ALTERED WALL ROCKS ALONG VEIN DEPOSITS IN THE CENTRAL CITY-IDAHO SPRINGS REGION, COLORADO[1]

By

E. W. TOOKER

U.S. Geological Survey, Denver, Colorado

ABSTRACT

Wall-rock alteration along veins in the Central City-Idaho Springs region, Gilpin and Clear Creek Counties, Colorado, superficially resembles alteration around similar base-metal sulfide deposits, but differs in some details. Mesothermal-type veins of early Tertiary age cut deformed Precambrian metasedimentary, igneous, and metamorphosed igneous rocks; the veins contain pyrite, galena, sphalerite, chalcopyrite, and tennantite as principal constituents and minor gold, silver, and uranium minerals. A spatial zonation of ore minerals relates to distinct stages of ore deposition.

Detailed studies show that three of the wall rocks in the area—granodiorite, biotite-muscovite granite, and biotite-quartz-plagioclase gneiss—are altered to varying degrees and in varying amounts. Clay-mineral formation was a major feature of the process. The alteration sheath around fractures and veins is divided into four gradational but regular zones: (1) Least altered (fresh) rock; (2) weakly altered, hard rock; (3) moderately altered, soft clay-mineral rock—(a) montmorillonite-rich, (b) kaolinite-rich, and (c) illite-sericite-rich; and (4) strongly altered, hard (silicified) rock. The sequence of silicate alteration is believed to relate first to the relative stability of primary mineral structures in the alteration environment, but ultimately to the chemistry of the environment.

The host rocks are significant factors in localization of altered mineral assemblages as they supply the requisite elements for argillic-type alteration. Structures of the host rocks and veins play a prominent role in localization of altered rocks and the zoned ore deposits. Coincidence of alteration and mineralization processes may have more spatial than temporal significance.

A working hypothesis explaining the geological evidence proposes that most alteration was accomplished by meteoric and/or hypogene solutions before ore minerals were deposited. Later solutions of the pyrite stage may have intensified the early zone 4 alteration assemblage close to the source channels, but base-metal sulfide stage solutions were not competent to impress additional alteration effects. Most supergene alteration occurs close to the surface. Therefore, in these areas alteration zonation does not afford a reliable guide to ore.

INTRODUCTION

Folded, faulted, and metamorphosed quartzose-feldspathic gneisses and granites of Precambrian age are among the host rocks in the Central City-Idaho Springs mining districts, Gilpin and Clear Creek Counties, Colorado (Fig. 1), which are altered along mesothermal veins containing precious and base-metal ore minerals. This study was undertaken to determine the mineralogy of the altered wall rocks, the effects of the lithology and structure of the original rocks upon the alteration, and the relation of alteration to different types of ores.

This paper presents some preliminary results of the study; it has been done in conjunction with detailed investigations of the ores and country rocks of the region that have been carried on largely by other scientists of the U. S. Geologi-

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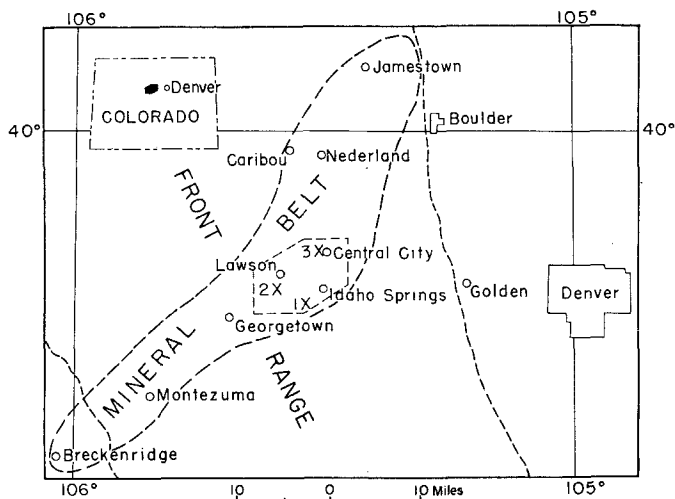[1] Publication authorized by the Director, U.S. Geological Survey.

