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Arsenic as an Indicator Element for Mineralized Volcanic Pipes in the Red Mountains Area, Western San Juan Mountains, Colorado

By WILBUR S. BURBANK, ROBERT G. LUEDKE, *and* FREDERICK N. WARD

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By Wilbur S. Burbank, Robert G. Luedke,
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ABSTRACT

In the Red Mountains and adjacent areas, southwestern Colorado, selective testing was done for residual arsenic in surface rocks that have undergone strong acid-sulfate leaching. Analytical results from samples taken across exposed and partly concealed known mineralized volcanic pipes in this solfataric-type altered environment show the general usefulness of arsenic as a geochemical indicator element. The values of arsenic, enhanced by mercury, silver, lead, and locally bismuth and tin, increase over the ore bodies and outline sites for more detailed sampling and elaborate field and laboratory tests. This geochemical technique seems more applicable to preliminary testing for mineralized pipes than for fissures. Caution must be exercised in sample collection and preparation because the presence of pyrite interferes with the accuracy of field determinations.

INTRODUCTION

The Red Mountains mining district, Ouray and San Juan Counties, southwestern Colorado, lies astride the county line and mostly east of U.S. Highway 550 between Ouray and Silverton (figs. 1, 2). This district was noted in the 1880's and 1890's for its output of chiefly base-metal ores from small pipelike or chimney ore deposits, some of which contained small pockets of ore extremely rich in silver. Those early mining operations yielded several million dollars, but subsequent search for possible concealed ore bodies has been limited and handicapped because of the small irregular shape of the ore bodies, the complex structural controls, the intensely altered country rocks, and a large amount of surface overburden. Burbank (1947, p. 431) pointed out that geochemical methods of prospecting may prove applicable to finding concealed chimney deposits.

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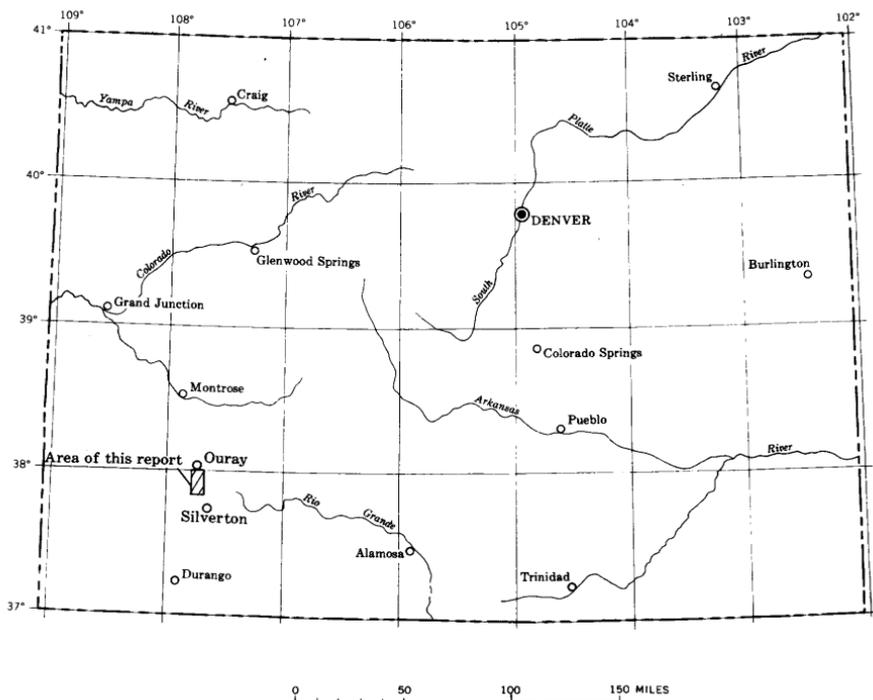
FIGURE 1.—Index map of Colorado showing area of this report.

Limited and selective geochemical sampling in and near the Red Mountains area was undertaken in 1965 to determine whether arsenic might serve as an indicator element for the chimney or pipelike deposits in an area where the rocks had been subjected to acid-sulfate alteration and leaching. The occurrence of arsenical minerals in the leached and oxidized ore deposits and the very low content of arsenic in acidified mine and surface waters led to the selection of arsenic (first suggested by Varnes and Burbank, 1945), for these preliminary tests. In this report, the distribution and concentration of arsenic and several selected elements are briefly summarized for several sites. For these types of pipelike deposits in a solfatarically altered environment, geochemical testing for arsenic is suggested as a useful prospecting technique.

The association of anomalous arsenic with certain mineral deposits has long been recognized, and its possible use as a pathfinder in geochemical prospecting has long been considered. Recent geochemical investigations in north-central Nevada used the distribution of arsenic and other metals to define low-grade gold deposits
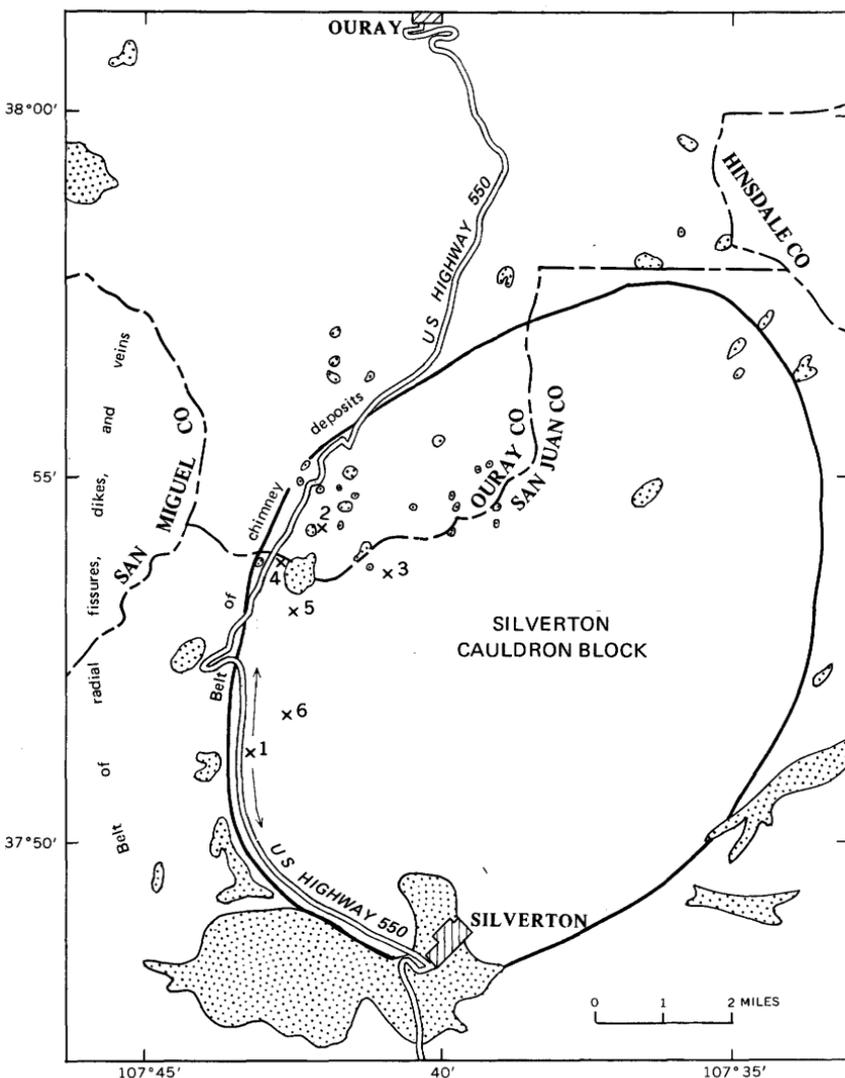
FIGURE 2.—The geochemical sampling sites in the generalized structural setting of the Silverton cauldron and vicinity. Intrusive bodies, stippled pattern; faults, heavy lines; sampling sites, x: 1, Mineral Creek; 2, National Belle; 3, Lark; 4, Longfellow; 5, St. Paul; 6, Brooklyn.

in hydrothermally altered, faulted, and folded sedimentary rocks (Erickson and others, 1964, 1966; Wells and others, 1969). To our knowledge, however, the use of arsenic as an indicator element has not been applied to very restricted chimney-type deposits in such intensively acid-sulfate altered, leached, and broken volcanic

rocks. Also, the arsenic here is associated principally with silver and base metals, not gold.

The opportunity to carry out these field tests was provided by F. C. Canney of the U.S. Geological Survey. The Denver laboratories of the Geological Survey verified field tests and supplied other analytical data; E. L. Mosier did the spectrographic analyses and J. B. McHugh, Margaret Hinkle, and Doris Price did the other chemical analyses. P. A. Burbank and R. A. DeHon assisted in the field studies. This work, done in cooperation with the Colorado State Mining Industrial Development Board, supplements other concurrent geochemical studies being conducted in the area by the Geological Survey.

GEOLOGIC SETTING

Rocks of the Red Mountains area consist of bedded middle Tertiary volcanic lava flows, breccias, and tuffs of intermediate composition that are intruded by upper Tertiary igneous and clastic materials (Burbank and Luedke, 1964). The volcanic rocks are part of the Silverton Volcanic Group. This group, which locally is several thousand feet thick, overlies Precambrian metamorphic and igneous rocks and local Paleozoic sedimentary rocks. These volcanic rocks, part of the great San Juan volcanic plateau built by middle and late Tertiary volcanism (Larsen and Cross, 1956), are spatially related to a nested complex of cauldrons (Luedke and Burbank, 1968; Burbank and Luedke, 1969). The Silverton cauldron, particularly, has been intruded along its margins and, to a lesser extent, in its interior by late igneous stocks, plugs, and dikes. The western margin of the Silverton cauldron, where the sample sites are located (fig. 2), consists of a fault zone which is locally a mile or more wide and which was subjected to hydrothermal alteration and leaching during the postvolcanic episode. Parts, and perhaps all, of this fault zone were probably the site of a large solfataric field. The rocks at the present erosion surface are brilliantly stained yellow, orange, and red, largely as a result of the oxidation of pyrite.

