

Geochemical Characteristics of Mineralized Breccia Pipes in the Red Mountain District, San Juan Mountains, Colorado

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By FREDERICK S. FISHER and WILLARD P. LEEDY

G E O L O G I C A L S U R V E Y B U L L E T I N 1 3 8 1

A study of the distribution of oxides and elements in altered volcanic rocks around and within breccia pipes in the northwest San Juan Mountains



UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOCHEMICAL CHARACTERISTICS OF MINERALIZED BRECCIA PIPES IN THE RED MOUNTAIN DISTRICT, SAN JUAN MOUNTAINS, COLORADO

By **FREDERICK S. FISHER** and **WILLARD P. LEEDY**¹

ABSTRACT

Distinctive geochemical anomalies associated with upper Tertiary breccia pipes in the northwest San Juan Mountains, Colo., provide useful prospecting guides and help in characterizing and delineating types of altered rocks in the area.

Highly altered silicified rocks in the central zones of the pipes have been extensively leached of aluminum, magnesium, calcium, sodium, and potassium and consist of porous masses of quartz and sparse diaspore, barite, alunite, rutile, and leucoxene. Moderately altered rocks adjacent to and somewhat intermixed with the quartzose zones are composed of abundant clay minerals and lesser amounts of quartz, alunite, pyrophyllite, and rutile. These rocks have also been leached, but less completely than the highly altered rocks. The least altered rocks, in the outermost zones of the pipes, are characterized by fine-grained micaceous minerals, quartz, and pyrite; they are depleted of calcium and magnesium but are relatively unchanged in their content of aluminum, potassium, and sodium.

Sulfide minerals associated with the pipes have high ratios of sulfur to metal and comprise silver-bearing copper and lead sulfosalts of arsenic and antimony and common base-metal sulfides. The concentrations of ore metals are generally greatest in the most intensely altered rocks and decrease progressively in less altered rock types. Silver, arsenic, gold, bismuth, lead, and antimony are probably the most useful elements in the prospecting for new breccia pipes.

INTRODUCTION

Pods, lenses, and vertical chimneys of ore in breccia pipes of the northwest San Juan Mountains, Colo., were intensively mined during the late 1800's. Even though much favorable ground still remains, subsequent mining and production of breccia-pipe ore have been minor and sporadic. Total production from the pipes is unknown; however, it probably exceeded \$10 million (Burbank, 1947, p. 430). Prospecting for new pipes is difficult because of the small size of the structures, the complex geology, and the widespread hydrothermal alteration of the country rocks. Burbank (1947, p. 430-431) suggested that geochemical methods of prospecting might be useful in searching for new breccia-pipe targets. Fischer, Luedke, Sheridan, and Raabe (1968) noted that

¹Kalium Chemicals Ltd., Prescott, Ariz.

silver, copper, antimony, bismuth, mercury, and tin were more abundant in samples of pipe ore and gangue than in country rock; Burbank, Luedke, and Ward (1972) discussed the occurrence of arsenic and several other trace elements in samples from five localities in the Red Mountain district.

The objectives of our study were to (1) determine the geochemical characteristics of altered rock types associated with the mineralized breccia pipe, (2) statistically examine the variability in the geochemical data as an aid to its interpretation, and (3) determine what elements are most useful in searching for new breccia pipes.

GEOLOGIC SETTING

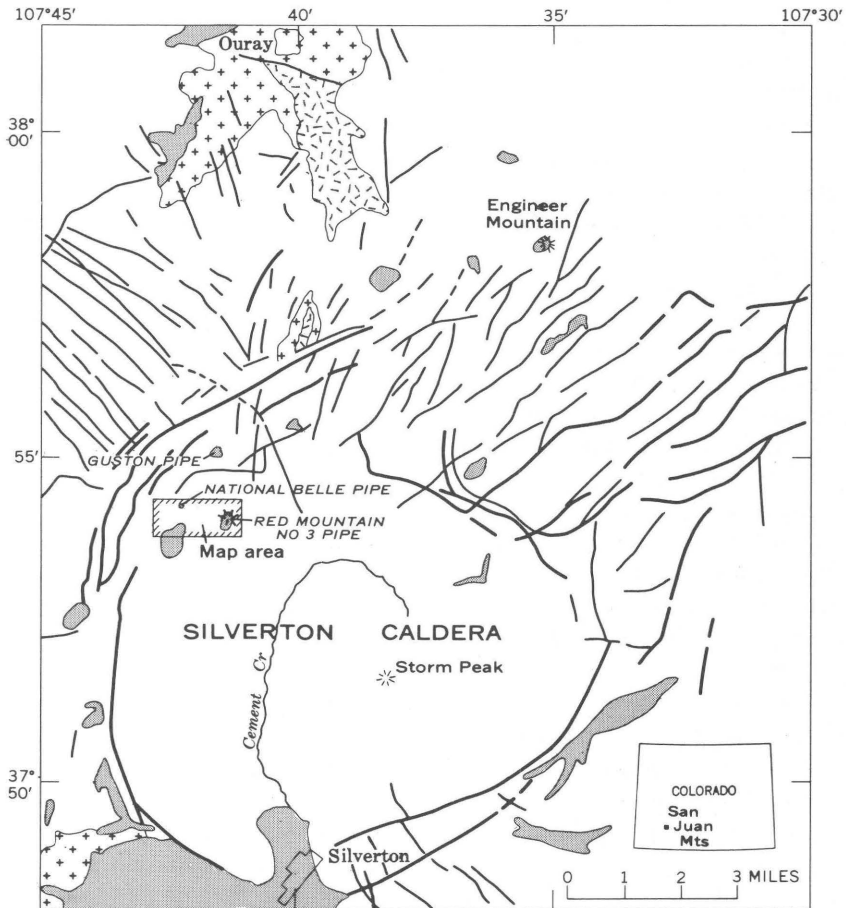
The breccia pipes of the Red Mountain district are in or near the ring-fault zone along the northwestern side of the Silverton caldera (fig. 1), a collapse structure that subsided as a result of the eruption of large volumes of rhyolitic and latitic ash flows during mid-Tertiary time. After subsidence, the collapsed block and surrounding area were faulted and resurgently domed, and numerous intrusive bodies were emplaced in the ring-fault zone and elsewhere in and near the caldera (Luedke and Burbank, 1968).

Widespread propylitic alteration, characterized mainly by the addition of water and carbon dioxide (Burbank and Luedke, 1969; Burbank, 1960), occurred during and after the late igneous activity. Later, hydrogen ion metasomatism and the resultant base cation leaching occurred in local areas within the caldera, especially in the Red Mountain district within and near breccia pipes and along numerous faults and fractures. This later alteration, called solfataric by Burbank and Luedke (1969) and Burbank (1950), resulted from hydrogen ion metasomatism as described by Hemley and Jones (1964). The term "solfataric" implies, by definition, a surface or near-surface phenomenon associated with volcanism, whereas the altered rocks now exposed in the Red Mountain area were metasomatized at depths from several thousand feet to as much as a mile below the ground surface (Burbank and Luedke, 1969, p. 31; Burbank, 1950, p. 310, fig. 4).

STRATIGRAPHY

Layered volcanic rocks in the Red Mountain district are part of the middle Tertiary (Oligocene) Silverton Volcanic Group and are composed of several thousand feet of rhyodacitic, andesitic, and rhyolitic lava flows, breccias, and tuffs. Numerous small stocks, dikes, and breccia bodies ranging in composition from rhyolite to quartz latite and andesite cut all the layered rocks (Burbank and Luedke, 1964).

In the Red Mountain district layered volcanic rocks have been divided into the Burns and Henson Formations (Burbank and Luedke, 1964). The Burns Formation is composed of several thousand feet of



EXPLANATION

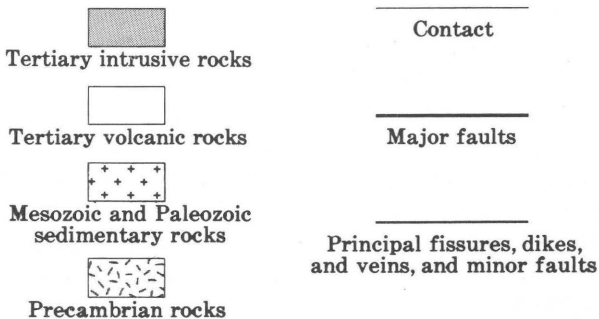


FIGURE 1. — The National Belle and Red Mountain No. 3 areas, the area shown in figure 2 (hachures), and principal structural features in the vicinity of the Silverton caldera. (Modified from Burbank, 1947, pl. 28.)

thin to thick lava flows, breccias, and tuffs that are mainly rhyodacitic in composition. The formation has been divided into lower and upper members, each consisting of several units (Burbank and Luedke, 1969, p. 10).

The overlying Henson Formation is defined as andesitic to rhyodacitic tuffs, lava flows, and breccias and scattered rhyolitic and quartz latitic lava flows and tuffs. Its maximum thickness is generally 800-1,000 feet, possibly more in a few areas (Burbank and Luedke, 1969, p. 12).

In the western part of the Red Mountain district (fig. 2) where the rocks are somewhat less altered, the flow-layered unit of the lower member of the Burns Formation has been recognized. This unit comprises most of the country rocks surrounding the National Belle and Hero pipes. The remainder of the mapped area (fig. 2) is probably composed of the flow unit of the upper member of the Burns and possibly the lower part of the Henson Formation.

Because of the extensively altered character of the country rocks, the relatively sparse outcrops, and the limited extent of the mapped area (fig. 2), we believe that identification of the rocks as specific formations for the purposes of this study would be impractical and possibly misleading. Therefore the rocks are distinguished on the map according to lithology.

Four rock types were mapped: quartz latite intrusives, propylitized flows and breccias, intensely silicified rocks, and illitic rocks.

Small irregular stocks of quartz latite are commonly associated with the breccia pipes. Their emplacement was undoubtedly controlled in large part by the same structures that controlled the emplacement of the pipes. In hand specimens the quartz latite is dark to light gray and contains large (1-4 cm) phenocrysts of potassic feldspar and smaller phenocrysts of ferromagnesian minerals and quartz all set in an aphanitic groundmass. The groundmass makes up 50-60 percent of the rock, and as seen in thin section it has a felted to pilotaxitic texture and consists of microlites of potassic feldspar, plagioclase, quartz, and some magnetite. Where altered, these rocks are bleached light gray to white. Feldspars are altered to sericite and clay; augite, to chlorite and calcite; and biotite, to sericite. Pyrite is common in the groundmass.

Propylitized flows and breccias are common in the western part of the mapped area and occur elsewhere as scattered isolated patches of rocks (fig. 2). Despite various degrees of alteration, the original character of the rock usually is still evident. In hand specimen these rocks are purplish to greenish to dark gray and commonly contain small (1-2 mm) phenocrysts of feldspar and ferromagnesian minerals. The groundmass of the flow rocks ranges in texture from cryptocrystalline to felted to pilotaxitic. Phenocrysts are mostly augite, plagioclase (An_{30-45}),

hornblende, and biotite. Glomeroporphyritic clusters of these minerals are fairly common, as are lithic and crystal fragments. Accessory minerals are magnetite, rutile, and apatite. In some flows the ground-mass contains abundant potassic feldspar and quartz.

Interbedded locally with the flows are volcanic breccias. These rocks, in their overall mineralogical characteristics, are similar to the just-described flows. The fragments in the breccias are small (1-10 cm) and in general are composed of the same type of materials as the flows. Commonly the breccias are highly altered, and therefore their original mineralogy cannot be definitely determined.

Where altered, the propylitic rocks are characterized principally by epidote, carbonates, chlorite, and albite and subordinate amounts of fine-grained micaceous minerals (sericite(?) and illite). The degree of propylitization was rather variable in the area, and the propylites in hand specimen range from greenish-gray rocks having their original texture and mineralogy well preserved to highly bleached rocks consisting of fine-grained alteration products in which the original texture and mineralogy have been completely destroyed.

Intensely silicified rocks are abundant in the mapped area and occur mainly in the upper parts of the breccia pipes and, to a lesser degree, adjacent to some fractures. The silicified rocks range from vuggy, cavernous breccias to dense, massive rocks composed of very fine grained silica. Quartz, the predominant mineral, occurs in many forms. Within the breccias it ranges from cryptocrystalline to chalcedonic to anhedral grains in both the groundmass and fragments. Small (< 2 mm) crystals of quartz commonly line cavities within the breccias. In more massive rocks the quartz occurs as very fine grains (< 1 mm) within a siliceous cryptocrystalline groundmass. Rock fragments in the breccias are generally angular and range in size from < 1 cm to approximately 10 cm. They are composed of the same material as the groundmass. Irregular veinlets of silica are common in both the breccias and the massive rocks. In many places the rocks are stained with iron oxides from the oxidation of pyrite. Sparse barite, leucoxene, alunite, rutile, and diaspore are also in the siliceous rocks.

Irregular zones, pods, and lenses of argillic material occur within and adjacent to the intensely silicified rocks and, for mapping purposes, were included as part of the silicified rocks. They are also associated with some fractures. In hand specimen these rocks are grayish-white to yellow fine-grained to massive aggregates of clay and quartz. They contain kaolinite, dickite, quartz, and alunite; minor amounts of pyrophyllite, rutile, and diaspore; and sparse barite.

