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ABSTRACT

The Montezuma mining district, in the Colorado mineral belt, is defined by an assemblage of porphyry, ore, and altered rocks that originated in the venting of a Tertiary batholith through weak structures in Precambrian rocks. The ore consists of silver-lead-zinc veins clustered on the propylitic fringe of a geometrically complex system of altered rocks, which is centered on the intersection of the Oligocene Montezuma stock with the Montezuma shear zone of Precambrian ancestry. Alteration chemistry conforms to the standard porphyry-metal model but is developed around several small intrusives strung out along the shear zone and is expressed as a mottled pattern, rather than as the usual thick concentric zones centered on one large plug. The distribution of trace amounts of molybdenite is consistent with the postulate of molybdenite deposits in the district, but the mottled alteration pattern may signify small and scattered, possibly very deep, deposits. Disseminated molybdenite is essentially coextensive with altered rock and increases slightly in quantity toward the inner alteration zones. Two groups of molybdenite veins, associated with phyllic and potassic alteration, represent possible diffuse halos of molybdenite deposits. One group of veins resembles the Climax and Henderson deposits but was seen only in a small and isolated area of outcrops. The second group of molybdenite veins is in a bismuth-rich part of the Montezuma stock and underlies an area of bismuth veins; this group records the passage of contact metasomatic ore fluids. Another bismuth-rich area is in the southeast corner of the stock in a region of bismuth veins and may indicate a third group of molybdenite veins.

INTRODUCTION

Molybdenite occurs in trace amounts in the rocks and ores of the Montezuma district. Molybdenite mineralization is assigned to the Oligocene porphyry-ore association of the Colorado mineral belt (Tweto, 1968). This Colorado porphyry-ore association belongs to the remarkably consistent and worldwide porphyry-metal class of ore deposits. The pattern of molybdenite distribution in the Montezuma district provides evidence to help locate probable porphyry-molybdenum deposits in the district.

ACKNOWLEDGMENTS

Information regarding the character of rocks at depth in the Montezuma district was obtained largely through the kindness of other people, beginning with the many who prospected and mined the district from 1864 to date. John A. Thomas, of AMAX Exploration, Inc., permitted us to examine much drill core from the Geneva Creek cirque. Douglas N. Stevens, of Earth Sciences, Inc., permitted us to sample core from near Webster Pass. These cores and parts of the Roberts Tunnel collection, obtained for the U.S. Geological Survey by C. S. Robinson, were of exceptional value in characterizing the pervasive alteration of the district. Molybdenite distribution at depth in the western third of the stock was determined from the Roberts Tunnel collection, Denver Water Board drill core in the U.S. Geological Survey core library, and from data obtained by P. K. Theobald in his visits to the Roberts Tunnel access shaft. The bismuth analyses summarized herein were made by Eric P. Welsch of the U.S. Geological Survey.

GEOLOGY

The Montezuma district, situated along the Continental Divide just south of Loveland Pass, includes one of the clusters of porphyry, ore, and altered rock composing the Colorado mineral belt (fig. 1). The clusters that have stockwork molybdenite deposits (King and others, 1973) are virtually contained by the −300 milligal gravity contour of the central Colorado Rocky Mountains (fig. 2). The gravity low probably closely outlines the long-hypothesized

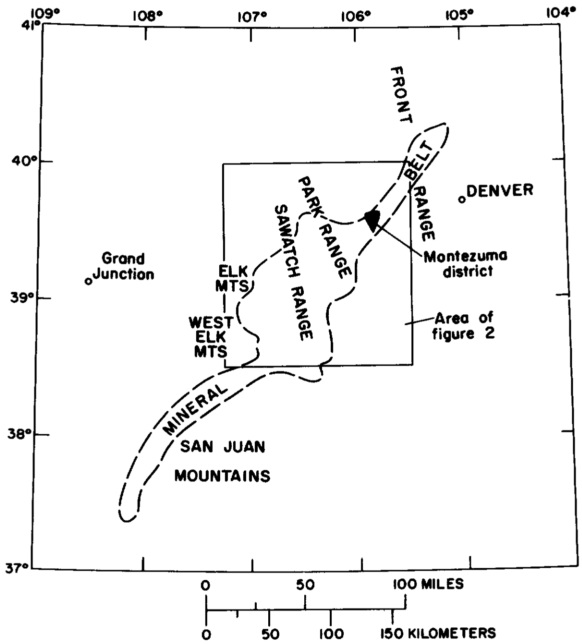


FIGURE 1. — Index map of central and western Colorado, showing Montezuma district in relation to the Colorado mineral belt.

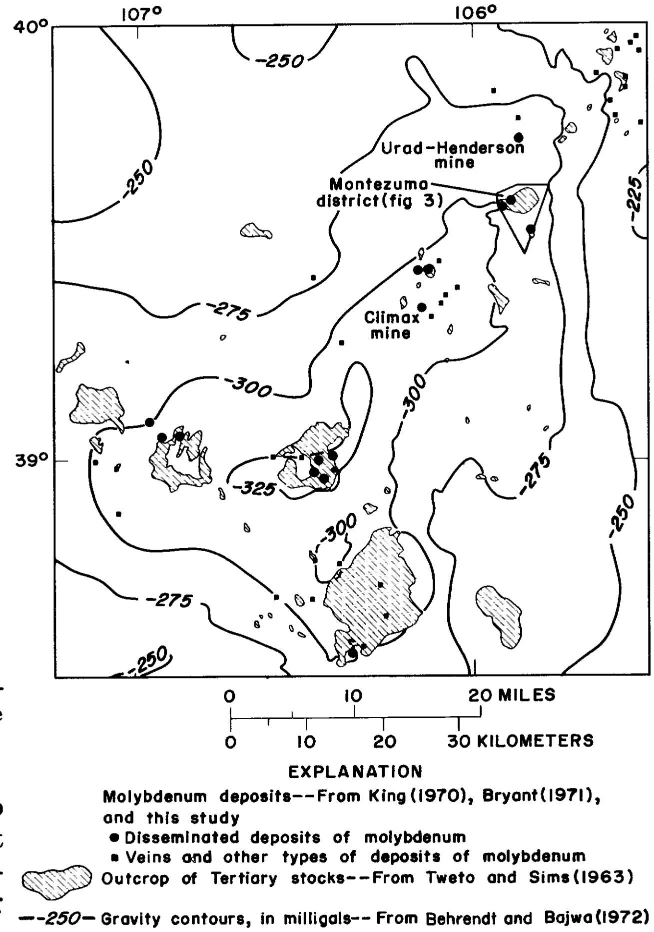


FIGURE 2. — Map showing molybdenum deposits in relation to Tertiary stocks and gravity contours.

mineral-belt batholith (Crawford, 1924; Tweto and Case, 1972), and coincides with an element of structural weakness of Precambrian ancestry, expressed as zones of recurrent shearing (Tweto and Sims, 1963).

The porphyry stocks, ore deposits, and altered rocks are cogenetic products of the underlying batholith, and they locate sites of venting of the batholith. The Colorado porphyry-ore assemblage is evidently a normal product of calc-alkalic batholiths that have vented (Hulin, 1944; Kennedy, 1955, p. 496–497; Sillitoe, 1972, p. 189–191).

The geology of the Montezuma district (fig. 3) is dominated by the Montezuma stock, which underlies most of the district, by the Montezuma shear zone, and by a large field of altered rock centered on the intersection of the stock and the shear zone (Neuerburg and Botinelly, 1972). Other structures control the distribution of small porphyry intrusives, ore deposits, and related altered rock within the district. Precambrian gneisses, amphibolites, granites, and pegmatites, and Cretaceous black shales are the host rocks for the assemblage of porphyry, ore, and altered rock.

Glacial scour and debris are prominent. Talus and rockslides cover large segments of the lower valley walls. Ocher-cemented gravels and bog-iron deposits, both preglacial and postglacial, cover large areas of the lower slopes and valleys and some of the preglacial upland surfaces in the large field of altered rock along the Montezuma shear zone. The bedrock outcrop varies greatly in amount but has been estimated to be on the order of 5 percent (Wahlstrom, 1964).

The Montezuma stock consists of several varieties of quartz monzonite, granite aplite, and rhyolite. Variation is largely exhibited by different intergradational porphyritic textures; the principal varieties are listed in table 1 and are plotted in figure 4. The composite nature of the stock resulted from repeated intrusions, dilatancy differentiation (Mead, 1925; Emmons, 1940; Nielsen, 1968; fig. 5), and pressure