ROCK ALTERATION AND ASSOCIATED ORES AND GANGUES

The nature of the rock alteration, including that resulting from hydrothermal activity as well as that from the continued effects of acidified surface waters, has an important bearing on the local problems of geochemical prospecting. Most of the rocks within and

closely surrounding the cauldron area were subject initially to pervasive propylitic alteration caused by effusions of water and carbon dioxide. The resulting altered rocks range from those weakly carbonatized and chloritized to those albitized and epidotized. This type of alteration probably took place during or shortly after the late resurgence of magmas that emplaced the larger igneous stocks and their associated dikes (Burbank, 1960).

More intense hydrothermal alteration was localized and coincided with intrusions of porphyritic quartz latite and rhyolite in volcanic pipes along the cauldron margin. This type of alteration, formerly called solfataric, is actually a surface phenomenon (Burbank, 1950) and is more correctly termed advanced argillic (Hemley and Jones, 1964). The highly altered rocks consist of quartz, various clay minerals, natroalunite, diaspore, and pyrite; most primary minerals were completely destroyed, and the rock bases were strongly leached. The association of dickite, pyrophyllite, and alunite is characteristic of acid-surface alteration, which generally is considered to be of hypogene origin (Hemley and others, 1969).

The acid-sulfate alteration was superimposed upon the earlier propylitic alteration, thereby driving out carbon dioxide from any carbonates present and leaching and redistributing the rock bases. In extreme examples of leaching, solution channels contain cavities and in places have an enclosing envelope of silicified rock. These silicified casings contain some residual titania as rutile and some residual alumina as clay and usually grade downward and outward to argillized and chloritized rock. At those places where large volumes of rock have been altered by acid-sulfate solutions, most of the original iron has been converted to pyrite.

The associated sulfide ores commonly fill the cavernous spaces in the upper leached parts of the channels or pipes and also replace the walls in part; at depth, less preore leaching is evident, and replacement or filling of small fissures is more typical. The principal ore minerals are pyrite, enargite, bornite, sphalerite, galena, tennantite, and chalcopyrite. Additional minerals identified include stromeyerite, chalcocite (massive), arsenian bournonite, argentite, proustite, pyrargyrite, covellite, argentiferous cosalite, kobellite, guitermanite, and, rarely, free gold. Colusite, a tin-bearing complex sulfosalt analogous to tennantite, has also been identified in the ores of two pipes.

Gangues associated more or less closely with the ores include dickite, pyrophyllite, illite, zunyite, barite, and fluorite. Quartz is not common in massive sulfide ores of the pipes, except in the walls

and silicified envelopes or as a local inclusion. Late calcite or a maganiferous carbonate mineral occurs locally.

The surficial oxidation of pyrite has acidified the ground waters, and the ground waters in turn have attacked minerals and leached metals. Mine waters carry considerable iron as well as copper and zinc locally. Veinlets of gypsum and clays in altered ground may be supergene. Native sulfur was found at one locality in altered pyritized ground that was associated with veinlets of unaltered pyrite or molybdenite. In places it becomes difficult to distinguish between the recent effects of supergene acidified waters and the possible effects of the intermingling of original hypogene solutions and shallow meteoric waters. Although galena and other sulfides are found at the surface in protected spots, some cavities near the surface contain carbonate of lead, cerussite, anglesite, limonite, scorodite, and silver minerals such as cerargyrite and native silver. In general, the products of oxidation were superficial and of little economic importance; however, at the Lark mine, sizeable bodies of carbonates of lead and zinc occur alongside sulfides and extend to considerable depths. Whether these bodies are of hypogene or supergene origin is problematical. No residuals of the original ore are apparent, and the absence of secondary minerals of other sulfides seems inconsistent with the usual assemblages of base-metal ores.

SAMPLING AND ANALYTICAL METHODS

Most samples collected were of hydrothermally altered country rock, but also included were some of the silicified rock in the pipes; a few samples were of the propylitically altered country rock. Chips of rock a few millimeters across were collected at each sample locality; each sample totaled about 100 grams. The sample was ground to a fine powder and was then analyzed in the field laboratory for arsenic, using the modified Gutzeit apparatus method described by Ward, Lakin, Canney, and others (1963, p. 40–44). The samples were then forwarded to the Denver laboratories of the Geological Survey where they were analyzed chemically for arsenic, mercury, and silver and spectrographically for selected elements. Arsenic was determined by the same method used in the field. Mercury was determined both chemically by a catalytic method (Hinkle and others, 1966) and instrumentally by an atomic-absorption technique (Vaughn and McCarthy, 1964). Silver also was determined by a catalytic method (Nakagawa and Lakin, 1965). The spectrographic values were obtained by using a three-step semiquantitative procedure which was devised by Myers, Havens, and Dunton (1961).

SAMPLE LOCALITIES

Six localities were sampled in the Red Mountains area (fig. 2) within the drainages of Red Mountain Creek, Mineral Creek, and Cement Creek. Five of the localities selected were individual mineralized deposits; the sixth locality—locality 1—was not. It was selected to provide background information to compare with the information obtained from the mineralized localities. All localities had moderate to intense acid-sulfate-altered country rock.

MINERAL CREEK SITE (LOC. 1)

To provide background data on altered rocks not directly adjacent to major ore deposits, a section along U.S. Highway 550 in the valley of Mineral Creek (fig. 2) was selected. This section, about 4 miles long, contains only a few minor veins and little other indication of significant metallic mineralization. Most of the rocks exposed along the southern part of the section (fig. 3) were strongly altered by acid-sulfate waters, in part of hypogene origin and in part of supergene origin from the oxidation of pyrite. The slopes east of the valley are colored by oxides of iron. Rocks along the northern part of the valley have been subject to propylitic and locally to acid-sulfate alteration.

With few exceptions, arsenic and mercury did not much exceea their normal content in the volcanic rocks, assuming that from the least altered rocks (fig. 3; table 1) the background for arsenic

TABLE 1.—*Chemical analyses of rocks and slope wash along U.S. Highway 55U in Mineral Creek valley*

[Chemical and atomic-absorption analyses by M. E. Hinkle and J. B. McHugh, U.S. Geol. Survey. Sample localities site shown in fig. 2]

Field No.	Description	Parts per million			Parts per billion	
		As		Ag	Hg	
		Field	Lab	Lab	Cata-lytic	Instru-mental
SM–1	Altered shaly rock, much sheared	0	30	1.5	60	40
2	Pyritized rock	5	20	1.2	100	40
3	Partly silicified rock, iron-stained	5	30	.02	<30	60
4	Limonite-cemented slope wash	10	20	.1	<30	20
5	Pyritized rock	20	30	.1	75	<5
6	Silicified rock	60	30	.1	40	60
7	Bleached rock	0	10	.01	40	10
8	Chloritized-kaolinized rock, gray	10	10	.02	60	80
9	Porous bleached rock, gray	15	15	.2	30	<5
10	Limonite-stained rock	5	10	.1	30	10
11	Bleached kaolinized rock	0	15	.02	30	30
12	Pyritized-chloritized rock	5	<10	1.2	60	110
13	Bleached-kaolinized rock	0	<10	.2	30	20
14	Pyritized rhyolitic rock	0	20	.2	30	<5
15	Do	0	<10	.02	30	40
16	Pyritized rock	20	10	.8	60	30
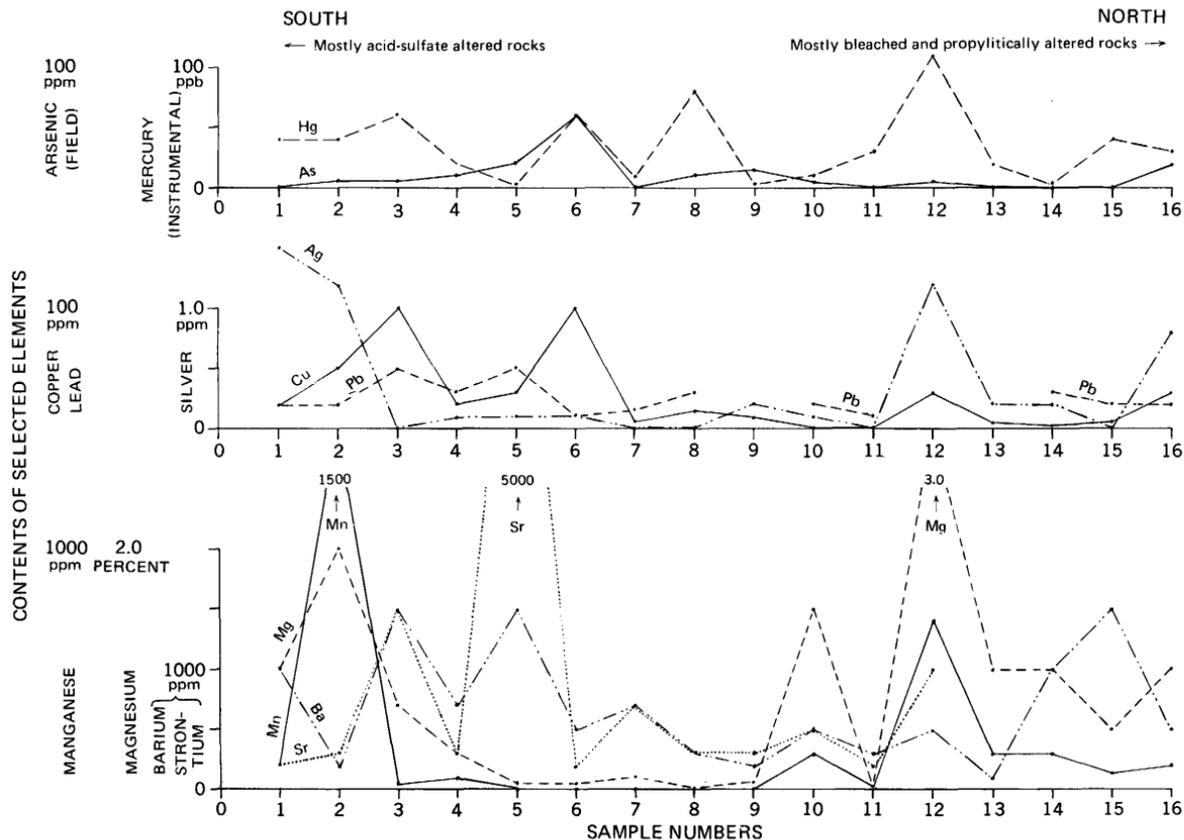
FIGURE 3.—Selected chemical data of a section along U. S. Highway 550 in Mineral Creek valley (fig. 2, loc. 1).

is no more than 20 ppm (parts per million) and for mercury no more than 100 ppb (parts per billion). Mercury appears somewhat more sensitive to minor spotty reflections of silver and copper. On the basis of our sampling, the normal background for silver in this area appears to be about 1 ppm. The background for copper (table 2) ranges from 20 to 50 ppm; the background for lead is about 20 ppm.

