Tertiary Mineralization and Hydrothermal Alteration in the Stinkingwater Mining Region, Park County, Wyoming

GEOLOGICAL SURVEY BULLETIN 1332-C

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By FREDERICK S. FISHER

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A study of a porphyry copper deposit in the Absaroka Range, its altered volcanic rocks and metal distributions

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TERTIARY MINERALIZATION AND HYDROTHERMAL ALTERATION IN THE STINKINGWATER MINING REGION, PARK COUNTY, WYOMING

By FREDERICK S. FISHER

ABSTRACT

Disseminated copper-molybdenum mineralization was associated with multiple intrusions of Tertiary granodioritic to dacitic stocks in the Stinkingwater mining region, Wyoming. In the mineralized zone, which covers about 1 square mile, rock outcrops are highly fractured, bleached, and silicified, and they are commonly stained with iron oxide. Chalcopyrite, molybdenite, and pyrite occur as disseminated grains and also as coatings on fracture surfaces within the main area of mineralized rock. Crudely clustered around this area are narrow, steeply dipping veins and stringers that contain pyrite, galena, sphalerite, and chalcopyrite, along with the major gangue minerals quartz, calcite, and some dolomite. Gold occurs sporadically along the veins, and silver is present in galena-rich parts of the veins.

An oxidized and supergene copper-enriched zone formed during Miocene(?) and Pliocene(?) time across the area of primary disseminated sulfide minerals. Parts of this zone were removed by glaciation and erosion during Quaternary time, and therefore only remnants of the original leached mineralized cap and underlying supergene-enriched zones are present.

Hydrothermal alteration in the region resulted in a central quartz-sericite-pyrite zone which contains irregular potassium-rich areas and which is surrounded by a fringe of propylitically altered rock. The intensity of alteration was extremely variable; however, in general it increased toward the center of the zone of disseminated-sulfide mineralization. Metal distributions indicate a central zone of copper-molybdenum minerals surrounded by a fringe area of veins that contain minerals of silver, gold, lead, zinc, arsenic, and possibly mercury. The elements of the fringe zone are important in prospecting for similar but "blind" disseminated-sulfide deposits elsewhere in the Absaroka Range.

INTRODUCTION

The Stinkingwater mining region (fig. 1) is about 50 miles southwest of Cody, Wyo., in the southern Absaroka Range. It lies in the southeast corner of the Ishawooa quadrangle (Hague, 1899b) and within the South Absaroka Wilderness area (fig 2). The region is about 8 miles from the nearest road and is accessible on the ground only by foot or horseback.

FIGURE 1.—View from the top of Needle Mountain upstream (south) along the South Fork of the Shoshone River valley, showing the Stinkingwater mining region. The main area of disseminated sulfide minerals is on the lower slopes of Crater Mountain, in the approximate center of the area shown in the photograph. Landslide debris at the base of Crater Mountain partly covers the western side of the mineralized area. Linear features in the left-center of the photograph are rock masses in the Crater Mountain Dacite that have slumped because of gravity.

The exact time when mineralized rock in the Stinkingwater region was first discovered is not known. Hague (1899b) reported that some adits and prospect pits were present in the region in 1893 but that they were not being worked at that time. The entire known history of the region involves mainly sporadic prospecting. Several adits and numerous prospect pits were dug at various times; however, there have been no known shipments of ore. In recent years prospecting in the region has been relatively intense, and some diamond drilling has been done in the area. Early prospecting in the region was undoubtedly directed at gold-silver minerals in veins, whereas recent work has been concentrated on the occurrence of disseminated copper and molybdenum of the porphyry type.