TABLE 1.—*Principal rock types of the Montezuma stock*

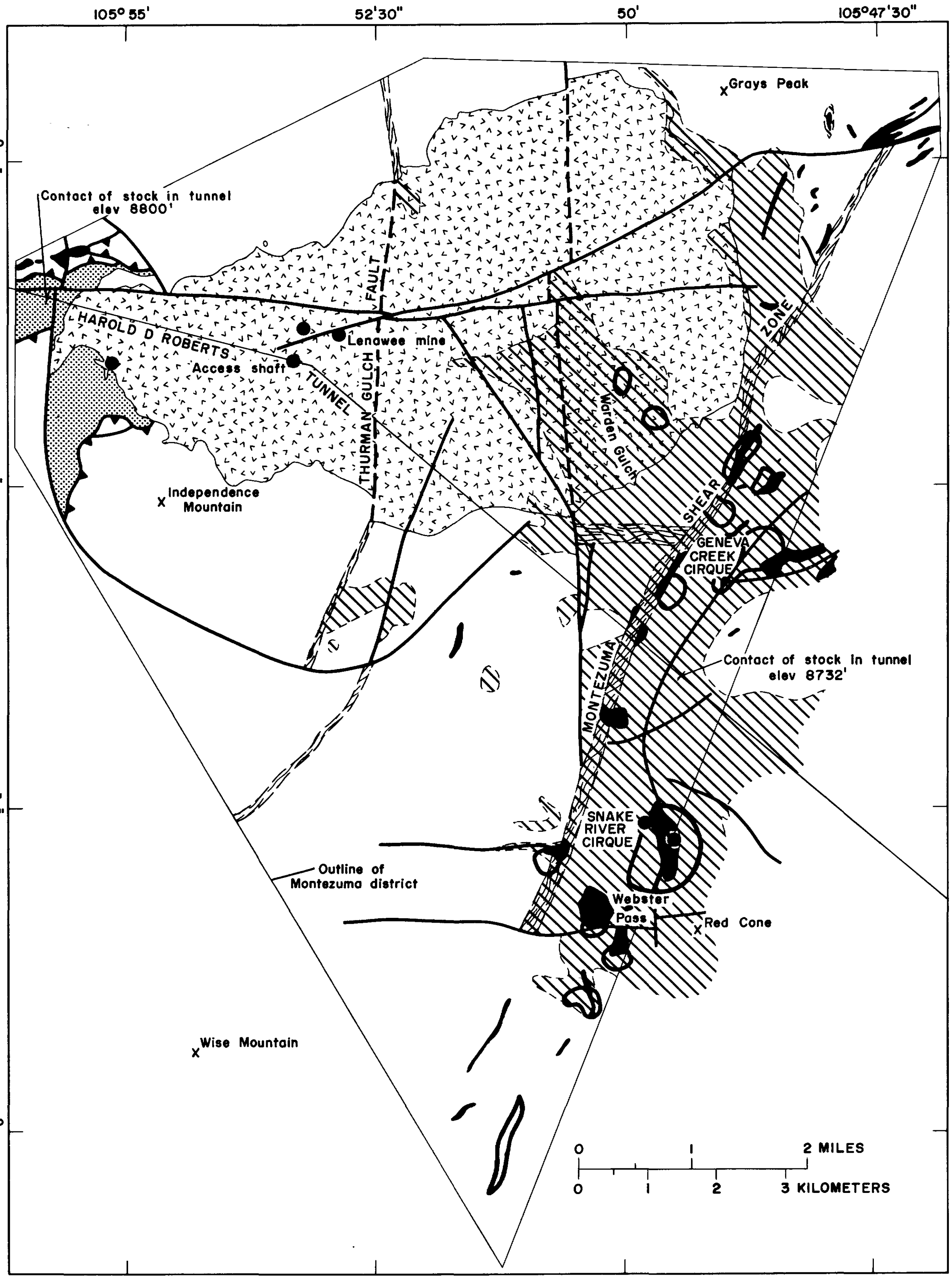
[All rocks occur in the Roberts Tunnel as well as on the surface]

Order No.[1]		Rock type, description, and remarks
0	Porphyritic biotite quartz monzonite.	Medium-grained hypautomorphic; 0–20 percent ragged potassium feldspar porphyroblasts. Makes up most of the western third of the stock; occurs among apophyses in the Williams Fork thrust fault. Some volatile loss at an early stage of crystallization, producing contact metasomatism but leaving no record in the igneous texture.
1	Porphyritic-seriate biotite quartz monzonite.	Medium-grained hypautomorphic in an interstitial web of fine-grained xenomorphic-graphic. Sparsely miarolitic; 0–25 percent ragged potassium feldspar porphyroblasts. Occurs independently as ill-defined masses in the porphyritic quartz monzonite and as a transitional zone between the porphyritic quartz monzonite and the quartz monzonite biporphyry; occurs among apophyses in the Williams Fork thrust fault. Volatiles were lost late in crystallization but incompletely, as shown by miaroles and porphyroblasts.
2	Seriate biotite quartz monzonite.	Medium- to fine-grained hypautomorphic to xenomorphic. Very sparse plagioclase phenocrysts and ragged potassium feldspar porphyroblasts. Mode of occurrence undetermined; seen only in isolated outcrops. A slow, steadily accelerating and complete loss of volatiles beginning midway in crystallization.
3	Biotite quartz monzonite porphyry-biporphyry.	Medium-grained hypautomorphic biotite-quartz-plagioclase aggregates, plagioclase crystals, and corroded quartz bipyramids in an aplitic to aphanitic groundmass, thereby grading into quartz latite. Sparsely miarolitic; 0–35 percent ragged to euhedral potassium feldspar porphyroblasts. Occurs mostly as large irregular masses in much of the eastern half of the stock, but also as sparse small intrusives and as the mesostasis for breccias (fig. 5). Makes up most of the dikes and plugs outside the stock. Volatiles exsolved quietly and rapidly early in crystallization, but the loss was incomplete so as to produce miaroles and porphyroblasts. The materials removed with the volatiles left a slightly more basic rock than would have otherwise crystallized.
4	Biotite rhyolite porphyry.	Medium-grained phenocrysts, variously euhedral, broken, or corroded; include potassium feldspar as well as biotite, plagioclase, and quartz; the groundmass is very fine grained aplitic to aphanitic. Euhedral potassium feldspar porphyroblasts are uncommon. Occurs as small intrusives, as transitional zones on aplite bodies, as joint selvedges, and as the mesostasis of breccias (fig. 5), especially near the upper contacts of the stock. Occurs as dikes and sills in Precambrian rocks, mostly off the southeast edge of the stock in the Geneva Creek cirque. Volatiles were exsolved early and suddenly, in part violently, during crystallization; the surging exsolution of volatiles was instrumental in the in situ differentiation of rhyolite.
5	Granite aplite	Very fine to fine-grained, xenomorphic to graphic. Essentially the same chemical composition as the rhyolite, although very little biotite is present. Sparse euhedral potassium feldspar porphyroblasts and pegmatite patches with pyrite, molybdenite, and (or) hyalophane. Occurs as tabular bodies, ranging in thickness from a fraction of an inch to several hundred feet, and as dilatancy differentiates (fig. 5); not known outside the stock. Volatile loss was essentially complete and was sudden, beginning before the onset of crystallization, and was instrumental in the differentiation and intrusion of the aplite magma.

[1]Rock types are arranged in order of suggested extent of volatile loss during crystallization (fig. 4).

quenching through "sudden" devolatilization (Neuerburg, 1971).

The fine-grained groundmass and partly resorbed quartz phenocrysts of the porphyries resulted from pressure quenching (Jahns and Tuttle, 1963) and accompanying changes in chemical equilibrium. Subsequently, after hermetic sealing of residual fluids in the near-solid rock (Neuerburg, 1958), large potassium-feldspar "phenocrysts," properly identified as porphyroblasts, formed to give rise to the pegmatitic crystallization-recrystallization described by Jahns and Burnham (1969). These large potassium feldspar porphyroblasts in a porphyry with smaller quartz and feldspar phenocrysts are the essential element of the



105° 55'
52'30"
50'
105°47'30"
39°
37'
30"
35'
32'
30"
39°
30'
Contact of stock in tunnel
elev 8800'
Grays Peak
HAROLD D ROBERTS
TUNNEL
Access shaft
Lenawee mine
THURMAN GULCH
FAULT
Warden Gulch
SHEAR
ZONE
MONTEZUMA
Independence
Mountain
GENEVA
CREEK
CIRQUE
Contact of stock in tunnel
elev 8732'
SNAKE
RIVER
CIRQUE
Outline of
Montezuma district
Webster
Pass
Red Cone
Wise Mountain
0
1
2 MILES
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1
2
3 KILOMETERS

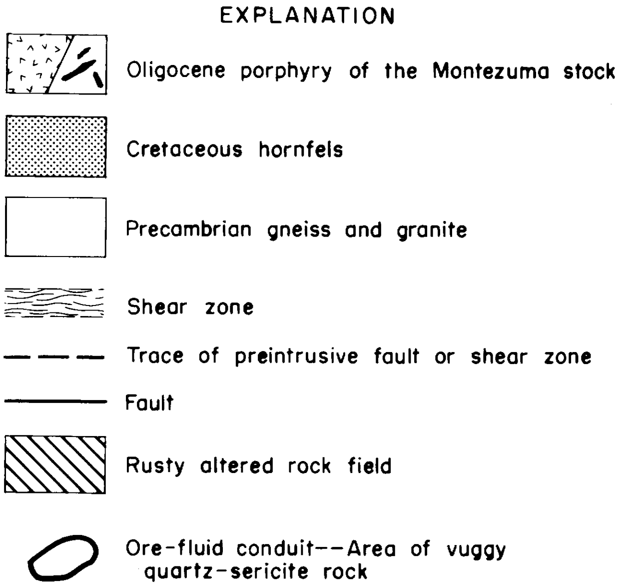

FIGURE 3 (facing page and above). — Principal geologic elements of the Montezuma district, emphasizing the distribution of porphyries and altered-rock fields and showing ore-fluid conduits.

Lincoln Porphyry type of texture (Emmons, 1886, p. 328), or biporphyry (Neuerburg, 1971), so common in the porphyry-metal model (Fournier, 1967).

The chemical and textural changes in the Montezuma stock that relate to pressure gradients are a record of the selective loss of water, other volatiles, and dissolved metals. The changes thus identify source rocks for ore fluids. The volatile loss is interpreted to be greater as the groundmass grain size is finer and the proportion of phenocrysts is less. The distribution of the different rocks within the stock (fig. 4), ranked according to the suggested degree of volatile yield, conforms to the geometry of the hydrothermal plumbing shown by vuggy quartz-sericite rock (fig. 3), except that the aplites plugged the vent structures they now occupy and, thus, were not appreciably involved with the later passage of hydrothermal fluids.

Quartz monzonite, quartz latite, rhyolite, and sparse lamprophyre form dikes, sills, and plugs, mostly in and along the Montezuma shear zone; a very few occur in the stock. Small bodies of Silver Plume Granite also occur mostly in and along this shear zone (fig. 6) and show that this shear zone localized intrusion as early as the Precambrian. Repeated venting in any one area is common on a short-term basis, as in the Montezuma district (Neuerburg and Botinelly, 1972), at Climax (Wallace and others, 1968), and at Urad-Henderson (MacKenzie, 1970).

Rusty to bleached altered rocks form brightly colored fields of outcrop and talus above timberline in the Montezuma district. The largest of these fields, whose extent is sketched in figure 3, identifies the strong relation of altered rock to the Montezuma shear zone and associated porphyries above the roof of the Montezuma stock. Other, much smaller fields of altered rock occur scattered in the district; some of these are shown in figure 3.