In relatively fresh volcanic rocks of the area, the normal content of manganese determined spectrographically ranges from 1,000 to 1,500 ppm; magnesium ranges from 1.0 to 1.4 percent. These elements (fig. 3) appear somewhat more strongly leached and transported in the southern part of the traverse, as might be expected from acid-sulfate action, and their higher values in the northern part of the traverse perhaps reflect a greater proportion of propylitized rocks not subject to leaching by acidified waters. In the propylitized rocks, manganese and magnesium are locally transported by carbon dioxide solutions.

Strontium, barium, and other minor elements do not vary significantly. Spotty high values of strontium (for example, the sample at locality 5 in fig. 3) do not correlate with other significant elements except for relatively high barium. Further data for these samples are given in table 2. The relatively small number of samples collected along U.S. Highway 550 in Mineral Creek valley are questionably representative of the altered rocks in the area, but comparison of analytical results of these and other samples collected in the area (Fischer and others, 1968; F. S. Fisher, written commun. 1971) indicate that the data from the samples taken along the highway provide reasonable background information; more elaborate analysis does not appear justified.

NATIONAL BELLE MINE SITE (LOC. 2)

The National Belle mine was selected as a site for sampling because of its exposure as a prominent knoll that contains a central core of silicified and leached rock surrounded by weakly propylitized rocks (figs. 2, 4). Because of strong surficial leaching of the exposed parts of this ore deposit, this site should indicate whether tests for the presence of any residual indicators, such as arsenic, are tenable. The ore-bearing pipelike deposit, or "chimney" as locally known, is about 400 by 300 feet in diameter (Burbank, 1941, p. 185–187). It consists of an outer envelope of strongly silicified and locally cavernous rock enclosing a core of partly brecciated material replaced by quartz, clay minerals, natroalunite, barite, and sulfides. The lead-zinc-silver ore bodies occupied cav-

TABLE 2.—*Spectrographic analyses of rocks and slope wash along U.S. Highway 550 in Mineral Creek valley*

[Spectrographic analyses by E. L. Mosier, U.S. Geol. Survey. n.d., not detected. Ag, As, Cd, Nb, Sb, Sn, W, and Zn were not detected spectrographically; Be <1 except SM–13 which is 5; Bi <20 except SM–3 which is 70. Sample localities site shown in fig. 2]

Field No.	Percent			Parts per million																
	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	Ga	La	Mo	Ni	Pb	Sc	Sr	V	Y	Zr
SM–1	5.0	1.0	0.1	10,000	100	10	1,000	10	20	20	30	30	5	5	20	30	200	300	10	200
2	10	2	5	2,000	1,500	n.d.	200	15	15	50	20	30	n.d.	7	20	10	300	100	10	50
3	1	.7	.1	7,000	20	10	1,500	n.d.	7	100	15	70	1	n.d.	50	15	1,500	150	10	150
4	10	.3	.07	5,000	50	10	700	n.d.	10	20	20	30	7	n.d.	30	15	300	100	15	200
5	5	.07	.5	5,000	2	10	1,500	n.d.	15	30	15	70	1	1	50	15	5,000	150	10	200
6	7	.07	.05	5,000	<2	10	500	15	10	100	10	50	2	7	10	20	200	200	10	300
7	2	.1	.1	10,000	2	10	700	n.d.	15	5	20	70	n.d.	n.d.	15	20	700	300	7	150
8	1.5	.01	.1	>10,000	2	10	300	n.d.	15	15	n.d.	n.d.	n.d.	n.d.	30	5	300	50	n.d.	200
9	.05	.07	.07	10,000	2	10	200	n.d.	20	10	10	n.d.	n.d.	n.d.	n.d.	10	300	200	n.d.	100
10	3	1.5	.1	2,000	150	n.d.	500	n.d.	n.d.	2	15	50	1	n.d.	20	7	500	50	10	100
11	.1	.1	.07	5,000	<2	10	300	n.d.	5	2	20	n.d.	n.d.	n.d.	10	10	200	150	5	300
12	15	3	7	5,000	700	n.d.	500	5	5	30	20	50	1	2	n.d.	20	1,000	200	30	200
13	.7	1	.05	1,500	150	10	100	n.d.	n.d.	5	20	n.d.	2	n.d.	n.d.	n.d.	n.d.	10	n.d.	50
14	2	1	.1	3,000	150	10	1,000	n.d.	2	3	20	70	n.d.	n.d.	30	10	n.d.	20	20	300
15	2	.5	.05	3,000	70	10	1,500	n.d.	n.d.	5	20	50	2	n.d.	20	10	n.d.	20	30	300
16	5	1	.15	5,000	100	10	500	10	5	30	20	50	3	5	20	15	n.d.	150	20	200
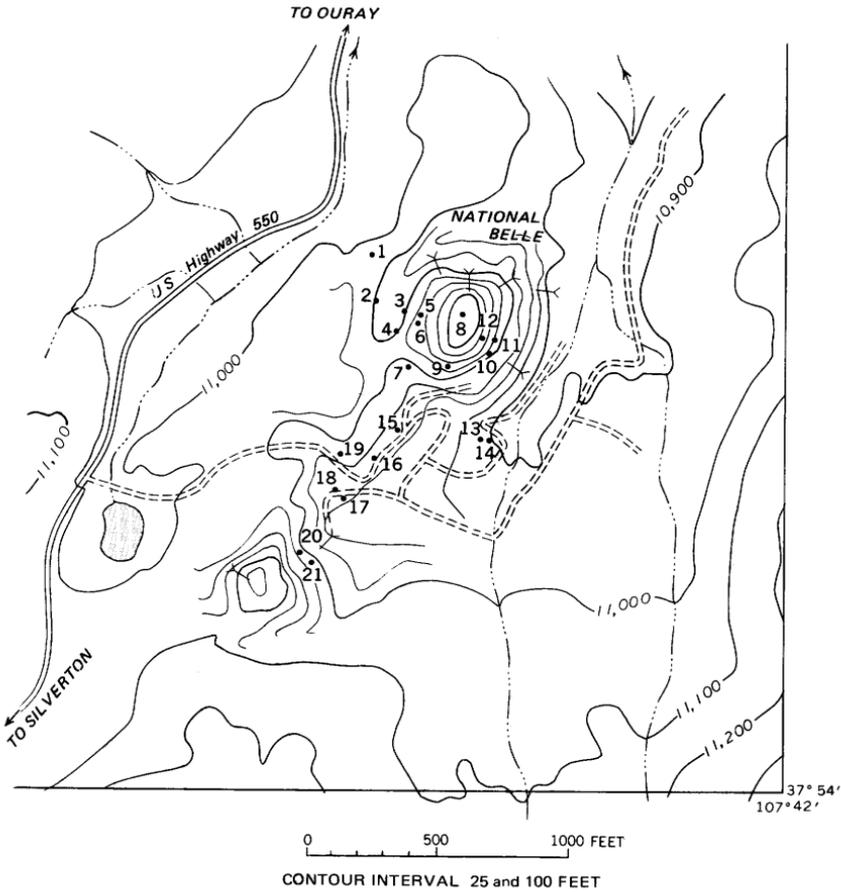
FIGURE 4.—Sample localities at the National Belle mine site. Base from U.S. Geological Survey advance map of Ironton and vicinity, 1927–29 and 1980.

erns or fissures that generally terminated in the outer siliceous envelope. Mining and erosion have removed all of any original ore from the few near-surface cavernous bodies examined. There are, however, small isolated remnants of galena, sphalerite, enargite, and pyrite in the massively silicified rock or in the clayey gouges. Fragments of ore in the dumps also contain tennantite, chalcopyrite, and colusite. Other silver-bearing sulfosalts common to the Red Mountains' pipes also possibly were constituents of the ore.

The grade of ore from the National Belle mine (Ransome, 1901, p. 231–236) ranged from 10 to 40 percent copper and from 5 to 25 ounces of silver per ton. Lead ranged from 15 to 60 percent in

some ores. The gold content was reported at less than 0.1 ounce per ton. The better grade of ore appears to have bottomed at about the 400-foot level of the mine. Total production was at least several hundred thousand dollars prior to the early 1900's, but this mine was not one of the larger producers of the Red Mountain mining district.

Examination of some of the caverns above the water level in the National Belle mine showed extensive leaching of sulfides. Ransome (1901, p. 233) reported that the oxidized residues consisted originally of carbonate of lead, iron oxides, lead sulfate, and arsenates. Identity of the arsenates is uncertain, although scorodite has been recognized in some local mines. Material collected by W. S. Burbank from the walls of a cave in the silicified rock was identified by Charles Milton of the U.S. Geological Survey as pitticite, a hydrated sulfate and arsenate of ferric iron. These occurrences of arsenic minerals in strongly leached ground in part led to the belief that arsenic might be a useful indicator element for geochemical prospecting.

Sampling locations and results at the National Belle site are shown in figures 4 and 5 and tables 3 and 4.

The arsenic content is within background limits (20 ppm) within short distances outward from the pipe and its peripheral altered zone, but its value rises gradually in the bleached and argillized rock. The high arsenic values of samples at localities 9 and 10 are related to mineralized and silicified fissures in the pipe. At sample locality 8 on the top of the knoll, where leaching appears most complete, arsenic values attain four times the background value in the bleached and silicified rock; the adjoining soil sample (NB–8S) has a lower arsenic content. Mercury shows a similar variation between bedrock and soil, although the values are of a much higher order of magnitude than the background value. Both arsenic and mercury have their higher values in samples NB–5 to 12, which closely define the limits of the pipe. Within these same limits, bismuth and tin, both relatively minor constituents of the ore, are detectible spectrographically (fig. 5; table 4). Only sample NB–10 was above the detection limit (200 ppm) for antimony, with a value of 500 ppm.