The present study is one of several on the Stinkingwater mining region on which I have reported as a result of my field investigations during 1963 and 1964. The genesis of recent gypsum in the region has been briefly discussed (Fisher, 1965), and the geology has been mapped and discussed in detail, with emphasis on the

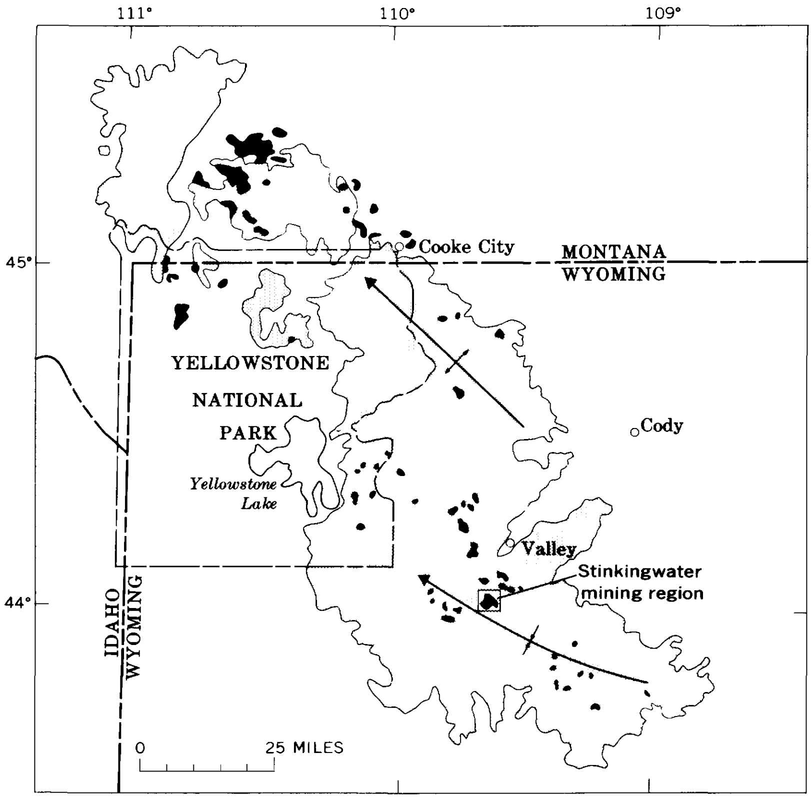

FIGURE 2.—Index map of the Absaroka volcanic field (stippled). Solid black, intrusive bodies. Axes and plunges of major folds shown by arrows.

petrology of the intrusive bodies in the region (Fisher, 1967). More recently, geochemical data and sample locality maps of the region have been released (Fisher, 1971).

Previous geological studies of the Stinkingwater region were limited to reconnaissance. Hague (1899a, p. 16) briefly discussed in general terms the broad geological features of the region. Rouse (1934, 1935) studied the volcanic rocks, physiography, and glacial geology in the Valley area, about 10 miles north of the Stinkingwater region (fig. 2). His main discussion centered on the extrusive rocks; however, he also presented a map showing the intrusive body in the Stinkingwater region. W. H. Wilson (in Osterwald and others, 1959, p. 121) did geological reconnaissance and briefly discussed the mineralized rock in the Stinkingwater region.

The Absaroka volcanic field is a dissected volcanic plateau composed primarily of andesitic volcanoclastic rocks, lava flows, and flow breccias that unconformably overlie folded Paleozoic and Mesozoic rocks (Wilson, 1964a, b; Parsons, 1958; Keefer, 1957; Rouse, 1940, 1937; Love, 1939; Hague, 1899b; Hague and others, 1899). Numerous intrusive bodies, which range in composition from gabbro to rhyolite and in size from thin dikes to stocks a few square miles in area, cut the entire layered volcanic sequence (Ketner and others, 1966; Wilson, 1964b; Parsons, 1960; Rouse, 1940; Larsen, 1940; Love, 1939; Hague, 1899b). Sulfide minerals are associated with several of the intrusive centers which are characterized by a complex igneous history and several episodes of intrusive activity. Chadwick (1970) suggested that the intrusive rocks in the Absaroka volcanic field could be divided into two northwestward-trending belts. He further suggested that the "igneous rocks of the Eastern Absaroka Belt are more potassic than those of the Western Absaroka Belt." The Stinkingwater region is near the south end of the western Absaroka belt.