FIGURE 1. — Index map of Central City-Idaho Springs area, Colorado.

cal Survey. All studies were on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Previous descriptions of the altered wall rocks in the Central City-Idaho Springs regions are incomplete. Spurr, Garrey, and Ball (1908, p. 143, 150-152, 158, 165, 168), and Bastin and Hill (1917, p. 97-98, 101-104, 107-109, 111, 112) noted some features of the altered rocks but did no detailed work. Lovering and Goddard (1950, p. 76-77, 142-144, 171-173) summarized these early observations and added some new data. Elsewhere within the Front Range, however, detailed studies were made on the tungsten deposits in adjacent Boulder County by Lovering (1941) and by Lovering and Tweto (1953, p. 57-63), and on the silver-bearing base-metal uranium ores at Caribou by Wright (1954). Tooker (1955) indicated some of the difficulties encountered in alteration studies in these districts, and outlined the methods used in the present study.

GEOLOGIC SETTING

Lithology and Structure

The three rock types studied—granodiorite, biotite-muscovite granite, and biotite-quartz-plagioclase gneiss[1] —show evidence of many common lithologic and structural features. The unaltered rocks vary from light to dark gray, are medium-grained and equigranular, and are composed of quartz, plagioclase feld-

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[1] Sample localities, numbered 1-3, respectively, on Figure 1, include: 1. Granodiorite, Dixie vein, M & M Tunnel level, Dixie Mine, Chicago Creek area, Clear County, Colorado; 2. Biotite-muscovite granite, Jo Reynolds No. 1 vein, Elida Tunnel level, Jo Reynolds Mine, Lawson mining district, Clear Creek County, Colorado; 3 Biotite-quartz-plagioclase gneiss, Essex vein, 150-foot level, Essex Mine, Central City mining district, Gilpin County, Colorado.

spar, microcline feldspar, and biotite and muscovite mica (Table 1). Locally the large feldspar phenocrysts are in a subparallel planar arrangement but more commonly biotite flake alinement causes the rock foliation; some phases of these rocks are massive and nonfoliated. These metamorphosed Precambrian igneous and sedimentary rocks were folded and faulted into complex northeast-trending structures. Intrusive into these rocks are porphyritic-monzonitic dikes and stocks of early Tertiary age.

Vein Deposits

Zoned, mesothermal-type veins fill open spaces in east-, northeast-, and north-west-trending Laramide faults. Two distinct stages of mineral emplacement, an early pyrite and later base-metal sulfide stage, are separated by structural re-adjustment along the vein. These minerals occur in successive oval zones elongated parallel to the major northeast fold and fault structures (Sims, P. K., oral communication). The central zone contains pyrite. A composite, or mixed zone,

TABLE 1.—MODAL ANALYSES OF THIN SECTIONS OF LEAST-ALTERED HOST ROCK NEAR VEINS, CENTRAL CITY-IDAHO SPRINGS MINING DISTRICTS, GILPIN AND CLEAR CREEK COUNTIES, COLORADO.[1]

Minerals	Volume percent		
	Granodiorite	Biotite-muscovite granite	Biotite-quartz-plagioclase gneiss
Essential:			
Quartz	34.2	29.5	32.0
Plagioclase	33.4	29.7	43.1
Potash feldspar	2.1	30.0	10.1
Biotite	21.6	5.9	9.2
Muscovite	—	1.7	—
Accessory:			
Sphene	.7	.9	.5
Apatite	.7	.4	.5
Zircon	—	tr.	—
Opaque:			
Hematite	—	.1	1.7
Leucoxene	—	.5	.7
Magnetite	2.3	.1	—
Pyrite	.4	tr.	—
Secondary:			
Clay minerals	4.5	(5.0)[2]	2.0
Chlorite	—	1.5	—
Calcite	tr.	—	tr.
Totals	99.9	100.3	99.8

[1] Analyses derived from counts of 1,000 points in thin section. Rock names are derived from district-wide rock composition and locally may vary from strict classification.
[2] Clay mineral mostly from altered plagioclase, whole crystal not always altered, thus value not included in total as clay, but as plagioclase.

lies between the central zone and galena-sphalerite zone; beyond this outer zone the veins are sparse and barren. The pyrite-gold ore zone veins are typically sheared and recemented by cryptocrystalline quartz and the wall rock and breccia fragments are pervasively pyritized. In the galena-sphalerite ore zone the rock is commonly sheared and recemented by carbonate and quartz; no pyritization of the walls occurs, but breccia fragments in the vein commonly are pyritized.

The typical veins vary from a simple fracture one inch to one foot wide to a complex lode zone ranging up to tens of feet wide and containing several related veins and the separating altered rock.