Chemically and mineralogically, pervasive alteration in the Montezuma district accords well with the standard porphyry-metal model (Lowell and Guilbert, 1970; Sillitoe, 1973), first sketched by W. H. Emmons (1927). Geometrically, it differs appreciably from the model of nested cylinders (fig. 7). The Montezuma shear zone has profoundly modified the usual pattern of porphyry-ore venting from the single plug–cylindrical strain pattern exemplified by the Climax and Urad-Henderson deposits, to a linear swarm of plugs and dikes stemming from a relatively flat-roofed stock. The different types or zones of alteration are distributed among numerous permeable structures to yield a mottled pattern (fig. 8*A*). All parameters of mineralization have this mottled distribution pattern and at all scales, from a single hand specimen to the entire district.

The innermost potassic alteration zone of the porphyry-metal model is recognized here only in two neighboring outcrops of quartz latite porphyry in the Snake River cirque (fig. 3). The adjacent rocks are argillized gneiss and sericitized porphyry. Alteration in these two outcrops consists of recrystallization of the groundmass to a granoblastic mosaic of quartz and potassium feldspar, with unaltered plagioclase and biotite phenocrysts, and of veining by a stockwork of quartz-magnetite-pyrite-molybdenite veinlets. Corundum, otherwise very rare in porphyries of the Montezuma district, is relatively abundant in these two zones and amounts to one-tenth of one percent by weight. Corundum, so easily overlooked except in HF-separates, is mentioned here because it may be

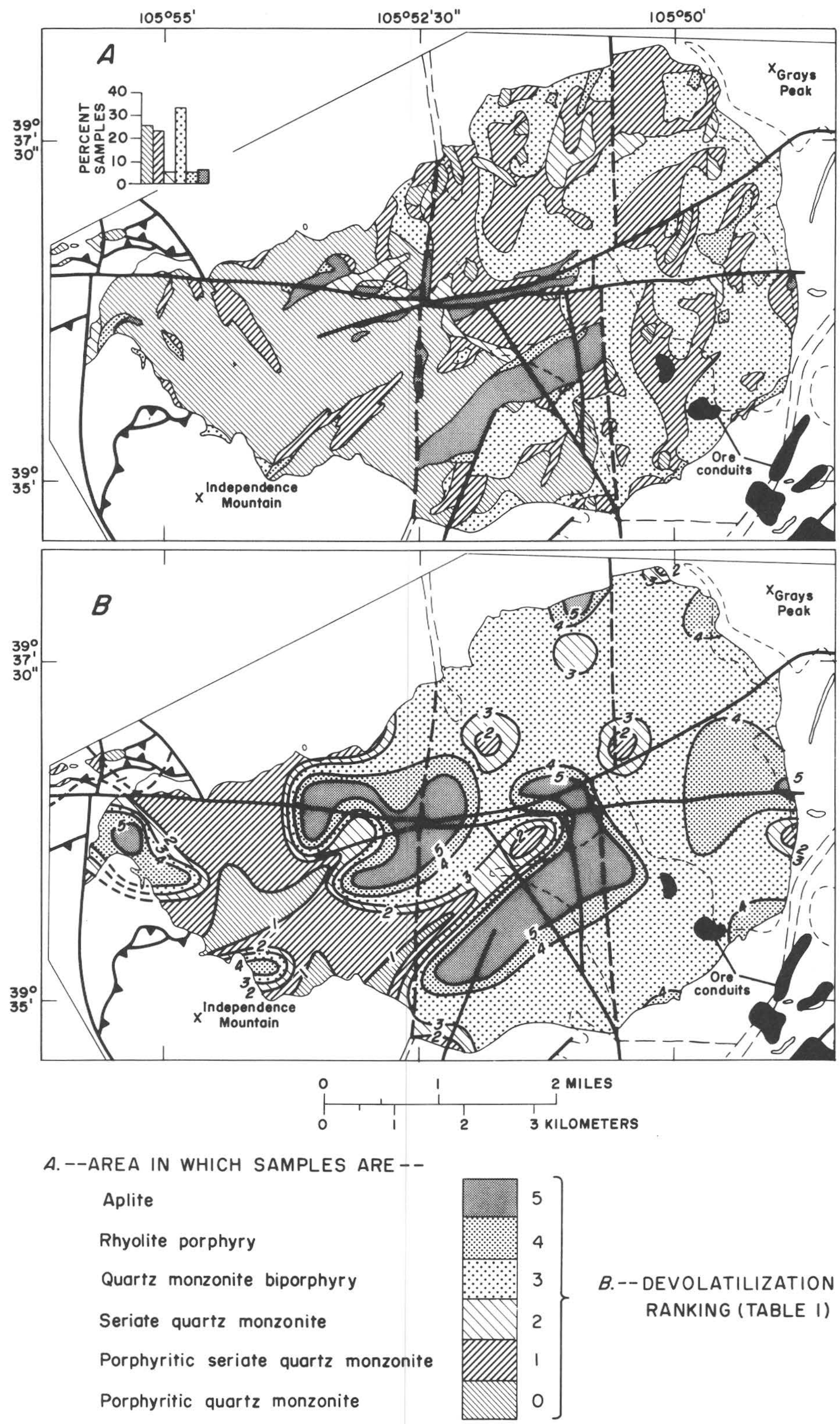

FIGURE 4. — Petrography of the Montezuma stock. *A*, Map and histogram showing the distribution of rock types among samples. *B*, Contours showing ranking of volatile loss during crystallization as represented by textures. (See text.) Based on maximum rank per cell in a 2,000-foot (610-m) grid.

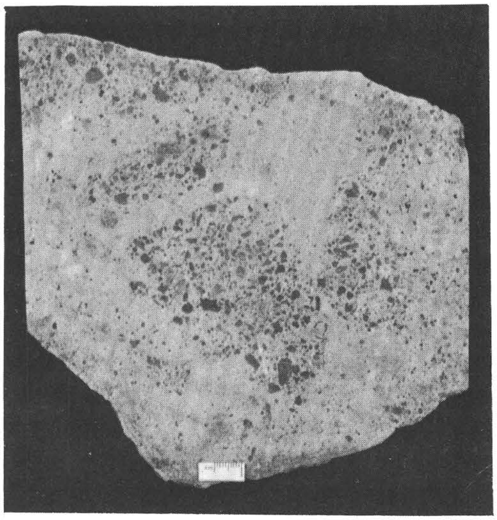

FIGURE 5. — Dilatancy differentiate of fine-grained granite aplite, leaving as a residue quartz monzonite porphyry. Stained slab: dark-gray crystals are plagioclase; medium-gray, quartz and potassium feldspar.

an index mineral of the potassic zone of alteration.

Irregular cylindrical or tabular bodies of phyllic rock occur in the altered rock field scattered along the Montezuma shear zone. The phyllic rock is commonly in abrupt contact with rock of varying and commonly much lesser alteration. Phyllic alteration is concentrated principally within the satellitic porphyry intrusives. It also occurs in the Precambrian rocks, particularly the Silver Plume Granite, and is localized by faults and other planar structures.

Phyllic zone alteration produced a pyritic quartz-sericite rock, whose original texture was commonly destroyed. Quartz and quartz-pyrite veinlets, locally grading into silicified rock, are common in random distribution. Although pyrite is conspicuous and abundant, the amount of iron in the pyrite is less than the original iron content of the rock. Other sulfides, which include bismuthinite, chalcopyrite, molybdenite, and sphalerite, are relatively rare. Chemical analyses show very little added ore metals in phyllic zone rocks as compared to the rocks of the propylitic zone. Andalusite, diaspore, pyrophyllite, and (or) talc uncommonly take the place of some of the sericite. Barite occurs erratically but is usually present in the larger quartz-pyrite veins of the phyllic zone. Lavender anhydrite and colorless gypsum veinlets occur sparingly but may increase in abundance with depth.

Some of the phyllic rock is very vuggy and highly permeable, a structure which has been called bug-hole porphyry at Urad (MacKenzie, 1970, p. 41) and elsewhere (Taylor and King, 1967, p. 12) in the mineral belt. This structure is not restricted to porphyry at Montezuma; several areas containing abundant examples of the bughole structure are shown in figure 3. The vugs are concentrated in but not restricted to phenocrysts and are lined with euhedral terminations of muscovite and quartz upon which are perched euhedral crystals of pyrite, rutile, and rarely sphalerite. This vuggy phyllic rock is commonly accompanied by quartz-pyrite veins and identifies major conduits in the hydrothermal plumbing.

The argillic zone is volumetrically unimportant in the district. Mineralogically, it is only rarely argillic; the usual rock of this zone is one in which biotite and plagioclase are sericitized and epidotized — that is, saussuritized; about 1 percent pyrite was formed, and the potassium-feldspar was left unchanged. Like the phyllic rocks, rocks of the argillic zone show a structurally controlled "mottled" distribution. Locally, these rocks form incomplete shells on bodies of phyllic rock.

Propylitic alteration is present in most of the district. Although it is most apparent in the fields of rusty altered rock, it extends far beyond their limits. This alteration consists of chloritized biotite and moderately sericitized plagioclase, together with added pyrite, carbonate, and, locally, minor sphalerite. The propylitized rocks are generally enriched in ore elements, especially zinc. Precipitation of pyrite, carbonate, and sphalerite is apparently catalyzed by the biotite structure (Schwartz, 1958, p. 174; Al-Hashimi and Brownlow, 1970, p. 991), with or without concomitant alteration to chlorite. The amount of pyrite, however, is unrelated to the amount of chloritized biotite, and the iron content of biotite is the same as the amount of iron in chlorite. The added pyrite apparently represents iron removed from the phyllic zone; the propylitic alteration results from the fluids modified by the reactions of the phyllic zone (Spurr, 1905). Mineralogically, propylitic alteration grades out through a region in which only biotite is altered (fig. 8).

