a thin stringer before dying out, but the northeastern end branches into several main strands that die out in about 200 feet from the main part of the vein. The vein is a complex of nearly parallel bands of vein minerals and altered wall rock. The vein minerals in the outcrop are coarse pyrite probably of the quartz-pyrite assemblage, quartz and chalcedony of the quartz-pyrite-chalcopryrite assemblage, and late barite. The former presence of other primary minerals cannot be ascertained with certainty. The quartz is fine-grained, milky, and compact.



The milky quartz forms two main lens-shaped groups of bands and a few smaller groups, most of which thin rapidly. The strong, parallel milky quartz bands are separated by equally strong bands of either siliceous pyrite boxworks or altered wall rock. The vein as a whole, and the groups of quartz bands, are bordered intermittently along their length by either chalcedony bands or highly silicified wall rock that forms a discontinuous sheath of microcrystalline quartz. The quartz bands are cut by chalcedony stringers that merge into the sheath. Toward the southwest, the major quartz bands thin and pinch out and their position in the structure of the vein is occupied by chalcedony. The banding is unbroken; the quartz becomes very fine-grained until it is microcrystalline; it loses its milky color and imperceptibly changes to the chalcedony type of vein material.. The same changes occur in the branching quartz strands to the northeast, and at their northeast ends each strand has changed from the quartz type of vein to the chalcedony type of vein. The most northerly strand of the vein is also lens-shaped and shows the change from quartz to chalcedony in a slightly different way. In its central part, it is about 3 feet wide and consists of sericitized wall rock cut by many stringers of very fine-grained milky quartz. Both to the northeast and southwest, the quartz stringers become fewer in number and die out. This change is accompanied by an increase in the microcrystalline quartz in the wall rock within the zone of stringers. The introduction of microcrystalline quartz has been so intense that it has replaced nearly 100 percent of the wall rock a few feet farther along strike beyond the last visible milky quartz.

## ALTERATION

### General features

Nearly every vein in the area has an envelope of altered rocks arranged in a symmetrical pattern on each side of it. The altered envelope consists of several bands, each of which is defined by a single mineral produced during alteration. The pattern is much like that described by Sales and Meyer (1948) for the veins at Butte. This consists essentially of a band of sericitic rock adjacent to the vein and bands of argillic rock further away. The major difference from the altered rocks at Butte is that in the mineralized area the iron-bearing minerals of the rock have passed through a more complex series of steps. The iron-bearing minerals also are arranged in bands which occupy much the same space as the argillic and sericitic bands. The successive bands of iron-bearing minerals from the vein outward consist of pyrite, iron-bearing carbonate, and iron oxides.

The different bands of altered rock are not considered to be the result of several stages of alteration, but rather to be the result of one or more reactions between interstitial pore fluids and minerals of the quartz monzonite. In general, the alumina and silica of the igneous rock minerals remain together and tend, through one or more intermediate steps, to become an end product consisting of sericite and quartz. The iron, calcium, and magnesium of the igneous rock follows a similar path of several steps and tends toward a final product

in the form of pyrite or ankerite. The different courses followed by the two main groups of chemical constituents are shown on figure 16. The different altered bands can be seen anywhere in the area by crossing an altered zone in a direction normal to the strike.

The products of alteration are not the same around all of the veins, but the differences are completely gradational and can be related to the type of vein associated with the altered rocks. In general, as veins tend to change along strike from quartz veins to chalcedony veins, the innermost altered bands become thinner and pinch out against the vein, so that further along strike the vein is adjacent to successively outer bands of altered rock. If this trend has gone far enough, the vein near its ends is bordered by nearly fresh rock. Stated differently, if the vein extends far enough along strike, it passes into unaltered rock.

In this section of the report, the different mineralogical bands of altered rock are described along with their structural control and some of the chemical changes that have accompanied alteration.

### Purpose of additional work and method of study

In 1953 and 1954, Sam Rosenblum, U. S. Geological Survey geologist, made a preliminary study of altered rock samples from several veins. He concluded (Becraft, Pinckney, and Rosenblum, 1963, p. 42) that the alteration pattern around quartz veins was much like that at Butte (Sales and Meyer, 1948) and consists mainly of sericite near the vein, clay minerals beyond the sericite band and an outer fringe of chlorite. However, he found that at least one chalcedony vein lacked the inner or sericite band near the vein. When the gradual change from the quartz type of vein to the chalcedony type was found, it was thought that an accompanying change in the altered rocks may also occur. The work was greatly hampered by lack of complete exposures across most altered zones so that many details are not well known. The major features, though, seem apparent.

The field work consisted of noting, mapping, and sampling the altered rock along the strike and across the strike of many veins to the extent permitted by underground and surface exposures. Surface exposures of altered rock are very poor; the workings of the accessible mines are not extensive, and the crosscuts that are accessible, rarely extend from the vein to unaltered rock. A pattern of altered rocks has been pieced together by observing major features in outcrops, studying

them in more detail underground and in the laboratory, and by correlating the alteration pattern with the vein type. The altered rocks around hundreds of veins were observed and noted in as much detail as possible. Dozens of veins were followed for their entire length and all changes in their alteration pattern that were discernible in outcrops were noted. Many of these were mapped in detail on the surface and wherever possible they were mapped and sampled in much greater detail underground. Samples were taken underground at irregular intervals from the edge of 32 veins to the least altered rock exposed. The field work was carried out to what was thought to be the point of diminishing returns.

The laboratory work has confirmed all zone boundaries that were recognized in the field. Over 300 thin sections of altered rocks were examined and suites of altered rocks from 14 veins were analyzed by X-ray methods. The minerals of the altered rocks were identified by standard polished section, thin section, and X-ray techniques. The clay minerals were identified by the basal spacing of untreated and ethylene glycol-treated specimens on glass slides. Other minerals were identified largely from thin sections only as to their group, but detailed optical measurements were not made, and most species within the groups (or solid solution series) have not been identified. The iron oxide minerals are often soft, earthy aggregates than can be polished only with great difficulty; consequently they were identified only as iron ores except in a few specimens. Similarly, no attempt

was made to identify specific titanium oxide minerals that form masses of leucoxene. Carbonate minerals were identified as iron-bearing or non-iron-bearing only. Most specimens probably are ankerite or dolomite.

## Structural control of alteration

The model of alteration developed in this paper requires that altered mineralogical bands be symmetrical on each side of the feeding fissure. The fissure is, therefore, considered to be the most important single control of alteration. Bilateral symmetry was seen in the field along thousands of simple fissures. In contrast to this, the altered rocks along many veins are asymmetrical. They may be very wide on one side of the vein and narrow on the other, and altered areas of this sort have been described in the literature as being pervasive in nature and not related to the veins within them. These wide zones of altered rock have resulted from the merging of altered bands formed along a series of closely spaced fissures. It must be emphasized that all asymmetry of alteration is geometrical only, and not mineralogical.

The manner in which structure has controlled alteration is best seen by examples. Figure 5 shows a simple joint system at the end of the vein in the Bunker Hill (14) mine along which alteration is

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Figure 5. Geology of the Bunker Hill mine. Lower Adit.

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closely controlled by joints. The symmetry of alteration is both geometrical and mineralogical. Where the rock is sheared between mineralized joints (fig. 5B) the hanging wall is weakly cracked and alteration extends a little further out into the hanging wall than into the footwall.

An example of more extensive breaking and alteration along one side of the vein is shown in figure 6, ✓ in which alteration extends

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✓ Figure 6. Extent of alteration, W. Wilson vein.

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about 65 feet into the hanging wall and only about 10 feet into the footwall. Many examples of geometric asymmetry of alteration have been seen and they all are related to extensive fissuring on one side of the vein, usually on the hanging wall side.



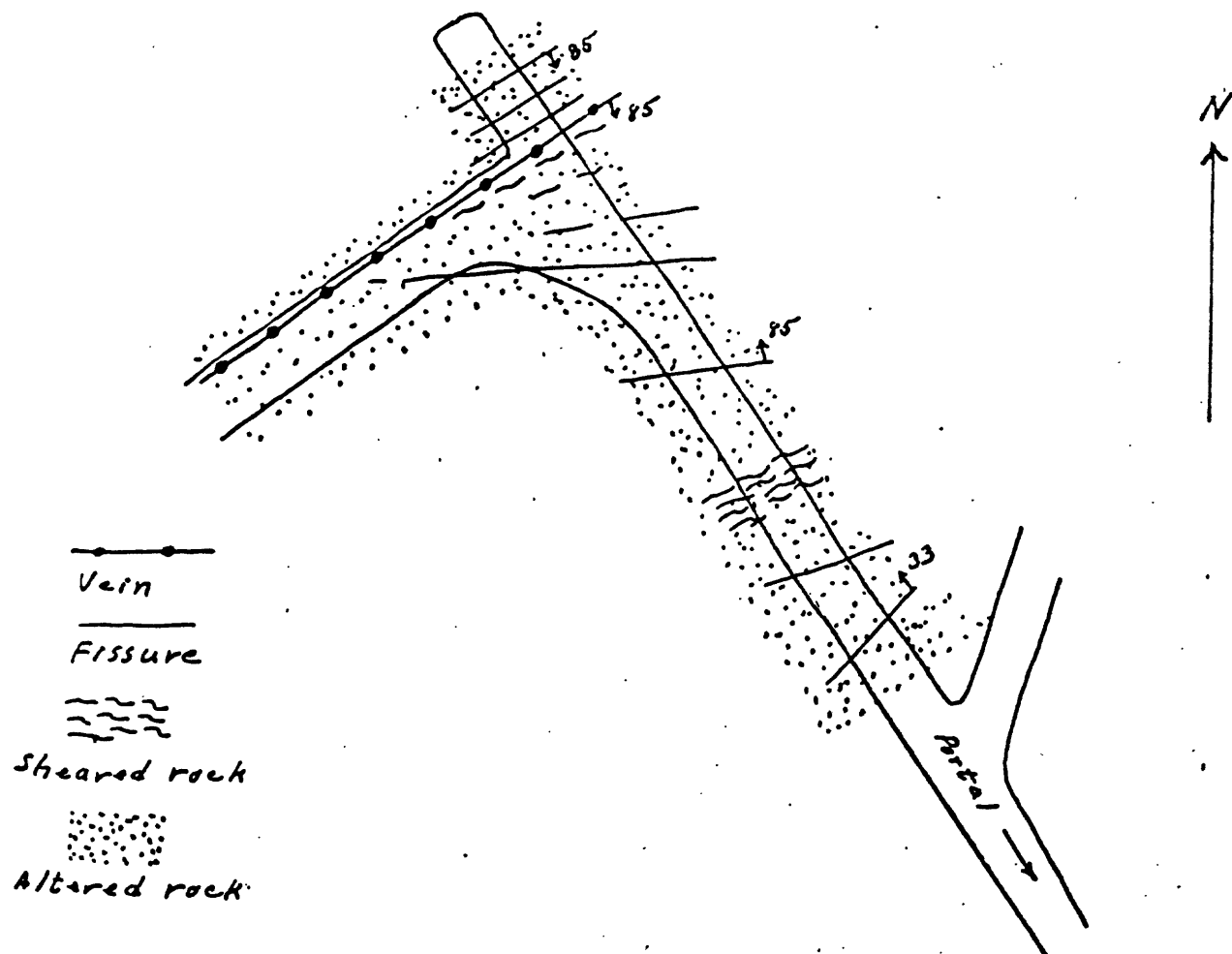


Figure 6. Extent of Alteration - W. Wilson Vein

### Method of presentation

The altered rocks described herein are discussed in terms of the products of alteration arranged in bands beside the vein. Each band is named for the mineral that was produced at its outer edge. The bands are shown schematically in figure 7.

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Figure 7. Minerals in bands of altered rock.

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The width of the band shows the interval of rock in which a particular product is found. For example, the kaolinite band refers to only one mineral produced by alteration. This band contains minerals from the igneous rocks, such as, potassium feldspar, quartz and often biotite. It may also contain other alteration minerals, such as, leuc-xene, chlorite, carbonate, iron oxides, or varieties of quartz, but the edges of the bands of these minerals are not coincident with the edges of the kaolinite band.

The term band is used in this sense in place of the more common usage of the word zone only to avoid confusion with structural zones and areal mineral zones.

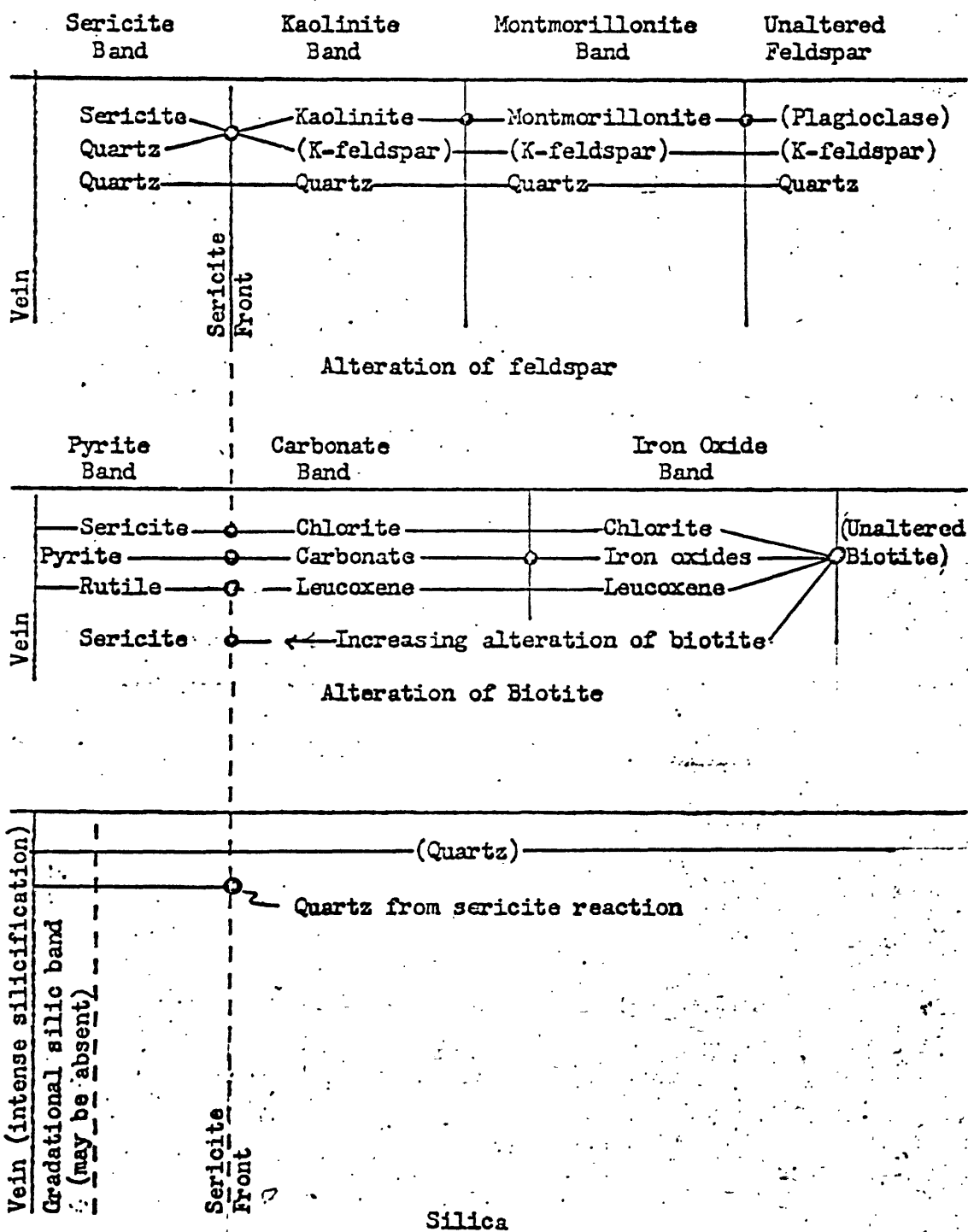


Figure 7. Mineral bands in altered rock. Dots indicate points at which a mineral is generated or destroyed. Lines show the interval through which a mineral persists. Igneous rock minerals enclosed in parentheses or otherwise indicated.