WALL-ROCK ALTERATION

Alteration of wall rocks produces gradual and generally simple and regular changes in rock lithology, mineralogy, and chemistry. The zonal sequence from fresh through bleached, softened rock to silicified rock adjacent to the vein is common, but the widths of the altered rock sheath and of individual zones in the sheath bear no fixed ratio to each other or to the width of the vein.

Zones

Because the three kinds of host rock are similar, the pattern of wall-rock alteration is essentially the same for each. The gradual changes in texture and mineralogy, observed in thin section and by x-rays, and megascopic observation of veinward lithologic modification are the basis of an arbitrary division of altered rock into four zones for purposes of discussion. These changes in the least- to most-altered wall rock are thought to reflect the variations in intensity of the alteration process caused by differences in temperature, chemical potential, time, or some other factors.

Zone 1.—Unaltered or least-altered rock is described previously.

Zone 2.—Weakly altered wall rock is hard, with the original structures and textures preserved. Plagioclase feldspar crystals may have a dull luster or may be completely converted to pseudomorphs of the clay mineral montmorillonite. Biotite and quartz are unaltered.

Zone 3.—Moderately altered wall rock is a soft, clay-mineral rock with primary textures preserved or indistinct. It can be subdivided on the basis of the presence of the predominant clay mineral:

(*a.*) Montmorillonite-rich rock is found most frequently along weakly mineralized or altered shears, joints, or foliation surfaces, and as the most intense alteration phase in the near-surface supergene environment.

(*b.*) Kaolinite-rich rock is characteristic of the white clay rock, but it is always mixed with illite-sericite and with montmorillonite.

(*c.*) Illite-rich rock may include sericite in the more intensely altered parts of the zone.

Subzone *a* represents less intense alteration environment than subzones *b* and *c* which are of near or equal intensity; the illite zone is generally closer to the vein. Biotite may or may not be altered in zone 3; the color of the altered flakes ranges from black to brown-green (chlorite-biotite) to gray-white (illite-sericite). Potash feldspar is altered to kaolinite and perhaps other clay minerals. Quartz is in part corroded and recrystallized.

Zone 4. — Strongly (intensely) altered wall rock is hard and the original structures and textures are obliterated whereas new shear and recrystallized features are abundant immediately adjacent to the vein. The rock is silicified, sericitized, or pyritized separately or in combination depending on the vein environment.

Mineralogy

The mineralogical changes during wall-rock alteration, implied from the zonal intensity sequence in the rocks, involve the destruction of primary silicate minerals and the formation of a clay mineral–recrystallized quartz assemblage. Both primary and secondary minerals evidence an order of stability in the alteration environment as shown in Figures 2, 3, and 4. The host-rock minerals react to the changes in a regular sequence: plagioclase is stable into zone 2,
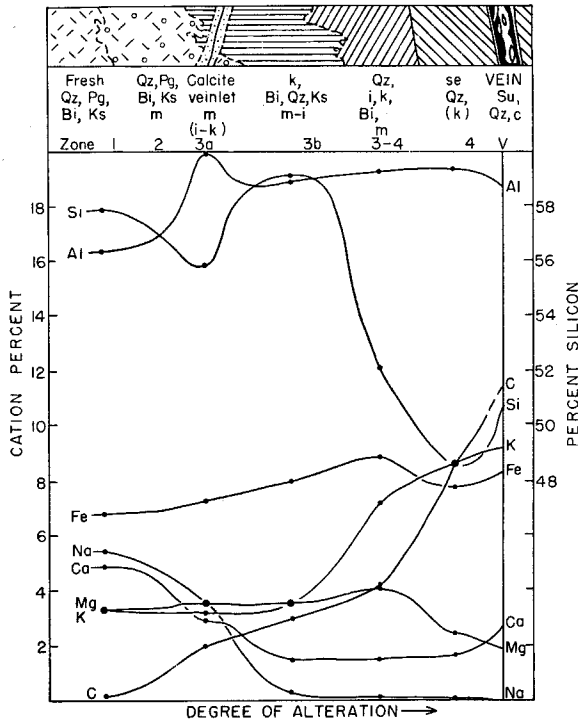

FIGURE 2.—Sketch of zones in altered granodiorite and a summary of the mineralogy and chemistry of a 1-foot altered rock sequence in the footwall of a 1-inch vein. The major chemical constituents are shown as cation percent in the variation diagram, and the modal minerals are listed in their relative order of amount. Qz=quartz, Pg=plagioclase, Bi=biotite, Ks=potash feldspar, Su=sulfide minerals (pyrite, sphalerite, and galena), m=montmorillonite, k=kaolinite, se=sericite, i=illite, c=carbonate, parentheses enclose minor constituents.

microcline into zones 3 and 4, biotite into the outer edges of zone 3, and quartz into zone 4. The stability ranges of the clay minerals overlap and therefore are indistinct compared with the sequence above. The clay mineral that predominates is regarded as the most characteristic phase in the zone: montmorillonite is stable in zones 2 and 3*a*; montmorillonite-illite mixed-layer clay mineral most common in zone 3, illite in zones 3*c* and 4; and sericite in zone 4. Kaolinite is stable in zones 3*b* and 3-4.