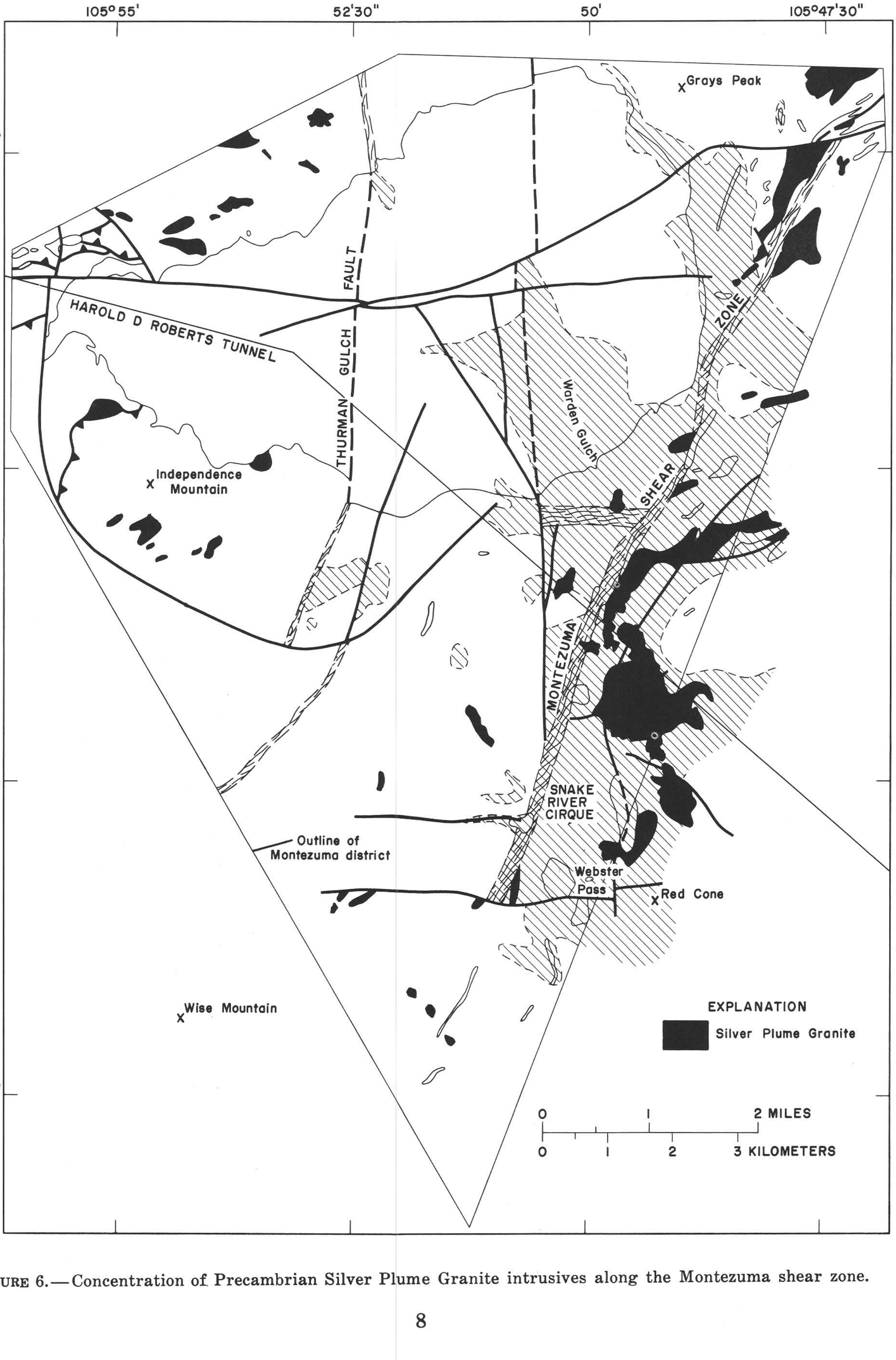

FIGURE 6.—Concentration of Precambrian Silver Plume Granite intrusives along the Montezuma shear zone.

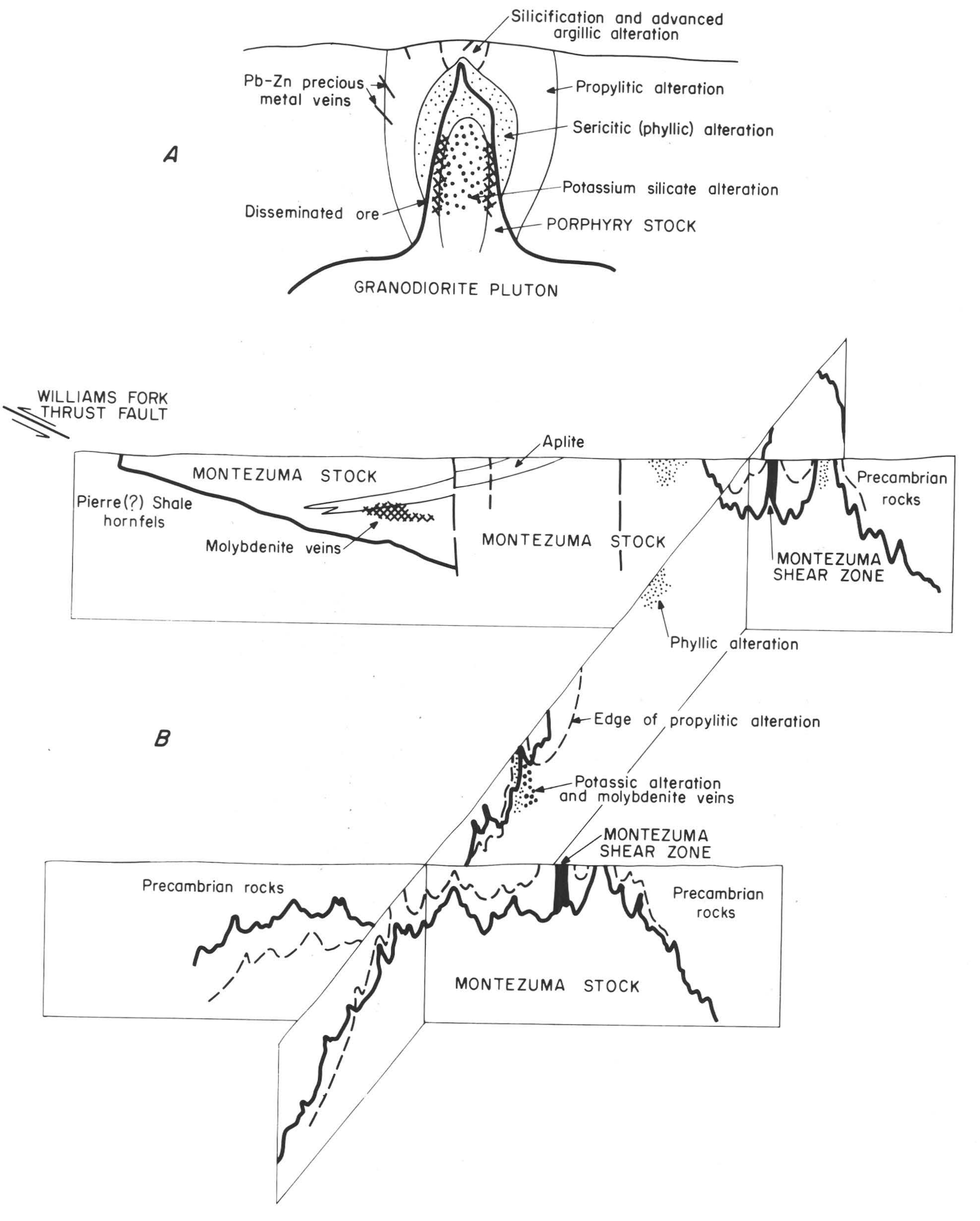

FIGURE 7. — Diagrams showing alteration zoning of porphyry-metal deposits. *A*, The usual model, centered on a pluglike intrusive (modified from Sillitoe, 1973). *B*, The Montezuma pattern.

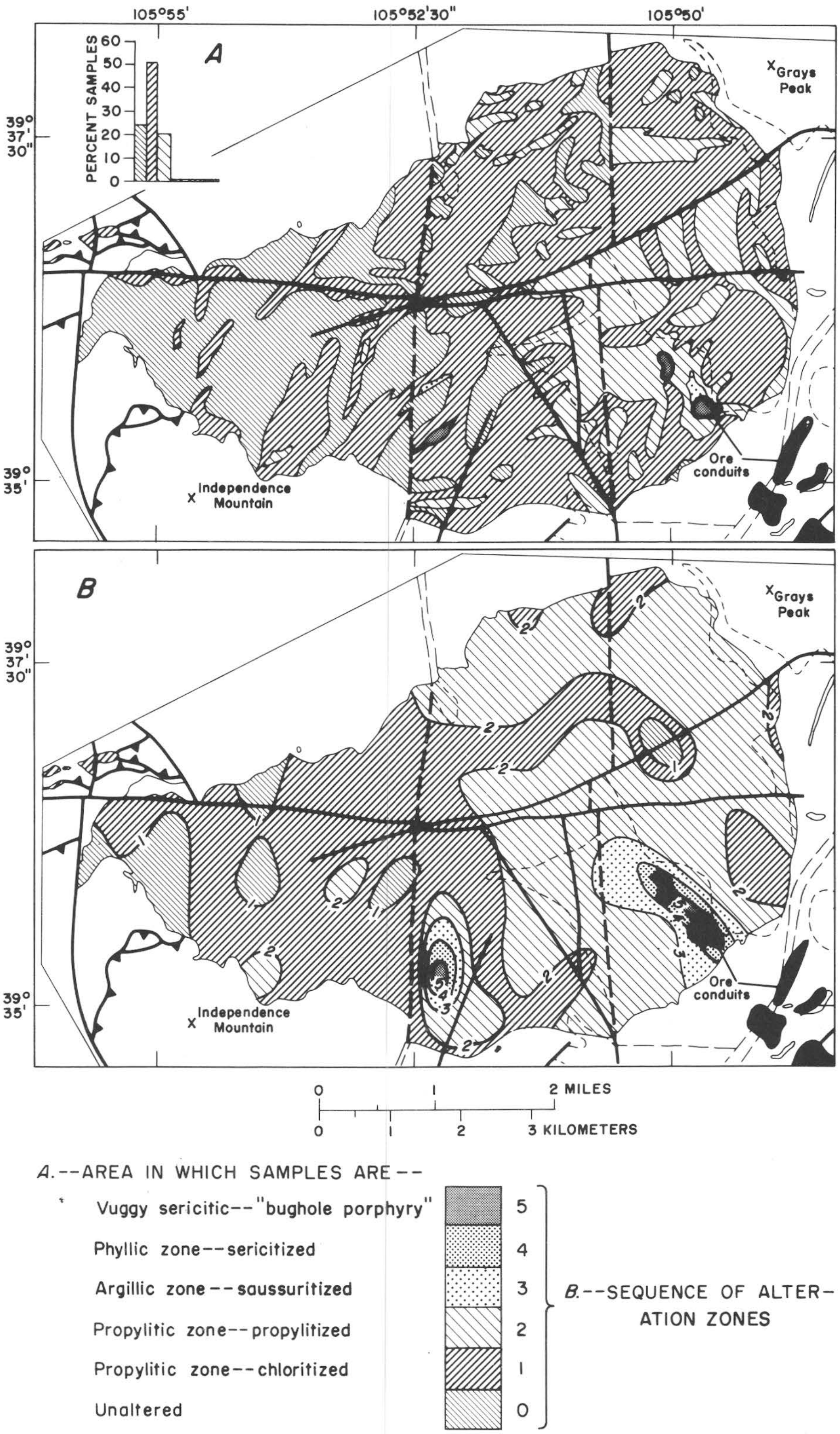

FIGURE 8. — Pervasive alteration of the Montezuma stock. *A*, Map and histogram showing the distribution of alteration types among samples. *B*, Contours showing distribution of maximum alteration among cells in a 2,000-foot (610-m) grid.