The layered rocks of the southern Absaroka Range are flat lying to gently inclined. Local areas of faulting and folding, many of which are related to igneous activity, have been described (Fisher, 1967; Wilson, 1964a, b; and Love, 1939). On a regional scale the layered volcanic rocks of the southern Absaroka Range are folded into a broad shallow westward-trending syncline (Fisher and Ketner, 1968). The Stinkingwater region is on the axis and approximately in the center of the syncline.

ACKNOWLEDGMENTS

I gratefully acknowledge the assistance received during this study. The Wyoming Geological Survey underwrote part of the research expense. William H. Wilson provided considerable help and criticism throughout the study. The Bear Creek Mining Co. and Mrs. Grace Wight cooperated in many ways and released the diamond-drill core to me for the research. All the drill cores discussed in this report were from diamond drilling done by the Bear Creek Mining Co.

All analyses were done in U.S. Geological Survey laboratories. Semiquantitative spectrographic analyses were by E. E. Martinez and J. M. Motooka. Gold analyses were made by atomic-absorption spectrometry by W. L. Campbell, W. H. Ficklin, W. D. Goss, R. F. Hansen, Claude Huffman, Jr., H. D. King, R. W. Leinz, H. G. Mandeville, E. E. Martinez, S. K. McDanal, R. L. Miller, D. K. Parker, M. S. Rickard, T. A. Roemer, and A. J. Toevs. Mercury analyses were made by the vapor detector method by J. V. Desmond, R. F. Hansen, H. D. King, S. K. McDanal, and R. L. Miller.

GENERAL GEOLOGY OF THE STINKINGWATER REGION

LAYERED ROCKS

The exposed stratigraphic sequence in the Stinkingwater region comprises rocks that range in age from Eocene to Holocene. The Eocene formations are flat lying to gently dipping and consist of middle Eocene early basic breccia, named the Wapiti Formation by Nelson and Pierce (1968) ; the middle Eocene early basalt flows, named the Trout Peak Trachyandesite by Nelson and Pierce (1968) ; and the middle and upper Eocene Wiggins Formation. These three formations are composed primarily of andesitic to basaltic material and in the Stinkingwater region are mainly lava flows, breccias, and flow breccias with some volcanic sediments.

The Wapiti Formation is about 300–400 feet thick in the Stinkingwater region, where it is exposed in only two relatively small areas (fig. 3). It is flat lying and consists mainly of dark-brown to grayish-brown flow breccias and volcanic breccias. The fragments in the breccias are angular to subrounded, make up about 40–65 percent of the rock, and are composed of pyroxene andesite, hornblende-pyroxene andesite, and andesite. Most of the fragments are about 1–6 inches in diameter. The groundmass of the breccias is composed of the same material as the fragments. It consists of small rock fragments, sand- and silt-sized particles, some tuffaceous material, and minor feldspar and pyroxene phenocrysts.

The Trout Peak Trachyandesite is well exposed in the Stinkingwater region. Individual flows within the unit commonly display columnar jointing, and locally the tops of some of the flows are vesicular. The unit is characterized by lava flows with minor amounts of interbedded breccia. The flows and breccias are composed of pyroxene and plagioclase basalt, andesite, and some hornblende andesite. In the flows, phenocrysts of plagioclase, pyroxene, some olivine, and, in places, hornblende are set in a pilotaxitic to hyalopilitic matrix which is composed of feldspar and ferromagnesian minerals. In hand specimen the flows appear as dark-gray to black aphanitic to porphyritic rock.

The Wiggins Formation comprises the bulk of the layered rock in the Stinkingwater region. In this report all rocks in the region that overlie the Trout Peak Trachyandesite are assigned to the Wiggins. The Wiggins Formation is extremely varied lithologically. Andesitic volcanic breccias, flow breccias, and lava flows are the most common rock types; however, some conglomerates and sandstones are also present in the sequence.