Plagioclase is the least stable mineral in these rocks in the alteration environment, and possibly the initial transformation in the sequence of mineralogical adjustment during alteration is represented by the appearance in zone 2 of 15 A montmorillonite along cleavage and twin planes and crystal edges of plagioclase. There is no obviously marked orientation of the clay minerals with respect to plagioclase prismatic surfaces, but there is orientation along the cleavage and twin planes. At first only small irregular patches of clay mineral form, but in the more intense position nearer the vein montmorillonite and montmorillonite-illite mixed-layer clay minerals pseudomorphically replace the entire plagioclase
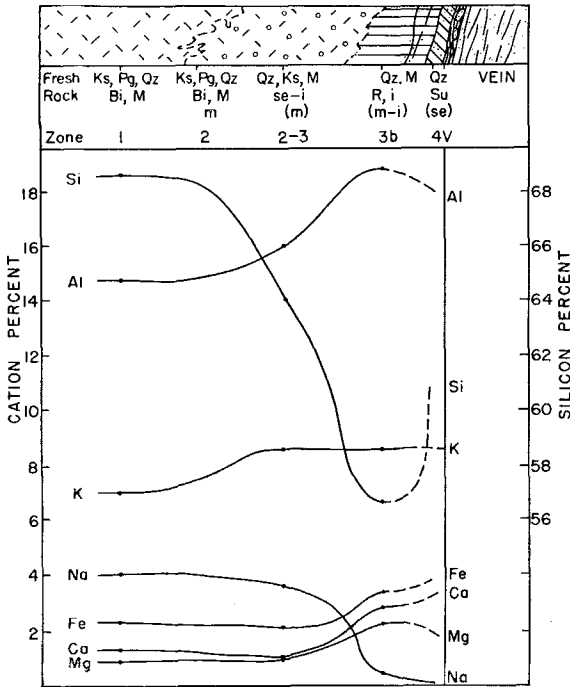

FIGURE 3.—Sketch of zones of altered biotite-muscovite granite and a summary of the mineralogy and chemistry of a 2-foot altered rock sequence in the hanging wall of a 12-foot vein lode zone. The major chemical constituents are shown as cation percent in the variation diagram, and modal minerals are listed in their relative order of amount. Qz=quartz, Pg=plagioclase, Bi=biotite, M=muscovite, Ks=potash feldspar (microcline), Su=sulfide minerals (pyrite, sphalerite, and galena), m=montmorillonite, k=kaolinite, se=sericite, i=illite, parentheses enclose minor constituents.
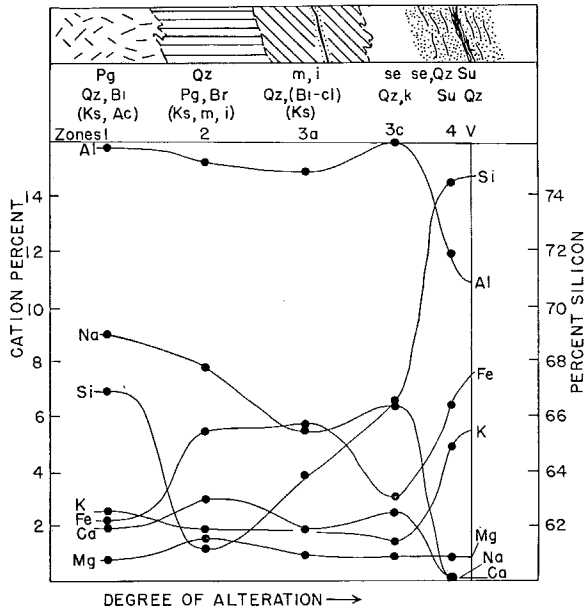
FIGURE 4.—Sketch of zones in altered biotite-quartz-plagioclase gneiss and the mineralogy and chemistry of a 6-foot altered rock sequence in the footwall of a 2-foot lode zone. The major chemical constituents are shown as cation percent in the variation diagram, and the modal minerals are listed in their relative order of amount. Qz=quartz, Pg=plagioclase, Bi= biotite, Ks=potash feldspar, Ac=accessory minerals, Su=sulfide minerals (pyrite, sphalerite, galena), m=montmorillonite, k=kaolinite, cl=chlorite, i=illite, parentheses enclose minor constituents.

crystal. This replacement is gradual across zone 2 and essentially complete in zone 3.