Physically, it grades into unaltered rock through restriction of alteration to widely spaced joints and foliation planes.

The known ore deposits of the Montezuma district are silver-lead-zinc veins, concentrated in and on the edges of the altered rock fields (fig. 9) and extending into regions of unaltered rock. Episodes of repeated venting have produced telescoping and the emplacement of a few veins deep within the phyllic and argillic zones. The vein deposits were precipitated from large volumes of solutions channeled through restricted structures. In contrast, metal-enriched pervasive propylitic alteration zones formed where similarly large volumes of solutions permeated large masses of rock.

The vein deposits are encased in envelopes of altered rock, ranging from phyllic, next to the vein, to the zone that characterizes the host rock. The argillic zone of alteration envelopes, where present, is mostly represented by a saussuritized rock like that of the pervasive alteration. In contrast to the pervasively altered phyllic and argillic rocks, the corresponding altered rocks flanking vein deposits are notably enriched in ore metals and contain disseminated ore and gangue minerals. No distinction is apparent between pervasive propylitic rock and the propylitic rock flanking veins.

Alteration associated with veins in the western third of the stock differs from the pattern just described. In this region, quartz monzonite is replaced by coarse-grained sericite and quartz, in places with clots of pyrite and (or) molybdenite, and the altered rock resembles greisen. Sericitization is first evident in biotite and progresses through plagioclase to potassium feldspar; it is localized by joints. The change from unaltered to altered rock is abrupt in most places. This alteration is related to contact metasomatism on the southwest contact of the stock (Neuerburg and others, 1971).

MINERALOGY AND DISTRIBUTION OF MOLYBDENITE

This study is based upon dissimilar groups of samples, each of which has its own bias or error (Miesch, 1967). Extensive sampling of outcrop has been almost confined to the igneous rocks. Unaltered quartz monzonite is poorly exposed and much is weathered to a friable state. Propylitic zone rocks are well represented in outcrop, as shown in the sample distribution by alteration type in the stock (fig. 8*A*, histogram), whereas phyllic and argillic zone rocks are rarely found in outcrop. Samples of argillic and phyllic rocks have come largely from mines and prospects and probably compose a reasonably homogeneous set. Samples of vein material are extremely variable intrinsically, as well as being the "capricious" discards of the miner.

Sampling was designed to test for evidence of contact with ore fluids shown by the presence of altered minerals and the addition of ore elements, and the chemical composition of the hydrothermal fluid indicated by the amount and variety of added elements and by the zonal sequence of alteration and mineralization. To evaluate these hydrothermal effects, the maps were gridded on a 2,000-foot (610-m) interval, and the highest value of the chosen parameter among the samples in each square was plotted at the center of that square. A similar maximizing procedure has been followed for linear traverses, as in the Roberts Tunnel and in diamond-drill holes, except that for the linear traverses the interval is reduced to 1,000 and 100 feet (300 and 30 m), respectively. The maps and curves so generated will be called the blip surface or blip curve and serve to make more legible both general trends and relations of local maximums to one another and to geologic structures.

MINERALOGY

The only molybdenum mineral found in the Montezuma district is molybdenite. The possibility that molybdenum substitutes in a major way in rock mineral structures of the Montezuma stock seems ruled out by the rarity of molybdenum in biotite and chlorite; only 21 out of 500 spectrographic analyses of biotite and chlorite showed any molybdenum (lower limit of determination: 5 ppm Mo). Molybdenite has the 2H polytype (Traill, 1963; Frondel and Wickman, 1970) in all occurrences but one, in which a molybdenite grain from a stream sediment is a mixture of the 2H+3R polytypes. The crystals are generally thin and tabular hexagonal' euhedrons to irregular space-filling anhedrons. Most disseminated crystals of molybdenite are 2 mm (millimetres) or less in maximum dimension. Molybdenite in fracture

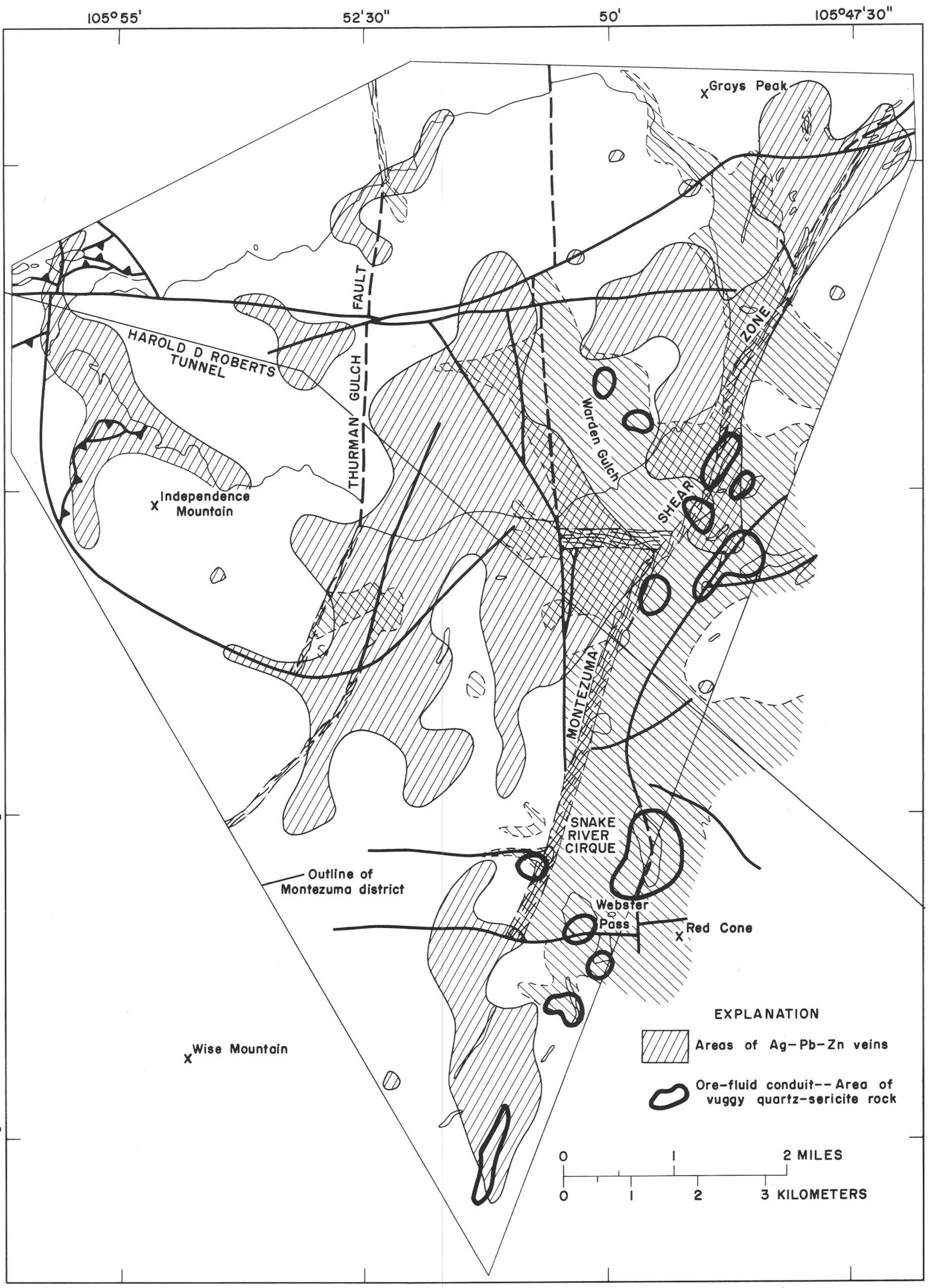

FIGURE 9. — Areas of known silver-lead-zinc veins in the Montezuma district.

fillings, in veins, and in the rare pegmatitic pockets in aplites ranges from 1 μm (micrometre) to 2 cm (centimetres) in maximum dimension. Supergene oxidation of molybdenite is indicated by the presence of molybdenum in ammonium carbonate leaches of some altered rocks, but no secondary molybdenum minerals have been identified.

Molybdenite is common in HF separates (Neuerburg, 1961) from 100-g (gram) samples of rocks from the district. Molybdenum is seldom reported in chemical or spectrographic analyses of matching samples because molybdenite, a flexible mineral concentrated into a relatively few crystals, is very difficult to disperse evenly enough to assure the detection of molybdenum in the small samples used for chemical (0.1 g) or spectrographic (0.01 g) analysis — that is, the same particle sparsity effect encountered in gold analyses (Clifton and others, 1967, 1969). For example, 28 of 86 samples of Silver Plume Granite showed molybdenite in HF separates; only 2 of these showed molybdenum by spectrographic analysis.