### Alteration of feldspar

During alteration, both plagioclase and potassium feldspar were eventually converted to sericite; but they followed different steps to arrive at this end product. Plagioclase was first altered to montmorillonite which in turn was converted to kaolinite, and this subsequently was converted to sericite. Potassium feldspar was converted directly to sericite, and the excess silica was precipitated as quartz.

### Montmorillonite and kaolinite bands

The three alteration products of plagioclase are arranged in three distinct bands. The <sup>outer</sup> ~~other~~ band consists of montmorillonite, the next inner band consists of kaolinite; and the band closest to the vein consists of sericite. Each band is the product of the alteration of the next outer zone. At any point the successive mineralogical steps in alteration are identical to that which can now be seen in crosscuts extending veinward from unaltered rock.

The montmorillonite band is the farthest from the vein of the plagioclase altered zones. Its outer edge, representing the beginning of plagioclase alteration, is usually gradational through a distance of a few feet. The extreme outer edge of the montmorillonite zone is distinguished in mine workings by a sprinkling of plagioclase grains that swell and protrude from the walls. At this place, montmorillonite was produced mainly as patches in the calcic cores of only a few of the plagioclase grains. Further alteration nearer the vein, has converted first all of the more calcic cores and zones of all plagioclase grains to montmorillonite (fig. 8), and finally even the more sodic zones are

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Figure 8. Montmorillonite selectively replacing a plagioclase crystal along a composition zone and along fractures. 100X.

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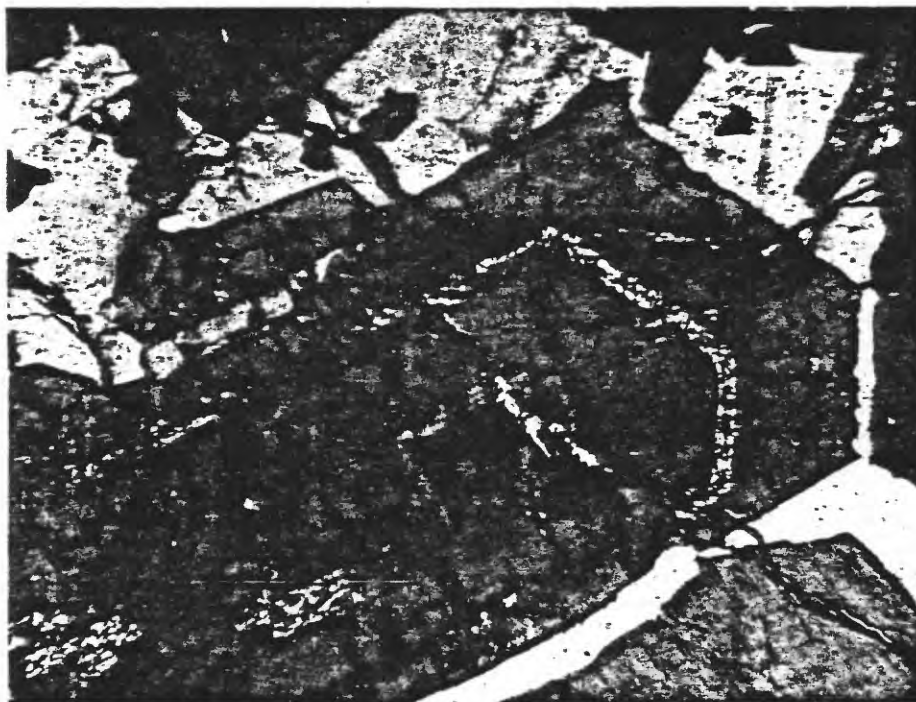


Figure 8. Selective alteration of plagioclase. Montmorillonite selectively replacing a plagioclase crystal along fractures and along a composition zone. 100X.

altered. Albitic rims are the last part of the crystals to alter, but finally the former plagioclase crystals are completely converted to an aggregate of montmorillonite crystals. These aggregates retain the form of the original plagioclase grains and, in many places, even the cleavage and twinning are preserved in the pseudomorphs. The band of pure montmorillonite is often several feet wide, and nearly everywhere it is the widest of all of the altered bands. Toward the inner edge of the montmorillonite band the plagioclase pseudomorphs contain an increasing amount of kaolinite mixed with montmorillonite. Toward the vein the montmorillonite band grades into the kaolinite band by a continued increase in the amount of kaolinite and a corresponding decrease in the amount of montmorillonite. The width of the gradation is usually two feet or less, and on the veinward side all montmorillonite has been converted to kaolinite. The kaolinite band is commonly less than one-third the width of the montmorillonite band. In the kaolinite band, the shape and a little of the cleavage of the original plagioclase is preserved; but all visible sign of former plagioclase composition zones or twinning has been destroyed.

The montmorillonite and kaolinite bands can easily be distinguished in the field on the basis of color. The montmorillonite is dark greenish gray, and imparts this color to the rock. The kaolinite is white, and in contrast to the montmorillonite band, the kaolinite band appears almost white. It may have a pinkish cast due to the presence of potassium feldspar.

Throughout the argillic bands of plagioclase alteration, the potassium feldspar appears to have been much more stable than the

plagioclase. The major change is a tendency to become clouded as the vein is approached, and to be most clouded in the kaolinite zone. However, in many suites of altered rock, no direct correlation could be made between degree of cloudiness and distance from the vein. The cloudiness is apparently due to incipient scattered alteration of potassium feldspar to kaolinite as indicated by X-ray analyses.



### Sericite band

The inner edge of the kaolinite band is marked by a sharp change from kaolinite to sericite ✓ within 1 or 2 inches, and from

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✓ The term sericite is used here to designate a fine-grained white mica with a basal spacing of about 10 Å.

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this point to the vein, all of the feldspar is represented by sericite.

The sericite-kaolinite boundary, nearly everywhere, is in sharp contrast to the gradational boundaries between kaolinite and montmorillonite and between montmorillonite and unaltered plagioclase.

The outer edge, or front, of the sericite band is a narrow zone in which all of the clays, chlorite, any biotite, and the potassium feldspar were converted to sericite. Toward the outer side of this narrow zone, kaolinite was completely converted to sericite, but potassium feldspar was not. At the inner side, all of the potassium feldspar was altered to sericite, and the excess silica was deposited as quartz. At the sericite front the sericite is very fine-grained where it was produced in the kaolinitic pseudomorphs of plagioclase. For a short distance toward the vein, the sericite becomes increasingly coarser-grained, and large shreds and plates extend across old feldspar grain boundaries so that the original granitic rock texture was completely destroyed. With the first noticeable increase in grain

of the sericite crystals, irregular fingerlike masses of coarser-grained sericite project into or through plagioclase pseudomorphs of fine-grained sericite, or the coarser-grained sericite surrounds what appear to be relic areas of fine-grained sericite. These relations suggest that the coarser-grained sericite resulted from recrystallization of the fine-grained sericite, and that it encroached on the finer-grained sericite. Similarly then, the sericite front must have encroached on the kaolinite band.

The sericite band can usually be identified easily in the field. In many places the flakes of sericite are coarse enough to be seen with a hand lense. Where the grain size is too small for this, sericite can be identified by its pearly luster, which distinguishes it from kaolinite, which has a dull luster. In addition, rock from the sericite band contains no potash feldspar.

### Alteration of iron-bearing minerals

Biotite is the chief iron-bearing mineral of the quartz monzonite. During alteration of biotite the iron and titanium are separated from the alumina and silica, and they follow independent paths. The iron went through three successive steps, being contained first in iron oxides, then in iron-bearing carbonate, and finally it ended up in pyrite. Titania, released from the biotite along with the iron, usually persists as leucoxene throughout much of the altered envelope, and eventually ends up as rutile. The alumina and silica of the biotite were converted to chlorite and finally to sericite.

Some hornblende and a small amount of augite are also present in much of the quartz monzonite. These minerals started to alter sooner than biotite, but they appear to have altered in the same manner as biotite. After alteration to chlorite, they lose their original identity, and for this reason they were not studied in detail. However, all sites of mafic minerals contain the same alteration products whenever alteration has proceeded beyond the initial stages. For this reason the alteration of hornblende and augite is believed to be almost identical to that of biotite.

The alteration of biotite took place throughout a wide band. At the outer limit of this band, biotite first started to alter either to chlorite or to change in composition or both. At the inner limit of the band, biotite and chlorite were converted to sericite at the sericite front. The freshest biotite from underground exposures

frequently has been slightly altered to bright green chlorite around its edges or along cleavages. This chlorite is thought to have resulted from deuteric alteration rather than hydrothermal alteration because it does not increase in the direction of the vein. Increased alteration of biotite converts it from an iron-rich variety to a magnesium-rich variety. Unaltered biotite or biotite associated with bright green chlorite is deep reddish-brown in color, and probably is rich in iron; but as the vein is approached, the first sign of hydrothermal alteration of biotite is a change of color. In thin sections, the color gradually becomes lighter shades of brown or green, then yellow, and finally almost colorless.

In the interval through which biotite changes color and probably composition, it becomes partly or wholly converted to chlorite. The chlorite is a fine-grained colorless aggregate of subparallel plates that grew along the biotite cleavages or along the edges of biotite grains (see fig. 9).<sup>✓</sup> The green chlorite was converted to

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<sup>✓</sup>Figure 9. First alteration of biotite; chlorite and carbonate around the edge of biotite grain. 100X.

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colorless chlorite. In the direction toward the vein, the chlorite masses increase in size at the expense of the biotite (see fig. 10),<sup>✓</sup>



Figure 9. First alteration of biotite: chlorite and carbonate around the edge of biotite grain. 100X.

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✓ Figure 10. More advanced stage of alteration of biotite.

The biotite is bleached and largely replaced by chlorite and carbonate.

Note the start of the alteration of plagioclase.

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until, along most veins, the biotite has been completely chloritized before the sericite front is reached. In a few places, a little of the biotite remains unchloritized up to the sericite front where it appears to have been converted directly to sericite.

At the site of the first change in color of the biotite, or a little outward from this point, some iron and titania were deposited in and around the biotite grains, and appear to have been released from the biotite. In the direction toward the vein, more and more iron and titania were released as the biotite continually changed composition as more of it was converted to chlorite. The titania is in the form of leucoxene and this product does not appear to have changed except at or near the sericite front where it was converted to rutile. The iron, however, took on at least three different forms. Where first released from the biotite, it usually occurs as tiny grains of magnetite, or occasionally hematite, intergrown with biotite. Closer to the vein, a point is reached at which all of the iron oxides were converted to an iron bearing carbonate, and farther inward from this, the carbonate was converted to pyrite. This sequence of iron-bearing minerals is arranged in bands parallel to the vein in the same manner as the clay minerals and sericite. Iron-bearing carbonate always occupies the space between



Figure 10. More advanced stage of alteration of biotite. The biotite is bleached and largely replaced by chlorite and carbonate. Note the start of the alteration of plagioclase. 400x.



iron oxides and pyrite. In some places the outer iron oxide band, is absent, and iron carbonate extends outward to the site of the first alteration of biotite. In other places the inner pyrite band, is absent, and carbonate extends from the iron oxide band to the vein.

The exact nature of the two boundaries between the iron bearing mineral bands is not well known because the minerals are difficult to see in mine workings. Pyrite crystals near the vein occur as small euhedral crystals and are easily seen, but further from the vein the crystals are anhedral and very tiny; they are scattered in small groups in the biotite and chlorite and are almost impossible to see underground. The unweathered carbonate minerals are pink and could be distinguished from potassium feldspar only with difficulty or by using acid. In a similar manner, the exact position of the iron oxide carbonate boundary appears obscure because the magnetite is difficult to distinguish from the black biotite. Examination of thin sections indicates that in most places the boundaries are narrow and in some places a complete change from one mineral to another was noted in sections spaced only a few inches apart. In outcrops the boundaries can usually be located within 1 or 2 feet, if weathering has not converted the minerals to hydrous iron oxides. Even so, some indication of the primary mineralogy of the iron bands can be obtained. Pyrite usually weathers to a brown iron oxide, whereas the color of the iron oxide produced from weathered carbonate is often orange-brown. Weathering of the iron oxides produces a red hematite stain in the rock, but this cannot always be considered indicative of the iron oxide band because the weathering of pyrite sometimes produces a similar stain.



### Silicic band

All of the quartz veins are bordered by silicic bands in which the rock has been enriched in quartz, although along some of the quartz veins this can be seen only in thin sections. The enrichment of quartz has taken place by two methods. Wherever potassium feldspar was altered to sericite, silica was released and this silica was precipitated as quartz. The new quartz occurs mostly as overgrowths on grains of igneous quartz but also as small grains in the sites of the potassium feldspar grains. The overgrowths have replaced potassium feldspar and sericite and seem to have had a strong preference to replace biotite or either the chlorite or sericite that occupied the biotite sites. Frequently, the first noticeable addition of quartz is at the biotite sites.