Microcline feldspar is more stable under zone 2 alteration conditions as evidenced by its persistence unaltered into zone 3, but rarely closer to the vein. The specific clay-mineral alteration product of potash feldspar is not clearly indicated; generally kaolinite is found in abundance coincident with the observation of the destruction of orthoclase and microcline structures. Montmorillonite-illite mixed-layer clays and illite begin to occur in abundance in zone 3, but also may represent instability of the montmorillonite derived from plagioclase.

Biotite alteration is variable; in most rocks biotite persists in part unaltered into the soft clay zone 3, and, aside from quartz, it seems to be the last essential mineral to convert. Thin sections show that there may be a slow but progressive microscopic alteration of biotite in zone 2; the mineral is bleached mostly along (00l) crystal boundaries. Further alteration of biotite and secondary chlorite produces fine-grained clay and sericite-like aggregates,[1] possibly via an illite intermediate stage. Some kaolinite may well originate from the altered biotite.

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[1] Sericite in this paper refers to a clay-size particle with well-resolved muscovite x-ray pattern.

Release of excess iron from biotite coincides with the appearance of hematite as an accessory mineral in granodiorite and granite.

The modal quartz content varies slightly within the altered zones; in general, there is a loss of quartz in the soft clay-mineral zone (3). Granodiorite walls along galena-sphalerite veins are probably less intensely altered than the granite or gneiss walls, as indicated by the prevalence of carbonate gangue and paucity of cryptocrystalline quartz and pyrite. Granodiorite zone 4 shows a loss of modal quartz. The modes of biotite-quartz-plagioclase gneiss indicate no appreciable gain or loss of quartz in zone 4, and in altered granite there is only a slight increase of quartz in zone 4. The increase of Si in altered biotite-quartz-plagioclase gneiss adjacent to the vein, due to the introduction of cryptocrystalline quartz along shears and foliation surfaces, may be related to the pyrite ore stage. Silicification is more of a recrystallizing process than an additive one. Indeed, chemical loss of silica (mostly from feldspar adjacent to the vein) indicates a possible source for vein quartz independent of a hypogene origin.

Chemistry

The gain or loss of chemical constituents, aside from water, in these zones of altered wall rocks is slight. The trends of the chemical changes are detailed in Figures 2, 3, and 4 as cation-anion variations.[1] These illustrations are derived from data presented in Tables 2, 3, and 4.

There is a general resemblance of chemical distribution trends in the three rock types studied which permit the following generalities: 1. *Silica* decreases toward the vein zone, especially in the soft clay mineral zones, but increases again toward the vein coincident with silicification and sericite formation. Except in the more strongly altered gneiss the increase of silica adjacent to the vein does not make up for a net loss of silica. 2. *Aluminum* gradually increases toward the vein, reaching a maximum in the kaolinite-rich zone, but the concentration drops off toward the vein. There is a net decrease of Al in the intensely altered zones associated with pyrite and possibly composite ore zones, and a net increase in Al in the outer lead-zinc and composite ore zones. 3. *Potassium* gradually increases toward the vein and is most concentrated in the sericite zone adjacent to and in part in the vein zone. 4. *Sodium* and *calcium* are released from feldspars; sodium decreases regularly toward the vein whereas calcium dissipates more gradually, in part being retained in clay-mineral and carbonate structures. 5. *Magnesium* increases slightly in the clay zone and is present until biotite and biotite-chlorite-illite mixtures are destroyed; magnesium content decreases in the rock immediately adjacent to the vein zone. 6. Total *iron* increases toward the vein. The ferrous iron component increases most markedly toward the vein culminating in pyrite in the vein; the ferric iron decreases more slowly toward the vein. 7. The *hydroxyl* anion contribution far exceeds the total cation content. It reaches a maximum in the clay-mineral zones, but is diminished in zones 4 and 5. 8. The remaining minor cation and anion constituents seem not to influence the over-all pattern of alteration chemistry.