Of the common base metals, copper is erratic because of migration during leaching or of inhibition to leaching by the type and density of alteration products. Lead is well above the background (20 ppm) across the mineralized core, and lead, silver, and bismuth together attain maxima at locality 9. This locality is also the only place where zinc is detectable (200 ppm). Locality 9 is on a strong
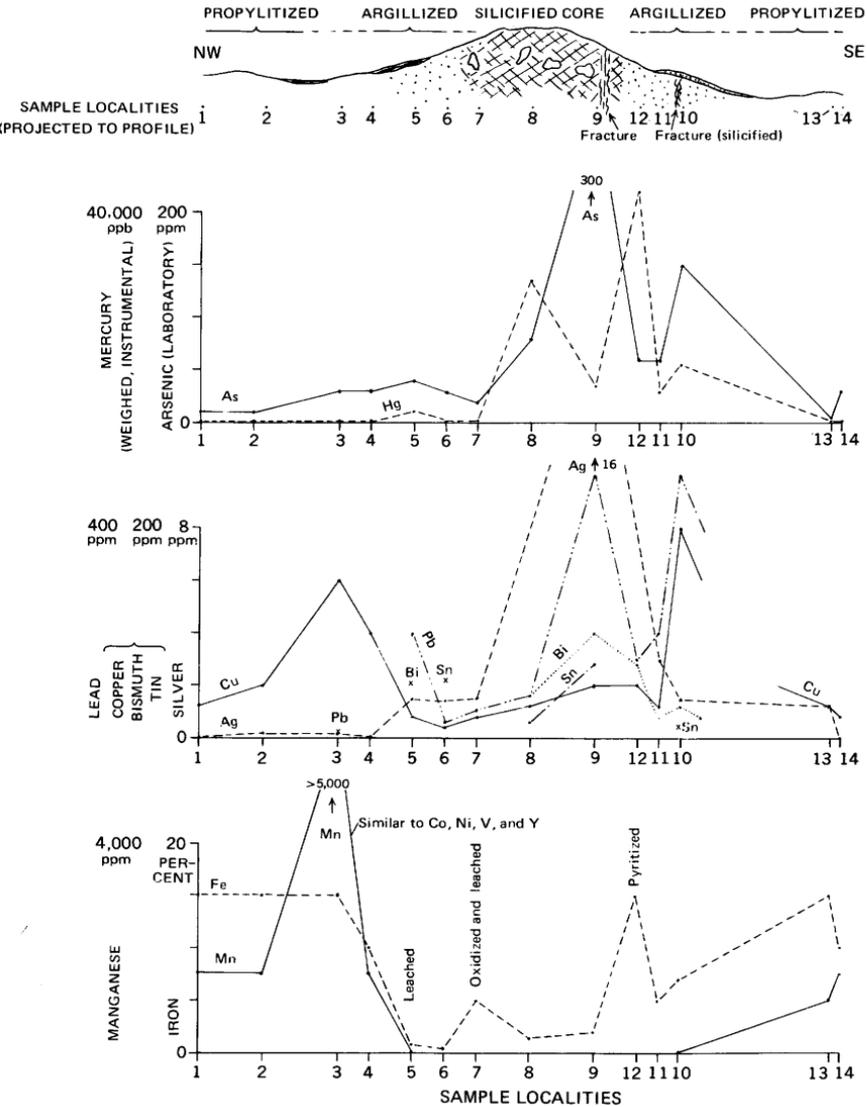
FIGURE 5.—Diagrammatic profile and graphs showing selected chemical data across the National Belle mine outcrop. Sample localities shown in figure 4.

northeast-trending fissure; underground in this fissure is a vein which extends along the east side of the pipe and which contains unoxidized sulfides above the water level.

Manganese and iron, although largely leached within pipe limits, show erratic maxima, owing partly to fixation of iron as pyrite

TABLE 3.—*Chemical analyses of rocks and soil at the National Belle mine site*

[Chemical and atomic-absorption analyses by M. E. Hinkle and J. B. McHugh, U.S. Geol. Survey. Sample localities shown in fig. 4]

Field No.	Description	Parts per million			Parts per billion		
		As		Ag	Hg		
		Field	Lab		Cata-lytic	Instru-mental (scooped)	Instru-mental (weighed)
NB–1	Chloritized rock	0	10	0.01	75	30	40
1S	Soil	20	20	.4	<30	40	40
2	Chloritized rock	0	10	.2	<30	<5	20
3	Green argillized rock	10	30	.2	<30	20	10
4	Red argillized rock	0	30	.02	<30	10	40
5	Leached-argillized rock	60	40	1.5	1,200	2,500	2,300
6	Clay-silica cavity filling	200	30	1.4	60	250	240
7	Silicified-argillized rock	0	20	1.5	500	250	325
8	Siliceous rock	80	80	8.0	8,000	25,000	27,000
8S	Soil	20	30	1.5	400	250	350
9	Sinterous cavity filling with sulfides	320	300	16.0	1,000	8,000	7,000
10	Silicified rock	200	150	1.5	1,500	15,000	11,000
11	Argillized-silicified rock	70	60	3.0	1,500	9,000	6,000
12	Silicified breccia	180	60	8.0	3,000	30,000	44,000
13	Oxidized-chloritized rock	0	<10	1.2	150	150	350
14	Chloritized rock	0	30	.1	150	110	90
15	Chloritized-argillized rock	20	30	1.5	100	150	325
16	Bleached argillized rock	10	40	.2	200	250	450
17	Do	<10	30	.1	300	750	1,400
18	Oxidized-argillized rock	40	30	1.5	400	500	725
19	Argillized loamy rock	30	40	.02	300	120	170
20	Oxidized-argillized bleached rock	320	80	5.0	400	650	650
21	Do	30	30	1.5	150	180	275

and partly to some migration of manganese and iron. Barium and strontium are locally high over the pipe core, reflecting the common occurrence of barite in ores. Of the rarer elements, vanadium, nickel, and cobalt are definitely leached along with other base elements.

In general, arsenic, mercury, lead, silver, tin, and bismuth all reflect the core and indicate the strongest metallization. As anticipated, arsenic, which is mainly associated with the copper minerals enargite and tennantite, is inconsistent with copper showings except at locality 10 where leaching was inhibited. Aresnic is more consistent with lead, bismuth, and tin than is mercury; the reasons for this are unknown.

A few samples along an altered streak extending southwest of the National Belle pipe (samples NB–15 to 21, fig. 4; table 4) give erratic and spotty indications of silver, mercury, and lead, but arsenic is only slightly above the background value. However, sample NB–20, from a prospect cut at a small iron-stained and

TABLE 4.—*Spectrographic analyses of rocks and soil at the National Belle mine site*

[Spectrographic analyses by E. L. Mosier, U.S. Geol. Survey. n.d., not detected. Sample localities shown in fig. 4]

| Field No. | Percent | | | Parts per million | | | | | | | | | | | | | | | | | | |
	Fe	Mg	Ca	Ti	Mn	Ag	B	Ba	Bi	Co	Cr	Cu	Ga	La	Ni	Pb	Sc	Sn	Sr	V	Y	Zr
NB–1	15.0	1.5	7.0	10,000	1,500	1.0	50	1,000	n.d.	7	15	30	20	100	10	n.d.	30	n.d.	300	300	30	300
1S	10	1	.7	10,000	2,000	n.d.	50	500	n.d.	15	15	30	20	50	10	20	10	n.d.	150	150	15	300
2	15	1	7	5,000	1,500	n.d.	50	700	n.d.	10	15	50	20	100	10	n.d.	20	n.d.	200	200	30	300
3	15	.7	.3	3,000	>5,000	n.d.	70	300	n.d.	15	10	150	20	30	15	10	15	n.d.	n.d.	100	30	200
4	10	.7	7	5,000	1,500	n.d.	50	300	n.d.	10	15	100	20	70	15	n.d.	20	n.d.	150	600	30	200
5	.7	.015	.05	3,000	5	3	n.d.	>5,000	50	n.d.	10	20	20	30	n.d.	200	5	n.d.	1,500	70	n.d.	30
6	.2	.02	.07	>10,000	20	3	10	70	n.d.	n.d.	7	10	n.d.	n.d.	n.d.	30	10	50	150	30	n.d.	1,000
7	5	.015	.05	10,000	5	1.5	n.d.	150	n.d.	n.d.	7	20	10	50	n.d.	50	10	n.d.	1,000	100	10	200
8	1.5	.015	.05	3,000	10	15	10	>5,000	50	n.d.	5	30	n.d.	n.d.	n.d.	100	5	15	500	10	n.d.	>1,000
8S	5	.7	.7	5,000	200	1.5	50	700	n.d.	5	15	30	10	30	10	20	10	n.d.	200	70	20	700
9	2	.02	.07	>10,000	5	30	10	1,000	100	n.d.	10	50	15	n.d.	n.d.	>500	15	70	1,500	70	n.d.	300
10	7	.01	.05	2,000	5	20	n.d.	500	30	10	7	200	70	50	10	>500	5	10	1,500	70	n.d.	30
11	5	.015	.1	3,000	5	7	n.d.	>5,000	20	n.d.	3	30	n.d.	50	n.d.	200	5	n.d.	>5,000	50	n.d.	50
12	15	.01	.07	>10,000	10	7	n.d.	700	70	10	3	50	n.d.	30	15	150	10	n.d.	1,500	30	7	500
13	15	1	1	5,000	1,000	n.d.	20	500	n.d.	10	7	30	15	n.d.	15	n.d.	15	n.d.	150	200	15	100
14	10	1	10	2,000	1,500	n.d.	20	500	n.d.	15	10	20	20	30	15	n.d.	15	n.d.	200	150	15	100
15	5	.01	.15	10,000	15	1	n.d.	200	n.d.	n.d.	7	15	10	50	n.d.	50	15	n.d.	700	100	20	300
16	1	.5	.15	5,000	100	n.d.	50	700	n.d.	n.d.	10	5	20	50	n.d.	n.d.	15	n.d.	500	300	20	150
17	7	.015	.03	3,000	70	.5	n.d.	700	n.d.	n.d.	7	30	10	30	n.d.	20	10	n.d.	150	100	5	200
18	5	.01	.02	5,000	10	.5	n.d.	500	n.d.	n.d.	7	20	10	30	n.d.	10	15	n.d.	n.d.	100	10	200
19	1	.5	.1	3,000	150	n.d.	70	200	n.d.	n.d.	15	22	20	70	n.d.	30	15	n.d.	150	300	30	200
20	2	.015	.1	5,000	7	10	n.d.	>5,000	30	n.d.	10	20	10	70	n.d.	300	10	10	2,000	50	5	200
21	.07	.01	.05	3,000	2	5	n.d.	700	n.d.	n.d.	10	1	15.	50	n.d.	200	5	n.d.	1,000	30	n.d.	70

silicified knob, gave higher values of arsenic, silver, lead, and mercury than the samples from the altered streak.