In addition to the quartz derived from the potassium feldspar, much quartz has been introduced into the rock; the quantity of this introduced quartz ranges from nil to a large, but undetermined, amount. The rock adjoining nearly every quartz vein, regardless of size, contains an abnormal amount of quartz and in many places the silicification is so intense that only scattered shreds of sericite remain of the original wall rock. Almost all of the rest of the rock is quartz. The result is that wall rock has been converted into a quartz vein. Where silicification is most intense, near the quartz veins, many of the quartz crystals are elongate parallel to the C axis; they frequently possess some prism faces, and contain only a few inclusions of sericite.

Farther from the vein they contain numerous inclusions of sericite, have very few crystal faces, and are either roughly equal in their dimensions, or conform largely to the space between the sericite pseudomorphs. It seems that silicification advanced through the wall rock, and as it did so, the earlier formed quartz crystals grew at the expense of the sericite.

Several steps in the process of silicification that has converted wall rock to vein can be seen in a series of thin sections taken at intervals from the sericite front to the vein. In the first step, silica released from potassium feldspar is precipitated as overgrowths on igneous quartz grains and as small grains in the feldspar. An overgrowth on a quartz vein is shown in figure 12. A little nearer the vein many of these small grains are no longer visible as discrete grains; they seem to have merged with other grains to form larger irregular masses of quartz. All parts of these masses have nearly the same optical orientation. In the third step, the masses of quartz merge with neighboring masses through the addition of overgrowths. The overgrowths replace sericite and join with other overgrowths that formed around igneous quartz grains. In many of these, the entire mass of quartz has taken on the same optic orientation even though it may include 2 or 3 grains of igneous quartz that must have had diverse orientation. Often, however, such crystallographic joining together of igneous quartz crystals and their overgrowths has not happened, but rather each cluster of small crystals and each grain of igneous quartz maintains its crystallographic orientation. Overgrowths merge and gradually replace nearly all of the sericite, so that the former wall

rock becomes part of a replacement vein. The texture is a mosaic pattern of roughly equidimensional grains, whose edges are quite irregular in detail and usually interlocking. In many specimens, some crystal faces have been developed against sericite, and the vein superficially appears to have been deposited in an open space. These steps in silicification are illustrated in figures 11, 12, and 13.

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Figure 11. Early stage of silicification.

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Figure 12. Advanced stage of silicification, quartz overgrowth.

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Figure 13. Advanced stage of silicification, mosaic pattern.

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Throughout the mineralized area, quartz of the quartz-pyrite-chalcopyrite assemblage has invaded and silicified the sulfide minerals of the earlier assemblages. This has occurred on a large scale. Partly it occurred by filling of open fractures, but, while this is very common, it accounts for only a small part of later quartz in these earlier assemblages. A large part of the sulfide minerals have been replaced by quartz. The process seems to have been a type of silicification, much like the replacement of the sericitic wall rock by quartz, i.e., quartz crystals grew into the sulfide minerals. Figure 11 shows an initial





Figure 11. Early stage of silicification: overgrowth on grain of igneous quartz. Note the included flakes of sericite in the overgrowth. 32x.

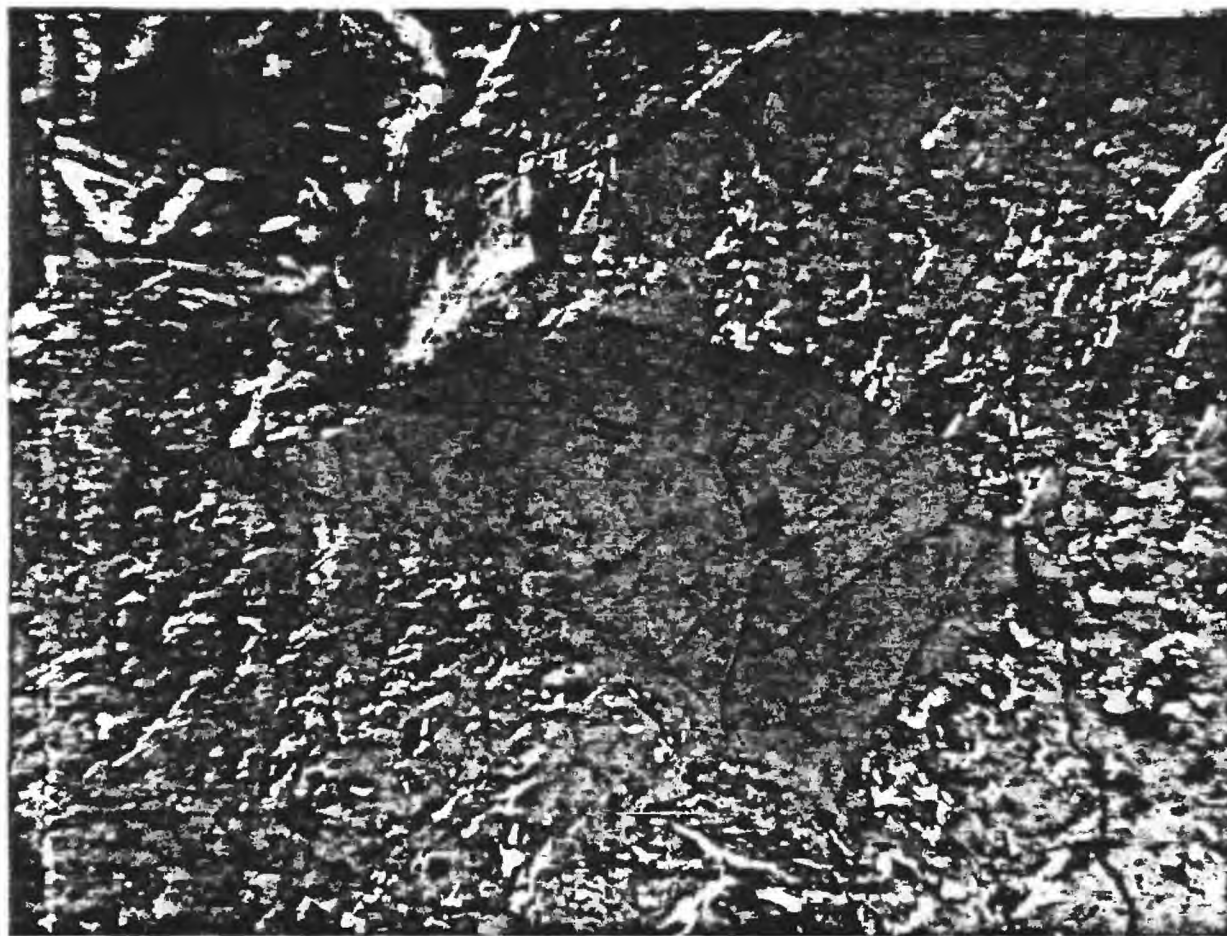


Figure 12. Advanced stage of silicification: quartz overgrowth has replaced a large area of sericite. The overgrowth and igneous quartz grain have the same optical orientation. 100x.



Figure 13. Advanced stage of silicification; mosaic pattern of interlocking quartz grains replacing sericite. Note that some grains are elongate. Identification of igneous quartz grains is nearly impossible. 100x.

stage of this process.✓

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✓Figure 14. Quartz crystal of the quartz-pyrite-chalcopyrite assemblage growing into and replacing galena.

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Silicification in the chalcedony veins is a little different than that just described for the quartz veins. In these veins, igneous quartz grains appear to have had little influence as centers for the precipitation of silica, and they exhibit only narrow borders of chalcedony. Instead, chalcedony and microcrystalline quartz were precipitated at many sites, and as silicification proceeded the number of sites of precipitation increased. The end product of this process is a rock consisting almost entirely of microcrystalline quartz grains, and in which the aluminum silicate minerals were almost completely replaced. Grains of igneous quartz, pyrite, carbonates, iron oxides, and tiny shreds of clays or sericite indicate that such a rock was part of the wall rock before intense silification occurred(see fig. 15).✓

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✓Figure 15. Silicification in a chalcedony vein.

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Figure 14. Quartz crystal replacing galena. Quartz crystal of the quartz-pyrite-chalcopyrite assemblage growing into and replacing galena. The quartz along the galena cleavage is in optical orientation with the large quartz crystal which contains a large inclusion of galena in its center and many tiny inclusions of galena around its border. 100x.



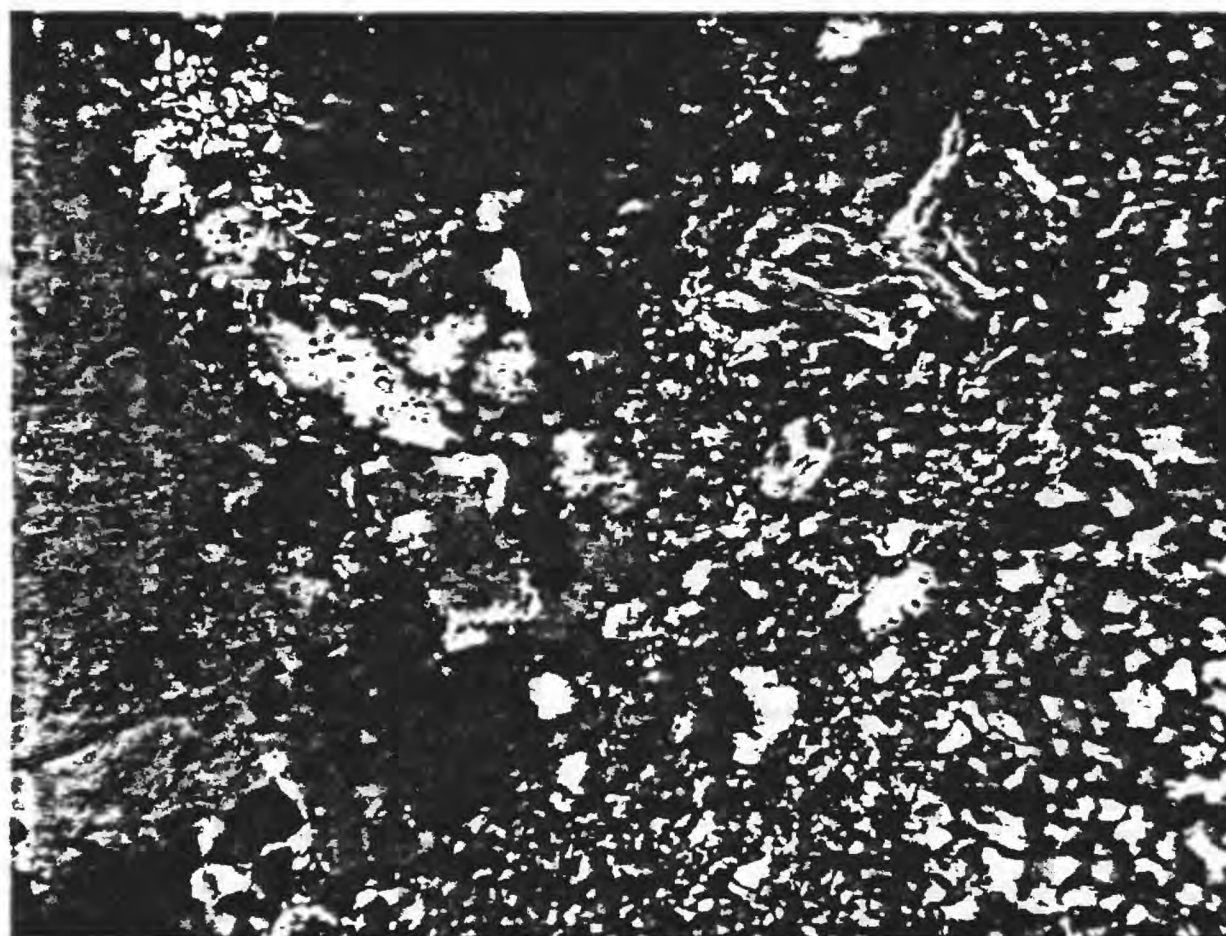


Figure 15. Silicification in a chalcedony vein. Note the microcrystalline quartz of two grain sizes, the shreds of relic sericite and the overgrowth of microcrystalline quartz on the large grain of igneous quartz. 200x.

### Changes in alteration along strike

In most places the bands of altered rock appear to be parallel to the veins, except for minor irregularities. However, along strike the inner bands become thinner and finally pinch out against the side of the veins. In effect, the boundaries between altered bands converge with the veins. The silicified band is the only known exception.

In addition, the bands belonging to the two main groups of alteration minerals (the aluminum silicates and the iron-bearing minerals) converge with the vein at different rates, that is, the bands of iron-bearing minerals converge more rapidly than the bands of aluminum silicate minerals, and they cross through the aluminum silicate bands. Consequently, the mineral assemblages of an altered envelope change along the veins. A simple alteration pattern that shows a succession of bands extending outward from the vein cannot be applied to either all veins or to all parts of one vein in the area. Instead, a pattern that shows both the succession of bands and the manner in which they converge is required. Such a pattern of alteration effects is shown schematically in figure 16.✓

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✓Figure 16. Relation of veins and alteration.

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The position of boundaries, determined either by mapping or from crossections of altered rock, have been linked together along the

horizontal axis by using the grain size of the quartz as a guide in constructing the composite diagram. The horizontal and vertical axes of the diagram are necessarily of different scales in order to have space to show the more important features. The horizontal dimension of the diagram represents from a few hundreds of feet to several thousands of feet, and the vertical dimension represents a few tens of feet to a few hundreds of feet.

A series of bar scales along the top and one side of the diagram in figure 16, shows the main minerals within the altered bands, the varieties of quartz (from coarse-grain to fine-grain), and the type of veins and altered rocks typical of each zone in the zonal pattern. Going from left to right in the diagram, shows the sequence of aluminum silicate alteration products (sericite, kaolinite, montmorillonite) in the wall rock adjacent to the veins. A similar sequence of pyrite, carbonate, and iron oxide is also apparent. Parts of these sequences can be seen along many veins in going from their cores to their ends. In addition, within the veins a change from pyrite to carbonate occurs along strike, and at this point the wall rock changes from pyritic to carbonate. From a study of thin sections, a similar change from carbonate to iron oxide is thought to occur, but this is obscured by weathering products so was not mapped.