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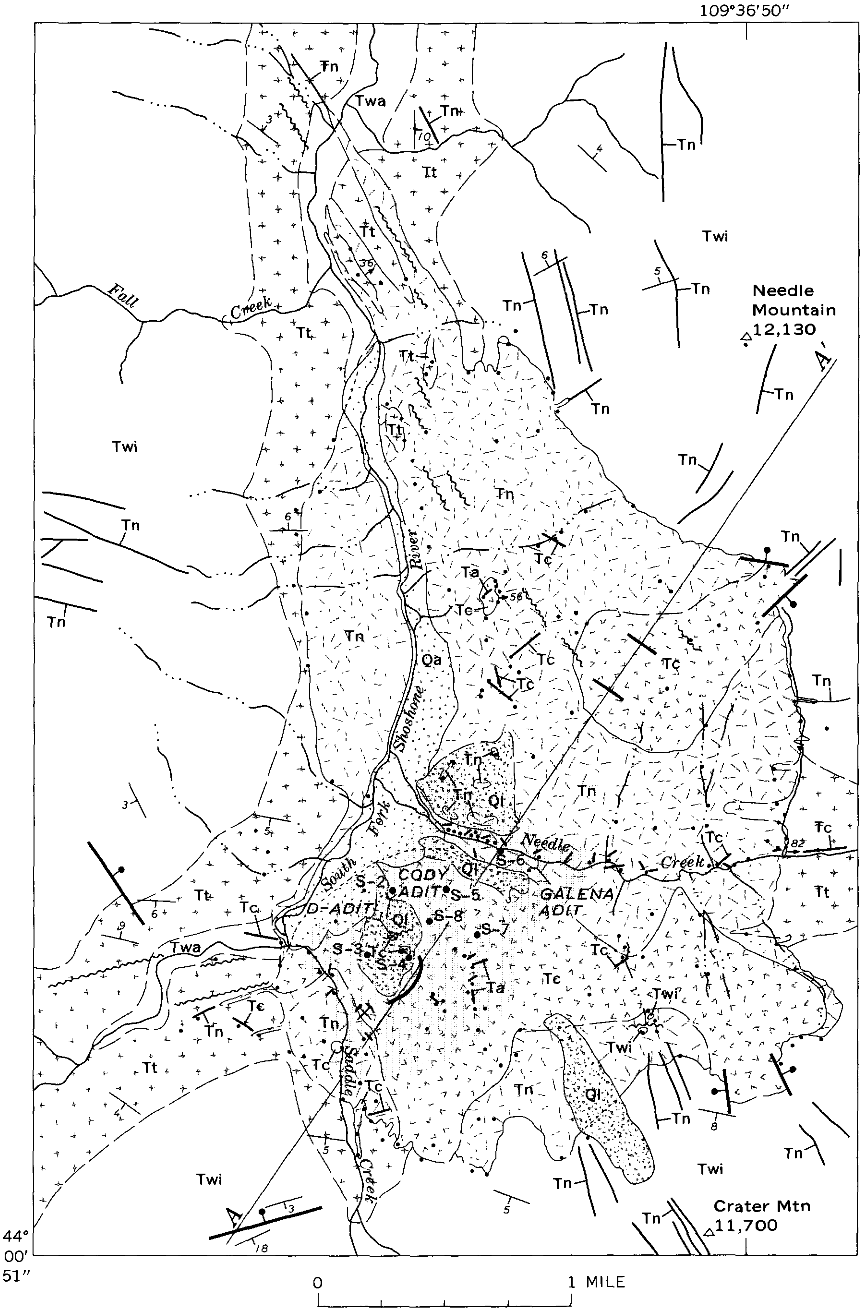
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00'
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Mountain