The fourth mapped unit (fig. 2) consists of fine-grained light-gray to yellowish illitic rocks that are composed mainly of quartz, pyrite, and fine-grained micaceous minerals. In thin section these rocks are seen to



EXPLANATION

<div>Qs</div>	<div>Contact</div>
Quaternary surficial deposits	<i>Approximately located</i>
<div>Tql</div>	<div>U</div>
Tertiary quartz latite intrusives	D
<div>Tp</div>	Ring fault of Silverton caldera
Tertiary propylitized flows and breccias	U, upthrown side; D, downthrown side
<div>Ts</div>	<div>Fault or fissure</div>
Tertiary intensely silicified rocks	> Adit
<div>Til</div>	■ Shaft
Tertiary illitic rocks	x Prospect pit
	• ² Sample locality

be cryptocrystalline to microcrystalline and to be composed of quartz, illite, sericite(?), and minor amounts of clay, carbonates, chlorite, and rutile. Epidote is present as small irregular crystals in the groundmass



FIGURE 2. — Geologic map of the National Belle and Red Mountain No. 3 areas. Geology Mapped by Willard P. Leedy and F. S. Fisher, 1968-69. Base from U.S. Geol. Survey Iron-ton 7 1/2-minute topographic map, 1955.

and as somewhat larger crystals occupying plagioclase voids. Commonly the original texture of these rocks has been obliterated by alteration products. These rocks are relatively common in the area and occur in the outermost zones of the breccia pipes and also near fractures.

STRUCTURE

Ring faults of the Silverton caldera are the major structural features within the mapped area (fig. 2). These faults undoubtedly controlled the localization of many of the breccia pipes in the district by providing

channelways for the altering and mineralizing solutions. Less obvious fissures and fractures in the mapped area also may have acted as channelways for solutions and thus may have localized breccia pipes. The linear nature of many of the breccia pipes, particularly at depth (Burbank, 1941, p. 187; Ransome, 1901, p. 106), indicates the importance of fracture control in their formation. Innumerable small fissures and fractures, not shown on the map, are probably related to the major fractures in the area. Many of these contain fillings of pyrite, but other sulfides are scarce.

The layered volcanic rocks in the mapped area dip a few degrees to the west and northwest or are generally flat lying. Local variations in attitude occur, particularly near the major faults and in the vicinity of the breccia pipes.

GEOLOGICAL FEATURES OF BRECCIA PIPES IN THE RED MOUNTAIN DISTRICT

PHYSICAL CHARACTERISTICS

Individual breccia pipes are irregular in plan view, and usually their horizontal dimensions are considerably smaller than their vertical dimensions which range from several hundred to at least a thousand feet. The axes of the pipes are steeply dipping to nearly vertical; changes in the axial pitch of individual pipes are common. Generally the pipes crop out as low mounds of silicified rock. Well-defined pipes commonly have a zone of vertical sheeting around the outer edge; in less well defined pipes the breccia grades continuously outward into relatively unbroken country rock. Many contain small intrusive bodies which range in composition from rhyolite to quartz latite.

Rocks within the breccia pipes are highly shattered and altered. Apparently brecciation in some of the pipes caused almost no vertical movement of solid rock material. The brecciation may have resulted from one or more processes: explosive release of hot juvenile gases, a more passive release of gases and slow brecciation of the surrounding country rocks by chemical and volume changes (Burbank, 1941, p. 177), and brecciation due to the emplacement of the intrusive bodies. In some places the country rock is a volcanic breccia, and intense alteration of this breccia adjacent to fractures in local areas produced a pipelike structure in the rocks.

ORE BODIES AND ALTERED ROCKS

Individual ore bodies within the pipes have highly irregular shapes and range in form and size from small pods and lenses a few feet in the longest dimension to nearly vertical chimneys several hundred feet in height and several tens of feet in width (Ransome, 1901, p. 103). The ore chimneys are composed of massive sulfides and were formed by open-

space filling in the upper cavernous parts of the pipes and by replacement at depth.

In general the ore minerals are vertically zoned within the pipes, changing with increasing depth from lead-rich ores to copper-silver ores to pyritic copper-arsenic ores (Burbank, 1941, p. 181). There is considerable overlap and telescoping of the different ore zones within individual pipes, and in some pipes the zoning is exceedingly complex. Principal sulfide minerals in the ore bodies are pyrite, enargite, chalcopyrite, chalcocite, covellite, bornite, sphalerite, and galena. Other minerals that are economically important in some of the ores are pyrargyrite, proustite, stromeyerite, tennantite, and free gold. Numerous other sulfides are locally present in trace amounts in the ores. With the exception of pyrite, quartz, and clay, the gangue minerals are sparse and consist of alunite, barite, fluorite, zunyite, diaspore, and pyrophyllite.

The distribution patterns of the altered rocks within the pipes indicate that the intensity of base cation leaching decreased downward and outward from the center of the pipes (Burbank, 1950). Ideally, highly silicified breccias form caps or irregular massive bodies near the upper-central parts of the pipes or next to major channelways. Adjacent to and intermixed within the silicified breccias are kaolin-rich clays of the argillic rock group. The argillic rocks commonly are poorly exposed in outcrop but appear to grade laterally into illitic rocks at the perimeter of the pipes. The pattern of alteration was thus one of decreasing hydrogen ion activity away from the center of the pipes or away from the major channelways. With increasing depth within the pipes, the silicified rocks give way to the argillic rocks, which pass into quartz-illitic rocks at still deeper levels, where base cation leaching was less intense.

AREAS OF DETAILED STUDY

Two areas in the Red Mountain district were selected for detailed study: the National Belle breccia pipe and the Red Mountain No. 3 breccia pipe (fig. 2). The National Belle pipe is generally typical of the district's mineralized breccia pipes; rock exposures in and around the pipe are adequate for study, it is readily accessible, and silver, lead, copper, gold, and zinc ore have been mined from it in the past. The Red Mountain No. 3 pipe is a large, conspicuously altered pipe that has not been adequately explored, and our reconnaissance samples from the pipe had shown anomalous amounts of metallic elements.

NATIONAL BELLE PIPE

The National Belle pipe, about 400 feet in diameter, crops out as a circular knob about 200 feet high. The core of the pipe is a silicified and kaolinized breccia and is encircled by a zone of highly silicified cavernous breccia which makes up the sides of the knob. The outermost

envelope of the pipe is a poorly exposed zone of pyritized illitic rock which grades into propylitized country rock. Rocks of the core of the pipe and of the silicified rim have been extensively altered and leached. They are composed mostly of quartz and kaolinite, with lesser amounts of pyrite, alunite, and barite (Burbank, 1941, p. 185).

The National Belle mine (fig. 2) was active during the late 1800's. Total production is unknown, but it was probably valued at several hundred thousand dollars to \$1 million. The mine was developed to a depth of about 450 feet, but most of the ore was produced from the upper 300 feet (Ransome, 1901, p. 231-236; Schwarz, 1890). The ore occurred as oxidized material in caverns in the upper parts of the mine and as sulfide minerals in the deeper parts. The oxidized ore was mainly carbonates of lead and iron, lead sulfates, iron oxides, sphalerite, and arsenates. Some residual galena and enargite were present as cores within the oxidized masses of ore contained in the caverns. The caverns, some of which were as large as 50 feet in diameter, decrease in size and number with depth (Schwarz, 1890, p. 141).

The sulfide ore deeper in the mine occurred as irregular masses in the altered rock and consisted mainly of enargite with lesser amounts of chalcopyrite, galena, sphalerite, and tetrahedrite. The ore was generally argentiferous and also contained some free gold.

RED MOUNTAIN NO. 3 PIPE

The Red Mountain No. 3 breccia pipe is exposed as a crudely elliptical zone of silicified and kaolinized rock about 2,500 feet long that trends northeast (fig. 2). An elongate quartz latite intrusive body is exposed in the center of the pipe. The remainder of the central part of the pipe is mostly covered by soil and talus but appears to be composed of altered, kaolinized breccia. A zone of highly silicified rock surrounds the pipe and is conspicuous on the southwest side. Vugs and large caverns are common in the silicified rocks. Quartz and kaolin are the most abundant minerals, and alunite occurs in lesser amounts. Meteoric water has leached most of the original pyrite from the rock, and so only minor pyrite and some oxide boxworks remain. Rocks outside the silicified zone are either propylitized material similar to the country rocks near the National Belle pipe or fine-grained altered rock containing quartz, micaceous minerals, pyrite, and some clay.

Some exploration beneath the Red Mountain No. 3 pipe was undertaken in the late 1940's (Hillebrand and Kelley, 1957, p. 194). Two crosscuts at an elevation of about 10,800 feet were driven from the main drift of the Genessee-Vanderbilt mine beneath the areas of silicified rock on the eastern and western sides of the pipe (fig. 2). Diamond drilling was done from the crosscuts along the sides and toward the center of the pipe. Some mineralized rock was penetrated in the drilling and crosscuts; however, no production of ore is recorded. Pyrite, enargite,

and minor chalcopyrite were found, mainly in northward-striking fissures, together with a gangue of kaolin and some alunite. The country rocks are highly altered and contain abundant fine-grained disseminated pyrite and clay.

SAMPLING METHODS

To determine the geochemical anomalies associated with the breccia pipes and to help characterize the nature of altered rocks in the area, 126 rock samples collected from 63 sample sites were chemically analyzed. The sample sites (fig. 2) were randomly selected from available rock outcrops. Two samples, each consisting of about 3 pounds of rock chips 1-2 cm in size, were collected from each site. Each sample was ground to a powder before a split was taken for chemical analysis. The analytical results for selected elements are given in table 1.

On the basis of X-ray and petrographic analyses the altered rocks were classified into four types: propylitic, silicified, argillic, and illitic. These types coincide only partly with the four mapped rock types. The propylitic rocks were formed by districtwide propylitization, whereas the other three types were formed locally by hydrogen ion metasomatism and represent an advanced argillic alteration assemblage.

METHODS OF STATISTICAL ANALYSIS

The geochemical data were statistically analyzed to determine and evaluate differences in the chemistry of the various rock alteration assemblages. Histograms and geometric means were used to summarize and characterize the data. Analysis of variance was used to examine variability and to estimate variance components. The statistical significance of the differences between geometric means for each element in the various groups of altered rock was determined by use of a two-tailed Student's *t*-test.

Most of the frequency distributions of the original chemical data are positively skewed; accordingly a log transformation was used to normalize the data (Bennett and Franklin, 1954, p. 91; Miesch, 1967, p. B5). In general the transformation of the data to logs was effective in producing distributions that tend to be normal or at least roughly symmetrical. The transformed data were plotted as histograms, one for each element in each of the four main types of altered rocks in different areas (figs. 3-6). Geometric means for each distribution, also shown in figures 3-6, were estimated by use of the antilog of the arithmetic mean of the logs (Bennett and Franklin, 1954, p. 18). The geometric mean is an estimate of central tendency of a frequency distribution that is roughly symmetrical on a log scale, and it is therefore useful for describing and characterizing the abundance of a given element in an individual sample group (Miesch, 1967).

TABLE 1. — *Geochemical data for selected elements*

[Sample localities shown in figure 2. Silver, bismuth, copper, manganese, lead, antimony, strontium, zinc, gallium, SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , K_2O , and arsenic analyses were made by X-ray fluorescence by J. S. Wahlberg and B. Breeden, J. A. Thomas, G. D. Shipley, W. D. Goss, E. J. Rowe, and Wayne Mountjoy. Symbols used: L, detected