LARK MINE SITE (LOC. 3)

The Lark mine site is of particular interest because it is within highly altered rocks, and because the ore body is not marked at the present erosion surface by silicified rocks (Varnes and Burbank, 1945). Surface indications of the mineralized pipe consist of bleached and red- and brown-stained country rock containing some small cavities, probably spaces once occupied by sulfides, and some clayey streaks of oxidation products of lead and silver minerals.

The production figures for the Lark mine are unknown, as the output was included in the district production figures during World
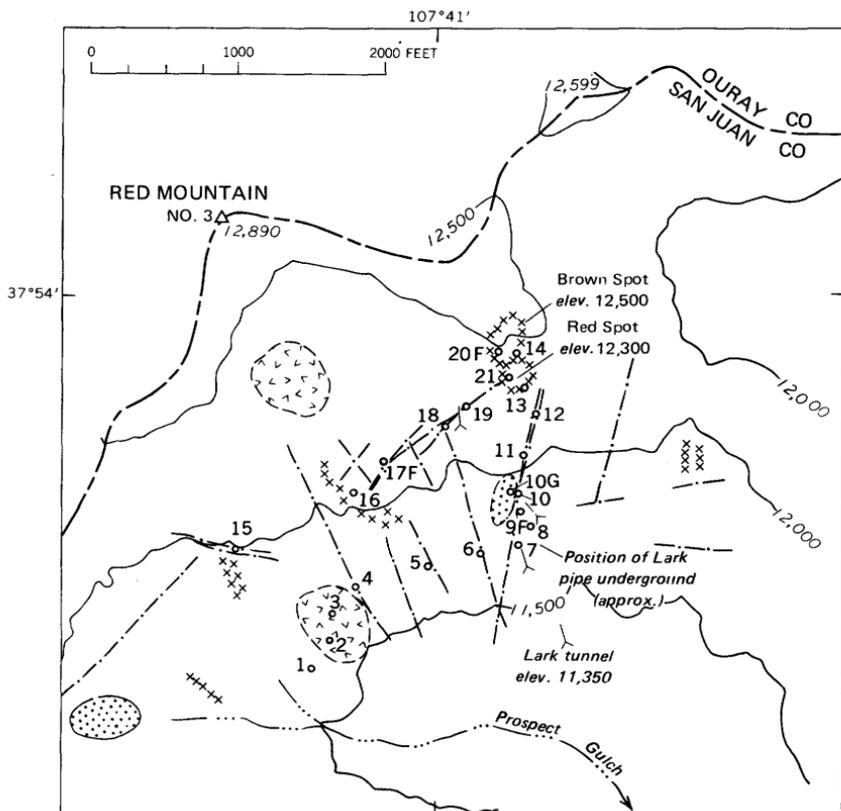

FIGURE 6.—Sample localities at the Lark mine site. Intrusive body, v-pattern; pipe, stippled pattern; silicified zone, x-pattern; vein, dash-dot line; o, sample locality.

War II. The mine is believed to have produced a substantial amount, although this amount was undoubtedly less in dollar value than that from several of the larger Red Mountains area mines that contained silver-rich ores.

The lower tunnel of the Lark mine, at an altitude of about 11,350 feet, is on the southeast slope of Red Mountain No. 3 ridge in upper Prospect Gulch, a tributary of Cement Creek (figs. 2, 6). A small pit, said to be the discovery cut, is about 675 feet above the lower tunnel. A tunnel about 200 feet below the discovery pit penetrated an ore body 30–40 feet in diameter, consisting of galena, sphalerite, and enargite with alteration products of the country rock; farther in beyond the main sulfide body, the tunnel penetrated another ore body, of unknown size, consisting of lead and zinc carbonate and sulfate minerals. At the pit representing the presumed outcrop of this body, a 10-foot channel sample taken by A. V. Heyl of the U.S. Geological Survey (written commun. 1954) gave a content per ton of 0.03 ounce gold, 1.2 ounces silver, 14.4 percent lead, 2.4 percent zinc, and 66.2 percent silica; the sample also contained 17.7 percent carbonate and 2.3 percent sulfate. Some carbonate high in iron content was also present.

Most shallow sulfide ores of the Red Mountains area show only surficial conversion of sulfides to carbonates or sulfates. In some pipes, calcite or a manganiferous carbonate mineral are minor late products, but carbonate minerals are not abundant. The ore body of the Lark mine may be an exception. The primary or secondary origin of this carbonate ore body is obscure. The possibility of a late hypogene effusion of carbon dioxide in converting sulfides to carbonates is conceivable but not established.

Two lines of samples were taken at the Lark mine site. The lower line, samples SL–1 to 14 (fig. 7; tables 5, 6), extended northeast through the discovery pit and thence north to a prominent point of the ridge heavily stained with iron oxides. The upper line, 400–500 feet higher on the slope (samples SL–15 to 21), extended northeast to the same ridge point. As shown in profile in figure 7 (see also tables 5, 6), the line through the discovery pit shows arsenic and lead values throughout, generally above the background values (20 ppm) obtained in the Mineral Creek section as well as above the background values obtained in propylitized rock near the National Belle site. Samples 10 and 10G from the discovery pit give arsenic values greater than those values obtained above the National Belle pipe. Associated with the high lead and silver contents in these samples were exceptionally high antimony values, probably indicative of antimonial sulfosalts such as tetrahedrite,
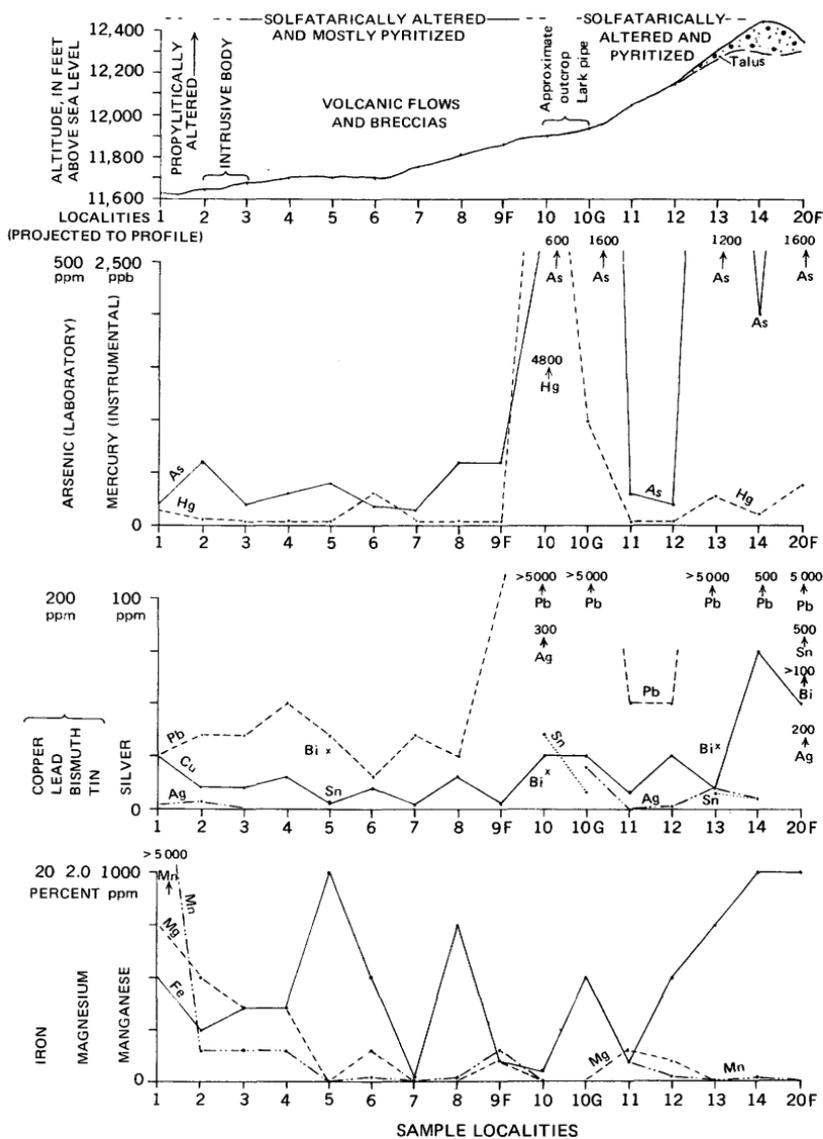
FIGURE 7.—Diagrammatic profile and graphs showing selected chemical data along the lower traverse (fig. 6) across the Lark mine site.

in the upper part of the ore body. Sample SL–10 also is relatively high in tin and bismuth values. The values of mercury are much lower relative to arsenic than those found at the National Belle mine.