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[1] Chemical analyses of rocks from each zone have been converted to cation percent values, after Barth (1955). The chemical analyses will be presented in a later U.S. Geological Survey publication. The cation percent values permit closer comparison with other data, and, because we are probably dealing with mobile ions in an oxygen structural network rather than with oxides, this method of illustration seems warranted.

TABLE 2. — APPROXIMATE ION DISTRIBUTION IN PROGRESSIVELY MORE ALTERED
GRANODIORITE, DIXIE MINE, CHICAGO CREEK AREA, CLEAR CREEK
COUNTY, COLORADO[1]

Cations	Least altered Zone 1	Altered granodiorite Zone 3a	Zone 3b	Zone 3-4	Zone 4	Net gain or loss of ions
			percent			
Si	57.8	55.9	59.1	52.1	48.6	— 9.2
Ti	1.1	1.0	1.3	1.3	1.3	+ .2
Al	16.4	20.0	18.9	19.3	19.3	+ 2.9
Fe^{3+}	2.6	3.1	3.5	2.5	1.2	— 1.4
Fe^{2+}	4.2	4.2	4.6	6.3	6.6	+ 2.4
$(Fe)^2$	(6.8)	(7.3)	(8.1)	(8.8)	(7.8)	(+ 1.0)
Mn	.2	.1	.1	.2	.6	+ .4
Mg	3.3	3.6	3.4	4.1	2.5	— .8
Ca	5.0	3.0	1.6	1.6	1.7	— 3.3
Ba	.08	.02	.04	.05	.05	— .03
Na	5.4	3.1	.3	.2	.2	— 5.2
K	3.3	3.3	3.5	7.3	8.6	+ 5.3
P	.5	.4	.6	.8	.8	+ .3
C	.3	2.2	3.0	4.3	8.6	+ 8.3
TOTALS	100.0	100.0	100.0	100.0	100.0	— .1

Associated anions						
F	.6	.9	1.0	1.1	1.2	+ .6
S	.1	.3	.2	.2	.4	+ .3
OH	4.6	32.7	38.8	26.1	16.5	+11.9
O	162.6	151.8	155.2	153.0	157.1	— 5.5
TOTALS	167.9	185.7	195.2	180.4	175.2	+ 7.3

[1] Calculated values shown are after Barth (1955) ; original chemical analyses were by J. L. Theobald, analyst, U.S. Geological Survey, Denver laboratory.
[2] Values not included in totals.

The general chemical nature of alteration is a rearrangement of ions in space and amount coincident with silicate crystal structure reorganization. The introduction or loss of ions locally is related to the larger vein system in which there was little addition from outside except for water. Locally the wall rock is enriched veinward in K, Fe, C, Al, and OH, and the wall rock adjacent to the vein is relatively depleted in Si, Na, Ca, and Mg; the total decrease in numbers of cations almost equals the gain in OH. Bulk-density and pore-space estimation of analyzed rocks indicate generally that as alteration becomes more intense porosity increases and density decreases; the density is generally lowest in the soft clay zone (3). One may conclude that as alteration proceeds, chemical elements are rearranged in a more space-saving manner providing a crystal structure which carries loosely bound water.

Distribution

Altered wall rocks occur around most veins in the Central City-Idaho Springs region (Fig. 1) ; however, the distribution of alteration has more fundamental

spatial and temporal parameters. The alteration-space factors relate to geography, the host rocks, rock and vein structures, and ore zonation. The factor of time of alteration is more tenuous but includes interrelations of the ore stages and alteration, and the influence of post-sulfide solutions.

The alteration mineralogy is consistent throughout the geographic unit outlined in Figure 1. Lovering and Goddard (1950, p. 77) note that there is a progressive change in type of alteration along the mineral belt from southwest to northeast and that in the northeast part, "hypogene clay minerals became more and more prominent members of the alteration suite."

The host rocks influenced the distribution of alteration in two ways—through mineralogy and through structures. The majority of rocks in the region are quartzose-feldspathic gneisses, granites, and schists. Since the rocks are chemically similar no one rock is more competent to localize ore or alteration minerals. The types of primary minerals (chemical and structural types) presage the argillic alteration assemblage which is so consistent throughout the region. Bastin and Hill (1917, p. 95) note that veins narrow and ore is restricted as

TABLE 3. — APPROXIMATE ION DISTRIBUTION IN PROGRESSIVELY MORE ALTERED BIOTITE-MUSCOVITE GRANITE, JO REYNOLDS MINE, LAWSON MINING DISTRICT, CLEAR CREEK COUNTY, COLORADO[1]