DISTRIBUTION OF MOLYBDENITE IN THE DISTRICT

Molybdenite is disseminated in trace amounts in many of the rocks of the Montezuma district and, uncommonly, in vein and fracture fillings. Disseminated molybdenite shows no obvious preferential fabric site, or mineral association, whereas vein molybdenite is commonly concentrated along the edges of veins. Molybdenite conforms to the general distribution pattern of ore elements and minerals in the district, except that it has not been found in any of the silver-lead-zinc veins. The general pattern of distribution is that ore elements vary independently from each other and are independent of host-rock type, in accord with the mottled pattern of distribution of alteration zones. Small-scale variance differs among rock types and between outcrops of the same rock type, as exemplified by molybdenite and pyrite (table 2, fig. 10). Detected regularities of element distribution relate to types of alteration, to permeable structures, and to the relative quantities of fluid that passed through these structures, as indicated by the extent of hydrothermal-related change in the structure. Overall, the addition

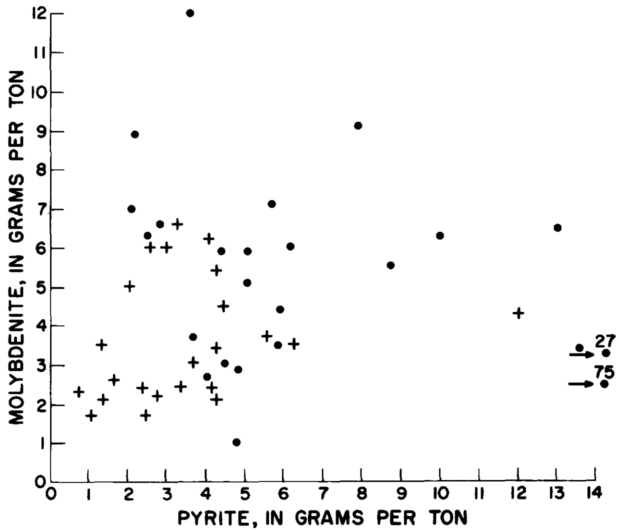

FIGURE 10. — Diagram illustrating the independence of pyrite and molybdenite abundances within one block (+), and among 24 additional blocks (•) of unaltered aplite scattered over a small mine dump.

of elements (Neuerburg, 1971) from heterogeneous fluids of time-dependent composition to rock where access of the fluids was channeled and constantly shifting at all scales is superimposed on an earlier igneous pattern of ore-element removal (table 1, fig. 4).

Patterns of molybdenite distribution in the different major rock units of the Montezuma district, apart from the Montezuma stock, remain undetermined for the most part. Molybdenite is known to occur in trace amounts in some of the Precambrian gneisses. It is a minor component of the Silver Plume Granite, to which it has probably been added from the district ore fluids. Molybdenite has been found in the tactites developed from the Cretaceous shales, and molybdenum has been found spectrographically in the Cretaceous shale-hornfels, but only in samples collected from mineralized structures.

Statistically, molybdenite in the Montezuma stock shows a slight increase in abundance with decrease in grain size of the groundmass (fig. 11); this trend is like that exhibited by pyrite, but less pronounced. The degree of propylitic alteration also increases in rocks with finer grained groundmass. However, the decrease in groundmass grain size (fig. 4), along with the increase in pyrite and molybdenite abundance (fig. 12) and the degree of propylitization, is

TABLE 2. — *Molybdenite and pyrite variances in eight igneous rocks according to sample area, rock type, alteration, and weight of analyzed fragments*

Rock type and alteration	Sample[1]		Molybdenite (g/ton)			Pyrite (g/ton)	
	Nature	Weight (grams)	Number[2]	Range	Avg.	Range	Avg.
Silver Plume Granite, unaltered.	Sawed block.........	35±3	24	0	0	735 –1,930	1,200
Porphyritic quartz monzonite, unaltered.[3]	......do......................	40±5	7	0.8–109	22	95 –1,850	355
		120±15	5	2.3–85	19	75 –7,200	510
		110±8	10	1.7–75	14	45 –1,190	255
Granite aplite, unaltered[4]..........	Broken block........	65±15	....	1.7–6.6	3.6	0.8–12	3.5
	Mine dump............	56±6	....	1 –12	5.4	2.1–75	9.5
Porphyritic quartz monzonite, chloritized.	Sawed block..........	35±5	....	4.8–130	35	14 –750	115
Porphoritic-seriate quartz monzonite, chilled.	......do......................	35±3	3	.7–30	7.6	15 –600	175
Quartz latite biporphyry, propylitized, pervasive.	......do......................	33±5	24	0	0	11 –975	310
Porphyritic quartz monzonite, phyllic, vein envelope.	......do......................	40±4	15	20 –93	49	1,220 –14,600	4,900
Quartz latite biporphyry, vuggy-sericitic, pervasive.	......do......................	34±4	24	0	0	38,500 –61,700	51,800

[1]Blocks of rock weighing 5-10 kg were sawed or broken into many fragments; from each group of fragments, 24 samples were taken for analysis.
[2]Entry is number of samples, out of the total of 24, with no molybdenite.
[3]Three sample groups from the same roadcut, 300 ft long, near the western edge of the stock.
[4]These two sample groups are from the same mine dump, on the north edge of Montezuma. See also fig. 10.

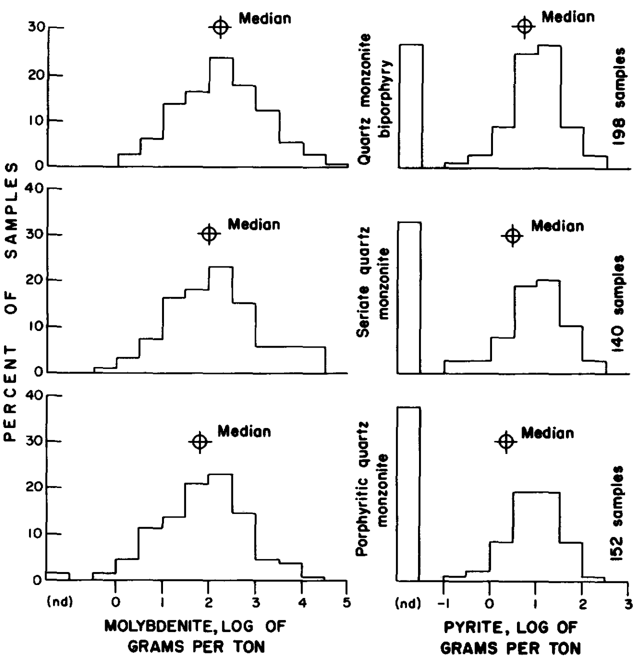

FIGURE 11. — Molybdenite and pyrite abundance distributions among the three principal porphyritic varieties of quartz monzonite composing the Montezuma stock; nd, not detected.

more meaningfully correlated with the position of major venting regions, as identified by vuggy quartz-sericite rock, than with each other.

Molybdenite distribution in the argillic and phyllic zones, both in the porphyries and in the Precambrian rocks, appears to be very uneven, and no estimate of abundance is hazarded. Disseminated molybdenite is relatively uncommon and haphazardly distributed. Veinlet- and fracture-filling molybdenite is likewise randomly distributed but appears to increase with increasing silicification.

Two somewhat contrasting groups of molybdenite veins are known in the district; neither constitutes ore deposits. The stockwork of quartz-magnetite-pyrite-molybdenite veinlets in the potassic alteration zone in the Snake River cirque (fig. 3) is flanked several hundred feet to the west by sericitized porphyry containing molybdenite-faced fractures. These outcrops resemble parts of the Climax and Henderson deposits. Satisfactory characterization is not possible because weathering is intense, and these small outcrops are isolated in a great field of bog-iron deposits and ocher-cemented gravels.

The molybdenite veins on the north flank of Independence Mountain (fig. 3) occur over a large area. This group is known from three caved mines, from the Roberts Tunnel access shaft, and from the Roberts Tunnel. The occurrence is of scattered quartz veinlets with coarse molybdenite in thin envelopes of coarsely sericitized quartz monzonite. The occurrence was early noted in a geographically misleading entry under Summit County (Horton, 1916, table, p. 64): "Lenawee mine, between Kings-