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GALENA ADIT
D-ADIT
S-2
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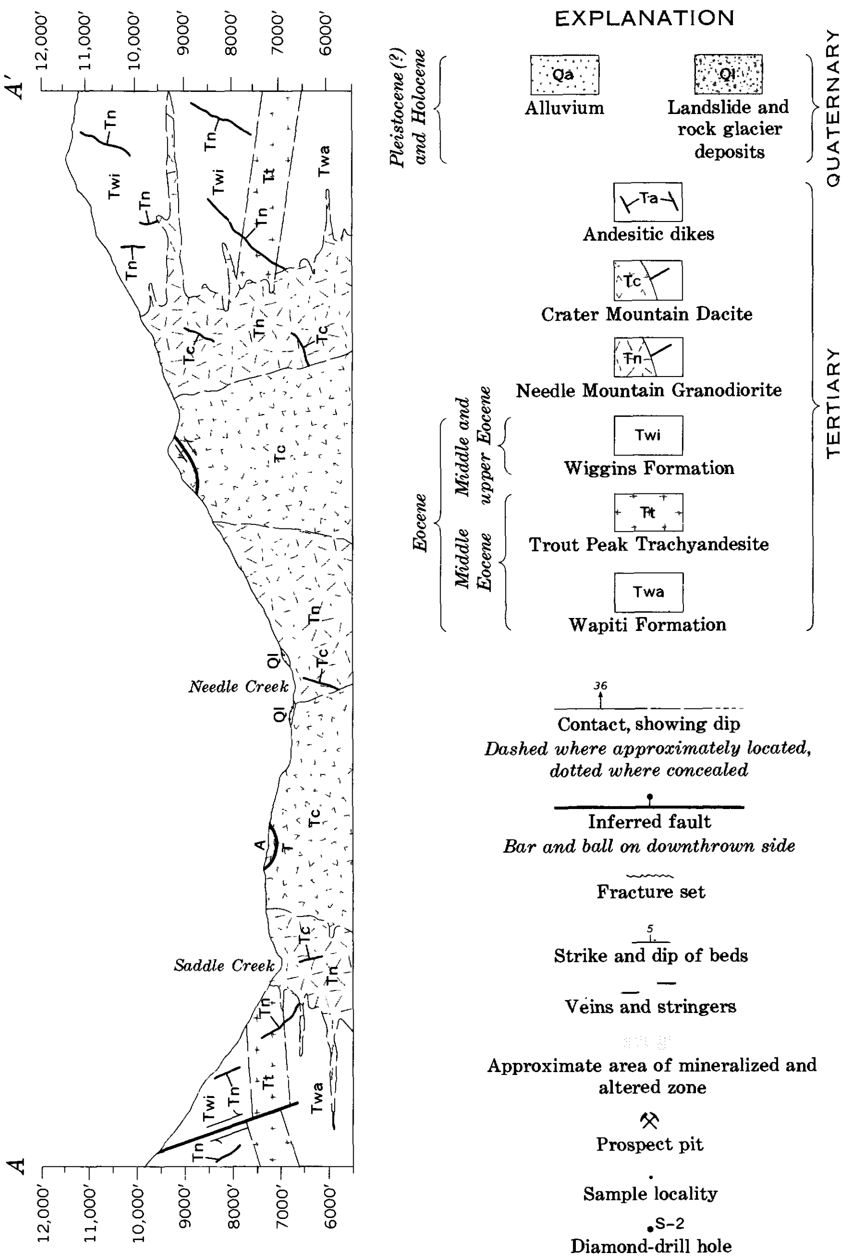