The positions at which the bands of sericite, kaolinite, pyrite, and carbonate pinch out against the vein are not rigidly fixed points as might be assumed from the diagram. The sericite pinchout ranges from the location of the last fine-grained milky quartz to well out in the chalcedony segment of the veins, and all milky quartz lies

X

within sericitic wall rock. The pyrite pinchout lies within sericitic rocks and has a considerable range along the diagram relative to the varieties of the quartz. The carbonate pinchout has been found in veins ranging in type from moderately coarse-grained quartz to chalcodony.

## Chemical analyses of altered rocks

Suites of altered rocks from three veins have been analysed chemically, and the results of the analyses are presented in Table I. ✓

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Table I. Chemical analyses of altered rocks.

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The suites were selected to represent veins characteristic of different places along the x-axis of the alteration diagram (fig. 16). Analyses from a non-sericitic chalcedony vein are not included in table I because these have recently been published by Rosenblum (Becraft, Pinckney, and Rosenblum, 1963, Table 12). The Boulder vein (116) is a fine-grained quartz vein with a little chalcedony enclosed in an altered envelope about 12 feet wide at the place sampled. The Crescent vein (27) is a moderately fine-grained quartz vein (no chalcedony) enclosed in an altered envelope that is less than one foot thick in many places. The Crystal vein (100) consists of coarse-grained quartz and abundant sulfides enclosed in a wide altered envelope. This vein is representative of the left side of the alteration diagram (fig. 16).

Some of the analyses have been recalculated. Rocks that were cut with a diamond saw cooled by oil, were found to contain from one to five percent organic material, even though they had been soaked in solvents for several days to remove the oil and then dried in an oven at 35°C. for two weeks. Analyses of these rocks were recalculated so that the inorganic constituents total 100 percent.

Table I - Chemical Analyses of Altered Rock

Crystal vein (100)						
Altered bands	Unaltered	Chlorite and iron oxide	Montmorillonite and carbonate	Kaolinite and carbonate	Kaolinite, carbon- sericite, carbon- ate, and pyrite at the sericite front	1/ Sericite near the vein
Lab. No.	155579	155580	155581	155582	155583	155584
SiO <sub>2</sub>	67.3	67.4	66.2	66.0	65.3	65.7
Al <sub>2</sub> O <sub>3</sub>	14.9	15.3	16.8	15.8	15.1	15.8
Fe <sub>2</sub> O <sub>3</sub>	1.9	1.7	2.4	1.6	.2	.4
FeO	1.8	1.6	1.0	1.5	5.4	1.8
MgO	1.2	1.2	.72	.86	1.1	.55
CaO	3.4	3.2	2.2	.71	.57	.18
Na <sub>2</sub> O	3.2	3.2	2.9	.28	.08	.09
K <sub>2</sub> O	4.1	4.2	3.4	6.4	4.9	4.8
H <sub>2</sub> O	1.2	1.2	3.8	4.6	2.1	2.5
TiO <sub>2</sub>	.42	.40	.37	.45	.40	.44
P <sub>2</sub> O <sub>5</sub>	.17	.15	.16	.17	.12	.11
MnO	.10	.09	.04	.20	1.8	.16
CO <sub>2</sub>	.34	.40	< .05	1.1	1.1	.34
FeS <sub>2</sub>	< .10	< .10	< .10	< .10	1.6	6.9
SO <sub>3</sub>	< .10	< .10	< .10	< .10	< .10	< .10
	100.	100.	100.	100.	100.	100.
Total Fe	2.8	2.5	2.5	2.4	5.4	6.1

Table I (Cont.)

	Crescent vein (27)			Boulder vein (116)		
	<u>2/</u>		<u>2/</u>		<u>3/</u>	<u>2/</u>
	Chlorite	Montmorillonite and kaolinite	Sericite and quartz (silicic band)	Chlorite and iron oxide	Montmorillonite, kaolinite and iron oxide	Sericite, and carbonate, and pyrite
Lab. No.	155588	155589	155590	155585	155586	155587
SiO <sub>2</sub>	62.7	63.6	71.3	64.7	63.8	62.6
Al <sub>2</sub> O <sub>3</sub>	17.4	19.2	16.2	16.1	17.4	16.6
Fe <sub>2</sub> O <sub>3</sub>	2.4	.9	.3	3.3	3.4	.5
FeO	2.9	2.2	1.9	1.6	.53	4.2
MgO	1.3	1.2	.71	1.3	1.0	2.0
CaO	3.6	.59	.14	2.8	1.4	.48
Na <sub>2</sub> O	3.2	.22	.11	3.0	2.7	.11
K <sub>2</sub> O	3.2	4.8	4.4	4.6	4.8	4.2
H <sub>2</sub> O	2.2	6.3	3.0	2.2	4.2	3.8
TiO <sub>2</sub>	.45	.53	.47	.55	.61	.55
P <sub>2</sub> O <sub>5</sub>	.26	.32	.16	.25	.28	.23
MnO	.23	.04	.14	.05	.10	.89
CO <sub>2</sub>	.34	< .05	< .05	< .05	< .05	3.4
FeS <sub>2</sub>	< .10	.15	1.4	< .10	< .10	.71
SO <sub>3</sub>	< .10	< .10	< .10	< .10	< .10	< .10
	100.	100.	100.	100.	100.	100.
Total Fe	4.0	3.3	2.6	3.6	2.9	4.1

✓ Paul L. D. Elmore, Ivan H. Barlow, Samuel D. Botts, Gillson Chloe, analysts.

1/ Corrected for 5 percent organic material.

2/ Corrected for 1 percent organic material.

3/ Corrected for 2 percent organic material.

Each analysed specimen was selected to represent a band of altered rock shown on figure 16. The major minerals are shown in table I, and the percentage variation of major chemical constituents is shown in figure 17. The gains and losses closely reflect the

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Figure 17. Variation of the constituents in altered rocks expressed in percent.

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mineralogy of the altered bands. Constituents lost from the altered rock are soda, magnesia, and lime. Added constituents are water, carbon dioxide, and sulfur, in addition to iron in the pyritic band and silica in the silicic band. Those constituents for which a stable mineral phase occurs, are retained to a large degree, whereas those constituents for which no stable phase occurs were almost entirely leached from the rock.

Soda is the most mobile of all the constituents. Most of the sodium released from plagioclase apparently remains in the montmorillonite, but in the alteration of montmorillonite to kaolinite, nearly all of the soda is removed from the rock. The Crystal (100) and Crescent (27) veins have well defined kaolinite fronts, and this is reflected in the marked change in the content of soda across the kaolinite fronts. The Boulder vein (116) on the other hand, has a broadly gradational kaolinite front in which soda was not so completely removed at the place sampled.

The variation of magnesia is complicated by the number of minerals that can contain it (biotite, chlorite, montmorillonite, and carbonate), and the fact that each may be generated or destroyed at



different places in the altered envelope. In the suites from the Crystal (100) and Crescent (27) veins, half of the magnesia was lost, although in the Crystal suite a gain in magnesia occurs at the sericite and pyrite fronts. This gain in magnesia coincides with a two to four inch wide band rich in carbonate that lies a few inches outside of the fronts of pyrite and sericite. A similar situation apparently exists at the Boulder mine (116) where the content of magnesia drops slightly from the chlorite to the argillic-iron oxide bands, but then increases sharply in the carbonate band at the pyrite front. The pyrite-deficient altered rocks at the Crescent mine (27) do not show a local enrichment of magnesia.


All of the suites of altered rocks show an increase of potash at the kaolinite front or in the kaolinite zone. The source of this potash is not known. However, veinward to this point in many of the altered envelopes, biotite was progressively destroyed and may have been liberating potash. A mineral in which this potash must have lodged has not been identified. Total iron shows a similar increase in amount, but this can be accounted for by the precipitation of iron as pyrite at the pyrite front. An increase in iron was not found at the Crescent mine (27) where the sericitic band is non-pyritic.

### Time of alteration


The time during which the alteration pattern was produced ranges from the deposition of the pyrite-quartz assemblage to nearly the close of alteration. Every vein, regardless of size, that contains the pyrite-quartz or a later assemblage, is associated with the same pattern of altered rocks arranged in mineralogical symmetry along the vein.

Many of the larger veins containing either quartz and tourmaline or quartz and molybdenite are also associated with this pattern of alteration. However, many small veins either have no altered rocks along them, or the pattern of alteration indicates the alteration is not related to the veins. Two examples illustrate the age relations.

In the Polaris adits (79 and 80), veins containing the quartz-molybdenite assemblage also contain either the pyrite-quartz assemblage or the galena-sphalerite assemblage and are enveloped in altered rocks typical of the intermediate type of veins. At the end of a crosscut in the northern adit (79), several small veins of quartz and molybdenite branch from a larger vein containing sphalerite, galena, molybdenite, and quartz, and extend through the wide argillic bands of the larger vein. The argillic bands contain unaltered residual boulders of quartz monzonite as well as thin bands of sericite along some of the molybdenite veins. The residual boulder shown in


figure 18,  is cut by a flat lying vein of quartz and molybdenite, but

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 Figure 18. Relation of quartz-molybdenite veins to altered rocks.

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it has not been altered by solutions that deposited the vein, and plagioclase crystals cut by this vein are fresh. Therefore, the solution that deposited the quartz-molybdenite vein, did not produce the argillic alteration. The sericitic bands are also younger than the quartz-molybdenite mineralization. The steeply dipping veins branch from the larger vein, and are enclosed in sericite, but the flat lying vein is not. Therefore, the alteration is thought to have been superimposed on the quartz-molybdenite veins, probably by the solutions that deposited the later mineral assemblages.

The relative age of the alteration and a quartz tourmaline vein is illustrated in figure 19,  which shows a small tourmaline

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 Figure 19. Relation of tourmaline vein to altered rock.

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vein in a crosscut at the Lone Eagle mine (49). The quartz monzonite along one side of the vein is altered, but that on the opposite side of the vein is unaltered, even though it is sheared and broken in places. If the solutions that deposited the vein also altered the rock, they would surely have produced alteration effects on both sides of the vein. Such asymmetric distribution of the altered rock strongly suggests that the altering solutions were restricted to one side of the

# Explanation



Unaltered quartz monzonite



Silicic-pyritic phase of unaltered quartz monzonite



Sericitic rock



Argillie rock

Quartz - molybdenite Vein

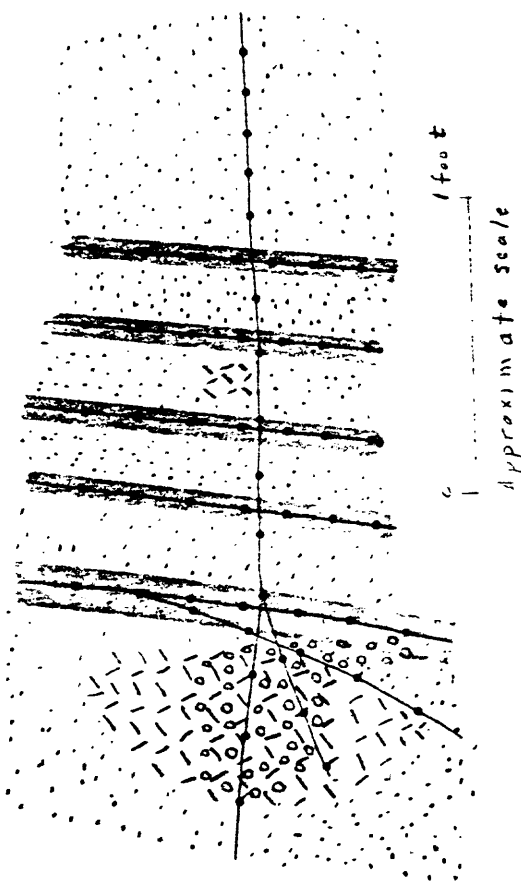


Figure 18 Sketch of wall of crosscut showing Relation of Quartz-molybdenite Veins to Argillie Altered Rock in the Polaris Mine (vertical crosssection)

Sketch by DMB, 1958

vein, and therefore, the alteration is younger than the vein.

Similar age differences between altered rocks and veins containing the earliest vein mineral assemblages have been seen in several places. They indicate that these veins are earlier than the altered rocks, and that the larger veins were re-opened during later stages of mineralization.

Near the close of mineralization, alteration apparently ceased along some chalcedony veins. This is indicated by late stringers that branch from the veins and pass through the altered envelope into fresh quartz monzonite. This is well illustrated by a stringer in the Mineral Hill mine (42) (figures 3B and 20). ✓

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✓ Figure 20. Late stringer of carbonate and chalcedony

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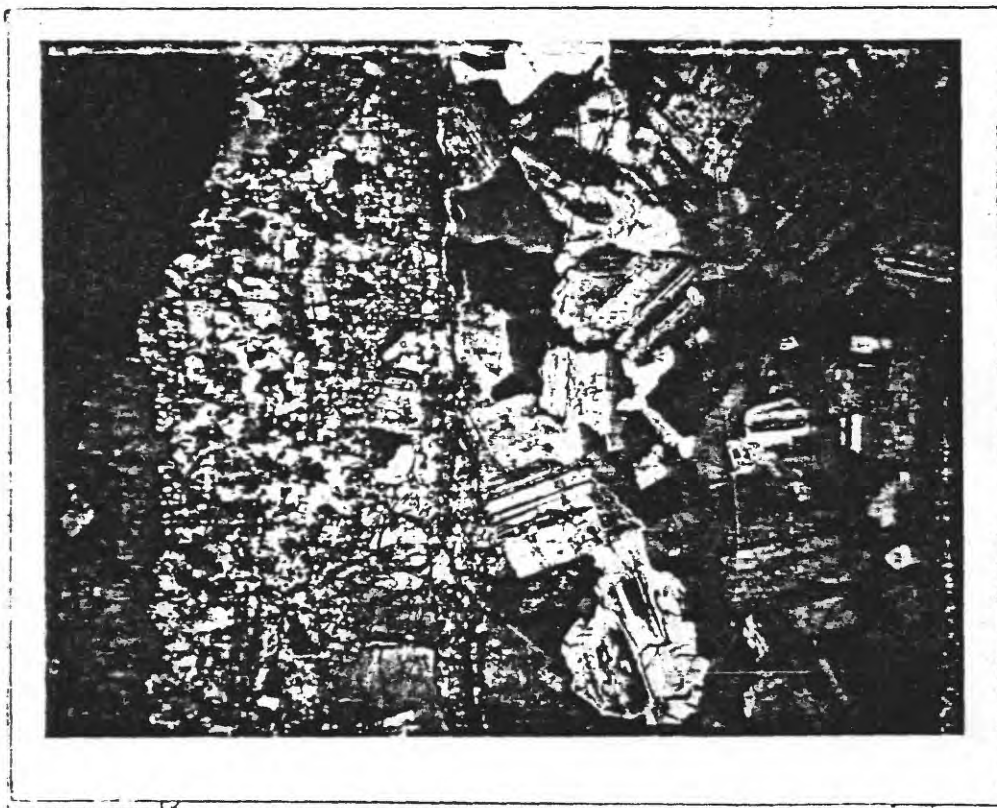


Figure 20. Late stringer of carbonate and chalcedony. The small vein of carbonate (fine-grained mosaic pattern) and chalcedony is in contact with biotite (black) and plagioclase. The rock contains no clay, sericite, or chlorite. The biotite is unaltered even though it is cut by carbonate. Carbonate part of stringer is 4 mm. wide.