Sample No.	Rock or alteration type	Oxide, in Percent							Ag
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	
1A	Silicified	95	1.0L	0.3	0.02	0.1L	0.01	0.1L	3.0N
1B	.....do	89	1.0L	.3	.02	.1L	.02	.1L	3.0N
2A	Illitic	55	17.0	.5	.01	.3	1.47	2.4	3.0N
2B	.....do	59	15.0	.7	.01	.3	1.26	2.4	3.0N
3A	Argillic	66	20.0	1.1	.02	.1L	.05	1.1	15.0
3B	.....do	66	19.0	..8	.02	.1L	.04	.1L	23.0
4A	Silicified	93	3.0	1.6	.01	.2	.01	.1L	45.0
4B	.....do	93	1.0	1.3	.01	.1L	.01	.1L	46.0
5A	.....do	88	2.0	4.4	.01	.1L	.03	.1	21.0
5B	.....do	91	1.0	4.5	.02	.1L	.02	.1L	20.0
6A	.....do	84	3.0	1.7	.02	.1L	.02	.1L	9.0
6B	.....do	91	1.0	1.7	.01	.1L	.01	0.1	7.0
7A	.....do	99	1.0L	1.0	.02	.1L	.02	.1L	5.0
7B	.....do	94	1.0L	.8	.02	.1L	.02	.1L	3.0N
8A	.....do	92	2.0	2.2	.02	.1L	.02	.1	35.0
8B	.....do	91	2.0	2.0	.01	.1L	.02	.1L	51.0
9A	.....do	95	1.0L	.5	.01	.3	.02	.1	3.0N
9B	.....do	99	1.0L	.5	.01	.1	.02	.1	3.0N
10A	Propylitic	58	15.0	8.3	1.09	3.7	1.87	3.6	3.0N
10B	.....do	60	19.0	8.6	1.15	3.9	1.91	3.7	3.0N
11A	.....do	60	16.0	10.4	1.09	.3	.07	3.3	3.0N
11B	.....do	65	14.0	10.7	.94	.3	.07	2.9	3.0N
12A	.....do	57	15.0	8.0	.89	4.5	1.00	4.2	3.0N
12B	.....do	64	23.0	8.1	.87	4.9	1.01	4.1	3.0N
13A	.....do	59	15.0	7.3	.92	5.4	1.02	4.1	3.0N
13B	.....do	59	15.0	7.8	.90	5.6	.90	3.8	3.0N
14A	.....do	54	14.0	9.2	1.04	4.9	1.50	4.0	3.0N
14B	.....do	54	16.0	9.5	1.11	5.4	1.04	3.9	3.0N
15A	Silicified	94	1.0L	2.7	.02	.1L	.02	.1L	15.0
15B	.....do	92	1.0	1.7	.02	.1L	.02	.1L	13.0
16A	Propylitic	58	14.0	7.4	3.06	3.8	.03	4.6	3.0
16B	.....do	56	14.0	7.2	3.10	3.6	.03	4.6	3.0N
17A	.....do	62	16.0	8.8	3.37	.2	.02	4.7	3.0N
17B	.....do	62	14.0	8.6	2.24	.3	.02	4.3	3.0N
18A	.....do	58	14.0	7.4	1.22	4.7	.05	4.3	3.0N
18B	.....do	61	17.0	7.6	1.19	5.0	.06	4.4	3.0N
19A	.....do	57	14.0	7.1	2.28	6.0	2.12	3.6	3.0N
19B	.....do	57	16.0	7.8	1.57	6.0	2.04	3.6	3.0N
20A	Silicified	95	2.0	.9	.01	.1L	.01	.1L	17.0
20B	.....do	95	1.0L	.5	.10	.1L	.01	.1	3.0N
21A	Propylitic	64	16.0	7.8	2.85	2.4	.03	3.7	3.0N
21B	.....do	59	15.0	8.2	2.90	2.3	.03	3.4	3.0N
22A	.....do	62	16.0	8.2	.81	3.9	.70	4.7	3.0N
22B	.....do	61	15.0	8.3	1.22	3.7	.69	4.5	3.0N
23A	.....do	63	14.0	11.5	1.82	1.5	.06	3.0	3.0N
23B	.....do	62	13.0	11.2	1.75	.8	.07	2.7	3.0N
24A	.....do	61	11.0	12.5	2.21	2.1	.03	2.0	3.0N
24B	.....do	64	14.0	11.8	2.06	1.3	.04	2.5	3.0N
25A	.....do	59	15.0	9.6	1.28	.4	.09	3.6	3.0N
25B	.....do	63	15.0	9.0	2.25	.4	.03	3.4	3.0N
26A	Argillic	81	10.0	.4	.02	.2	.01	.1	3.0N
26B	.....do	82	9.0	.3	.02	.2	.01	.1L	3.0N
27A	Propylitic	54	17.0	9.6	1.51	6.4	.71	2.9	3.0N
27B	.....do	52	17.0	9.7	1.64	5.7	.17	3.0	3.0N
28A	.....do	58	16.0	7.7	1.34	3.6	2.08	2.9	3.0N
28B	.....do	56	16.0	6.8	1.24	4.0	2.28	3.0	3.0N
28A	Argillic	70	16.0	2.9	.01	.1L	.02	.1	3.0
29B	.....do	71	15.0	2.6	.01L	.1L	.01	.2	3.0N
30A	Propylitic	59	18.0	5.9	1.42	5.4	.10	4.4	3.0N
30B	.....do	59	16.0	6.1	1.39	5.9	.11	4.0	3.0N
31A	.....do	57	16.0	6.7	1.48	6.2	1.36	3.0	3.0N
31B	.....do	55	15.0	6.6	1.54	6.2	1.30	3.1	3.0N
32A	.....do	60	15.0	7.5	1.70	4.0	2.36	2.1	3.0N
32B	.....do	58	15.0	8.0	1.74	3.8	2.60	2.0	3.0N
33A	.....do	67	12.0	10.3	1.36	1.4	.06	2.1	3.0N
33B	.....do	65	12.0	11.0	1.50	1.5	.07	2.2	3.0N
34A	.....do	60	14.0	7.6	1.75	4.6	2.02	2.9	3.0N
34B	.....do	56	18.0	7.4	1.05	5.0	1.92	3.2	3.0N

from the National Belle and Red Mountain No. 3 areas

lanthanum, and nickel analyses were made by direct-reader spectrometry by R. G. Havens, N. M. Conklin, and L. M. Lee. M. W. Solt. MgO, Na₂O, and gold analyses were made by atomic-absorption spectrometry by J. M. Gardner, V. M. Merritt, L. but less than value shown; N, not detected at or below value shown]

Element, in parts per million										
As	Au	Bi	Cu	Mn	Pb	Sb	Sr	Zn	Ga	Ni
400	0.30	10N	11	30	110	300N	60	300N	10N	50N
500	.20	12	12	24	120	300N	60	300N	12	50N
40L	.05L	10	6	7N	560	300N	420	300N	23	60
40L	.05L	14	8	7N	570	300N	380	300N	28	60
200	.20	10	62	9	1400	300N	3500	300N	46	100
40L	.20	14	38	9	1300	330	2000	300N	44	90
70	.40	28	24	36	190	350	30N	300N	10	50N
80	.40	20	20	7	130	300N	30N	300N	10	50N
130	2.90	110	59	15	210	590	400	300N	10N	50N
110	3.00	80	56	7N	170	575	255	300N	10N	50N
70	.40	12	72	10	290	300N	220	300N	10N	50N
50	.40	11	60	14	230	300N	150	300N	10N	50N
210	.30	10N	119	30	20N	300N	30N	500	10N	50N
260	.20	10N	124	18	20N	300N	30N	300N	10N	50N
4000	1.20	10N	1600	8	60	870	60	300N	10N	50N
3600	1.10	13	4000	11	75	1000	90	600	10N	50N
130	.10	10N	20	30	35	300N	130	300N	10N	50N
150	.20	10N	20	11	30	300N	90	300N	10N	50N
40L	.05L	10N	60	1700	20N	300N	600	300N	25	90
40L	.05L	10N	51	1800	20N	300N	440	300N	25	77
40L	.05L	10N	66	1200	20N	300N	30N	300N	26	60
40L	.05L	10N	66	1200	20N	300N	50	300N	23	50N
40L	.05L	10N	84	1100	20N	300N	360	300N	24	78
40L	.05L	10N	88	1300	20N	300N	420	300N	27	94
40L	.05L	10N	54	900	20N	300	330	300N	23	73
40L	.05L	10N	49	1100	20N	300N	340	300N	23	78
40L	.05L	10N	27	2700	20N	300N	260	300N	30	64
40L	.05L	10N	120	3000	20N	300N	320	300	27	80
290	.40	16	1400	14	47	300N	30N	1200	10N	50N
550	.30	15	1800	36	41	300N	30N	630	10N	50N
40L	.05L	10N	60	1800	20	300N	60	300N	27	71
40L	.05L	10N	60	1500	29	300N	30N	300N	26	54
40L	.05L	10N	49	1100	31	300N	30N	620	30	65
40	.05L	10N	60	690	20N	300N	30N	550	22	60
40L	.05L	10N	52	1300	20N	300N	300	300N	28	82
40L	.05L	10N	43	1200	23	300N	270	300N	34	83
40L	.05L	10N	42	1650	21	300N	1550	300N	25	74
40L	.05L	10N	43	1700	29	300N	1900	300N	25	78
130	.07	15	37	24	95	300N	100	300N	10N	50N
250	.05L	10N	25	7	70	300N	30N	300N	10N	50N
40	.05L	10N	70	3400	880	300N	30N	300N	30	70
40L	.05L	10N	60	3000	20	300N	30N	300N	30	61
40L	.05L	10N	53	1300	20N	300N	225	300N	26	60
40L	.05L	10N	60	1600	20N	300N	240	300N	24	63
40L	.05L	10N	84	790	30	300N	70	300N	26	50N
40L	.05L	10N	82	890	25	300N	90	300N	25	56
40L	.05L	10N	84	1450	35	300N	100	485	23	56
40L	.05L	10N	73	830	27	300N	30	300N	21	50N
40L	.05L	10N	51	2550	56	300N	60	300N	28	58
40L	.05L	10N	48	2400	76	300N	40	300N	24	50N
40L	.05L	10N	19	22	37	300N	300	300N	10N	50N
40L	.05L	10N	16	9	44	300N	370	300N	15	56
40L	.05L	10N	110	2100	20N	300N	160	300N	27	74
40L	.05L	10N	100	1600	20N	300N	120	300N	27	60
40L	.05L	10N	120	1200	20N	300N	490	300N	25	77
40L	.50L	10N	100	1100	20N	300N	370	300N	24	60
40	.05L	17	31	7N	470	300N	1100	300N	25	94
80	.05L	17	30	7N	415	300N	690	300N	22	95
40L	.05L	10N	61	1200	20N	300N	220	300N	29	69
40L	.05L	10N	60	1300	20N	300N	300	300N	25	80
40L	.05L	10N	46	1200	20N	300N	420	300N	28	64
40L	.05L	10N	49	1300	20N	300N	510	300N	26	60
40L	.05L	10N	51	1250	27	300N	420	300N	24	67
40L	.05L	10N	52	1200	38	300N	380	300N	22	60
40L	.05L	10N	60	1250	20N	300N	85	300N	22	76
40L	.05L	10N	60	1400	20N	300N	160	300N	24	60
40L	.05L	10N	49	2100	20N	300N	460	300N	26	74
40L	.05L	10N	46	2100	20N	300N	600	300N	24	72

TABLE 1. — *Geochemical data for selected elements from*

Sample No.	Rock or alteration type	Oxide, in Percent						
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O
35A	.....do	60	20.0	8.0	.93	3.0	1.80	3.2
35B	.....do	60	16.0	8.1	1.00	3.4	1.80	3.0
36A	.....do	58	16.0	15.6	.12	.2	.18	2.4
36B	.....do	59	14.0	15.7	1.30	.2	.06	2.3
37A	.....do	54	14.0	8.4	.86	5.5	.73	3.5
37B	.....do	55	15.0	8.3	.86	5.5	.77	3.6
38A	Argillic	74	12.0	.8	.01	.1L	.04	.1L
38B	.....do	77	12.0	.8	.01	.1L	.01L	.1L
39A	Intrusive quartz latite	56	14.0	6.2	6.10	4.2	.08	5.0
39B	.....do	56	13.0	5.9	5.99	4.2	.11	5.4
40A	Propylitic	55	17.0	8.3	1.73	6.8	.17	3.4
40B	.....do	57	13.0	9.8	1.60	5.5	.15	3.6
41A	Intrusive quartz latite	75	16.0	1.5	.02	.1L	.01	.1L
41B	.....do	71	16.0	2.0	.01	.1L	.01	.1L
42A	Silicified	96	1.0	.4	.01	.1L	.01L	.1L
42B	.....do	92	1.0L	.4	.02	.1L	.01L	.1L
43A	.....do	95	1.0L	.8	.02	.1L	.01	.1
43B	.....do	94	1.0	.8	.01	.1L	.01	.2
44A	Intrusive quartz latite	55	13.0	6.1	2.83	4.6	1.96	7.2
44B	.....do	57	14.0	7.4	7.35	5.1	2.00	7.6
45A	Silified	95	2.0	.8	.02	.1L	.01L	.1L
45B	.....do	95	1.0L	.9	.02	.1L	.01L	.1L
46A	.....do	94	1.0L	.7	.02	.1L	.01	.1L
46B	.....do	96	1.0L	.6	.02	.1L	.01	.1
47A	.....do	97	1.0L	.5	.02	.1L	.01L	.1L
47B	.....do	97	1.0L	.3	.02	.1L	.01	.1L
48A	.....do	98	1.0	.6	.12	.1L	.01	.1L
48B	.....do	92	1.0	.6	.02	.1L	.02	.1
49A	.....do	92	1.0L	.4	.01	.1L	.01	.1
49B	.....do	99	1.0	.3	.02	.1L	.01	.1L
50A	.....do	99	2.0	.8	.02	.1L	.10	.1L
50B	.....do	94	3.0	.2	.01	.1L	.01	.1
51A	.....do	93	1.0L	.3	.02	.1L	.02	.1L
51B	.....do	95	1.0L	.3	.01	.1	.01	.1L
51A	Intrusive quartz latite	64	12.0	.1L	.02	.3	.57	2.3
52B	.....do	62	12.0	.2	.02	.2	.70	2.6
53A	.....do	65	16.0	3.0	.42	.5	.07	3.7
53B	.....do	63	15.0	2.9	.40	.5	.07	3.5
54A	Silicified	94	1.0L	.2	.02	.1L	.02	.1L
54B	.....do	06	1.0L	.2	.01	.1L	.01	.1L
55A	Illitic	55	18.0	2.4	.02	.2	.17	1.8
55B	.....do	62	18.0	2.5	.02	.3	.14	1.8
56A	.....do	76	16.0	.9	.01	.2	.04	.1
56B	.....do	75	16.0	.7	1.74	.1	.05	.2
57A	.....do	42	21.0	.1	.01	.1L	.83	4.3
57B	.....do	41	21.0	.2	.01L	.2	.83	4.4
58A	Silicified	91	2.0	.8	.01	.1L	.04	.1L
58A	.....do	89	3.0	1.0	.01	.1L	.02	.1L
59A	Argillic	87	5.0	.5	.01	.2	.13	1.2
59B	.....do	76	4.0	.4	.03	.1	.16	1.1
60A	Silified	95	1.0L	1.0	.01	.1L	.02	.1L
60B	.....do	92	1.0	1.3	.02	.1L	.02	.9
61A	Argillic	71	13.0	2.7	.02	.3	.03	.2
61B	.....do	67	15.0	3.0	.01	.3	.04	.1L
62A	Illitic	46	17.0	.3	.01L	.2	.24	4.4
62B	.....do	44	17.0	.3	.01L	.1	.21	4.9
63A	Silified	98	1.0L	.6	.01	.1L	.01	.1L
63B	.....do	99	1.0L	.7	.01	.1L	.01	.1L

In some samples from each rock type, not all the elements considered were detected. In such censored distributions each undetected element was assigned a value equal to one-half its limit of detection. In distributions whose censored part is small, the replacement of values is justified because estimates of the geometric means are nearly independent of any reasonable values that are substituted in the distributions.