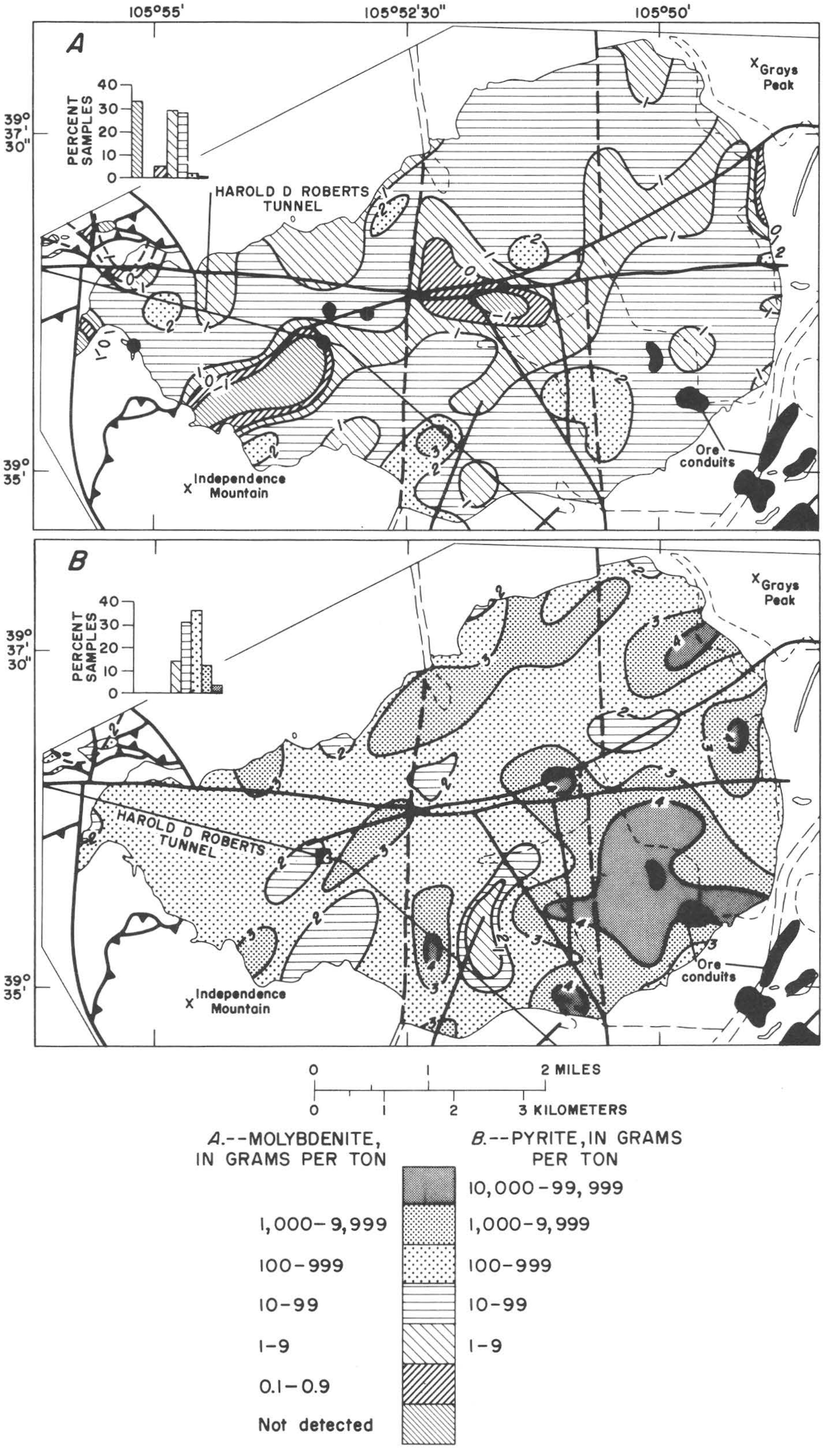

FIGURE 12.— The distribution of molybdenite (*A*) and pyrite (*B*) in the Montezuma stock as blip surfaces. (See text.)

ton and Montezuma"; to correct, substitute the word "Keystone" for "Kingston." Kingston was in Clear Creek County (Eberhardt, 1968, p. 65).

Molybdenite veins in the access shaft are concentrated in and below a body of aplite about 800 feet (250 m) below the collar of the shaft; veins above the aplite contain silver-lead-zinc minerals, except for one composed of a bismuth mineral. Molybdenite veins in the Roberts Tunnel are near the foot of the shaft. The region of molybdenite veining in the access shaft and the tunnel is clearly indicated by the blip curves for disseminated molybdenite, pyrite, and bismuth (figs. 13, 14). Bismuth veins overlie and partly overlap the molybdenite-vein region (fig. 15), which is in a bismuth-rich segment of the Montezuma stock (fig. 16). Apart from the three widely separated mines, noted above, this molybdenite-vein region is not reflected in surface exposures. It is clearly shown by the district plot of bismuth veins (fig. 15). The high bismuth content of rocks in Warden Gulch, where the field of rusty altered rock transgresses the stock (fig. 16), together with the nearby areas of bismuth veins (fig. 15) may outline another unexposed group of molybdenite veins. Areas of specularite veins (fig. 17) are related to bismuth mineralization (Neuerburg and others, 1971) and are larger and more easily located targets than are areas of bismuth veins.

The molybdenite veins of the Snake River cirque have characteristics typical of porphyry-metal deposits, paramount among which is the stockwork veining on pyroclastic structures in pressure-quenched porphyries. The molybdenite veins of Independence Mountain do not have these characteristics, differing particularly in the absence of pervasive alteration. Further, deposition was controlled by flow-restrictive major structures, such as the relatively impermeable aplite of the Roberts Tunnel access shaft. The ore minerals in both groups of veins were precipitated from metal-bearing fluids secreted from the subjacent batholith in response to pressure gradients; those of Snake River in a temporarily closed system, those of Independence Mountain in a continuously open system.

The Snake River veins derive from metal-bearing volatiles concentrated in a cupola by pressure-solubility equilibration in the gravitational field (Kennedy, 1955). The solubility of potassium, copper, and molybdenum in water varies directly with pressure (Kennedy, 1955, p. 498). Potassic alteration and precipitation of copper and molybdenum in shattered rocks resulted from explosive decompression of the cupola (Sillitoe, 1973, p. 812).

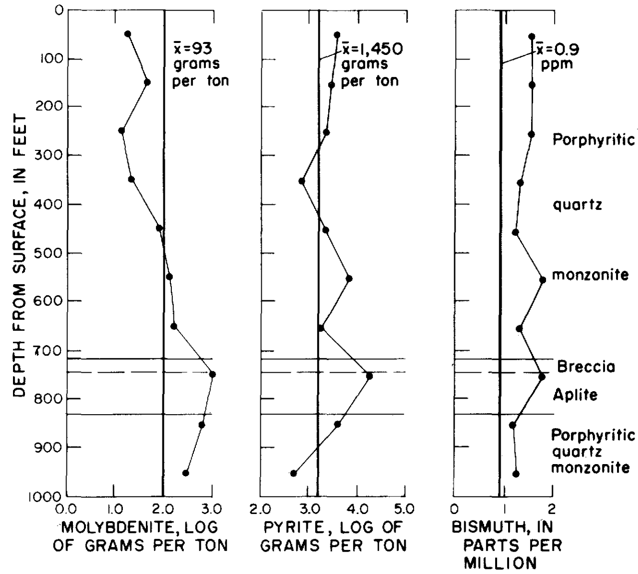

FIGURE 13. — Molybdenite, pyrite, and bismuth blip curves for 76 samples of drill core from line of Roberts Tunnel access shaft from depths of 32 to 942 feet (9.8 to 287 m).

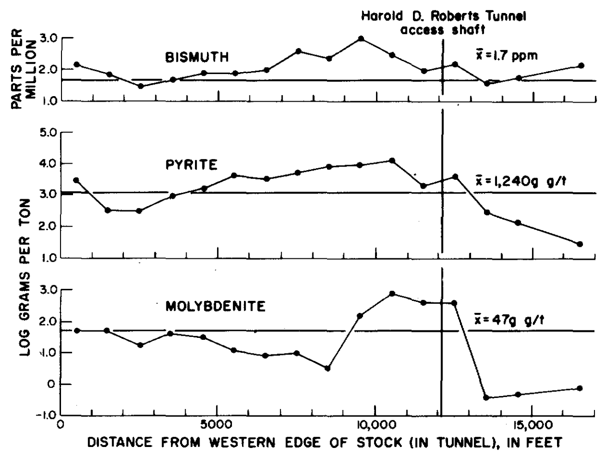

FIGURE 14. — Molybdenite, pyrite, and bismuth blip curves for 83 samples along Roberts Tunnel in western third of Montezuma stock (area I of Neuerburg, 1971).

The Independence Mountain molybdenite veins are related to contact metasomatism, a

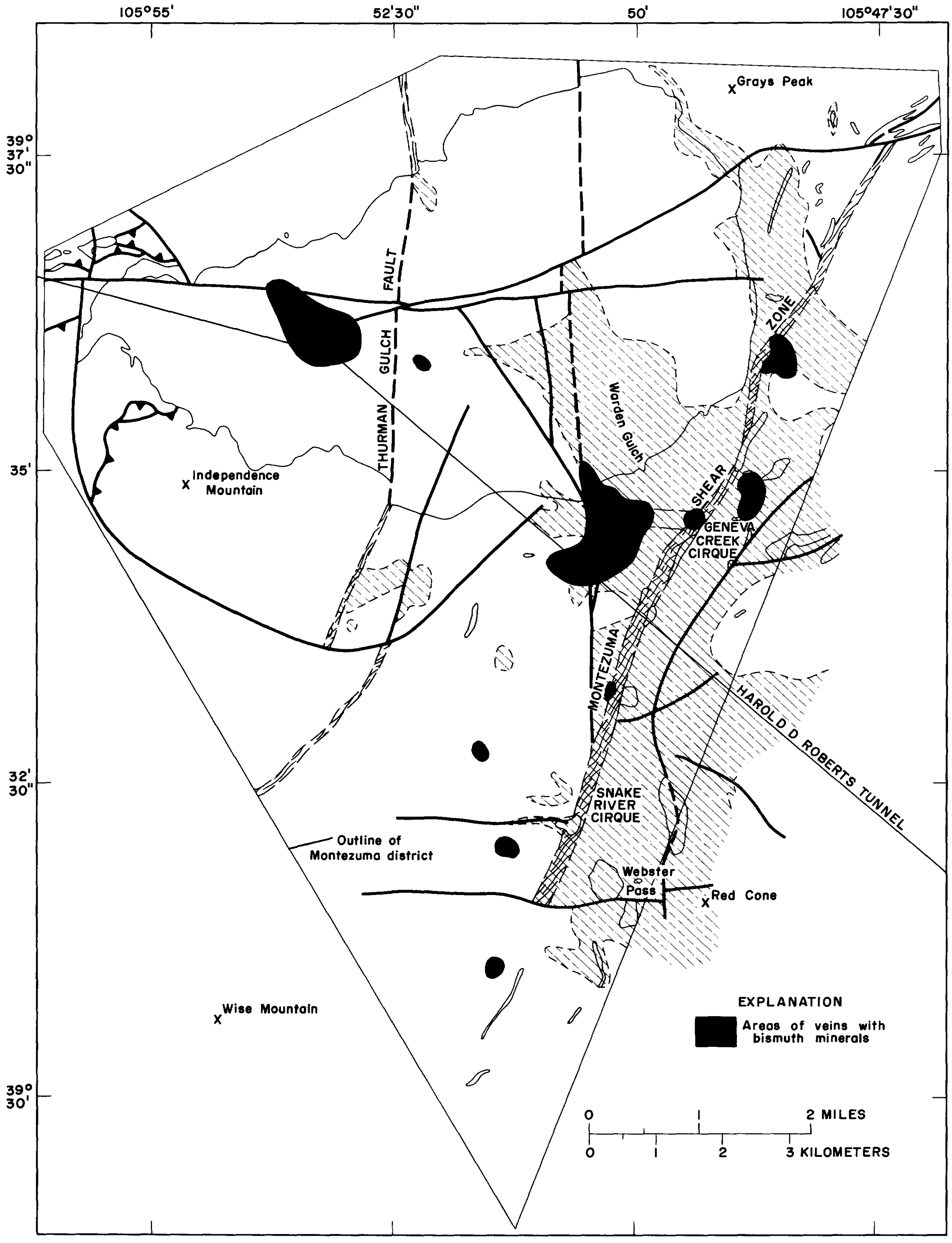

FIGURE 15. — The distribution of veins containing bismuth minerals.