## ZONING

The veins in the mineralized area are strongly zoned, and the over-all pattern of the zoning is much like that in the vein at locality 176, or the vein at the Mineral Hill (42) mine (fig. 3). In fact, veins of this sort, that change along strike from quartz to chalcedony and from sulfides to rhombic carbonates, were used as a guide in working out the zonal pattern. The relationship of these gradually changing mineralogic features, and other allied ones, were then seen to form areal and regional patterns.

Zoning was not noted by previous workers, probably for several reasons. In most places, the changes in mineralogy are gradual over distances ranging up to a few miles. The zonal pattern is mineralogically simple, but in contrast, it is areally complex. The areal complexity has resulted from zonal patterns having been developed around several centers, and the zones related to different centers often overlap in many places to form an over-all complex pattern. In addition, the zoning pattern is closely related to time and stages of mineralization. The zonal patterns, therefore, could not have been ascertained until the details of the depositional sequence had been established.

The zonal patterns shown on figure 2A are those developed during deposition of the quartz-pyrite assemblage. Since this assemblage and its associated altered rocks is the youngest and most widespread in the area, it is the most useful to show zonal patterns.

Zoning is shown on figure 2A on the basis of 1) the varieties of quartz, 2) the extent of sericitic alteration along the veins, and 3) the distribution of pyrite and carbonate.



## Quartz zoning

On the basis of the varieties of quartz, the veins are assigned to three major types: a central type, an intermediate type, and a peripheral type. This zonal classification is parallel to the descriptive classification (quartz veins, mixed veins, and chalcedony veins), except that finer-grained, and usually smaller, quartz veins are grouped together as the intermediate type. The main features of the zonal classification are shown in Table II✓ and the areas where each

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✓ Table II. Characteristics of zonal type.

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type is predominate are shown on figure 2A.

The main centers of mineralization are at or near the following mines:

Central type: Alta (76), Gregory (51), Comet (131), Crystal (100),

Intermediate type: Lee Mountain (5), Eureka (13), Crescent (27),

Peerless (26), Frohner (22), Liverpool (35), Baltimore (164),

Jib (121), and Minneapolis (125).

All of the centers when compared to each other, can be seen to progressively change outwardly toward the edges of the mineralized area.

As a rule each succeeding center outward from a central area of mineralization tends to be lower in the zonal pattern than the next inner center. In comparing veins in order to place them in their zonal position, the cores of veins were usually used. In this way only the

Table II. Characteristics of Zonal Types

Variety	Central Zone			Intermediate Zone		Peripheral Zone	
	Quartz			Quartz		Microcrystalline quartz and chalcedony	
Usual grain size	2-10 mm.			0.1-5 mm.		<0.1 mm.	
Habit	Subhedral to anhedral; compact to open			Usually anhedral; compact; free standing crystals in vugs		Compact to fibrous; rare, tiny quartz crystals in vugs	
Sericite	Wide bands (little known)			Few inches to five feet		Narrow to absent, often enclosed within wider zone of intense silification	
Clays adjacent to vein	No			No		Yes - where sericite is absent	
Rock minerals in vein	Quartz			Quartz		Quartz, K-feldspar with clays, rare biotite in a few veins	
Type	Thick complex inter-twined lenses of vein as replica of complex fault zone in wide sheared and altered zone.			Thinner complex intertwined lenses; simpler fault, breccia or sheeted zone replicas.		Simple sheeted zones to complex shear and breccia structure	
Size	Large			Small to large		Small to large	

Table II. (Cont.)

Minerals in the Veins			
	Central Zone	Intermediate Zone	Peripheral Zone
Sulfide minerals of vein	Pyrite Chalcopyrite Galena Sphalerite Arsenopyrite	Pyrite Chalcopyrite Galena Sphalerite Arsenopyrite	Pyrite  Very rare: Galena Sphalerite
Pyrite	Present in all veins	Absent in the ends of some veins	Present in small amounts; in many veins, absent in many veins
Iron Carbonates	Rare except at ends of vein	Common in many veins, absent in cores of some larger veins	Very common
Iron Oxides	Absent in veins	Absent in veins	Common in many veins

parts of the veins that are roughly equivalent are compared to each other.

The distribution of the veins around the centers forms a complex pattern; the influence of one center merges with that of other centers in many places. From a center outward the veins become successively more like the types shown to the left on the diagram of veins and altered rocks (fig. 16), and at some point or line between centers a reversal of types occurs where the influence of another center is met. Each center and the veins related to it is briefly described in the appendix.

### Zoning of pyrite and carbonate

The relations of pyrite to carbonate in the veins is spatially the same as that of quartz to chalcedony. Pyrite occupies a central position, either in the vein or areally, and carbonates occur around the pyrite. A pyrite-carbonate boundary is not shown for the main mineralized area on figure 2A because of the difficulties of distinguishing the oxidation products of pyrite from those of carbonate in many of the weathered outcrops. Zoning of these minerals was established and is shown areally in the Maupin Creek district on figure 2A. The zoning of pyrite and carbonate on the scale of a mixed vein is easily seen at the Mineral Hill (42) mine (fig. 3).

In the Mineral Hill (42) vein, pyrite is closely associated with the coarser-grained quartz, and carbonates are associated with chalcedony. In the outcrop (fig. 3A), all of the pyrite occupies a central position in the core of coarsest-grained quartz. The rest of the vein contains carbonate but no pyrite.

The Mineral Hill mine workings expose a group of small veins in the footwall of a larger brecciated chalcedony vein (fig. 3B and C). Near point A (fig. 3C) all of the veins are fine-grained milky quartz veins that contain pyrite and chalcopryite, but no carbonate. Diagonally across the strike of the veins, between point A and point B, the veins grade through fine-grained dark quartz veins to chalcedony veins. Along with this change, the veins change from sulfide-bearing veins to carbonate

bearing veins without visible sulfides. A similar change takes place along the strike of the veins. Along the northwest wall of the drift the veins contain sulfides and very little carbonate, but along the southeast side of the drift the veins consist of chalcedony and carbonate.

The only place pyrite-carbonate areal zoning could be reliably established is in the Maupin Creek district east of Clancy, in which pyrite occupies a central position.

### Areal sericite boundary

From the vein and altered rock diagram (fig. 16) it can be seen that veins extend beyond the pinch-out of the sericite bands. The only veins that do this are chalcedony veins of the peripheral zone, or the chalcedonic ends of mixed veins. This general relation, seen in many veins, seems also to be true for large areas of veins, and it is the basis for the sericite boundary shown on figure 2A.

The sericite boundary marks the outer limits of areas within which the veins are entirely enclosed in sericite, i.e., within these areas sericite is more extensive than the vein. Outside of the boundary, sericite occurs along many veins, but in all of these, chalcedony extends beyond the limits of sericitic alteration.

Mineralization beyond the limits of the sericite bands is found in three major forms. Usually veins are bordered by sericite for a part of their length, but their ends extend beyond this sericite pinch-out. In other veins, the vein is wider than the sericite bands. At such places the vein contains a band of sericite within it, but the borders of the vein lie out in the argillic bands. All veins of this sort consist predominately of silicified rock, and it is apparent that silicification in them has proceeded outward farther than the sericite front. In the third major form, the main body of the chalcedony vein lies within the sericite front, but many stringers of chalcedony branch out into the argillic bands.

The sericite boundary should not be considered as a sharp line along its entire length. Where the veins are widely spaced, the location of the boundary was easily determined. However, in some areas of closely spaced veins, especially south and east of Clancy, the location of the boundary could not be so easily determined and in these places the boundary should be considered to be a broad zone about 1000 feet in width. Also in some places south and east of Clancy, the location is uncertain because of weathering effects superimposed on altered rocks.

The sericite boundary roughly encircles the mineralized area. It can be identified around the north, east, and south sides of the mineralized area. Along the west side of the area, veins both with or without sericite extending to their outer limits are known, and presumably the sericite boundary could be drawn through this part of the mineralized area. In this part of the area, the boundary probably would be sinuous, but exposures of veins were considered to be too poor to permit extension of the boundary.



Relation of quartz and sulfide minerals  
to sericite boundary

All of the quartz veins, almost all of the mixed veins, and nearly all of the sulfide bearing chalcedony veins lie within the sericite boundary. Some veins outside of the boundary contain a little quartz and sulfide minerals, but where these minerals occur, they are within that part of the vein enclosed in sericite. Exceptions to this are rare grains deposited in open spaces, and a deposit filling an open breccia at the Obelisk mine (140) (Becraft, Pinckney, and Rosenblum, 1963, pp. 50-51, pl. 4).

### Collapse of the zonal pattern

Near the end of mineralization, minerals characteristic the the peripheral zones and out part of the intermediate zones were deposited well in toward the central zones and into centers of mineralization of the intermediate zones. A little data suggests that the areal sericite boundary may also have moved inward. Thus, the zonal pattern that was established during deposition of the quartz-pyrite-chalcopyrite assemblage appears to have collapsed.

## Causes of zoning

### Temperature

The temperature of filling of 144 fluid inclusions found in quartz of the quartz-pyrite-chalcopyrite assemblage are presented in figure 21. The filling temperatures range from 149°C. to 360°C. The

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Figure 21. Filling temperature of fluid inclusions in quartz crystals.

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inclusions are from 7 veins ranging in zonal type from low rank intermediate type to central type. Inclusions from the cores of higher rank veins filled at higher temperatures, and inclusions from the cores of lower rank veins filled at lower temperatures.

Nearly all of the inclusions were run by the writer in a Leitz heating stage. Sixteen inclusions from the Eureka (13), Basset, and Golconda (84) veins were run by either D. H. Richter or Corral F. Parker in Survey laboratories using different equipment. The fluid inclusions used for temperature determinations were in plates 1-2 mm. thick, cut parallel to the C axis of the quartz crystals. The inclusions were classified as being either primary or secondary after detailed examination of the crystal plate. Some primary inclusions are situated so that they could have been modified in some way. They are easy to recognize because they 1) lie close to fractures or the projection of fractures, 2) have thin walls, usually because of the

presence of other inclusions nearby, 3) have a large surface area, (e.g., thin flat inclusions) or a long tail-like extension, 4) or show signs of recrystallization after entrapment.

The filling temperature data plotted on figure 21 are mostly those of primary inclusions, but also include a few from the "modified" primary type. The value of carefully selecting the inclusions before determining their filling temperatures is apparent from figure 21. Nearly all of the filling temperatures from unmodified primary inclusions plot in small groups, whereas filling temperatures from modified primary inclusions show considerable scatter, and their values probably can be ignored. Filling temperatures of secondary inclusions are not shown; many secondary inclusions were run, and they all filled at lower temperatures than their neighboring primary inclusions.

The data show that higher temperatures prevailed in the centers of mineralization and that lower temperatures are characteristic of the veins around these centers. The highest filling temperatures found are from a major center of mineralization, the Crystal vein (100), and the next highest are from a small center, the Eureka vein (13). Veins away from these centers contain inclusions that filled at lower temperatures.

The temperature values for the Crystal center of mineralization are from a large zoned quartz crystal from near the west end of the ore body. The inner zones of this crystal were probably deposited during the main part of the quartz-pyrite-chalcopyrite assemblage. The outer zones, however, contain bands of carbonate inclusions

which indicates that they were deposited during the time the zonal pattern was collapsing, when carbonate was being deposited at the west end of the core of the Crystal vein. The inclusions from the inner part of the quartz crystal filled between 320°C. and 360°C. with the innermost inclusions filling at the highest temperature. Inclusions from the outer bands that contain the carbonate filled between 193°C. and 220°C. and show a systematic drop in temperature with time.

The filling temperatures from the outer bands are comparable to those from the Uncle Sam (108) and Vindicator (94) veins, about two miles to the north and south of the Crystal (100) vein. These veins are both of low rank intermediate type in the zonal pattern. The Uncle Sam vein typically contains very fine-grained quartz and carbonate; pyrite is sparse. Inclusions from it filled between 198°C. and 210°C. The Vindicator vein (94) is much like the Uncle Sam (108) vein except that the quartz is a little coarser-grained and a thin pyrite band is present. Both veins are enclosed in thin sericite bands. Fluid inclusions in small quartz crystals from the Vindicator vein (94) filled between 197°C. and 218°C., and most of them filled near 200°C. The base of these crystals contain pyrite grains; their tips are capped with chalcedony.

The lowest filling temperatures related to the Crystal center of mineralization are from the Ada vein (96). This small vein lies near the northeast edge of the group of veins zoned around the Crystal center. Filling temperatures of inclusions from it range from 149°C. to 163°C.

A similar difference in temperature was found in the Rimini district, where the filling temperatures of inclusions from the Eureka (13) vein are higher ( $220^{\circ}\text{C}.$ - $241^{\circ}\text{C}.$ ) than those from the smaller nearby O. H. Bassett vein ( $206^{\circ}\text{C}.$ - $214^{\circ}\text{C}.$ ).<sup>✓</sup> In addition, the highest

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<sup>✓</sup> Sample taken from adit 400 feet south of locality 11.

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temperature found for the Eureka vein (a small center of mineralization) are considerably lower than those found for the quartz pyrite deposition in the Crystal vein (a major center of mineralization).

The filling temperatures from the Free Coinage vein (32) are thought to be representative of the low rank intermediate veins of mixed type in the Clancy district. Inclusions from this vein filled between  $179^{\circ}\text{C}.$  and  $211^{\circ}\text{C}.$ , with most of them filling between  $202^{\circ}\text{C}.$  and  $206^{\circ}\text{C}.$  This is close to the values obtained from the Vindicator (94) and Uncle Sam (108) veins and may be characteristic of all of the low rank intermediate veins. Presumably the temperature of deposition of the chalcedony veins would be even lower.