Analysis-of-variance techniques, following the general mathematical

the Nation Belle and Red Mountain No. 3 areas — Continued

Element, in parts per million											
As	Au	Bi	Cu	Mn	Pb	Sb	Sr	Zn	Ga	La	Ni
40L	.05L	10N	60	2500	20N	300N	340	300N	30	89	18
40L	.05L	10N	55	2300	20N	300N	300	300N	25	76	15
40L	.05L	10	59	770	21	300N	120	300N	29	84	21
40L	.05L	10N	60	630	25	300N	80	300N	27	69	16
40L	.05L	10N	48	2000	20N	300N	270	300N	25	84	25
60	.05L	10N	42	1800	20N	300N	240	300N	24	60	20
40	.05L	10N	60	7N	550	300N	1300	300N	20	90	7N
40L	.05L	10N	55	7N	510	300N	1200	300N	17	90	7N
40L	.05L	10N	50	1300	30	300N	340	300N	30	180	160
40L	.05L	10N	39	800	23	300N	300	300N	25	160	120
40L	.05L	10N	60	2700	20N	300N	270	300N	24	61	20
40L	.05L	10N	70	2400	20N	300N	190	300N	30	60	16
40	.05L	11	21	7N	560	300N	690	400	36	100	12
40	.05L	11	24	9	490	300N	430	300N	45	99	17
40	.40	10N	7	30	89	300N	30N	300N	10N	50N	7N
40	.05L	10N	7	14	84	300N	30N	300N	10N	50N	7N
600	.07	68	29	13	430	600	250	300N	10N	50N	7N
700	.07	110	29	60	410	810	290	300N	10N	50N	7N
40L	.05L	10N	41	600	25	300N	4100	300N	25	180	160
40L	.05L	10N	50	900	37	300N	2900	300N	26	170	150
590	.30	415	71	13	190	890	30N	300N	10N	50N	7N
590	.30	300	60	32	140	660	30N	300N	10N	50N	7N
350	.40	10N	35	21	180	300N	60	300N	10N	50N	7N
130	.50	10N	32	10	100	300N	70	300N	10N	50N	7N
110	.20	10N	28	13	98	300N	30N	300N	10N	50N	7N
50	.20	10N	20	24	67	300N	30N	300N	10N	50N	7N
910	.50	300	44	19	420	590	110	300N	10N	50N	7N
1200	.80	250	51	7N	480	370	180	300N	10N	50N	7N
40L	2.00	29	25	14	260	300N	200	300N	10N	50N	7N
40L	1.90	74	20	26	220	330	130	300N	10N	50N	7N
110	.10	10N	17	13	220	330N	320	300N	10N	50N	7N
60	.20	10N	52	1300	32	300N	400	300N	30	140	13
40L	.80	13	8	25	65	300N	40	300N	10N	50N	8
40L	.60	11	24	19	60	300N	30	300N	10N	50N	11
40L	.06	10N	1N	22	660	330N	470	300N	35	130	9
40L	.06	10N	2	18	750	300N	300	300N	29	120	8
40L	.05L	10N	95	36	46	300N	640	300N	30	160	63
40L	.05L	10N	91	33	45	300N	670	300N	32	150	60
40L	.07	10N	22	17	110	300N	30N	300N	10N	50N	9
40L	.05	10N	93	14	210	470	30N	300N	10N	50N	8
40L	.05L	10N	21	8	110	300N	340	300N	36	74	11
40L	.05L	10N	20	8	140	300N	360	300N	32	72	10
40L	.05L	10N	10	11	120	300N	150	300N	24	60	8
40L	.05L	10N	9	11	180	300N	145	300N	24	60	8
40L	.05	17	4	7N	3500	300N	790	300N	73	64	9
80	.05	16	6	7N	3000	300N	930	300N	68	60	8
100	.60	17	16	18	160	300N	200	300N	12	50N	8
200	.50	28	19	13	200	300N	180	300N	17	50N	9
40L	.20	10N	7	8	550	300N	360	300N	37	96	8
40L	.20	10N	10	47	630	300N	380	300N	40	100	9
40L	.90	10N	26	12	190	300N	130	300N	10	50N	9
300	.90	10N	36	27	340	300N	150	300N	16	50N	9
600	.40	46	250	12	6000	300N	1300	300N	120	120	11
40L	.50	100	360	7	8300	300N	2900	300N	160	140	10
40L	.10	10N	7	7N	1600	300N	1300	300N	100	140	7
80	.10	10N	2	8	2700	300N	4100	300N	150	210	7N
40L	.50	10N	14	21	41	300N	30N	300N	10N	50N	9
40	.50	10N	12	17	66	300N	50	300N	10N	50N	9

methods described by Anderson and Bancroft (1952, p. 325-330), were used to examine the variation in the concentrations of different elements and to estimate the variance components between samples from the same site and between sample sites. The variance components are given in table 2.

Generally the variance components between sample sites are sufficiently large in comparison with the variance components between in-

TABLE 2. — *Logarithmic variance components for each element and oxide divided among different*

[Numbers in parentheses express each variance component as a percentage of the total logarithmic variance. Asterisks of the data were censored and accordingly

Type of rocks	Silicified						
Area	National Belle and Red Mtn. No. 3		National Belle		Red Mtn. No. 3		National and Red Mtn.
Number of samples	44		18		26		12
Variance between	Samples	Sites	Samples	Sites	Samples	Sites	Samples
Oxides (in percent)							
SiO ₂	0.00013 (56)	0.0001 (44)	0.00013 (42)	0.00018 (58)	*0.00011 (72)	*0.000042 (28)	0.00036 (23)
Al ₂ O ₃ .....							.0013 (3)
Fe ₂ O ₃ .....	.013 (12)	.1 (88)	.0078 (8)	.091 (92)	.017 (30)	.039 (70)	.004 (3)
MgO	*.057 (100)	*.0 (0)	*.079 (100)	*.0 (0)	*.047 (87)	*.0068 (13)	*.034 (68)
CaO							
Na ₂ O .....	.037 (56)	.029 (44)	.0075 (29)	.018 (71)	*.055 (62)	*.034 (38)	.078 (36)
K ₂ O							
Elements (in parts per million)							
Ag	0.044 (9)	0.46 (91)	0.089 (27)	0.24 (73)	0.019 (3)	0.62 (97)	
As .....	.035 (11)	.28 (89)	.012 (4)	.31 (96)	.052 (17)	.25 (83)	
Au .....	.045 (18)	.3 (82)	.021 (7)	.29 (93)	.062 (27)	.17 (73)	
Bi							
Cu .....	.025 (6)	.36 (94)	.013 (2)	.66 (98)	.035 (41)	.051 (59)	0.0084 (3)
Mn	*.16 (100)	*.0 (0)	*.1 (100)	*.0 (0)	*.21 (100)	*.0 (0)	*.066 (52)
Pb .....	.024 (16)	.13 (84)	.005 (2)	.21 (98)	.039 (36)	.07 (64)	.0028 (.5)
Sb							
Sr .....					.015 (5)	.27 (95)	.019 (14)
Zn							
Ga .....							.0061 (4)
La .....							.0013 (7)
Ni							

dividual samples from the same site to allow the recognition of differences in the concentration of a given element between sample sites.

An asterisk in table 2 indicates that the variance between two samples of the same site is significant at the 95-percent level of confidence. In those instances the variance components between sample sites are small in comparison with the components between individual samples from the same site, making it impossible to statistically distinguish differences between sample sites and also complicating the interpretation of geochemical anomalies. Using elements whose concentrations are highly variable in a given type of altered rock would require collecting more than two samples from each site. The number of

the two levels of the analysis-of-variance design within different altered rock types and areas

indicate significance at the 95-percent level of confidence; leaders (.) indicate that more than 30 percent analysis of variance was not attempted]

Argillic				Illitic				Pyrophyllitic	
Belle No. 3	National Belle		Red Mtn. No. 3		Red Mtn. No. 3		National Belle		
	8		4		10		50		
Sites	Samples	Sites	Samples	Sites	Samples	Sites	Samples	Sites	
Oxides (in percent) — Continued									
0.0012 (77)	0.000041 (3)	0.0015 (97)	*0.001 (33)	*0.002 (67)	0.00041 (4)	0.01 (96)	0.00018 (30)	0.00042 (70)	
.049 (97)	.00042 (2)	.018 (98)	.0033 (3)	.12 (97)	.00029 (12)	.0022 (88)	*.0024 (80)	*.0006 (20)	
.14 (97)	.0046 (3)	.13 (97)	.0028 (.8)	.32 (99.2)	.012 (6)	.2 (94)	.0003 (4)	.0079 (96)	
*.016 (32)	.011 (20)	.045 (80)	*.079 (100)	*.0 (0)	*.51 (89)	*.062 (11)	.025 (51)	.024 (49)	
.....	.....	.....	*.022 (34)	*.042 (66)	*.057 (86)	*.0092 (14)	.0035 (2)	.22 (98)
.14 (64)	*.11 (83)	*.023 (17)	.0059 (3)	.18 (97)	.0024 (.7)	.35 (99.3)	.018 (3)	.53 (97)	
.....	.....	.....	*.09 (15)	*.51 (85)	.0092 (2)	.38 (98)	.00054 (5)	.01 (95)
Elements (in parts per million) — Continued									
.....	
.....	
.....	.....	.....	0.0023 (4)	0.059 (96)	.....	.....	.....	.....
0.27 (97)	0.0065 (12)	0.05 (88)	.012 (9)	1.2 (99.1)	*0.034 (35)	*0.064 (65)	0.0094 (58)	0.0069 (42)	
*.061 (48)	.....	.....	*.16 (100)	*.0 (0)	.....	.....	.0033 (11)	.028 (89)
.53 (99.5)	.0013 (.3)	.42 (99.7)	.0058 (1)	.57 (99)	.0098 (2)	.41 (98)	.....	.....
.....	
.12 (86)	.013 (9)	.13 (91)	*.03 (11)	*.24 (89)	.025 (12)	.18 (88)	.023 (8)	.26 (92)	
.....	
.13 (96)	.0072 (11)	.056 (89)	.0041 (3)	.15 (97)	.0041 (4)	.092 (96)	*.0013 (68)	*.0006 (32)	
.017 (93)	.0013 (7)	.017 (93)	*.0011 (14)	*.0067 (86)	.0031 (8)	.036 (92)	.0031 (49)	.0032 (51)	
.....	.....	.....	*.001 (22)	*.0036 (78)	.0011 (18)	.005 (82)	.0036 (31)	.0081 (69)

samples needed could be estimated according to procedures suggested by Shacklette, Sauer, and Miesch (1970, p. C12).

A two-tailed *t*-test, as described by Guenther (1964, p. 23), was used to compare geometric means of the content of 20 elements and oxides in the different types of altered rocks and in different areas. The hypothesis tested in each case was that no difference existed between the geometric means for a given element or oxide in the two altered-rock types or areas being considered. In table 3, shown in the boxes for the various pairs of altered rock types or areas, are the elements and oxides which were determined by the *t*-tests to be nonsignificant (that is, having no statistical difference between means) at the 95-percent level of confidence. For example, when differences in geometric means were

compared for all 20 elements and oxides between silicified rocks and propylitized rocks, only two, copper and zinc, were nonsignificant at the 95-percent level of confidence. For the remaining 18 oxides and elements that were tested, the hypothesis — that there is no difference between geometric means for a given element or oxide between the silicified group of samples and the propylitized group of samples — was rejected; therefore, the differences in geometric means were significant for the remaining, unlisted oxides and elements.

DISTRIBUTION OF OXIDES AND ELEMENTS

ROCK TYPE DISTRIBUTIONS

The distribution and relative depletion or enrichment of the various oxides and elements are shown in figures 3-6. The statistical significance of the differences between geometric means of the oxides and elements for comparisons between the various altered-rock types is shown in table 3. The concentration of the oxides and elements in the propylitized rocks provides a reasonable estimate of the background content of these oxides and elements in the National Belle and Red Mountain No. 3 areas and is also useful for describing the chemical changes in the rocks affected by advanced argillic alteration.

SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , Mn, Sr, Ga, La, and Ni (figs. 3-6) were constituents of the propylitized country rock in the area and were, in general, leached by the later hydrogen ion metasomatism. Some of these constituents (SiO_2 , Sr, Ga, La; figs. 3, 6) are enriched in certain rocks; this enrichment is due not to their being added from the altering solutions but to depletion of other elements.

The abundance of SiO_2 (fig. 3) is about the same in the propylitic and illitic rocks but increases progressively from the illitic to the argillic and to the silicified rocks. The numerous quartz veinlets, abundant cryptocrystalline silica, and common quartz crystals in vugs in the silicified rocks all suggest that the silica was rather mobile. Most of this silica was probably derived from the original rock material and was not introduced by the altering fluids. This is evident from the content of titanium (not shown in tables and histograms), which is progressively greater in progressively more altered rocks. Vein silica in the area contains little or no titanium; pipe silica contains about 0.5 percent or slightly more titanium, or approximately the same amount as the country rocks; and the silicified rocks contain the greatest amount, with a mean value of 3.5 percent.

Strontium, gallium, and lanthanum (fig. 6) all show a slight increase in abundance in the illitic rocks as compared with the propylitized rocks, although for lanthanum the increase is not statistically significant (table 3). The concentrations of these three elements remain about the same in the argillic rocks as in the illitic rocks. In the silicified rocks

all three elements have been leached; gallium and lanthanum have been almost totally removed.

Alumina (fig. 3) was rather resistant to leaching, being only slightly depleted in the argillic rocks as compared with the illitic and propylitized rocks. However, in the silicified rocks, it has been extensively leached. Some of the aluminum was reprecipitated in alunite and diasporite in both the argillic and silicified rocks.