TABLE 5.—*Chemical analyses of rocks and gouge at the Lark mine site*

[Chemical and atomic-absorption analyses by M. E. Hinkle and J. B. McHugh, U.S. Geol. Survey. Sample localities sites shown in fig. 6]

Field No.	Description	Parts per million		Parts per billion	
		As		Hg	
		Field	Lab	Catalytic	Instrumental
SL-1	Limonite-stained rind on altered flow rock	30	40	300	140
2	Limonite-stained intrusive rock	60	120	<30	70
3	Bleached intrusive rock	5	40	<30	50
4	Bleached shaly rock	30	60	<30	50
5	Bleached shaly and sheared rock	60	80	<30	40
6	Sheared and bleached rock	20	40	100	325
7	Bleached rock	<5	30	75	40
8	Limonitic rind on altered rock	70	120	30	40
9F	Oxidized and bleached rock (local float)	30	120	<30	40
10	Bleached porous rock from pit	>320	600	3,000	4,800
10G	Yellow-stained gouge from pit	>320	1,600	600	1,000
11	Iron-stained bleached rock	20	60	<30	40
12	Altered rock from shear zone	30	40	<30	30
13	Yellow limonitic much altered rock	200	1,200	400	280
14	Brown limonite-coated much altered rock	65	400	50	110
15	Oxidized and bleached rock	30	120	30	50
16	Silicified iron-stained rock	60	80	<30	40
17F	Limonitic iron-stained rock (local float)	30	120	100	150
18	Oxidized and bleached rock	80	400	75	120
19	Do	160	600	<30	40
20F	Limonite-stained altered rock (local float)	200+	1,600	150	375
21	Silicified and limonite-stained altered rock	30	150	<30	40

In the upper line of samples (fig. 8), samples SL–15, 16, and 17F represent altered rock without appreciable metals; however, lead values gradually increase to samples SL–18 and 19 which were taken from outcrops of a small vein. This vein heads toward the high ridge point at localities 20F and 21. Sample SL–20F, shown at the termination of both profiles (figs. 7, 8), represents local debris from an outcrop of red and brown iron-stained silicified rock near the crest of the ridge point. This sample is high in silver, lead, tin, bismuth, and antimony, but low in mercury as compared with arsenic. The significance of the relatively low mer-

TABLE 6.—*Spectrographic analyses of rocks and gouge at the Lark mine site*

[Spectrographic analyses by E. L. Moiser, U.S. Geol. Survey. n.d., not detected. Sample localities sites shown in fig. 6]

| Field No.	Percent			Parts per million																				
	Fe	Mg	Ca	Ti	Mn	Ag	As	B	Ba	Bi	Cr	Cu	Ga	La	Mo	Ni	Pb	Sb	Sc	Sn	Sr	V	Y	Zr
SL–1	10.0	1.5	0.15	>10,000	>5,000	2	n.d.	100	1,000	n.d.	20	50	30	50	2	n.d.	50	n.d.	20	n.d.	100	300	30	500
2	5	1	.05	10,000	150	3	n.d.	70	500	n.d.	50	20	20	70	10	n.d.	70	n.d.	10	n.d.	n.d.	100	20	200
3	7	.7	.3	10,000	150	<1	n.d.	70	500	n.d.	20	20	20	100	2	n.d.	70	n.d.	10	n.d.	1,000	100	30	500
4	7	.7	.1	>10,000	150	<1	n.d.	50	1,000	n.d.	30	30	20	70	2	n.d.	100	n.d.	20	n.d.	200	200	30	300
5	20	.07	.15	3,000	10	<1	n.d.	20	500	50	7	5	20	n.d.	3	n.d.	70	n.d.	10	10	300	100	10	150
6	10	.3	.3	10,000	20	<1	n.d.	20	700	n.d.	15	20	20	50	2	n.d.	30	n.d.	30	n.d.	200	200	30	300
7	.2	.05	.2	10,000	5	<1	n.d.	n.d.	500	n.d.	15	3	20	50	n.d.	n.d.	70	n.d.	20	n.d.	700	200	20	500
8	15	.05	.1	10,000	10	<1	n.d.	20	300	n.d.	10	30	15	50	10	n.d.	50	n.d.	15	n.d.	>5,000	200	10	300
9F	2	.2	.5	10,000	150	<1	n.d.	20	200	n.d.	15	5	15	70	n.d.	n.d.	200	n.d.	15	n.d.	500	200	20	200
10	1	.02	.5	>10,000	5	300	n.d.	n.d.	300	30	20	50	70	150	n.d.	n.d.	>5,000	7,000	15	70	>5,000	200	7	500
10G	10	.01	.07	7,000	n.d.	20	3,000	n.d.	200	n.d.	10	50	100	50	5	n.d.	>5,000	1,000	5	15	500	150	10	300
11	2	.3	.2	5,000	100	<1	5,000	20	1,500	n.d.	7	15	20	70	2	<1	100	n.d.	15	n.d.	1,000	150	10	200
12	10	.2	.2	5,000	30	1	n.d.	50	700	n.d.	7	50	20	30	1	<1	100	n.d.	20	n.d.	500	150	15	200
13	15	.05	.07	5,000	5	10	n.d.	20	500	50	15	20	50	30	10	n.d.	5,000	200	5	10	500	70	n.d.	100
14	20	.01	.1	2,000	10	5	2,000	n.d.	200	n.d.	10	150	15	n.d.	3	<1	500	n.d.	5	10	300	150	5	150
15	10	1.5	.2	10,000	500	<1	n.d.	30	1,000	n.d.	20	50	20	150	2	5	30	n.d.	15	n.d.	100	150	20	300
16	10	.07	.1	10,000	50	<1	n.d.	20	300	30	15	50	15	50	<1	n.d.	150	n.d.	15	n.d.	700	200	20	300
17F	10	.01	.1	5,000	100	3	n.d.	10	200	30	10	70	15	70	1	n.d.	300	n.d.	15	n.d.	1,500	200	10	500
18	1	.01	.05	>10,000	n.d.	5	n.d.	n.d.	1,000	30	30	30	>100	30	1	n.d.	>5,000	n.d.	10	20	2,000	70	n.d.	200
19	15	.02	.15	10,000	10	7	n.d.	20	500	50	15	50	20	70	3	n.d.	3,000	n.d.	10	n.d.	1,000	200	10	300
20F	20	.01	.15	5,000	5	200	7,000	n.d.	700	>100	30	100	100	50	5	n.d.	5,000	3,000	10	500	1,500	300	5	300
21	10	.5	.2	10,000	20	2	n.d.	30	700	50	10	20	20	50	15	n.d.	150	n.d.	20	n.d.	700	200	20	300
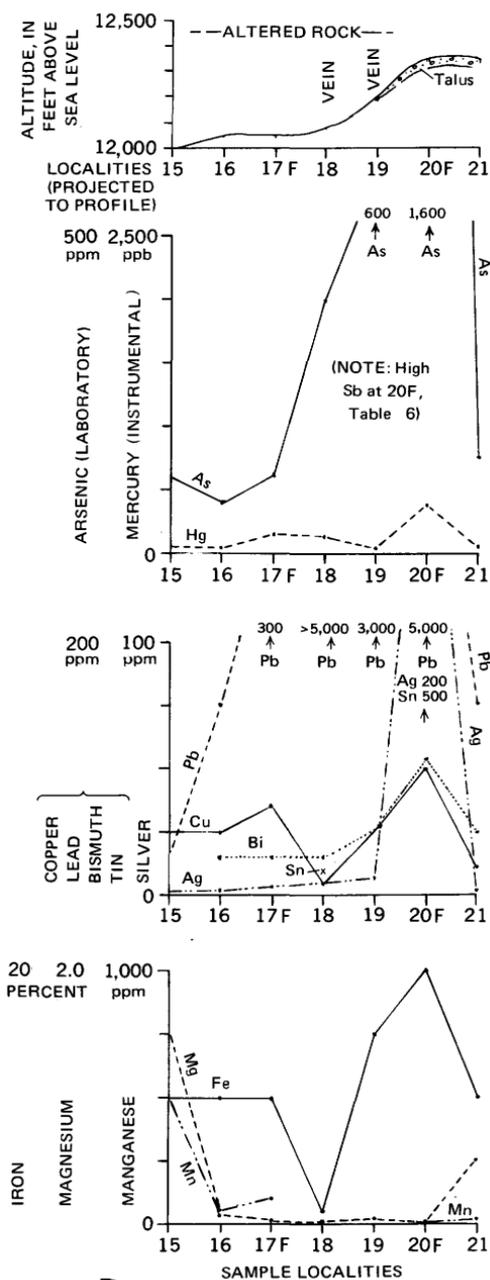
FIGURE 8.—Diagrammatic profile and graphs showing selected chemical data along the upper traverse (fig. 6) across the Lark mine site.

cury showings at the Lark mine site is problematical; we speculate that it might relate to a little known but relatively weak late-stage gold enrichment.

In general, the results of sampling at the Lark mine site appear to reflect the known pipe and possibly an unknown pipe. Judging by comparison of the Lark samples with the samples near other ore bodies, it would be worthwhile to take closer grid samples in the area of the ridge point to confirm the metal values and to check the size of the area of anomalies.

LONGFELLOW AND ST. PAUL MINE SITES (LOCS. 4 AND 5)

A few samples were taken from two small mines south of the National Belle mine (fig. 2). These two sites may be considered typical of chimney ore bodies that occur around the peripheries of pipes occupied by intrusive rocks. The results were not enlightening and indicate that more elaborate sampling would be required for significant results.

The Longfellow mine (fig. 9) was started in the late 1940's or early 1950's and was worked intermittently for several years. Mine development consists of a shaft and several short tunnels on the 150-foot level. Enargite, galena, and sphalerite in clays occur as irregular bunches in two ore bodies.

Two samples of altered volcanic country rock that were taken from a shallow pit south of the Longfellow shaft and near the edge of the silicic intrusive body (fig. 9) indicated only moderate arsenic, lead, silver, and copper were above background values; strontium was fairly high.

The St. Paul is one of the older mines of the Red Mountains mining district but was never a major producer. According to Ransome (1901, p. 238) the main vertical shaft, which was about 200 feet deep, had drifts at the 200-foot level. The ore, chiefly enargite and galena in irregular bunches, was reported to be low grade and was found by following seams of gouge clay. The mine workings were opened and prospected for gold-bearing ore in more recent years.