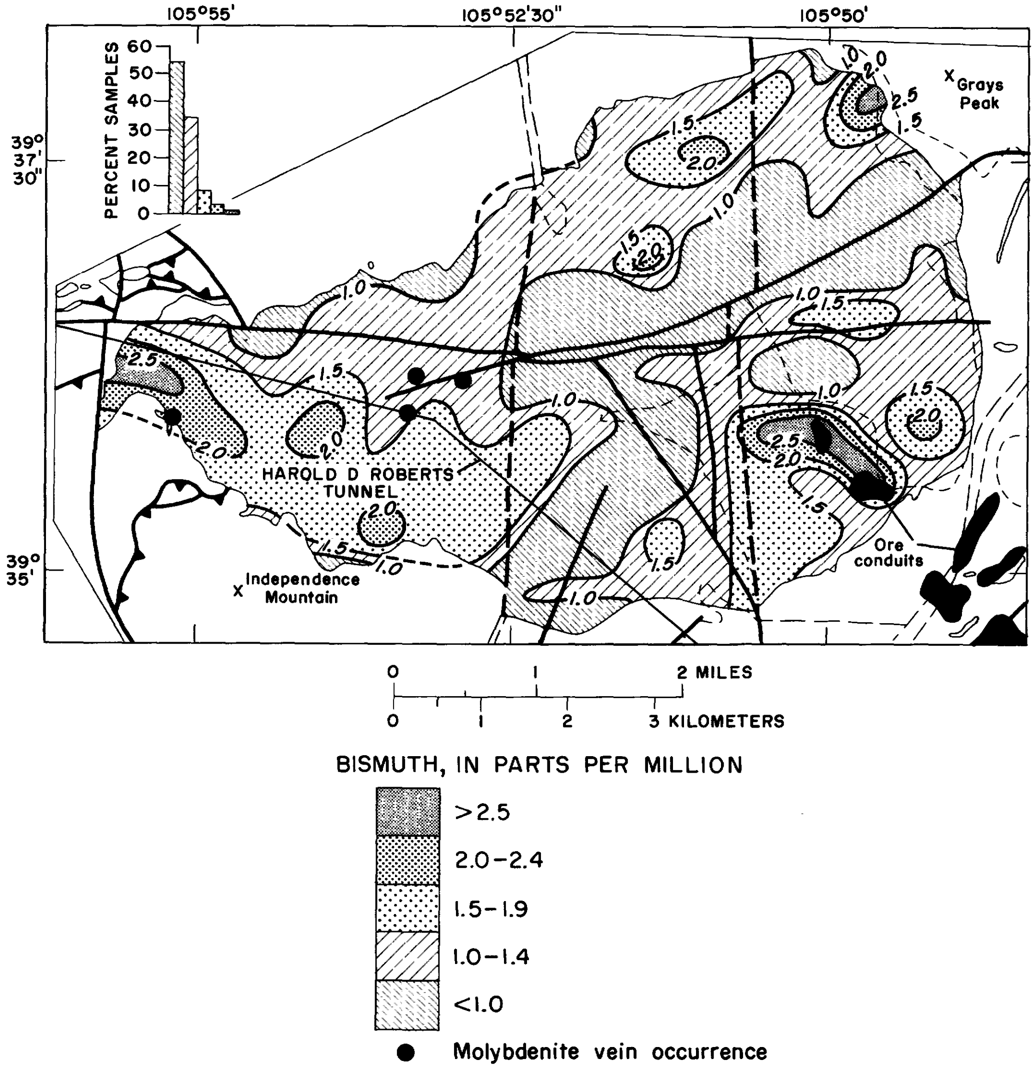

FIGURE 16. — The bismuth blip surface for the Montezuma stock. (See text.)

normal if apparently erratic companion of porphyry-metal deposits (Sillitoe, 1973, fig. 1). The metal-bearing volatiles for this skarn class of deposits are the same as for the porphyry-metal class, but here they move in response to an open-ended pressure gradient along an open structure, probably the Williams Fork thrust fault. Ore precipitation in this system results from the relative stagnation of structurally restricted flow or from contact with reactive rocks —at the edge of the intrusive or even at some distance away (Muilenburg, 1925, p. 54).

The two petrographically contrasting groups of molybdenite veins in the Montezuma district have equally contrasting significance for mineral deposit potential. The Snake River veins are the tip, or vanguard, of a porphyry-molybdenum deposit. The Independence Mountain veins are the roots, or spoor, of a skarn-molybdenum deposit, a deposit long since removed by erosion. If the high bismuth content of rocks in the Warden Gulch area is properly interpreted as locating another region of molybdenite veins, these veins must overlie another porphyry-molybdenum deposit because they are accompanied by porphyries and pervasive hydrothermal alteration.

SUMMARY

The Montezuma district conforms to the outer parts of a porphyry-metal model, extending from the outer tip of a potassic zone

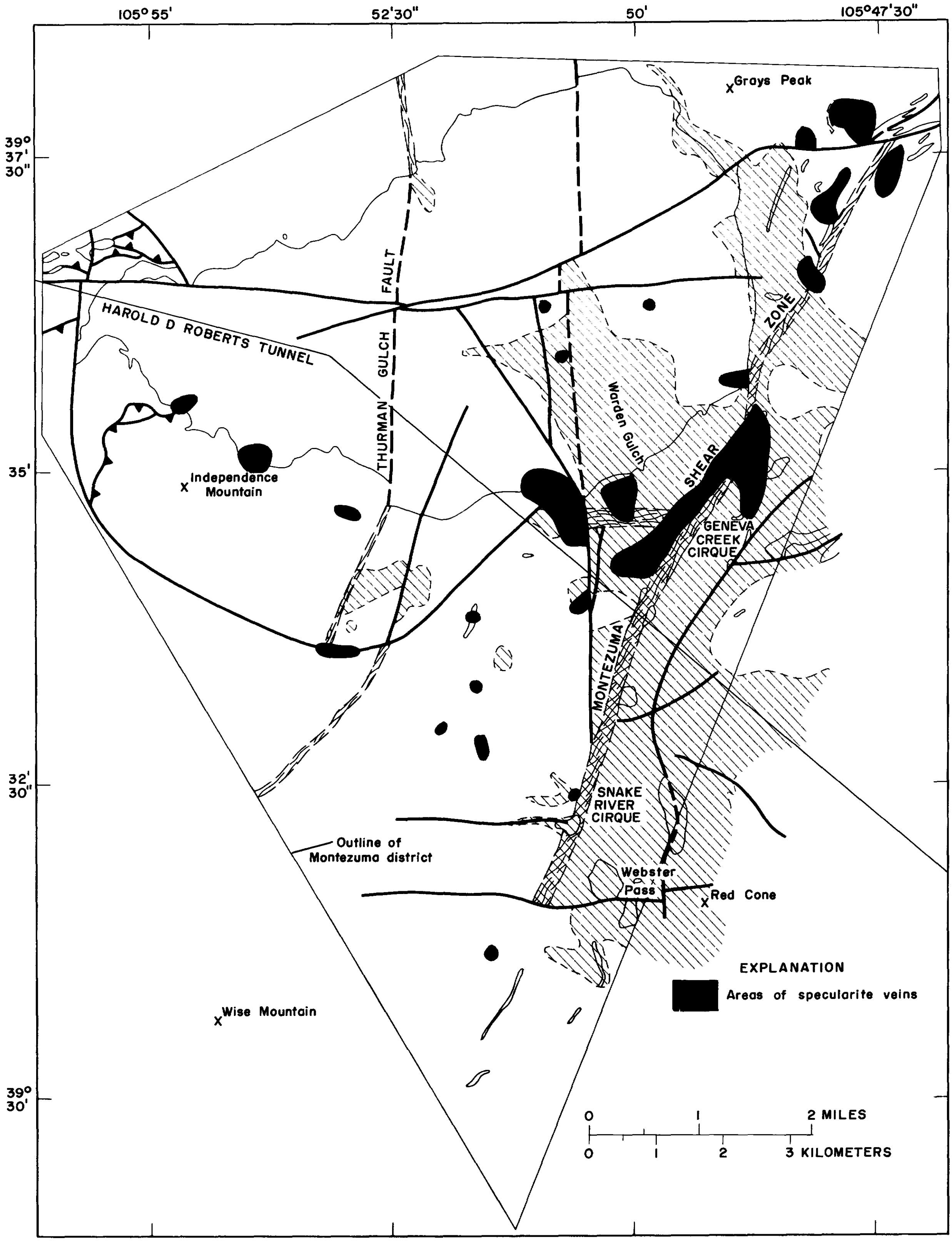

FIGURE 17. — The distribution of veins containing specularite.

through the propylitic zone with its fringe of silver-lead-zinc deposits. Owing to the linear influence of the Montezuma shear zone, the geometry of the alteration zones deviates from the standard pattern of concentric shells centered on an igneous plug. Intrusives and alteration zones are repetitive along the trend of the shear zone above the relatively flat roof of the Montezuma stock. As a result the alteration zones have a highly irregular, mottled distribution.

The worldwide consistency in the zonal composition of the porphyry-metal class of ore deposits suggests one or more disseminated deposits of molybdenum below present exposures. The exposed tip of a potassic alteration zone with molybdenite mineralization is consistent with this model-based postulate. Molybdenite mineralization in otherwise unaltered rock of the Montezuma stock records only the passage of contact-metasomatic ore fluids. If the abundant silver-lead-zinc veins are accompanied by a proportionately large amount of molydenum, the postulated molybdenite deposits of the Montezuma district may be a very large resource. However, the dispersed pattern of multiple small tendrils of phyllic alteration rather than a thick single blanket may mean that most of the molybdenite deposits are small and dispersed. In addition, molybdenite deposits at the bottom of this digitated phyllic zone might be too deep to be economically minable.

As a prospecting guide, regions defined by high rock-bismuth or by bismuth veins, respectively, contain or overlie regions of molybdenite veins. Some of these regions of molybdenite veins are probably halos of unknown thickness around molybdenite ore deposits. Areas of specularite veins are generally associated with bismuth veins, are larger targets that are more easily detected, and may serve to focus a search for areas enriched in bismuth.

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