Magnesium, calcium, manganese, and nickel (figs. 3-6) were readily leached by hydrogen ion metasomatism even in the illitic rocks, and calcium has been almost totally removed from the argillic and silicified rocks. Potassium (fig. 4) decreases continuously in abundance in progressively more altered rocks, whereas sodium concentrations (fig. 4) remain about the same from the propylitic to the illitic rocks and then decrease sharply from the illitic rocks to the argillic and silicified rocks. Alunite and natroalunite(?), or sodic alunite, contain most of the potassium and sodium that remains in the silicified rocks. Chemical analyses by Hurlburt (1894) indicate a K_2O content of 4.26 percent and a Na_2O content of 4.41 percent for "alunite" from the National Belle breccia pipe.

Silver, arsenic, gold, bismuth, copper, lead, antimony, and zinc (figs. 4-6) were all added to the rocks during hydrothermal alteration and mineralization of the breccia pipes; generally, the more intensely altered rocks contain higher amounts of metallic elements, the greatest concentrations occurring in the silicified rocks. However, the degree of enrichment among the different types of altered rocks is rather variable.

In the illitic rocks, lead (fig. 5) is significantly enriched (table 3), and arsenic, gold, and bismuth (figs. 4, 5) occur in more samples of these rocks, but their concentrations are not statistically different from their concentrations in the propylitic rocks.

Gold (fig. 4) is enriched in the argillic rocks as compared with the illitic and propylitic rocks; silver, arsenic, bismuth, lead, and antimony (figs. 4, 5) are more common in the argillic rocks but are not enriched to statistically significant amounts.

In the silicified rocks all the introduced elements except lead, zinc, and copper (figs. 5, 6) are enriched significantly. The content of lead decreases as compared with the argillic and illitic rocks. Zinc occurs more commonly in samples of the silicified rocks, but not in statistically significant amounts.

Copper (fig. 5) is depleted in the illitic rocks, and its concentration is about the same in the argillic, silicified, and propylitized rocks. It was undoubtedly added to the rocks along with the other metals during mineralization, but its mobility in the highly acid supergene environment of the breccia pipes makes interpretation of its concentration patterns exceedingly difficult.

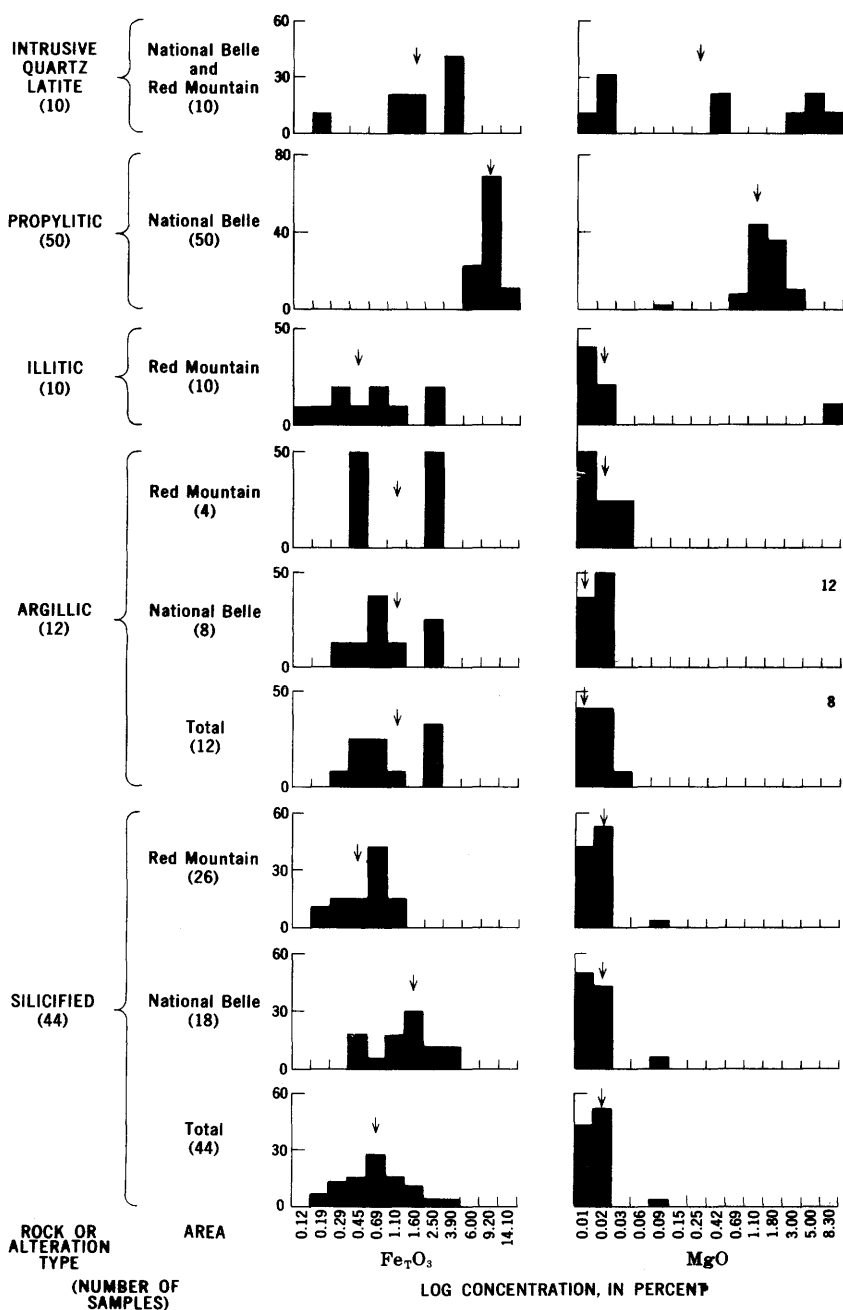
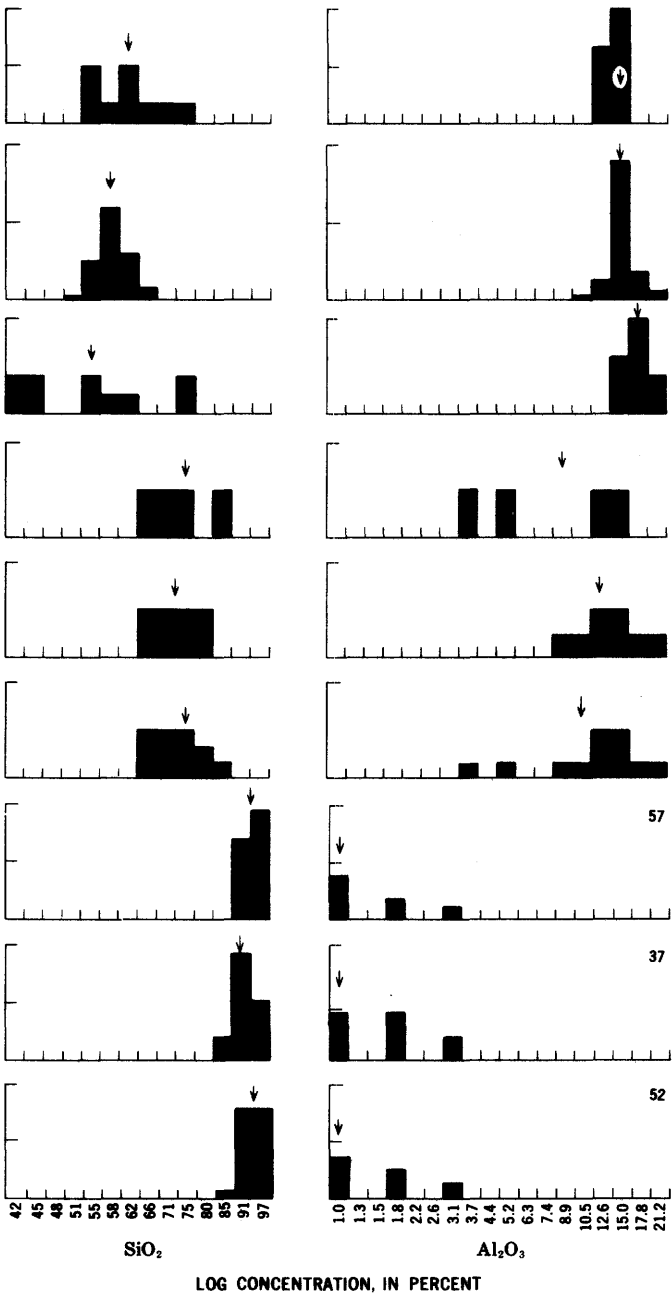


FIGURE 3.—Histograms showing concentrations of SiO_2 , Al_2O_3 , Fe_2O_3 , and MgO in rocks mean; figure at right indicates percentage of samples that contained less than



from the National Belle and Red Mountain No. 3 areas. Arrow indicates geometric lowest amount of oxide shown. Vertical scale is frequency, in percent.

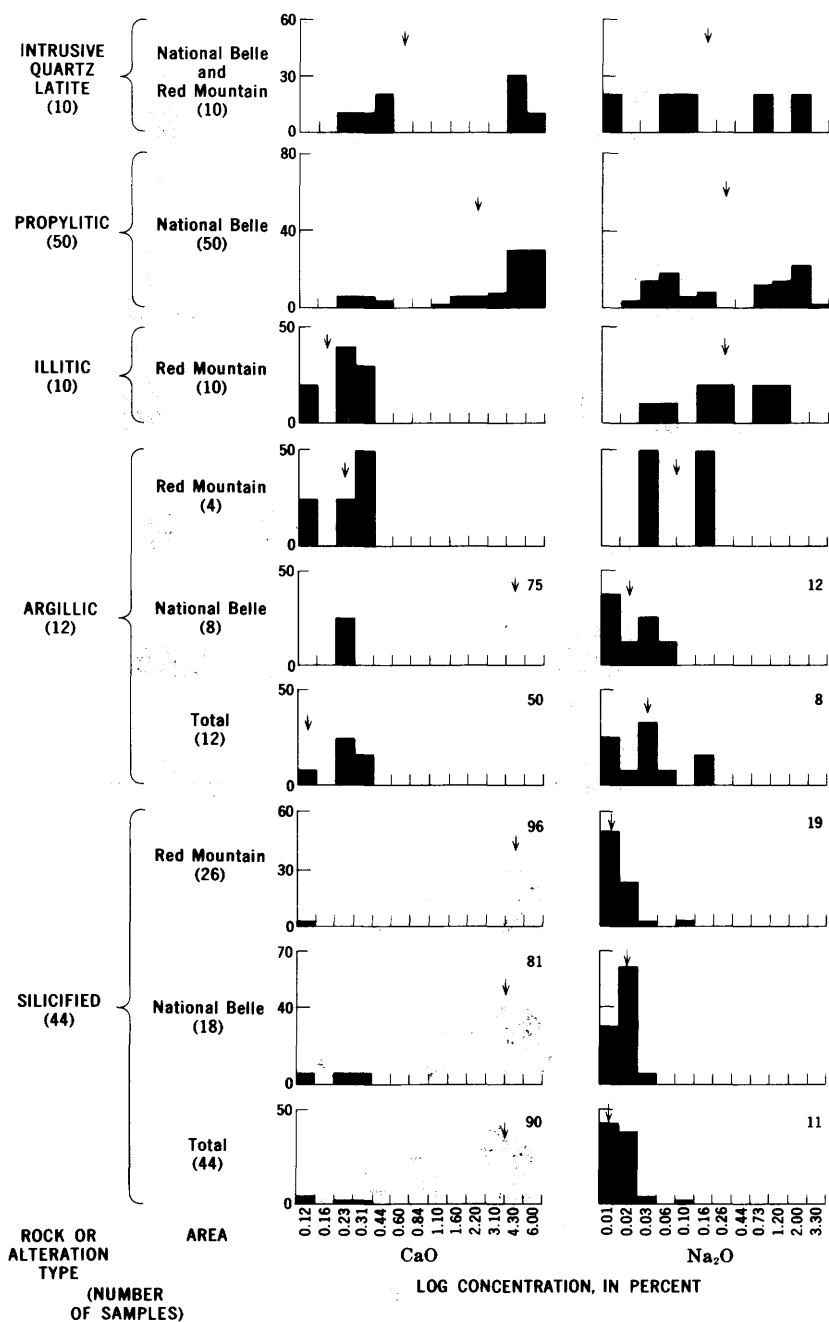
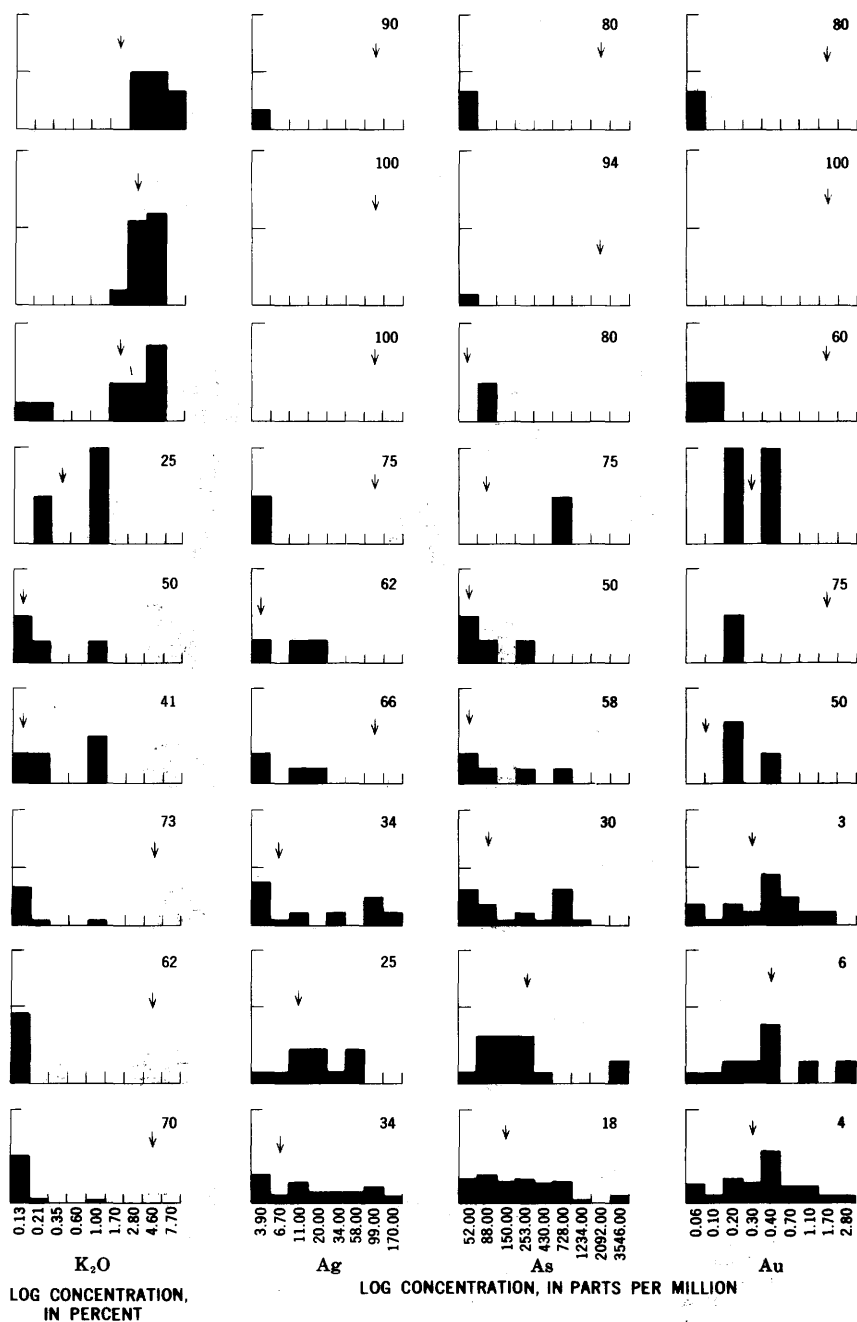