The mineralized fissure at the St. Paul mine, similar to those described previously near the National Belle mine and elsewhere, has a strike of about N. 30° E. in volcanic flows and breccias. Sampling along this fissure gave low values in arsenic except for location southwest of the shaft which had 80 ppm arsenic, 500 ppm lead, and 1 ppm silver (fig. 9; table 7). Enrichment in barium and strontium were noticeable in the walls locally; strontium was higher closest to the fissure.
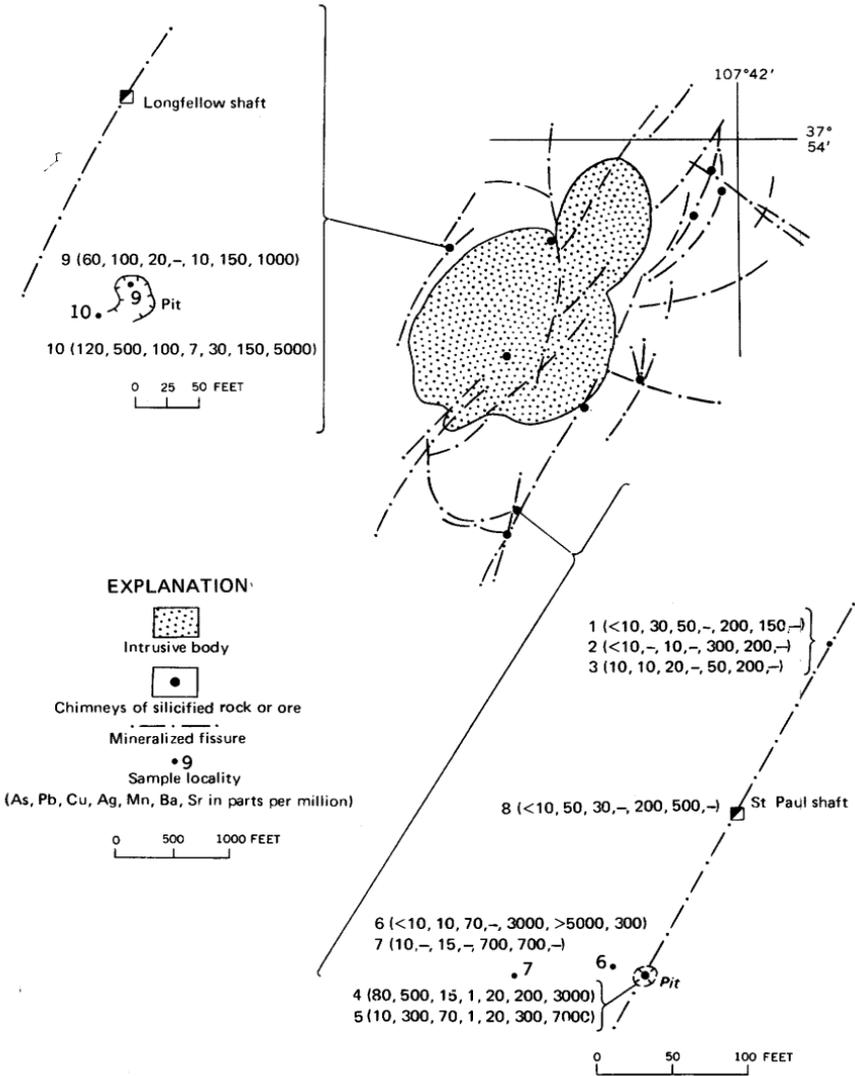
FIGURE 9.—Geologic sketch map of the Koehler compound volcanic pipe and sample localities at the Longfellow and St. Paul mine sites. From Burbank (1941, fig. 5).

BROOKLYN MINE SITE (LOC. 6)

The Brooklyn mine is north of Browns Gulch on the east wall of Mineral Creek valley (figs. 2,10). Its northeast-trending vein is poorly exposed except for a few small cuts at about 11,400 feet altitude on a valley-wall bench which is locally mantled with glacial

TABLE 7.—*Spectrographic analyses of rocks at the Longfellow and St. Paul mine sites*

[Spectrographic analyses by E. L. Mosier, U.S. Geol. Survey. n.d., not detected. Sample localities shown in fig. 9]

	Field No.	Description	Percent		Parts per million																		
		Mg	Ca	Ti	Mn	Ag	B	Ba	Co	Cr	Cu	Ga	La	Mo	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
	St. Paul mine																					
1	Red rind on altered rock	0.2–4	<1	7,000	200	n.d.	100	150	n.d.	7	50	20	70	2	<1	30	15	n.d.	100	20	n.d.	500
2	Gray rind on altered rock	.2–4	<1	5,000	300	n.d.	50	200	n.d.	5	10	20	50	n.d.	1	n.d.	10	n.d.	70	20	n.d.	150
3	Limonite-stained bleached rock	.2–4	<1	5,000	50	n.d.	50	200	n.d.	5	20	20	50	n.d.	<1	10	10	n.d.	70	20	n.d.	150
4	Oxidized rind on altered rock	<.2	<1	5,000	20	1	n.d.	200	n.d.	15	15	10	50	n.d.	<1	500	n.d.	3,000	70	10	n.d.	150
5	Do	<.2	<1	5,000	20	1	n.d.	300	n.d.	20	70	n.d.	150	n.d.	5	300	n.d.	7,000	50	10	n.d.	150
6	Oxidized rind on chloritized rock	.2–4	<1	7,000	3,000	n.d.	50	>5,000	10	10	70	30	100	n.d.	3	10	15	300	150	30	n.d.	500
7	Chloritized rock	.2–4	<1	5,000	700	n.d.	30	700	10	7	15	20	50	n.d.	3	n.d.	15	n.d.	100	20	n.d.	200
8	Pyritized and altered rock	.2–4	<1	5,000	200	n.d.	50	500	10	5	30	20	50	n.d.	3	50	15	n.d.	100	20	n.d.	200
	Longfellow mine																					
9	Oxidized rind on altered rock	<.2	<1	5,000	10	n.d.	n.d.	150	10	5	20	15	50	1	5	100	15	1,000	100	20	n.d.	150
10	Do	<.2	<1	5,000	30	7	20	150	n.d.	5	100	10	50	n.d.	<1	500	n.d.	5,000	50	n.d.	700	100
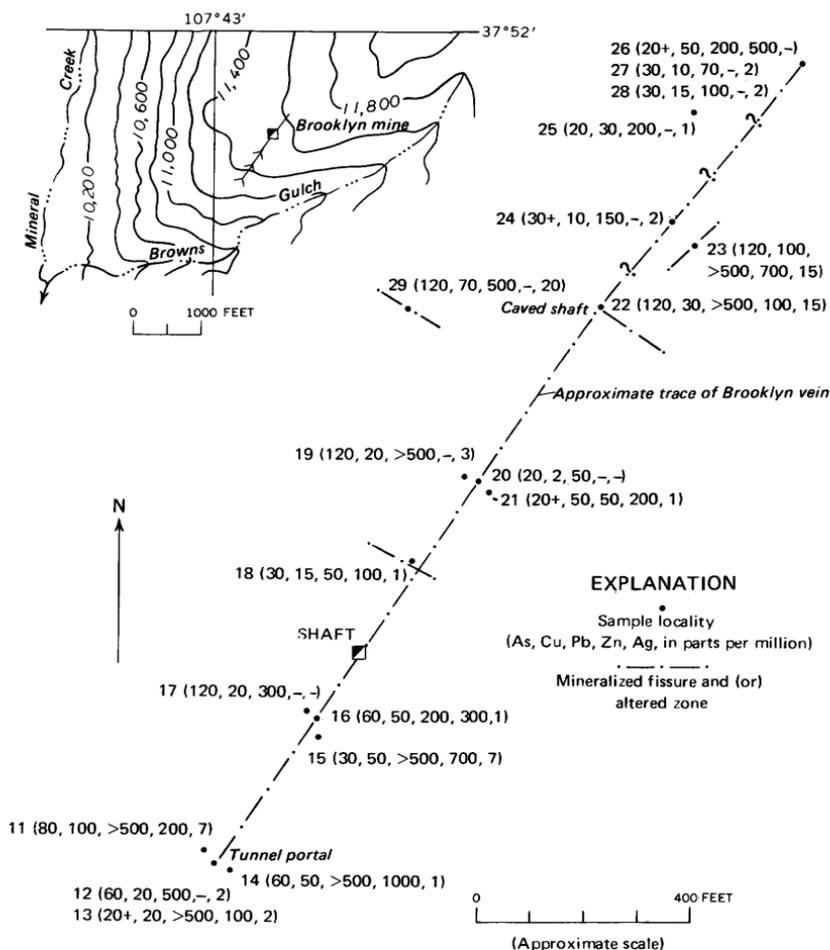
FIGURE 10.—Sketch map of sample localities at the Brooklyn mine site.

debris and slope wash. In addition, the vein walls of altered and sheared volcanic rocks are soft; this condition results locally in a trenchlike surface expression along strike. Most of the geochemical samples were collected along the vein and crosscutting fissures, but some of the samples were taken from the altered wallrocks from a few feet to as much as 30 feet on either side of the vein. Extension of the vein's course beyond the caved shaft (fig. 10) is somewhat uncertain.

The predominant ore minerals are pyrite, galena, and sphalerite, a little chalcopyrite, and possibly tennantite. Some narrow fissures contain native gold associated with a little manganiferous

carbonate and pyrite. At one time, small operations recovered sub-
stantial gold from these fissures along certain stretches of the vein.
The results of sampling, shown in figure 10 and tables 8 and 9,
indicate that trenching of the surface debris and closer spacing of
samples are required for more satisfactory delineation of anom-
alies. The relatively high values of arsenic and metals, shown by
the several samples taken in the walls 15–30 feet from the vein,
indicate a high permeability of the country rock. This high per-
meability is possibly a result of preore leaching by solutions of the
acid-sulfate stage. As shown by the spectrographic analyses (table
9), calcium, magnesium, and locally manganese are below the nor-
mal amounts in fresher rocks. These elements were partially re-
moved by leaching. Iron, on the other hand, is only locally leached
and, for the most part, has been increased by the addition of pyrite.
The barium content has a range somewhat like that of the back-
ground traverse along the highway in Mineral Creek valley west
of this site. Because these values are comparable, it is assumed
that the arsenic background also should correspond roughly to that
of Mineral Creek (fig. 3).

Correlation between the moderate arsenic values and the general
trend of the Brooklyn vein is obscure (fig. 10), possibly because
of poor sampling conditions and the limited numbers of samples.