Filling temperatures were determined for one vein outside of the main mineralized area, the Golconda vein (84). Only five inclusions were suitable, four of them filled at  $200^{\circ}\text{C}.$  and one filled at  $190^{\circ}\text{C}.$

The data presented above are uncorrected for pressure (Kennedy, 1950). The salinity of fluid inclusions from the Crystal (100) and Ada (96) veins was determined by Mrs. Martha Toulmin using a freezing stage (Roedder (1962) to be less than  $7\frac{1}{2}$  percent, with most inclusions containing about 5 percent equivalent NaCl.

The weight of the overlying column of rocks probably sets a practical upper limit of pressure at about 500 bars. The veins are in the upper part of the batholith and its roof rocks, and the batholith intruded through the middle unit of Elkhorn Mountains volcanics and into the lowermost part of the middle unit in many places, so that the thickness of covering rocks at the time of intrusion may have been approximately that of the upper unit or no more than about 5000 feet. The pressure under 5000 feet of this dense tuff would be about 380 bars if an average specific gravity of 2.5 is assumed for these rocks. The minimum pressure must have been great enough to prevent boiling of the solutions, i.e., approximately 153 bars for a 5 percent NaCl solution (Sourirajan and Kennedy, 1962, Table 3, p. 131). Pressure corrections, to be added to the filling temperature, based on the data for pure water (Kennedy, 1950) for the range 150 to 380 bars, are only 10°C. to 20°C. for a filling temperature of 200°C. and only 30°C. for a filling temperature of 350°C. at 380 bars.

### Concentration gradients

Attempts to systematize the chemical and mineralogical aspects of altered rocks have followed three main courses. Many writers for years have referred to altered rocks as belonging to types such as, argillic propylitic, or sericitic. Recently, Creasey(1959) and Burnham (1962) have attempted to redefine altered rock types, and have arranged their types into facies analogous to metamorphic facies. Requirements of this approach are that the minerals are contemporaneous in age and occur as equilibrium assemblages. The minerals of their assemblages are stable over a considerable range of temperature and pressure, and because of this, the facies type of classification fails to define conditions within this range. In addition, Creasey and Burnham consider only solid phases, and the nature of the intergranular fluid is largely overlooked.

Hemley and Jones (1964) have attempted to explain alteration in terms of hydrolytic exchange reactions in which elements such as Na, Ca, Mg, and K from silicate minerals are replaced by hydrogen ions from the solution. They stressed the controls exerted on the reactions by the ratios of alkali cations to hydrogen ion. Their method of treatment recognizes the important fact that alteration is largely a process of reactions between solid phases and constituents of the pore solution. This writer is in agreement with their approach and considers that each alteration front is a surface along which a reaction

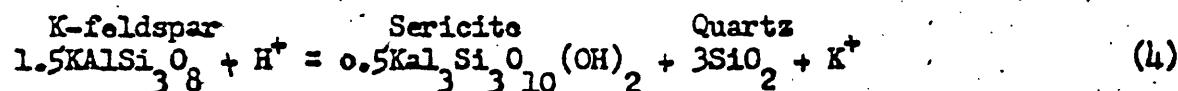
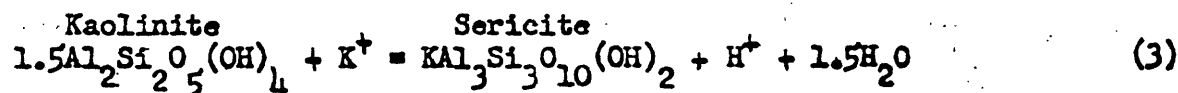
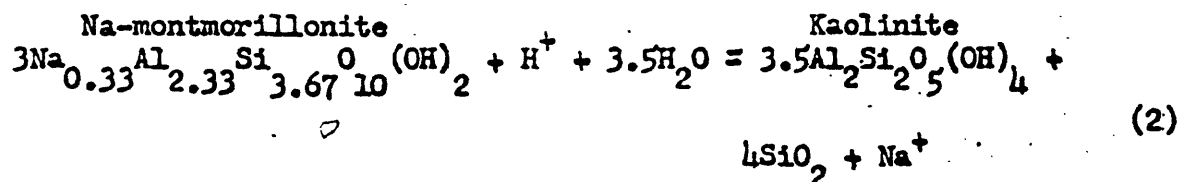
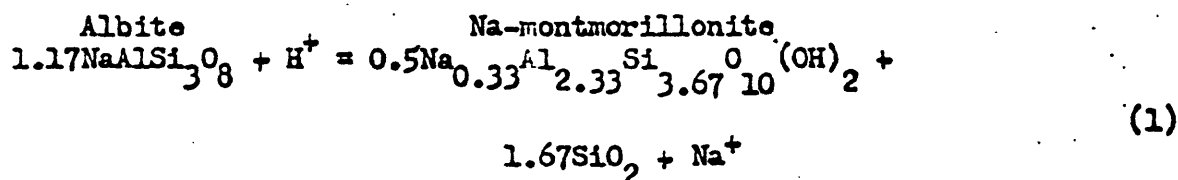


occurred, the reactants and products, other than solid phases, having been brought to and removed from the alteration front along concentration gradients that existed in the pore solution.

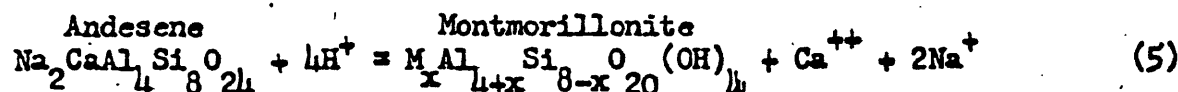
Gains and losses of chemical constituents in the altered rocks have been discussed; they are best accounted for by the movement of constituents into or out of a rock in response to concentration gradients maintained by diffusion. Such a mechanism has been outlined by many writers (e.g., Lovering, 1950 and Orville, 1962). Hemley and Jones (1964, Fig. 5) have proposed similar gradients in terms of activity.

Gradients of Na, Ca,  $\text{SiO}_2$ , C, S, and H probably existed in the wall rock. The gradient of each constituent must have been strongly influenced by reactions which either add or extract that constituent from the solution. Some of the reactions and gradients are discussed below.

Some experimentally determined reactions (Hemley and Jones, 1964) applicable to the alteration of quartz monzonite are:



A more realistic reaction for the plagioclase of the quartz monzonite is:



The mineralogy of the outwardly moving fronts indicates that all of the reactions as written went from left to right during alteration.

By means of such reactions as (1), (2), and (5),  $\text{Na}^+$  was released to the pore solution and  $\text{H}^+$  was removed. No other reactions are known to occur in the alteration of these rocks which uses  $\text{Na}^+$  as a major constituent. Consequently, nearly all sodium was removed from the altered rocks as indicated by the chemical analyses. The  $\text{Na}^+$  must have moved away from the site of the reactions, probably to

the vein along concentration-diffusion gradients as proposed by Orville (1962). The gradient for sodium is probably one of the most simple of the constituents in the rocks. Most others are complicated by one or more reactions.

A gradient for calcium would be affected by calcium being added to the solution at 3 places and removed at one. Calcium was added to the solution at the montmorillonite and kaolinite fronts (reactions 5 and 2), and some calcium was removed from the solution at the carbonate front to form iron-bearing carbonate. This same calcium was again released to the solution by the advance of the pyrite front.

The supply of  $H^+$  required for the hydrolytic reactions must have come from the solution in the vein, and  $H^+$  moved into the wall-rock in response to a gradient that sloped away from the vein, opposite to that of  $Na^+$  and  $Ca^{++}$ . Reactions (1), (2), (4), (5) required a continuing supply of  $H^+$ . Reaction (3) probably supplied  $H^+$  to the solution.

Gradients similar to that of  $H^+$  must have existed for carbon and sulfur, both of which were supplied to the rock in response to gradients sloping from the vein, so that carbon was supplied to the carbonate front, and sulfur was supplied to the pyrite front. Additional sulfur probably was supplied to the outward moving pyrite front throughout mineralization, but after the carbonate band was established, only part of the carbon had to come from the vein. Replacement of iron-bearing carbonate by pyrite at the pyrite front released carbon to the solution. This carbon was available so that some of it could

move to the carbonate front so that little, if any, carbon was removed from the solution in the vein once the system was established, and the pyrite front was advancing. Carbon could be recycled several times in such a system.

From the foregoing discussion it appears that since so many of the silicate reactions in the wallrocks use  $H^+$ , a gradient of activity of  $H^+$  was the most important single factor controlling the alteration pattern of the silicate minerals around a single vein. In the system described here the supply of  $H^+$  probably determined the sites of the silicate hydration reactions, i.e., determined the arrangement of the silicate alteration bands around a vein. Some place along these gradients the equilibrium ratio of  $a_{\text{alkali}}/a_{H^+}$  was established for each of the hydrolysis reactions. If  $a_{H^+}$  is high relative to  $a_{\text{alkali}}$  the reactions will take place a considerable distance from the vein, whereas if  $a_{\text{alkali}}$  is low, relative to  $a_{H^+}$ , the reaction will take place close to the vein. This probably has influenced the convergence of the altered bands of the silicate minerals. A large and continuing supply of  $H^+$  is necessary to move the kaolinite and montmorillonite fronts outward from the vein. The supply of  $H^+$  was probably greatest in the cores of the veins where the altered bands are wide, and it was probably less so adjacent to the ends of the veins where the alteration fronts lie nearer the vein and converge with it. The position of the pyrite front was probably controlled in a similar way.

### Silica and the sericite front

Reactions such as (1) and (2) release  $\text{SiO}_2$  as a product, and this silica is not precipitated at the sites of the reactions in spite of the fact that the activity of silica should be one because of quartz in the rock. Recent work by Hemley strongly suggests that the solution in altered rocks can become supersaturated with respect to silica, and that silica can move out of the rock (Hemley, J. J., oral communication, May 5, 1965).

Reactions (3) and (4) occur close together at the sericite front and from this point outward through the kaolinite band, potassium feldspar and kaolinite occur together in what appears to be metastability. Hemley's work, in progress, indicates that below about  $200^\circ\text{C}$ . or  $250^\circ\text{C}$ . kaolinite and potassium feldspar can react to produce sericite at equilibrium (Hemley, J. J., oral communication, May 5, 1965).

It should be noted that reactions (3) and (4), if added together, yield sericite and quartz, the minerals produced at the sericite front. In a kaolinitic rock such as altered quartz monzonite, in which kaolinite and potassium feldspar occur in equal proportions, additions of  $\text{H}^+$  or  $\text{K}^+$  are not needed, and the two reactions might be controlled by aqueous silica.

## CONCLUSIONS

Hundreds of veins in the mineralized area belong to one large hypogene system. They are near the top of the Boulder batholith, and are probably all about equidistant from a deep source of little known character. The veins change gradually from mesothermal to epithermal types as a result of systematic differences in the mineralizing system from one place to another. They form zonal patterns that range in scale from a single vein, through a small group of veins or a district, to the entire mineralized area.

The zonal pattern reflects differing rates of flow of the hypothermal solution. Greater rates of flow resulted in large, high temperature veins containing large sulfide ore bodies and enclosed in wide sericitic envelopes. Lesser rates of flow resulted in lower temperature veins of chalcedony without sulfides or sericite.

The uniformity running through the variety of veins is startling.

## APPENDIX

### Alta center

The vein system in the Alta mine (76) is the largest center of mineralization in the area. All other centers are subsidiary to it in size, known metal content, and the amount of mineralized and altered ground. The Alta center is in an east trending major zone of veins and altered rocks about four miles long and is near the intersection of this zone and a major northeast trending zone of veins. It is the site of the largest ore body in the Boulder batholith with the exception of those at Butte. The influence of this major center of mineralization extends a few miles in all directions and constitutes the Wickes mining district.

On the basis of the grain-size of quartz crystals only, the Alta center does not fit the general pattern; the quartz crystals seem much too small for a major center of mineralization. The quartz crystals in the Alta vein are rarely over 5 mm. across, and generally they are much smaller than this. The finer grain size seems to be a reflection of replacement of the fine-grained volcanic wall rock. Throughout the area quartz crystals that replaced wall rock are smaller than those that grew in open fissures, and within veins in the Elkhorn Mountains volcanics, this difference is much more accentuated than within veins in the much coarser-grained quartz monzonite. On the basis of everything except quartz grain size, the Alta vein is the outstanding center of

mineralization. Coarse-grained quartz occurs in veins in quartz monzonite on the east side of Alta Mountain at localities 74, 75, 77, and 78.

To the northeast, east and south of Alta Mountain, the veins become progressively smaller, the quartz becomes finer-grained, and the sericite bands become thin. Relations to the west are partly obscured by the quartz latite. The decrease in both the size of the veins and the grain size of the quartz is easily seen in the belt of veins extending northeastward from locality 75. The quartz in these veins becomes much finer-grained to the northeast across the west flowing tributary of Spring Creek. Further northeast in the vicinity of sections 35 and 36, all of the veins in the belt are the chalcedonic type. Eastward from the Alta center, on the east side of Alta Mountain, the quartz in the veins is progressively finer-grained, and further eastward between Beavertown and Spring Creeks, many of the veins consist largely of fine-grained quartz with a sugary texture. Southward from Alta Mountain the grain size of the quartz progressively decreases. At the Atlas mine (81) the quartz grains range in size from about 1 mm. to about 5 mm. and about one mile farther south, locality 82, the quartz is very fine-grained. Relations to the west are partly covered by the quartz latite tuff that overlies part of the veins, but beyond the tuff unit are some of the larger veins of the Wickes district. In all of these the quartz is finer grained than it is in the veins on the east side of Alta Mountain and the ore bodies and altered envelopes are smaller than in the Alta vein. The larger veins are briefly described. The most southerly of the larger veins, at the Salvail mine (69), consists mainly of very fine-grained quartz and pyrite. The Mount



Washington (68) vein to the north contains much silicified volcanic rock, very fine grained quartz, and chalcedony and dolomite in colli-form bands. ✓ The quartz in the Blizzard (67) vein and Elkador (66)

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✓ The large dump at the Mount Washington mine probably is a non-representative sample of this large vein. The last major mining operation used a selective flotation mill and probably almost all vein material was used as mill feed. The dump consists almost entirely of altered rock.