FIGURE 4. — Histograms showing concentrations of CaO, Na₂O, K₂O, Ag, As, and Au in metric mean; figure at right indicates percentage of samples that contained less than



rocks from the National Belle and Red Mountain No. 3 areas. Arrow indicates geo-lowest amount of oxide or element shown. Vertical scale is frequency, in percent.

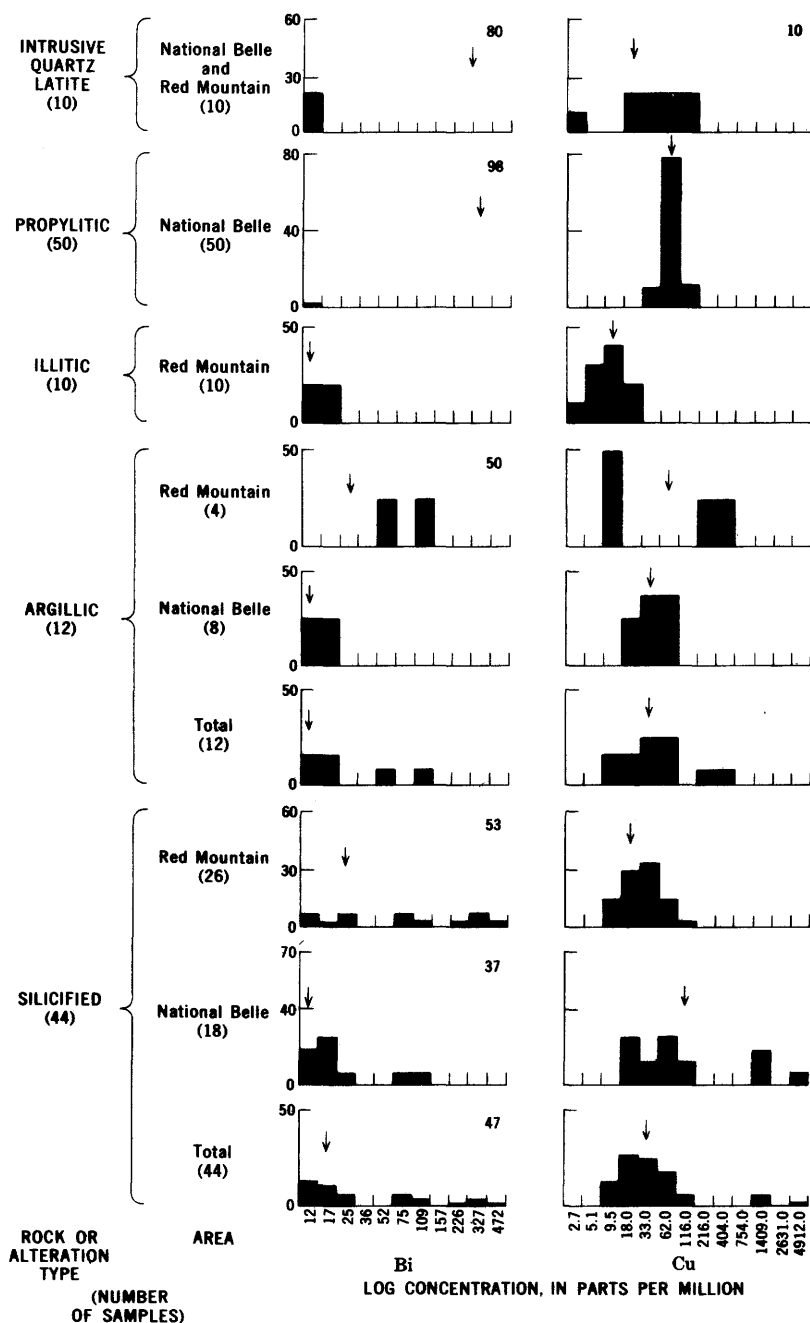
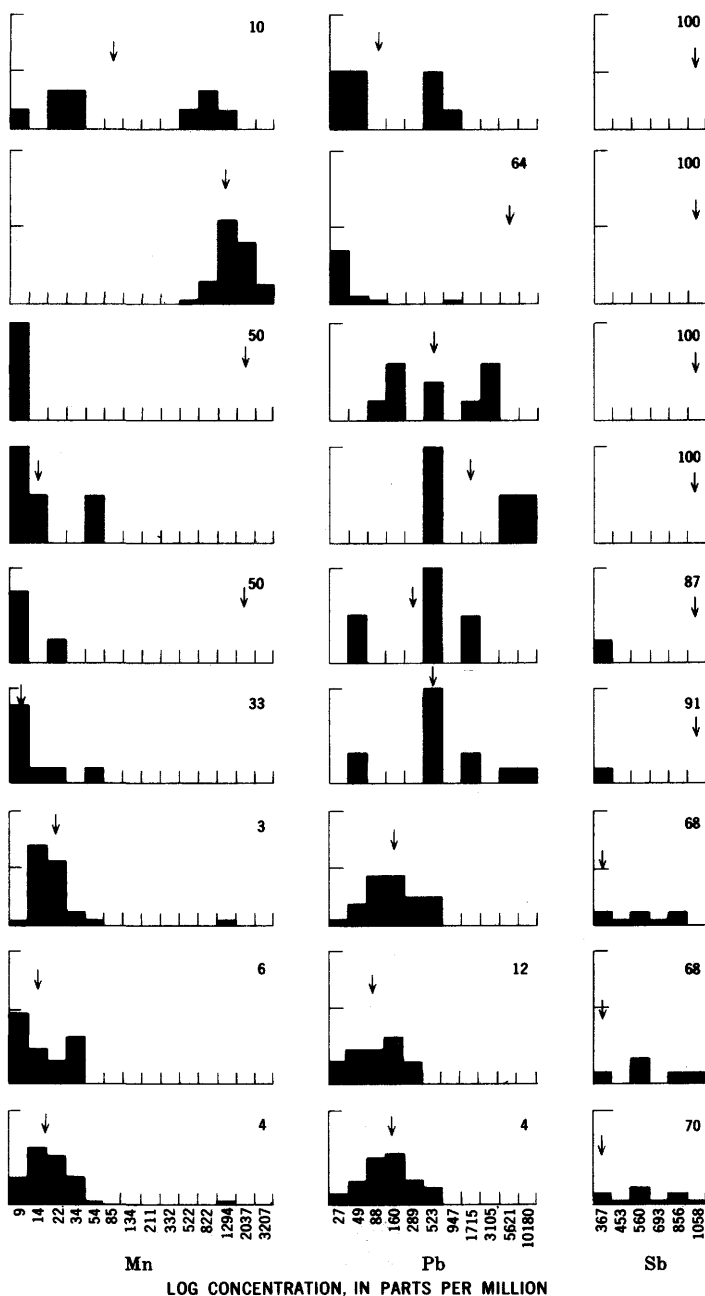


FIGURE 5. — Histograms showing concentrations of Bi, Cu, Mn, Pb, and Sb in rocks mean; figure at right indicates percentage of samples that contained less



from the National Belle and Red Mountain No. 3 areas. Arrow indicates geometric than lowest amount of element shown. Vertical scale is frequency, in percent.

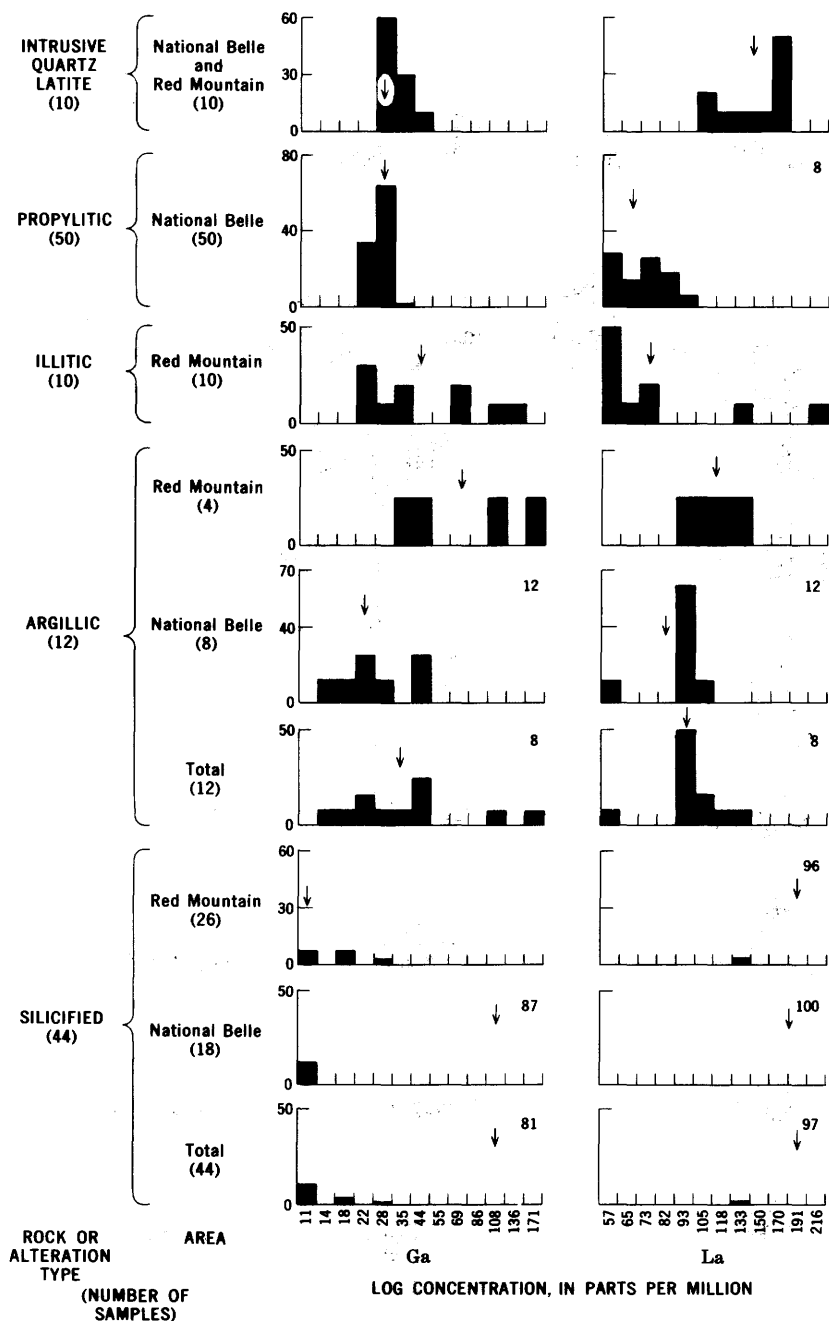
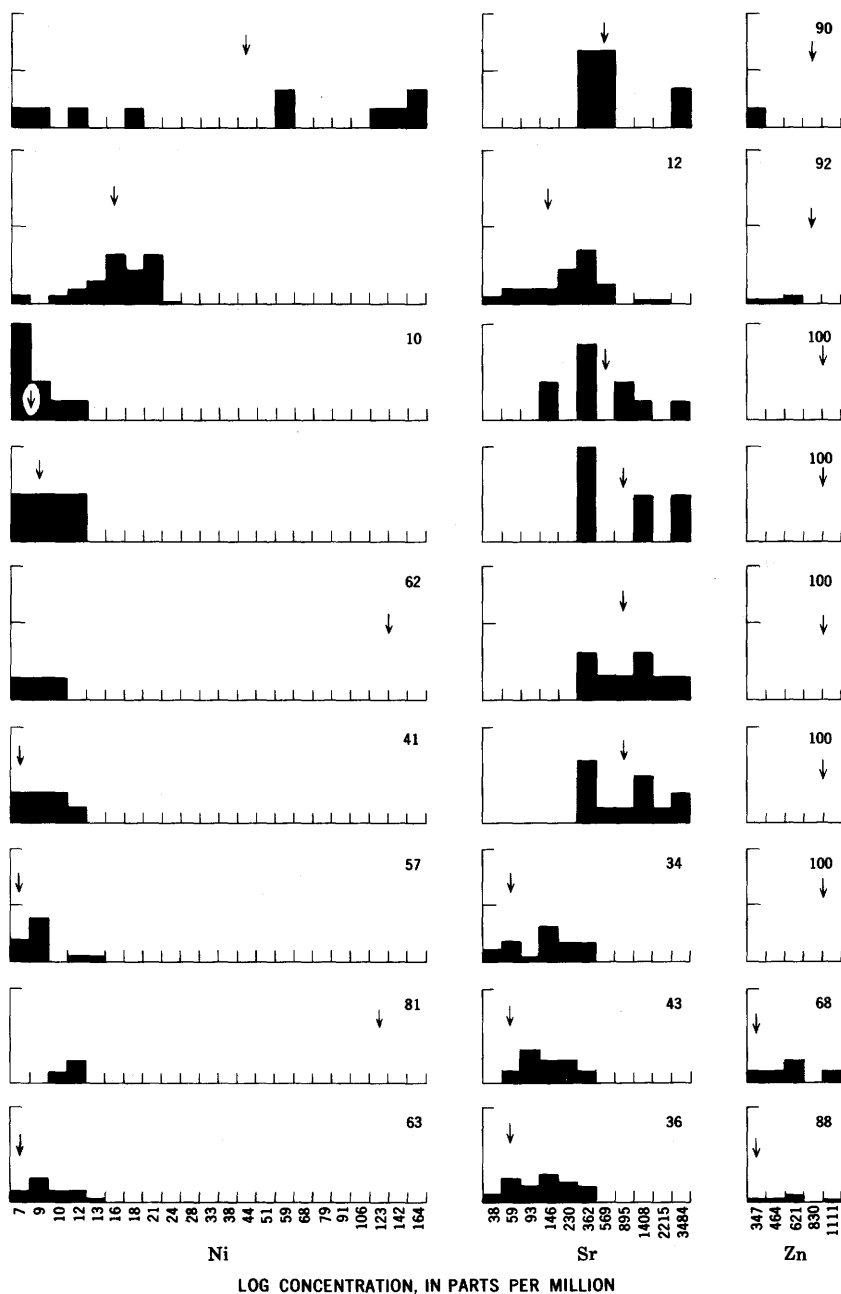