Cations	Least altered Zone 1	Altered granite Zone 2-3	Altered granite Zone 3b	Net gain or loss of ions
		percent		
Si	68.6	64.0	56.7	—11.9
Ti	.3	.3	.4	+ .1
Al	14.8	16.0	18.9	+ 4.1
Fe^{3+}	.9	.5	.7	— .2
Fe^{2+}	1.4	1.5	2.6	+ 1.2
(Fe)[2]	(2.3)	(2.0)	(3.3)	(+ 1.0)
Mn	.02	.03	.1	+ .1
Mg	.8	.9	2.3	+ 1.5
Ca	1.3	1.0	2.9	+ 1.6
Ba	.02	.02	.06	+ .04
Na	4.1	3.5	.4	— 3.7
K	7.1	8.5	8.5	+ 1.4
P	.2	.08	.3	+ .1
C	.4	3.6	6.3	+ 5.9
TOTALS	100.0	100.0	100.0	+ .2
Associated anions				
S	tr.	—	.2	+ .2
F	.2	.2	.4	+ .2
OH	3.9	5.6	17.8	+13.9
O	169.9	167.4	159.7	—10.2
TOTALS	174.0	173.2	178.1	+ 4.1

[1] Calculated values shown are after Barth (1955) ; original chemical analyses were by J. L. Theobald, analyst, U.S. Geological Survey, Denver laboratory.
[2] Values not included in totals.

TABLE 4. — APPROXIMATE ION DISTRIBUTION IN PROGRESSIVELY MORE ALTERED
BIOTITE-QUARTZ-PLAGIOCLASE GNEISS, ESSEX MINE, EUREKA GULCH AREA,
CENTRAL CITY MINING DISTRICT, GILPIN COUNTY, COLORADO[1]

Cations	Unaltered Zone 1	Altered gneiss Zone 2	Zone 3a	Zone 3c	Zone 4	Net gain or loss of ions
		percent				
Si	66.9	61.4	63.9	66.5	74.5	+ 7.6
Ti	.2	.4	.5	.4	.1	— .1
Al	15.8	15.3	14.9	16.1	11.9	— 3.9
Fe^{3+}	.8	2.5	2.5	1.7	.3	— .5
Fe^{2+}	1.4	2.8	3.3	1.4	6.0	+ 4.6
$(Fe)^{2}$	(2.2)	(5.4)	(5.8)	(3.1)	(6.3)	(+ 4.1)
Mn	.04	.1	.2	.1	.09	+ .05
Mg	.8	1.6	1.1	.9	.8	0.0
Ca	2.0	3.1	2.0	2.6	.03	— 2.0
Na	8.9	7.6	6.0	6.7	.2	— 8.7
K	2.4	1.9	1.9	1.4	4.9	+ 2.5
P	.03	.01	.1	.09	.02	— .01
C	.3	3.0	3.7	2.0	1.1	+ .4
TOTALS	100.0	100.0	100.0	100.0	100.0	— .1

Associated anions						
S	—	—	—	—	4.8	+ 4.8
OH	2.2	6.4	16.2	18.9	9.9	+ 7.7
O	169.3	165.8	164.9	164.2	164.5	— 4.8
TOTALS	171.5	172.2	181.1	183.1	179.2	+ 7.7

[1] Calculated values shown are after Barth (1955); original chemical analyses were by
L. N. Tarrant, analyst, U.S. Geological Survey, Denver laboratory.
[2] Values not included in totals.

veins pass from granite into schist, but this is probably more related to struc-
tural competence of the rock than its composition.

Structural control of ore concentrations in these vein deposits has long been
appreciated (Bastin and Hill, 1917; Harrison, 1955); the veins and ore min-
erals zones are related to fold and fault structures. It might, therefore, be as-
sumed that the distribution of alteration is similarly controlled, and further that
there should be a correlation between optimum sites of ore deposition and wall-
rock alteration if they are related processes. We have observed that such is not
always the case. Major vein structures are persistent and the early structural
pattern governed the location of later movement. Very few crosscutting rela-
tions are found.