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vein is fine-grained except for crystals a few millimeters across occurring in small vugs. The Minah (65) vein contains much coarse-grained quartz of the quartz-arsenopyrite assemblage, but that belonging to the quartz-pyrite-chalcopryrite assemblage is fine-grained. The veins (localities 62, 63, and 64) between the Minah (65) and Clancy Creek are largely carbonate.

Near the head of Clancy Creek, the quartz in the veins is very fine-grained and carbonates are abundant in some of them. Chalcedony veins occur in the east facing cirque walls at the head of Clancy Creek.

A minor reversal of the zoning occurs in the Bluebird (60) vein. Quartz in the Bluebird vein along the western extention of the Mount Washington structure, is very fine-grained at its eastern end. The grain size increases westward to the top of the hill and reaches a maximum size of 2-3 mm. near the top of the hill at the Bluebird mine shaft. Further westward the grain size decreases as the vein crosses Bluebird Meadows.

### Gregory-Rarus group

The Gregory-Rarus group of veins and altered zones lies along the north edge of the Wickes mining district. The group contains several veins as well as many altered zones within which are many veinlets but no large veins. This group of veins and altered zones extends eastward from Clancy Creek, near the Gregory (51) mine, through the Rarus (54) mine and merges with the northeast trending chalcedony veins that lie northwest of Corbin. The veins in the group range from quartz veins through mixed veins to chalcedony veins. They represent all three of the zonal types.

The main centers of mineralization in the Gregory-Rarus group are at the Gregory and Rarus mines. The Rarus vein is a mixed vein of the intermediate zone, whereas the Gregory vein contains no chalcedony, and it is assigned to the central zone. Zoning from central to peripheral types occurs within a short distance. From the Gregory mine eastward the veins change to mixed and chalcedonic types.

Quartz on the Gregory mine dump is milky and moderately coarse-grained. It was deposited either as crystals replacing altered Elkhorn Mountains volcanic rock or in narrow open fissures. The sericitic and pyritic bands of the Gregory vein are probably very wide. The old mine workings are thought to be extensive and almost all of the rock on the dump is sericitic and pyritic. In addition the rock from drift and crosscut adits east of the Gregory dumps is nearly all pyritic and sericitic. The bands of these minerals are probably as much as a few hundred feet wide.

East of the Gregory mine area, at the Monte Christo (52) mine, the veins and sericite bands are narrow. Quartz from the lower adit of the Monte Christo vein is dense and white to very fine-grained and bluish gray. About 500 feet further east along the vein about one-fourth of the quartz is the fine-grained, compact white variety and about three-fourths is the very fine-grained, dark flinty variety. To the south of the Monte Christo (52) mine some of the outer veins of the Gregory-Rarus group (near locality 53) are chalcedony veins. All veins east of the Monte Christo mine are mixed veins or chalcedony veins. A vein of milky quartz north of the Gregory-Rarus group (50) does not seem to fit the zonal pattern.

Eastward from the Gregory mine the change from quartz veins to chalcedony veins takes place in about one mile and the chalcedony veins occur only along one edge of the group. From the Rarus mine (54) eastward the change takes place in only one half of a mile. These relations are shown in figure 25 and described below.

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Figure 25. Geology of the Rarus vein and vicinity.

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The Rarus vein is a mixed vein lying along the central part of the Gregory-Rarus group of veins. The veins flanking the Rarus vein are almost all chalcedony veins. The vein zone contains at least five segments, two of which are exposed in mine workings. The western segment is fine-grained milky quartz enclosed in a chalcedony sheath that is very large at the western end of the vein segment. The second segment

is fine-grained milky quartz partly bordered by a thin sheath of very fine-grained quartz. The third segment lies along the creek east of the mine workings. The largest quartz crystals are in the eastern end of the second segment and in the poorly exposed part of the third segment along the creek. The fourth segment lies about one fourth of a mile farther east and consists of very fine-grained quartz and chalcedony. Another segment east of the creek (55) is entirely chalcedonic.

### Comet-Gray Eagle zone

A zone of sheared, altered, and mineralized rock extends eastward from Cataract Creek (Morning Glory mine 124) to the north end of the Boulder Valley (localities 158, 160, and 161). This zone, named for two of the mines along it, is strongly zoned along its length. In addition a major split from the Comet-Gray Eagle zone (the Van Armin zone) is also zoned and is described on p.

The main center of mineralization in the Comet-Gray Eagle zone is at the Comet mine (131); lesser centers are at each of the productive mines along it (see Becraft, Pinckney, and Rosenblum, 1963, pp. 83-91). Each lesser center is successively of lower rank toward the ends of the zone.

The main core of the Comet vein (131) consists of three large vein strands that merge down dip into a single vein about 100 feet wide. This part of the vein is considered to be high rank intermediate type to low rank central type. Quartz crystals from this part of the vein are about 2-5 mm. across and are associated with abundant pyrite and a little chalcopyrite. To the west across High Ore Creek the vein narrows, becomes rich in carbonate, and the quartz becomes finer-grained. To the east the quartz also becomes finer-grained but a carbonate segment of the vein has not been found.

The Gray Eagle mine (129), one and one half miles west of the Comet mine (131) contains two veins. The north vein is a moderately large vein of high rank intermediate type. The south vein, however, is narrower and is of lower rank intermediate type. It consists mainly of abundant carbonate and a lesser amount of pyrite and quartz. Much of the quartz on the dumps is the clear to cloudy variety which was deposited in vugs.

The Morning Glory vein system (124) is at the west end of the Comet-Gray Eagle zone and is characterized by carbonate rather than pyrite, and fine-grained gray quartz. The core of the two main veins consists largely of compact, dense, dark quartz with some pyrite and was the source of several thousand tons of high-grade silver ore. The bulk of the vein material in the deposit is dense quartz and abundant carbonate with a small amount of pyrite. This type of material probably makes up over eight-tenths of the vein material in the deposit. The sericite bands bordering the main veins are for the most part only a few inches thick. The Morning Glory deposit is considered to be of low rank intermediate type.

Zoning in the eastern part of the Comet-Gray Eagle zone is very similar to that in the western part. The quartz core of each more easterly vein is finer-grained; coarse-grained milky quartz of the cores gives way progressively to dense gray quartz and the place of pyrite is taken more and more by carbonate. In the Boulder Valley, where the strike of the zone swings northeastward, the veins change rapidly to fine-grained quartz veins with abundant carbonates; good examples are at localities 159 and 158. The main vein of the zone

at its eastern end (locality 160), is a mixed vein with a small quartz core, and all of the nearby veins are either chalcedony veins or veins of fine-grained, flinty quartz and carbonate.

### Baltimore center

The Baltimore center is represented by the veins in the Baltimore mine (164). It is smaller than the Alta or Comet centers and consists of a complex of veins at the intersection of a northwest trending structure and an east northeast trending structure. These veins are partly exposed in the workings of the Baltimore mine, and are mainly made up of two of the mineral assemblages. One large vein consists largely of the galena-sphalerite assemblage. Another large vein is composed of the quartz-pyrite-chalcopyrite assemblage. The quartz crystals in this vein are characteristically milky and compact. The average grain size is about 1-3 mm. and some of the quartz is very fine-grained. This large vein is considered to be intermediate in zonal type.

Outward from the Baltimore mine (164) the grain size of the quartz in the cores of the veins decreases rapidly, and within a few miles or less, only chalcedony veins are found. Carbonates also become more abundant and pyrite less abundant in many of the veins away from the Baltimore center. Mixed veins around the Baltimore center are found farther to the south and southwest than in other directions. The quartz in the cores of these veins also becomes progressively finer-grained with distance from the Baltimore mine. Southward as far as the N.E.  $\frac{1}{4}$ , sec. 18, the veins are dominately quartz veins, but the quartz



in many places is so fine-grained that it breaks with a rudely conchoidal fracture and a hackly surface. Southward and southwestward of N.E.  $\frac{1}{4}$ , sec. 18, the veins are chalcedony veins with the exception of a small number of mixed veins. The quartz cores of these mixed veins are very small and the quartz in them is very fine-grained. The most distant are found at locality 171. Beyond this place only chalcedony veins are known.

### Centers between Basin and Rimini

Many of the veins in the western half of the mineralized area lie in a broad north trending belt extending from the Boulder River near Basin to Rimini. The belt is four to five miles in width. Most of the veins in this belt trend easterly and many of them range in width up to several feet. Most of the veins in the Basin-Rimini belt are quartz veins, but many of them are the mixed type, and some are chalcedony veins.

The veins in the Basin-Rimini belt are zoned relative to four centers, but the zoning is not as strong as around the Baltimore center. The centers are (1) the Eureka-Lee Mountain vein system (localities 5 and 13), (2) the Crystal-Bullion-Eva May vein system (localities 100, 98, and 103), (3) the Big Limber Gulch veins, and (4) the Jib vein (121).

The Jib center is at the Jib mine (121) on the south side of the Boulder River at Basin. Two large veins and a small vein occur in the sheared and altered zone exposed in the mine. One of the large veins, according to Ruppel (1963, p.107), was mined for its base metal content, whereas the other one was largely quartz and pyrite and was mined for its silver and gold content. The outcrop of the quartz-pyrite vein is composed of compact milky quartz crystals about one to three millimeters across, accompanied by pyrite and fine-grained

flint-like quartz or chalcedony that contains abundant pyrite. It therefore would appear that the vein is one of the mixed type and is probably a middle to low rank intermediate vein. The altered rocks tend to confirm this. The quartz-pyrite vein outcrop is bordered by a sericitic band only about one foot thick, and the wide altered zone is mostly argillic. What is probably the eastern extension of the Jib vein system has been offset along a fault to a position north of the Boulder River. The veins of the eastern extension are chalcedony veins. Carbonate, however, was not seen.

To the southeast and east of the Jib mine the veins change rapidly to chalcedony veins. The Helper vein (122), about three-fourths of a mile southeast of the Jib vein (121), consists largely of fine-grained, compact, milky or bluish gray quartz and pyrite. The next vein to the southeastward is a chalcedony vein. The Merry Widow vein (123) to the east of the Jib, is a mixed deposit and only chalcedony veins lie to the east of it. The Red Rock vein (119) to the west of the Jib center is a large chalcedony vein.

Northward from the Jib similar changes occur within one or two miles. Chalcedony veins occur in the breccia bodies along Basin Creek, especially at localities 115, 113, and 112. A few quartz or mixed veins also occur in the same area south of locality 114, but in most of these the quartz is very fine-grained, carbonate is abundant, sphalerite, if present, is very light colored, and the sericite bands, where seen, are narrow. The Aurora vein (111) is a chalcedony vein that contains some sphalerite.

### Big Limber Gulch center

A center of mineralization is in the vicinity of the mouth of Big Limber Gulch. In this area no single vein can be selected as an outstanding center, but several veins are notably of higher rank. These veins are the Minneapolis-Manhattan (125), Boston-Buckeye (126), and nearby veins. Veins related to this center lie in an area roughly bounded by the ridge between High Ore Creek and Big Limber Gulch, the Boulder River, the Comet-Gray Eagle zone, and the divide between Basin and Cataract Creeks. Toward the edges of this area, nearly all of the veins are either chalcedony veins or mixed veins that contain a large proportion of either chalcedony or microcrystalline quartz. Many of them also contain abundant carbonate. These veins are considered to be either low rank intermediate or peripheral in type, whereas the more centrally located veins are about middle rank intermediate in type.

The zoning around the Big Limber Gulch center is not symmetrical with respect to either carbonates or chalcedony. Most of the chalcedony is in the veins on the ridge to the south and east of Big Limber Gulch, whereas the veins with more abundant carbonate are found from the Rose vein (127) northward and northeastward along the valleys of Cataract Creek and Big Limber Gulch.

### Crystal center

A major sheared, altered, and mineralized zone extends from the Bullion mine (98) eastward through the Crystal (100), Sparkling Water (101), and Eva May (103) mines. Throughout its known length of about 4 miles, it is altered, locally sheared, and in several places it is intensely mineralized. The zone may extend east of Cataract Creek under the valley of Hoodoo Creek and westward under glacial and aluvial deposits to the veins at Winter's Camp (91). Thus, it is comparable in size to the Comet-Gray Eagle zone, and it has exerted a strong influence on surrounding mineralization.

The veins in the Crystal mine are the center of a strongly zoned group of veins. These veins lie in the Basin-Rimini belt in an area extending from Saturday Night Hill northward at least as far as the Buckeye mine (87).

The Crystal-Bullion structure is zoned along its length and veins lying to the north and south are zoned relative to it also. Eastward along the Crystal-Bullion zone the deposits change from low rank intermediate type near Winter's Camp (91) to the central type at the Crystal mine (100), and back almost to peripheral type at the Eva May mine (103). The vein at Winter's Camp is probably a low rank intermediate vein. It is a fine-grained, compact milky quartz vein west

of Basin Creek, but it is a small chalcedony vein where it crosses Basin Creek. It also contains a few clear quartz crystals and colorless sphalerite in an open breccia at its intersection with a short northwest trending vein. Mineralization around locality 93 has produced chalcedony and carbonate veins that contain a little pyrite. The quartz vein at the Bullion mine (93), as indicated by material on the dumps, is characterized by medium to fine-grained quartz, both dark and milky varieties, some chalcedony, and abundant pyrite. The sphalerite is light reddish brown in color.

The vein system at the Crystal mine (100) is considered to be the center of mineralization along the Crystal-Bullion zone. Major strands of these veins are commonly 4 feet wide on the main adit level and lie in a mineralized zone as much as 25 feet wide. Some strands consist predominately of one mineral assemblage. A large strand of the quartz-pyrite-chalcopyrite assemblage contains large milky, intergrown crystals of quartz, many of which are 2 inches across and a few of which are larger.

The Crystal vein (100) appears to be zoned similarly to the Comet vein (131). Very fine-grained quartz, carbonates and possibly some chalcedony were found at the west extremity of the known veins. The eastern end of the Crystal vein lies east of Cataract Creek and was not investigated.

East of the Crystal mine, the quartz in the veins along the zone becomes progressively finer-grained. In the vicinity of locality 102, quartz on the dumps ranges from the fine-grained bluish gray variety

to milky crystals 3 or 4 mm. across. At the Eva May mine (103) nearly all of the quartz is extremely fine-grained and is associated with some carbonate. The sphalerite is light green in color. No chalcedony was found. If chalcedony veins exist at the east end of the Crystal-Bullion zone, they must lie under the glacial deposits in Hoodoo Creek.