FIGURE 6. — Histograms showing concentrations of Sr, Zn, Ga, La, and Ni in rocks from figure at right indicates percentage of samples that contained less than lowest



the National Belle and Red Mountain No. 3 areas. Arrow indicates geometric mean; amount of element shown. Vertical scale is frequency, in percent.

AREAL DISTRIBUTIONS

Histograms showing the distributions of oxides and elements in silicified and argillic rocks from the National Belle breccia pipe and the Red Mountain No. 3 breccia pipe are presented in figures 3-6. Rocks from the two areas generally are geochemically very similar. Concentrations of iron, copper, and lead (figs. 3, 5) in the silicified rocks were determined to differ significantly in the two areas, and concentrations of calcium, gold, lanthanum, and nickel (figs. 4-6) in the argillic rocks were significantly different (table 3).

TABLE 3. — *Elements and oxides determined by t-tests to be nonsignificant at the 95-percent level of confidence between different pairs of altered rock types or areas*

	<i>Argillic rocks</i> National Belle and Red Mountain No. 3 (12 samples)		<i>Illitic rocks</i> Red Mountain No. 3 (10 samples)			<i>Propylitic rocks</i> National Belle (50 samples)	
<i>Silicified rocks</i> National Belle and Red Mountain No. 3 (44 samples)	Fe ₂ O ₃	Zn	Fe ₂ O ₃			Cu	
	MgO	Ni	MgO			Zn	
	K ₂ O		Zn				
	Bi						
	Cu						
<i>Argillic rocks</i> National Belle and Red Mountain No. 3 (12 samples)	Fe ₂ O ₃	Au	Sr		Fe ₂ O ₃	Sb	
	MgO	Bi	Zn		Ag	Zn	
	CaO	Mn	Ga		As	Ga	
	Ag	Pb	La		Bi		
	As	Sb	Ni		Cu		
<i>Illitic rocks</i> Red Mountain No. 3 (10 samples)					SiO ₂	Au	
					Na ₂ O	Bi	
					K ₂ O	Sb	
					Ag	Zn	
					As	La	
<i>Silicified rocks</i> Red Mountain No. 3 (26 samples)	SiO ₂	K ₂ O	Mn	La			
	Al ₂ O ₃	Ag	Sb	Ni			
	MgO	As	Sr				
	CaO	Au	Zn				
	Na ₂ O	Bi	Ga				
<i>Silicified rocks</i> National Belle (18 samples)	SiO ₂	K ₂ O	Mn	La			
	Al ₂ O ₃	Ag	Sb	Ni			
	MgO	As	Sr				
	CaO	Au	Zn				
	Na ₂ O	Bi	Ga				
<i>Argillic rocks</i> National Belle (8 samples)	SiO ₂	K ₂ O	Mn	Ga			
	Al ₂ O ₃	Ag	Pb				
	Fe ₂ O ₃	As	Sb				
	MgO	Bi	Sr				
	Na ₂ O	Cu	Zn				

The difference in iron (fig. 3) and copper (fig. 5) concentrations may be due to different rates of supergene leaching in the two areas.

However, because mine workings were inaccessible, we could not collect below the zone of supergene leaching, and the extent and degree of supergene leaching are unknown.

The Student's *t*-test, as applied to the data for calcium, gold, lanthanum, and nickel in the silicified and argillized rock types, is biased because of the high variability in the data due to sampling (table 2) and censored distributions (figs. 3-6). Therefore, whether concentrations of these four elements actually differ in the two areas is uncertain.

Lead (fig. 5) reaches its greatest concentrations in the illitic and argillic rock types and is only moderately enriched in the silicified rocks. Figure 11 indicates that the lead anomaly does not coincide areally to the anomalies in silver (fig. 7), arsenic (fig. 8), gold (fig. 9), bismuth (fig. 10), and antimony (fig. 12). The relative enrichment of lead in the argillic rocks and the location of the lead anomaly outside the area enriched in the other introduced metals indicate a lateral zonal pattern around the breccia pipes or around the highly silicified major channelways within the pipes. Burbank (1941, p. 181) suggested a similar pattern of lead enrichment in the Guston breccia pipe, which is about 1 mile northeast of the National Belle pipe.

SUGGESTIONS FOR PROSPECTING

Figures 7-11 show the sample localities and the concentrations of silver, arsenic, gold, bismuth, lead, and antimony in samples from the National Belle and Red Mountain No. 3 areas. Obviously, samples with anomalous metal contents are associated with areas of silicified rock. It is also readily apparent that the highest metal anomalies in the Red Mountain No. 3 pipe are at the southern end of the structure. The southern end has not been explored in the subsurface, and thus it provides an interesting exploration target.

One further line of evidence concerning the possible target at the southern end of the Red Mountain No. 3 pipe should be considered. Schwarz (1890, p. 143), Ransome (1901, p. 111), and Burbank (1941, p. 156, 181) each called attention to the vertical zoning of ores and metals within the breccia pipes; they also pointed out that enargite and pyrite are characteristically the deepest ores within the pipes and that the richer silver, lead, copper, and gold ores occur higher in the structure. As previously mentioned (p. 10) the mineralized rocks penetrated in the crosscuts and diamond drilling under the northern part of the pipe contained mainly enargite and pyrite. This suggests that the southern end of the Red Mountain No. 3 pipe should be explored above the level of the northerly crosscuts (10,800 ft). The geochemical anomaly underscores Burbank's (1941, p. 205-208) suggestion, based on geologic evidence, that the ground under the south and west slopes of Red Mountain No. 3 presents a favorable exploration target.



EXPLANATION

Parts per million

- <1
- 1-10
- 10-100
- >100

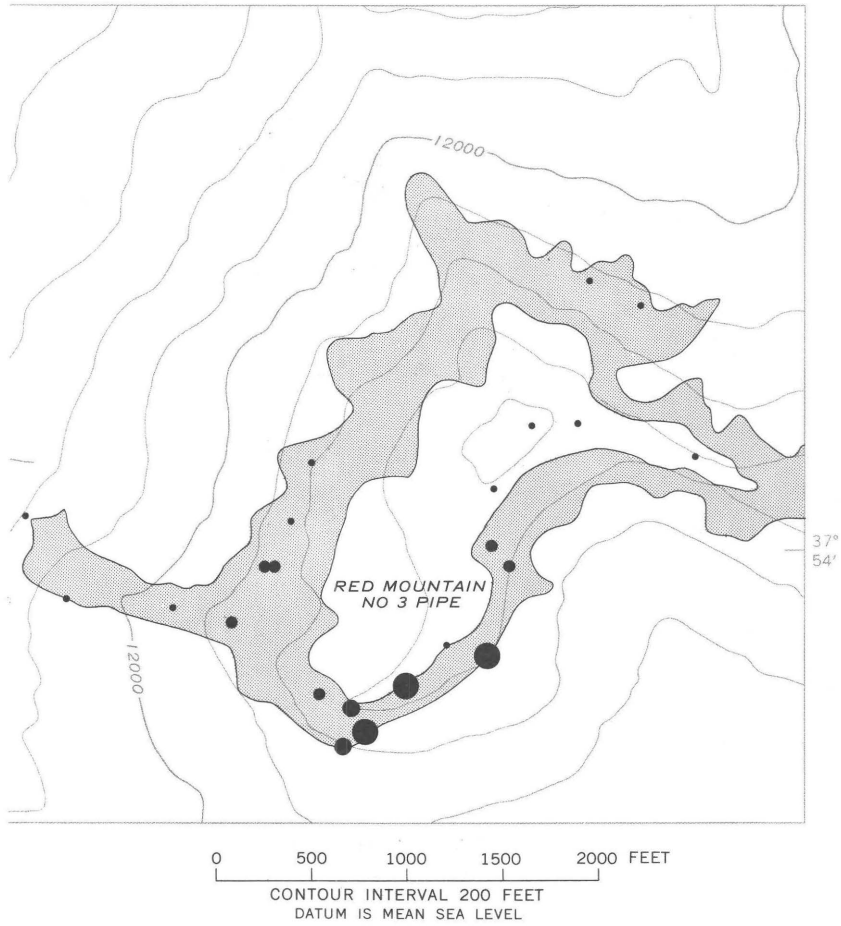


FIGURE 7. — Map showing concentration of silver in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.

**EXPLANATION**

Parts per million

- <40
- 40-200
- 200-1000
- >1000

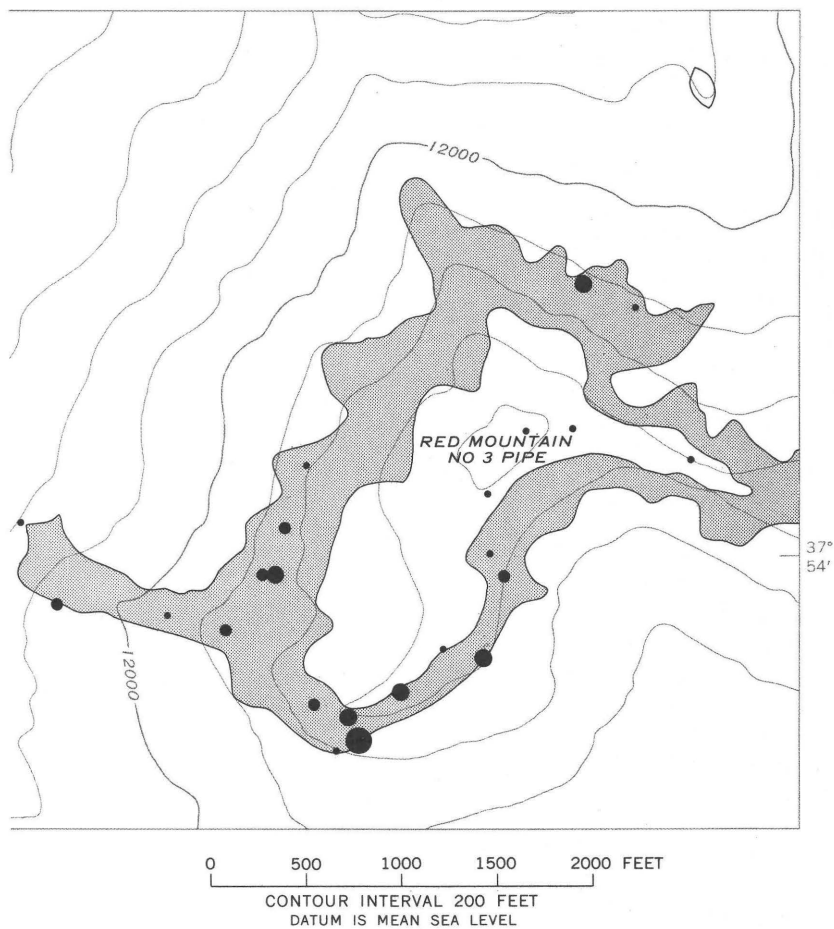


FIGURE 8. — Map showing concentration of arsenic in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.