Altered wall rocks were thought to be of possible use as spatial guides to ore,
and alteration studies have indeed proved helpful in investigations at Butte,
Montana (Sales and Meyers, 1948, p. 6), and reportedly elsewhere; however,
in the Central City-Idaho Springs area there are no consistent relations between
the size of the ore body and the size of alteration features. Ore zonation along
veins produces little variation in the size or quality of wall-rock alteration al-
though zonation at depth was not observed. Ore stages are separated by move-

ment along the veins, and the space anomalies between ore and alteration sug-
gest that there may have been similar movement separating an early widespread
alteration and subsequent ore stages. Where the pyrite stage is best developed
in the Central City district, the wall rocks are more pervasively pyritized, seric-
itized and silicified. In areas outside the central zone where pyrite stage of min-
eralization is less intense or absent, pyrite does not occur in the wall rock outside
the vein zone, and the sericitization-silicification of zone 4 is moderate.

   The time factor in distribution of alteration is closely related to the structure.
Vein structures were open in various places during geologic time. It seems
certain that some Tertiary alteration preceded base-metal and composite ore
deposition and reasonably possible also that it preceded pyrite-stage ore forma-
tion. Can we be equally certain that, once formed, the alteration minerals re-
mained unchanged through succeeding time to the present?

DISCUSSION

   The nature of the alteration process in the Central City-Idaho Springs region
must be interpreted from alteration effects—mineralogical and chemical—upon
the rocks. The geochemical interpretation of these effects however, must be
done with caution and within the framework of the host-rock geology.

   The progressive alteration of host rocks along veins in other areas was as-
sumed to be a response to changing physico-chemical environment associated
with the deposition of ore minerals because of the close spatial relations between
altered rock and ore. The alteration-mineral assemblages have been variously
explained as forming from a single hydrothermal parent solution which was
gradually modified by rock chemistry and temperature, or from a series of solu-
tions (ultimately related) of different chemical character which modified the
host rock in discrete stages. To still others alteration appears to be the result
of lateral secretion phenomena. The specific zonal assemblages of clay minerals,
which are sensitive to environmental changes, and the (often conflicting) re-
sults of various laboratory syntheses of clay minerals, have been used in such
discussions as basic indicators of conditions of temperature of formation, pres-
sure, pH, and chemical composition of the altering and ore-forming medium.
The influence of mineral crystal structure lineage on stability has hitherto re-
ceived little serious consideration in the alteration literature.[1]

Clay Minerals and Alteration

   Clay minerals form in the alteration environment as the decomposing host-
rock minerals provide the requisite chemical constituents and perhaps the skele-
tal crystal structures; the geochemical environment is largely unknown because
it is based upon so very many variables. Clay minerals may represent an assem-
blage of the remaining least-mobile elements in the original minerals. There is
an orderly sequence of stability for the primary three-dimensional framework
and layer-silicate minerals, and a less distinct sequence of clay-mineral (less well-
crystallized layer silicates) stability culminating in the sericite-recrystallized
quartz assemblage. Near-surface supergene conditions favor the stability of
montmorillonite as a most intense phase. The stability range of the clay minerals

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[1] See paper in this volume by Brindley, G. W., and Radoslovich, E. W.

produced during alteration is broad and not rigid; thus the environment favors the formation of mixed, not discrete phases. In summary, the possible formation of clay minerals along veins in the Central City-Idaho Springs region depends on the mineralogy (and chemistry) and the structures of the host environment; the chemistry of the altering solutions ultimately determines the stable clay-mineral phase.

Is it possible to derive some conclusions about the geochemistry of the altera-tion environment from clay minerals which are formed therein? This has been done in the past. Recent data on clay-mineral genesis and synthesis provide a wide range of conditions: (1) Recent marine sediment studies give evidence of geologically rapid changes in clay-mineral composition in response to changing chemical environment at atmospheric conditions (Grim and Johns, 1954) ; (2) laboratory hydrothermal syntheses of clay minerals have determined rather ele-vated upper stability limits (Roy, 1954). Because of these facts much more evi-dence and thought are needed before we can use clay minerals as geologic ther-mometers or pH indicators in these ore deposits.

A Working Hypothesis

These and previous geological considerations are the basis for the hypothesis that an early, district-wide, moderate phase of hydrothermal alteration by mixed meteoric and hypogene (hot-spring type) water preceded the ore deposit-ing solutions. Pyrite-stage hydrothermal solutions may have intensified the transformations of the previously altered rock, or these rocks may be more in-tensely altered initially by being nearer to the supposed source of the hot solu-tions and therefore subject to more hydrothermal solutions for a longer time. Base-metal depositing solutions were not competent to impress a further charac-teristic alteration effect.

If most wall-rock alteration preceded the sulfide phase of hydrothermal ac-tivity, alteration mineralogy cannot be considered a reliable guide to ore.

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