TABLE 8.—*Chemical analyses of rocks, gouge, and undersoil at the
Brooklyn mine site*

[Chemical analyses by Doris Price, U.S. Geol. Survey. Sample localities shown in fig. 10]

Field No.	Description	Parts per million		
		Arsenic		
		Field	Lab	Lab [1]
65–11	Chloritized rock	<10	80	80
12	Gouge	10	60	60
13	Rind on altered rock	<10	30	20+
14	Oxidized seam in rock	20	60	60
15	Altered seam in rock	10	20+	30
16	Manganese-stained altered rock	80	80	60
17	Iron-stained bleached seam in rock	60	120	120
18	Iron-stained seam in fractured rock	20	40	30
19	Bleached rock	80	120	120
20	Clayey undersoil (slope wash?)	10	20	20
21	Manganese- and iron-stained chloritized rock	10	30	20+
22	Partly oxidized rock	60	120	120
23	Oxidized altered rock	120	120	120
24	Bleached and iron-stained rock	40	40	30+
25	Oxidized rock	<10	20	20
26	Manganese-stained rock	30	30	20+
27	Limonite-stained rock	30	30	30
28	Bluish gouge	10	40	30
29	Silicified rock with limonitic selvage	80	120	......

[1] Sodium peroxide added.

TABLE 9.—*Spectrographic analyses of rocks at the Brooklyn mine site*

[Spectrographic analyses by E. L. Mosier, U.S. Geol. Survey. n.d., not detected. Sample localities shown in fig. 10]

Field No.	Percent			Parts per million																		
	Fe	Mg	Ca	Ti	Mn	Ag	B	Ba	Co	Cr	Cu	Ga	La	Mo	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
65–11	10	0.7	0.30	5,000	700	7	20	700	n.d.	7	100	20	n.d.	7	2	>500	20	n.d.	200	10	200	300
12	5	.5	.10	10,000	150	2	70	1,000	n.d.	10	20	20	100	5	n.d.	500	30	n.d.	500	50	n.d.	1,000
13	10	1.	.15	7,000	700	2	10	1,500	n.d.	7	20	20	50	2	n.d.	>500	20	n.d.	300	30	100	300
14	10	2.	.5	7,000	2,000	1	10	700	7	10	50	20	50	n.d.	3	>500	20	200	300	30	1,000	300
15	15	2.	.07	7,000	5,000	7	10	200	5	10	50	20	n.d.	70	n.d.	>500	20	n.d.	200	30	700	500
16	7	1.	.15	5,000	5,000	1	10	700	7	7	50	20	n.d.	n.d.	3	200	15	n.d.	200	20	300	200
17	7	1.	.15	7,000	700	n.d.	20	700	n.d.	10	20	20	70	1	n.d.	300	20	n.d.	300	30	n.d.	200
18	10	.5	.15	7,000	500	1	20	1,000	n.d.	10	15	20	70	1	2	50	20	n.d.	200	30	100	200
19	5	.5	.10	7,000	500	3	20	1,000	n.d.	10	20	20	70	1	n.d.	>500	30	n.d.	300	50	n.d.	300
20	3	.5	.2	10,000	200	n.d.	30	2,000	n.d.	10	2	20	100	1	n.d.	50	30	200	200	50	n.d.	300
21	7	1.	.2	7,000	5,000	1	30	1,000	10	10	50	20	70	1	5	50	20	n.d.	200	30	200	300
22	20	.2	.1	7,000	500	15	50	1,000	n.d.	10	30	20	70	2	2	>500	20	300	200	30	100	300
23	15	.5	.1	10,000	500	15	30	500	n.d.	10	100	20	n.d.	2	n.d.	>500	30	n.d.	300	30	700	500
24	3	.1	.15	5,000	500	2	30	500	n.d.	7	10	20	100	2	n.d.	150	15	200	200	30	n.d.	300
25	10	.7	.15	7,000	500	1	30	1,000	n.d.	10	30	20	70	1	2	200	20	300.	300	30	n.d.	500
26	10	3	.3	7,000	>5,000	n.d.	10	700	5	10	50	20	70	n.d.	5	200	30	n.d.	500	50	500	300
27	3	.5	.1	5,000	500	2	30	1,000	n.d.	5	10	50	70	n.d.	n.d.	70	20	200	300	50	n.d.	300
28	2	.5	.2	10,000	50	2	30	2,000	n.d.	10	15	50	70	2	n.d.	100	50	200	500	50	n.d.	500
29	2	.3	.1	7,000	500	20	30	1,000	n.d.	5	70	15	n.d.	n.d.	n.d.	500	15	200	150	20	n.d.	300

However, the higher arsenic values and the valuable metals do correlate fairly well; copper and lead in the higher grouping average about twice as much as those in the lower group, and silver averages three to four times as much. The sodium-peroxide-treated laboratory samples (table 8) were used for comparison and plotting (fig. 10) because of the relatively high amount of unoxidized pyrite in most of the samples.

The relatively high amount of zinc in some Brooklyn samples contrasts markedly with the generally low amounts noted at all other sites. Zinc was present below detection limits in about one-third of the samples. Probably, this variant is caused by the cover of slope wash and glacial debris, poor drainage conditions owing to very little adjacent surface area from which waters can drain across this site, and the incomplete leaching by acid-sulfate waters.

The Brooklyn vein, although in acid-sulfate altered rocks, must be considered possibly to have undergone a type of mineralization somewhat different than that of the chimneys; thus, the associated geochemical anomalies may be different. This possibility is suggested by the presence of chalcopyrite, by the apparent lack of enargite, and by the relatively anomalous occurrence of zinc near veins in the area (F. S. Fisher, written commun., 1971). Further corroboration of the difference in geochemical anomalies between veins and chimneys is provided by the fact that veins are less subject to supergene leaching than chimneys are.

CONCLUSIONS

Preliminary field tests for arsenic in areas that have undergone acid-sulfate leaching, such as the Red Mountains area of the western San Juan Mountains, seem to be very useful in geochemical prospecting, particularly for mineralized chimney deposits. The principal advantage is that these tests for arsenic residuals do not show anomalous broad halos but define specific areas, such as the relatively small pipe localities, for further and more elaborate sampling and laboratory tests. In general, residual lead, silver, and mercury conform to the residual arsenic values, whereas copper and zinc generally do not because they are easily leached by acid surface waters.

The background values of mercury are somewhat more erratic than those of arsenic but mercury also greatly exceeds arsenic in sensitivity to local metal concentrations. This greater sensitivity could be of advantage under some conditions. Because the metals are widely dispersed in the fractured and porous rocks of the area, the useful selectivity of mercury determinations is perhaps not

fully established by the limited sampling that was done. However, the larger number of samples required may also lessen its value as a prospecting technique.

These field samples were mainly taken from specific localized sites rather than from the altered fissures of northerly to northeasterly trend in the Red Mountains area that are characteristic of the western rim of the Silverton cauldron and that are related to the trend of its boundary faults. Bleached and pyritized rocks are typical along the more pronounced fissures between the major pipes, but concentrations of ore are spotty and generally weak; a few small veins and irregular masses of lead-silver ore have been prospected. Many of the pipe deposits at depth tend to assume linear forms or else become a series of fissures. The delineation of these fissured and mineralized breaks at the surface may of course be useful to outline broad patterns of mineral concentrations. Whether or not arsenic is sufficiently sensitive for this purpose is questionable without further testing.

Certain precautions in sampling and sample preparation are necessary to obtain the full advantage of the arsenic test. The large quantities of pyrite in many samples tended to interfere with the accuracy of the field determinations. Accordingly, fusion of the samples with sodium peroxide prior to field determinations seems to be desirable. Figure 11 illustrates the comparison between field and laboratory determinations for samples from the Lark and Brooklyn mine sites. Most field results were usually lower in value than the better controlled laboratory results, but this factor does not necessarily reflect the reliability of the field results; reliability was not tested. This difference probably results in part from the inexperience of the field operators and in part from the interfering effects of pyrite in many samples.

The results also indicate that somewhat closer spacing of field samples would have been helpful in the sites of established deposits. Where the overburden is fairly thick, trenching to the bedrock surface is of course desirable, as the local debris may be contaminated with transported clayey material and residual products of oxidation. Rapid erosion on the steep slopes of much of the area contributes to this contamination.

The tests made were intended only to determine if there was appreciable residual arsenic in leached and oxidized rocks of the area. No attempt was made to define areas for further testing or to locate sites for exploration.
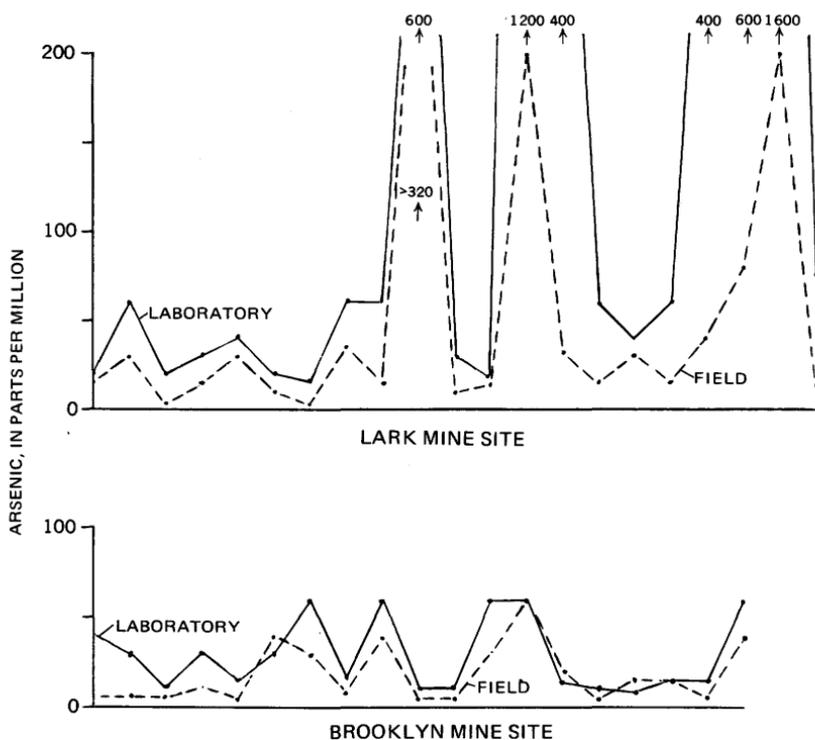
FIGURE 11.—Comparison of field and laboratory determinations for arsenic. See text and tables 5 and 8.

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