**EXPLANATION**

Parts per million

- <0.1
- 0.1-0.5
- 0.5-1.0
- >1.0

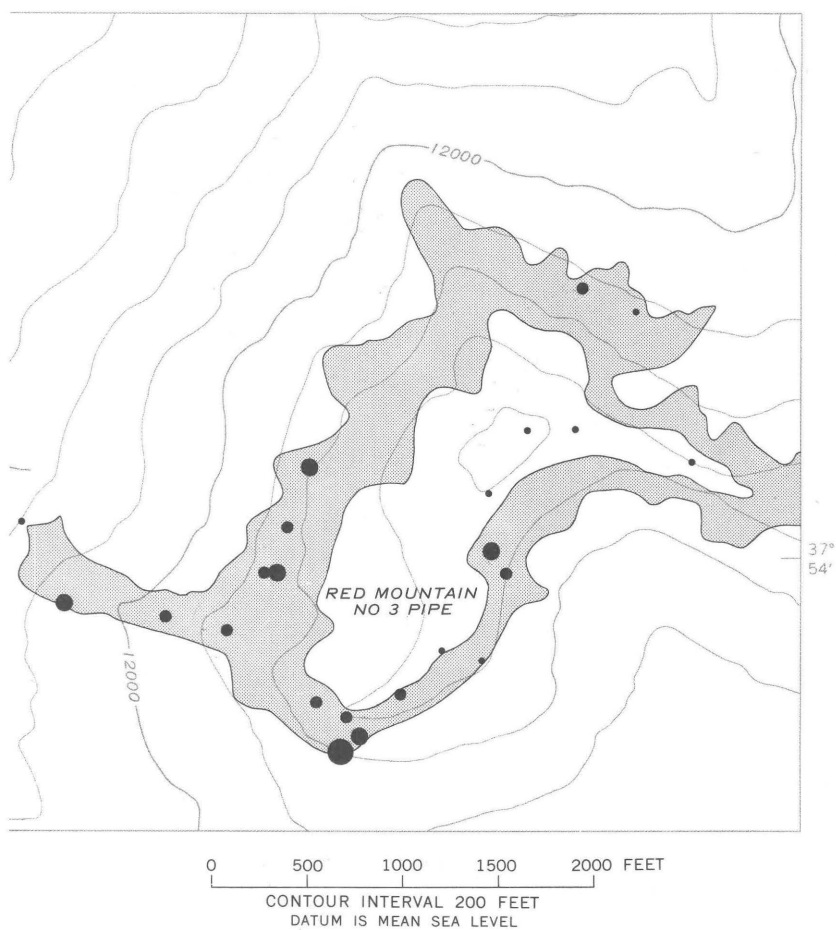


FIGURE 9. — Map showing concentration of gold in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.

**EXPLANATION**

Parts per million

- <5
- 5-50
- 50-100
- >100

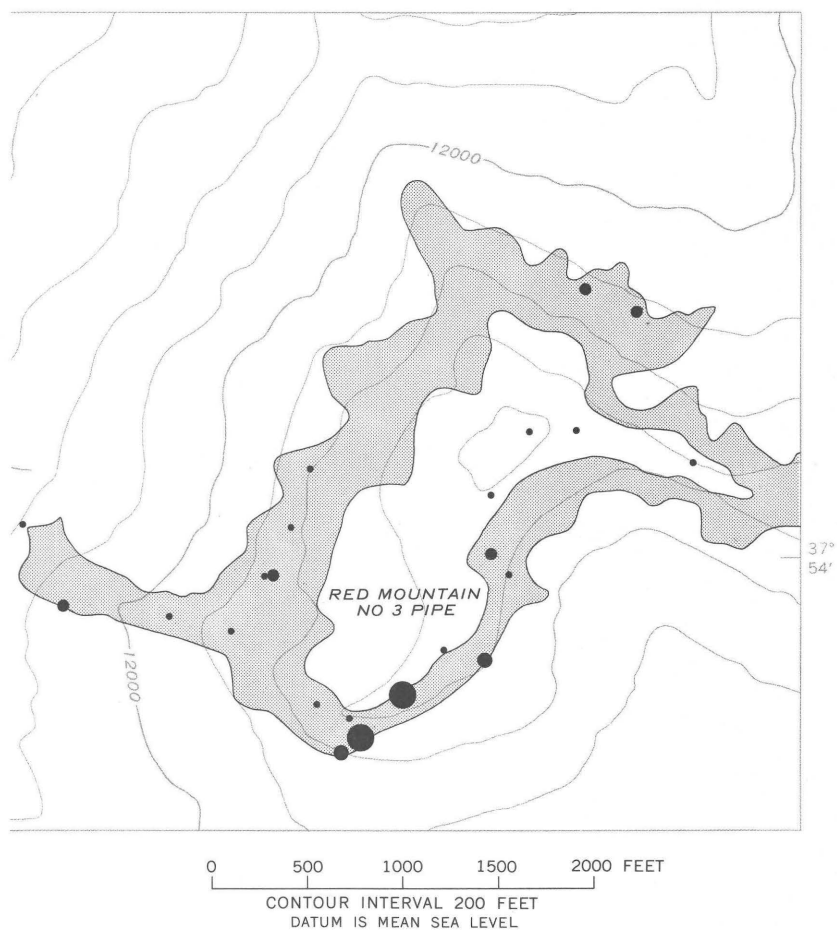


FIGURE 10. — Map showing concentration of bismuth in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.



EXPLANATION

Parts per million

- <50
- 50-200
- 200-1000
- >1000

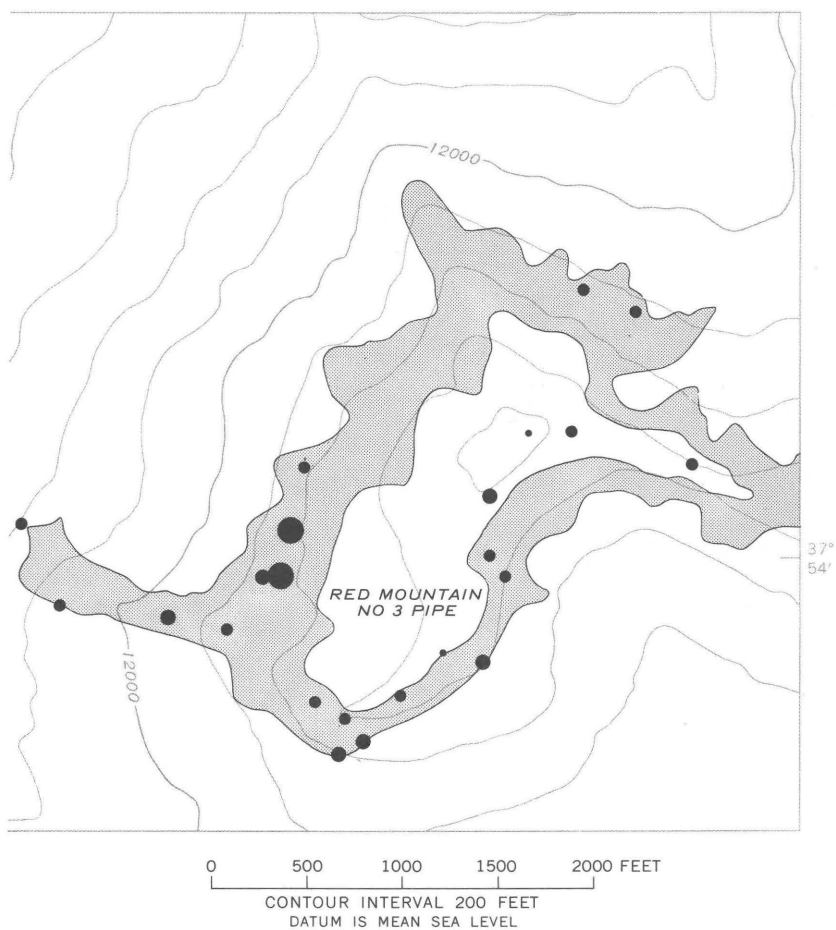


FIGURE 11. — Map showing concentration of lead in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.



EXPLANATION

Parts per million

- <100
- 100-250
- 250-500
- >500

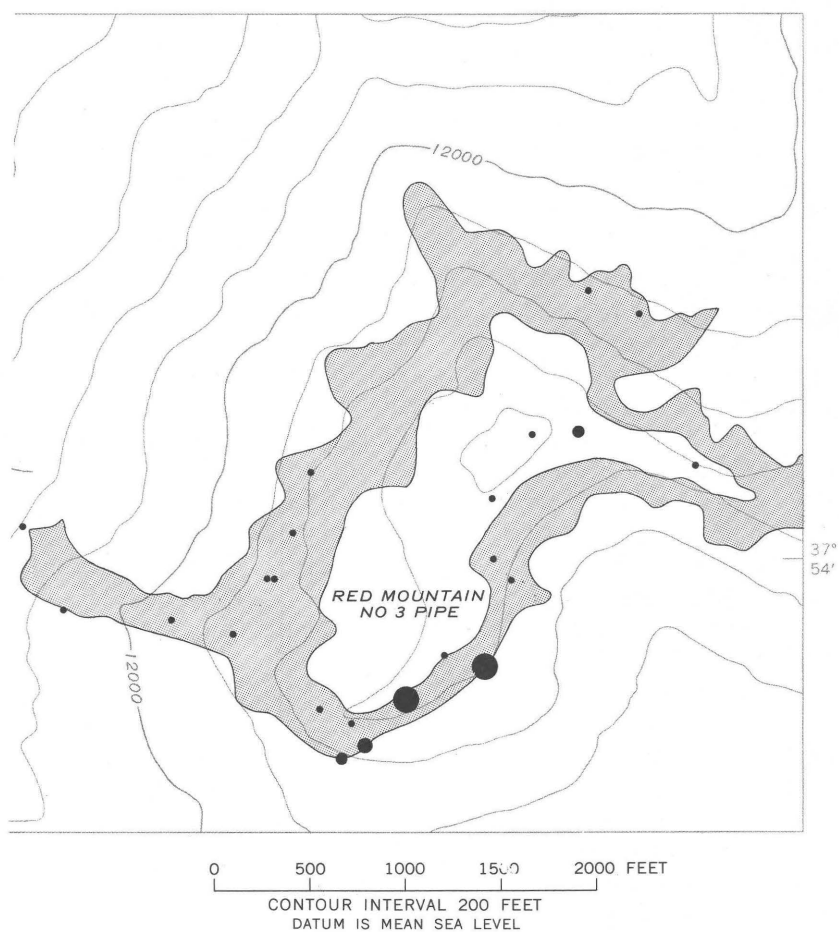


FIGURE 12. — Map showing concentration of antimony in the National Belle and Red Mountain No. 3 areas. Silicified rocks indicated by shaded pattern. Base from figure 2.

Silver, arsenic, gold, bismuth, lead, and antimony are probably the most useful elements for prospecting for new breccia-pipe targets in the Red Mountain district. Some precautions must be taken, however, in interpreting concentration patterns of these elements. The distributions for bismuth and antimony are severely censored in all four types of altered rocks (fig. 5); distributions are similarly censored for silver, arsenic, and gold (fig. 4) in all altered-rock types except the silicified rocks (fig. 3). Because of the censored distributions, the variance components for these elements in most of the altered-rock types (table 2) could not be reliably estimated from the available data. Without first obtaining variance components, interpreting the data is exceedingly hazardous because there is no reliable way to distinguish variability in the data due to differences between sample sites from variability within an individual sample site. For example, 97 percent of the variability of silver in silicified rocks from Red Mountain No. 3 (table 2) is due to differences between sample sites, and only 3 percent of the variability is due to differences within individual sample sites. In contrast, 13 percent of the variability of magnesia in the same rock type is due to differences between sample sites, and 87 percent of the variability is due to differences within the individual sample sites. The low variability makes it impossible to statistically distinguish significant differences in magnesia concentration between sample sites.

Some elements which were not enriched in statistically significant amounts in progressively more altered rocks are nevertheless useful for prospecting on the basis of their presence. Silver (fig. 4), though significantly enriched only in the silicified rocks (table 3), is present in 33 percent of the samples of argillized rocks, but it was not detected in any samples of illitic and propylitic rocks. Antimony was not detected in any samples of propylitic and illitic rocks but was present in 30 percent of the silicified rocks (fig. 5). Bismuth, present in only 2 percent of the propylitic rocks, was detected in 50 percent of the argillic rocks, and in 53 percent of the silicified rocks (fig. 5).

Lead is a favorable element to use for prospecting: it is severely censored only in the propylitic rocks (fig. 5), and most of the variability in its concentrations is due to differences between sample sites (table 2). Remember, however, that lead is laterally zoned around the areas of highest concentrations of the other introduced metals and that its highest concentrations are in the illitic and argillic rocks (fig. 5).

Gold and arsenic are probably the best elements to use for geochemical prospecting in the silicified rocks. In those pipes in the Red Mountain district where the silicified rocks are poorly developed or have been removed by erosion, the exposed rocks are argillic and illitic, and lead would be the best element to use for prospecting.

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the 1990s, the number of people in the UK who are employed in the public sector has increased by 1.5 million, from 2.5 million in 1980 to 4 million in 1995. The public sector has become a major employer in the UK, and its growth has been a major factor in the overall growth of the economy.

The public sector has also become a major provider of social services, and its growth has been a major factor in the overall growth of the economy. The public sector has become a major provider of social services, and its growth has been a major factor in the overall growth of the economy.

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the 1990s, the number of people in the world who are undernourished has increased from 600 million to 800 million. The number of people who are malnourished has increased from 1.2 billion to 1.5 billion. The number of people who are obese has increased from 100 million to 300 million.

The World Bank has estimated that the cost of malnutrition to the world economy is \$100 billion per year. The cost of obesity to the world economy is \$100 billion per year. The cost of undernourishment to the world economy is \$100 billion per year.

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