The veins as far south of the Crystal-Bullion zone as Saturday Night Hill are almost all mixed veins and some of them contain very little milky quartz. South of the center of section 29, milky quartz is inconspicuous in the veins. North of this point it is more abundant although it forms only a small part of the veins. The sphalerite in the veins is light colored and the sericite band along most of them is narrow. North of the Crystal-Bullion zone the veins change from quartz-pyrite veins to chalcedony-carbonate veins in going across their strike. The quartz at the Last Shot mine (99) is milky and moderately coarse-grained, sphalerite is reddish brown and pyrite is abundant. To the northeast at the Ada mine (96), carbonate is conspicuous and most of the quartz is the fine-grained variety, but large crystals filling cavities in a breccia are common. Pyrite and other sulfide minerals are abundant. At the Morning and Midnight mines (97) all of the quartz and pyrite are very fine-grained and the vein contains a fair amount of black chalcedony. The Vindicator vein (94) is similar to that at the Morning and Midnight mine but it is much narrower. As far north as locality 89, pyrite is dominate over carbonate, but north of this place carbonate appears to be dominate over pyrite. Also north of this point all of the quartz is exceedingly fine-grained and

much of it probably is chalcedony. The veins north of the Buckeye mine (87) may not be related to the Crystal-Bullion zone.



### Rimini area

Veins near Rimini range from central to peripheral in zonal type. The zonal pattern, however, cannot be shown arranged around a center as well in the Rimini area as elsewhere because most of the veins are the intermediate type and large areas are covered by rhyolite or glacial deposits. In addition, many of the veins occur in small groups scattered over a large area. The veins within each group are zoned, but these groups of veins do not seem to be closely related to each other. The chief groups of veins are 1) the Crescent-Peerless (26,27) group near the head of Banner Creek, 2) the Frohner (22) group west of Frohner Meadows, 3) the Sally Belle (20) group on the southeast flank of Red Mountain, and 4) the Lee Mountain-Eureka (5, 13) group lying to the east and south of the village of Rimini.

The Lee Mountain (5) and Eureka (13) veins are the largest veins in the Rimini mining district and form a dual center for the large group of veins to the east and south of them. They are considered to be high rank intermediate veins. Outward from them a progressive change is seen in the other veins in the group until chalcedony veins are reached. This change to chalcedony veins can be seen only along the east and south sides of the Lee Mountain-Eureka group. Veins were not found north of the Lee Mountain zone, and the area west of Ten Mile Creek is largely covered by younger rocks. Carbonates are rare in the Rimini district.

The Lee Mountain zone contains the Lee Mountain center. The zone is wide, intensely sheared, altered and mineralized and has complex internal structure. It is probably about  $3\frac{1}{2}$  miles long and is the longest zone in the Rimini district. It is comparable to the Comet-Gray Eagle (129, 131) and Crystal-Bullion (100, 98) zones. It has been mapped from a point east of the Valley Forge mine (6) to the rhyolite on Lee Mountain. It probably extends southwestward under the rhyolite and glacial deposits into the southeast corner of sec.1, T.8N., R.6W. The most intense mineralization along the zone is in the valley of Ten Mile Creek at and near the Lee Mountain mine (5). The veins at the Lee Mountain mine contain all of the mineral assemblages, and were sites of deposition all through the mineralizing period.

The quartz crystals at the Lee Mountain mine are typically anhedral, compact, milky, and a few millimeters across. The finer-grained bluish gray variety is abundant. At the Valley Forge mine, near the east end of the Lee Mountain zone, the finer-grained varieties of quartz predominate. In the veins (localities 7 and 8) east of the Valley Forge mine all of the quartz is very fine-grained. Further east near Chessman Reservoir, chalcedony veins occur. From the Lee Mountain vein eastward, the sericite bands along the veins become progressively narrower. At Locality 9, north of Chessman Reservoir, the sericite bands along a fine-grained quartz vein are only one half of an inch wide.

Quartz in the veins between the Lee Mountain mine and the Eureka mine (localities 10, 11, and 12) is fine-grained. The quartz at locality 10 is mostly the fine-grained gray variety and chalcedony is

conspicuous. In the Mammoth (12) and Free Speech (11) veins to the north, quartz becomes a little coarser-grained as the Eureka (13) center is approached. At the Eureka mine (13), quartz belonging to both the arsenopyrite-quartz and quartz-pyrite-chalcopyrite assemblage is very abundant. That associated with arsenopyrite tends to be in long subhedral grayish crystals lining the walls of open fissures whereas that belonging to the quartz-pyrite-chalcopyrite assemblage is mostly milky and compact. The milky quartz is coarse-grained and occurs as compact masses, as a filling in open fissures and as a replacement of sericitic rock. All of the rock on the large dump from the shaft is sericitic, and presumably the sericite bands are at least several feet wide.

The veins south of the Eureka vein are mostly fine-grained quartz veins. Southward as far as the Daniel Stanton (14) and Bunker Hill (15) mines, most of the veins contain fine-grained milky quartz along with finer-grained gray quartz and little or no chalcedony. Southward from these mines milky quartz in the veins is scarce and chalcedony is a common but minor constituent in many of the veins. The veins that cross Ruby Creek (19) represent the southern most extent of the Lee Mountain-Eureka group. The quartz in these veins is typically the very fine-grained, almost flint-like, variety.

### Sally Belle group

The Sally Belle group of veins consists of several small veins on the southeast flank of Red Mountain near the Sally Belle mine (20). The quartz in the veins is fine-grained milky to bluish gray. Outlying veins to the north, west, and east are almost all chalcedony veins.

### Frohner group

The Frohner group of veins is at and near the Frohner mine (22) about 2 miles south southeast from the top of Red Mountain. It consists of one large vein and several subsidiary veins. The Frohner vein system is poorly exposed but it has been traced intermittently through mines, prospect pits, and strips of altered rock, for a distance of about three miles. The main center of mineralization is at and near the Frohner mine (22) and is considered to be about middle rank intermediate in zonal type. In this part of the zone the quartz ranges from moderately fine-grained and milky to fine-grained and bluish gray; chalcedony and carbonates were not found. Chalcedony is predominate at the ends of the zone, and carbonates are abundant in one of the veins to the side of the zone.

Near the west end of the Frohner zone in the upper adit on the Loebber claim (21) the quartz veins become thinner to the westward and an accompanying chalcedony vein correspondingly increases in thickness to the west (partly shown in figure 23). At the Nellie Grant mine (23), east of the main center of mineralization, chalcedony is predominate at the east end of the quartz core. The veins at the east end (locality 23A) of the Frohner structure contain a chalcedony body and a small core of fine-grained milky to dark quartz. Most of the material on the dump is from the core which contains sphalerite and galena.

No veins are known along the north border of the Frohner zone, but to the south chalcedony and carbonate veins occur. The veins along the steep slope south of the western end of the Frohner zone are chalcedony veins. The vein (24) directly south of the Frohner mine consists mainly of milky quartz and carbonate cementing brecciated quartz, arsenopyrite, galena, and sphalerite. Some of the quartz, all of the carbonate and some fine-grained pyrite are intimately intergrown and appear to be contemporaneous. This vein is thought to represent that point on the alteration diagram (fig. 8) at which carbonates and pyrite were both deposited at the same time. One of the chalcedony veins is probably the western extension of this vein.

### Peerless group

The Peerless group of veins is about 2 miles south of Red Mountain in the headwaters of Banner Creek. The veins of the group are scattered, and are not arranged around a center that has been identified. All of the veins are considered to be of rather low rank intermediate or peripheral zonal type. The largest vein extends through the Peerless mine (26), and vein material on the dump from this mine indicates that the vein consists largely of very fine-grained dark quartz in sericitic and pyritic rock. The vein (25) to the north of the Peerless vein is largely fine-grained quartz and locally contains some chalcedony. The veins to the north of locality 25 are fine-grained quartz veins enclosed in narrow sericite bands. Veins in the Crescent-Ida May zone (27 and 28) are narrow fine-grained quartz veins set in narrow sericitic envelopes. They contain a little coarse-grained milky quartz in spots.

### Elliston district

The veins in the northwest part of the mineralized area are not well known. This area, west of the Continental divide, is known as the Elliston mining district. It is heavily timbered and partly covered by rocks younger than the veins. Forbes Robertson, who mapped the area, did not show the veins on his map (University of Washington, Ph.D. thesis, 1956) and the localities of mineralization shown on the geologic map (fig. 2) of this report mark the sites of mines only. Almost nothing is known about the veins. Some of the veins on Negro Mountain were mapped by the writer in 1953 and re-examined in 1959.

A brief examination of the dumps of the mines known to the writer indicates that most of the veins in the Elliston area could be fitted into the descriptive and genetic classifications used in this paper. The veins are quartz veins or mixed veins, and they appear, from the dumps, to be about middle to low rank intermediate types. No evidence was found of a dominate center of mineralization in the district, but rather each of the larger deposits may be a center for a small group of veins around it. These might be similar to the Frohner or Sally Belle groups of veins. Some of the veins on Negro Mountain illustrate what may be the pattern for veins in the district.

Several east trending veins occur on Negro Mountain. The two largest ones are shown on the geologic map (fig. 2). Of these, the Black Jack-Big Dick (1 and 2) vein is the largest and has been the most



productive. The Black Jack-Big Dick vein appears to be zoned along its length and the group of veins near the top of Negro Mountain also appear to be zoned across the strike of the veins. Near its western end, the Black Jack-Big Dick vein contains two ore shoots that contain all of the mineral assemblages within the Black Jack (1) and Big Dick (2) mines. The ore shoots contain no carbonate, but the vein between the two ore shoots is much narrower than in the shoots and consists dominantly of carbonate. The eastern extension of the vein (locality 3), recently exposed in trenches, is largely tourmaline and chalcedony, whereas the quartz in the ore shoots is moderately fine-grained and milky to bluish-gray.

### Clancy district

The Clancy mining district extends for several miles around the village of Clancy. Almost all of the veins within this area are chalcedony veins. The only exceptions are mixed veins; no quartz veins are known. Nearly all of the mixed veins are in the valleys of Lump Gulch or Prickly Pear and Clancy Creeks.

The quartz in the mixed veins occurs in small cores in veins that otherwise would be called chalcedony veins. The quartz crystals are typically milky to cloudy-white and less than 3 mm. across. Quartz, as distinct crystals up to 1 cm. across are known, but they are rare. Very fine-grained quartz is common in the form of gray, bluish gray and flint-like varieties, and it is usually associated with pyrite. The chalcedony in the cores is later than most of the quartz, and it is usually associated with carbonates. The cores also contain light colored sphalerite, galena, and silver minerals. Some of the cores are the sites of small high-grade silver deposits. All of the mines are now inactive.

Zoning in the Clancy district is not as well developed as in some of the other districts. No veins of the central zonal type have been found. All of the veins are either low rank intermediate or peripheral in zonal type and these can be easily distinguished from each other. Large areas contain veins of only the peripheral type,

but no area contains veins of only the intermediate type. However, the veins of intermediate type are not scattered throughout the area. Instead, they tend to be clustered together in a belt along Lump Gulch, in Clancy Creek, and near Alhambra.

The belt of intermediate veins in Lump Gulch extends from near the mouth of Buffalo Creek eastward almost to Prickly Pear Creek. This belt contains the largest of the mixed veins in the area and a few small ones. The largest quartz cores are at the Liverpool mine (35), Little Nell mine (33), Free Coinage mine (32), and Muskegen mine (30). The veins in all of these mines change to chalcedony veins along strike. The quartz cores of most of them contain quite a bit of chalcedony and carbonate and a moderate amount of galena and light colored sphalerite. Sericite bands along the cores are narrow.

Mixed veins in the valley of Clancy Creek are the Mineral Hill (42), King Solomon (34), and the vein at locality 36. Those along Prickly Pear Creek are the Alhambra (41), New Stake (37), Mammoth (40), and Legal Tender (39). The quartz cores in all of them are small.

### Outlying areas of mineralization

Three small mineralized districts lie outside of, but near, the main mineralized area. Two of them are east of Clancy; one of these is near the head of Warm Springs Creek and the other is north of it in the drainage of Maupin Creek. The third district is near the Boulder River, around Berkin Flat, west of the mineralized area. In addition, a few isolated veins lie outside of the main body of the mineralized area. Those in the map area are: the Golconda vein (84), northeast of the Boulder valley; the vein at locality 85, east of the Golconda vein; and the Monarch vein (29), west of the mineralized area.

Most of the veins in the outlying districts and the Golconda and Monarch veins are very similar to the low rank intermediate veins that occur in the outer part of the intermediate zones within the mineralized area. The altered rocks also appear to be similar. The outlying districts contain groups of veins much like the groups in the Rimini-Basin belt of veins. The Maupin Creek district is strongly zoned and the Warm Springs district probably is zoned. The Monarch vein is also strongly zoned. Evidence of zoning was not found in the Berkin Flat group of veins.

## Maupin Creek district

The zoning in the Maupin Creek district is defined on the basis of both quartz and very fine-grained quartz, and on the relation of pyrite to carbonate. The boundary between the areas of dominate pyrite and dominate carbonate deposition is shown on the map. The boundary between the pyrite and carbonate zones is sharp. Within the pyrite zone, no carbonate occurs in the veins although it was found as dissiminated grains in the wall rock. In the carbonate zone some pyrite occurs, but it forms a very small part of the vein and carbonate is a dominate mineral.

Quartz in the veins ranges from coarse-grained and milky to very fine-grained, flinty and gray. Some chalcedony was found. Coarse-grained, milky quartz occurs only in a small area within the pyrite area near its east end, localities 45 and 47, and at locality 46. Away from these places the quartz tends to become finer-grained and less milky.

As far as is known, all of the veins are enclosed in sericitic rock for their entire length.

### Warm Springs district

Some of the veins near the head of Warm Springs Creek were examined briefly. They are quartz veins that contain varying amounts of pyrite and carbonate. These veins appear to be zoned around the White Pine mine (48).

### Berkin Flat area

Many small veins occur on and around Berkin Flat. They are known almost entirely from prospect pits or the dumps of adits. Vein material from the dumps and pits is characterized by rather abundant carbonate and varying amounts of fine-grained quartz.

### Monarch vein

The Monarch vein (29) occupies an east trending fault zone near its intersection with a north trending fault or sheeted zone. At the intersection of the two structures, the vein consists of compact fine-grained quartz and sulfide minerals enclosed in sericitic walls. Away from the intersection the quartz vein gradually changes to a chalcedony vein, and the sericite bands pinch out against the vein.



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