FIGURE 3. — Geologic map of the Stinkingwater mining region, Park County, Wyo. Fault showing lateral movement, in section: T, toward observer; A, away from observer. Geology mapped in 1963–64. Base from aerial photographs taken in 1954.

INTRUSIVE ROCKS

Intrusive rocks which are exposed in the Stinkingwater mining region, and which cut all the layered rocks in the region, consist of two stocks, named the Needle Mountain Granodiorite and the Crater Mountain Dacite by Fisher (1967), and numerous dikes and some sills (fig. 3). At least three periods of emplacement of intrusive material can be demonstrated by crosscutting relationships among stocks and dikes.

Needle Mountain Granodiorite

The Needle Mountain Granodiorite, the oldest and largest intrusive body in the Stinkingwater region, is well exposed on both Needle and Crater Mountains (fig. 3). The contacts of the stock with the country rocks range from relatively narrow zones a few feet wide where the stock intrudes the Trout Peak Trachyandesite to broad zones several hundred feet wide where it cuts the Wiggins Formation. The layered rocks in the contact aureole of the Needle Mountain Granodiorite have been metamorphosed to the hornblende-hornfels facies (Fisher, 1967, p. 80).

The Needle Mountain Granodiorite is composed primarily of fine- to medium-grained light- to dark-gray phaneritic rocks that range in composition from diorite to granodiorite. The various rock types are similar in mineral composition, but they are different in the concentration, size, and distribution of various mineral components (Fisher, 1967, p. 78). Plagioclase (An_{35}–An_{48}) makes up about 45–60 percent of the minerals in the stock. Potassium feldspar (10–15 percent), quartz (10–15 percent), biotite (9–15 percent), hornblende (7–12 percent), and minor pyroxene (<1 percent) are the remaining principal minerals. Magnetite, apatite, sphene, zircon, and epidote are the common accessory minerals. With the exception of the area of altered and mineralized rock, which is discussed in a later section, the rocks of the stock are generally unaltered.

Crater Mountain Dacite

The Crater Mountain Dacite is exposed in two separate stocks, on Needle and Crater Mountains. Both stocks have been emplaced largely within the Needle Mountain Granodiorite. The contact with the granodiorite is very sharp, and the Crater Mountain Dacite has a well-defined fine-grained border zone about 3–15 feet wide.

The rocks of the Crater Mountain Dacite are porphyritic light- to medium-gray rhyodacite and dacite. Phenocrysts, as much as 10 mm (millimeters) in diameter and set in a light-gray aphanitic matrix, in most places make up 40–45 percent of the rock but in a few localities make up as much as 80–90 percent. In the finer grained border zones of the stocks they compose only about 10 percent. The phenocrystic minerals consist of about 50–60 percent plagioclase (An_{40}–An_{48}), 20–25 percent biotite, 10 percent quartz, 5–10 percent hornblende, and minor amounts of augite. Magnetite, apatite, zircon, and epidote are the common accessory minerals, and rutile is present in minor amounts as individual grains and as sagenitic inclusions in biotite.

The matrix material of the Crater Mountain Dacite is composed of an aggregate of small subhedral crystals of plagioclase and anhedral potassium feldspar and quartz. The matrix is nearly cryptocrystalline in the chilled border zones of the stocks. Some of the plagioclase microlites commonly display a preferred orientation due to flow in the border zones.

Dikes

Many dikes are related to, form a radial pattern around, and are apophyses of the Needle Mountain Granodiorite. Most of the dikes of this group are andesitic to dacitic in composition. Other dikes in the area, probably related to the Crater Mountain Dacite, are more restricted in extent and have more or less random trends. These dikes range in composition from porphyritic andesite to rhyodacite. A third but smaller group of dikes, mainly hornblende andesite and pyroxene andesite, crosscut all the other intrusive rocks and represent the youngest intrusive sequence in the region.

STRUCTURAL GEOLOGY

The layered rocks in the Stinkingwater region are flat lying to gently dipping. They have been domed slightly by the emplacement of the Needle Mountain Granodiorite, and the flanks of the dome dip from a few degrees to 10°. A few high-angle normal faults are in the region, and these are probably related to emplacement of the stocks and consequent readjustment of the host rocks. Exact displacements on these faults are difficult to determine; however, in some places movement of a few tens to a few hundreds of feet can be demonstrated.

Structurally the most important features involved in interpretation of the mineralizing and intrusive activity in the area are two fracture sets which crosscut the intrusive and layered rocks with generally northwest and east to northeast trends (figs. 3, 4). These fracture sets are expressed in a variety of ways. Generally, the sets are represented by steeply dipping well-defined joints or fractures. Displacement along these fractures is unknown, but in some places movement is suggested by slickensides.

Locally the fracture sets are represented by topographic depressions and (or) scarps, and the rocks in the vicinity of the scarps are highly fractured and in places slickensided. The fracture sets have controlled the drainage patterns in several places on the South Fork of the Shoshone River, Needle Creek, and Saddle Creek. Bends of 90° in streambeds are common, and in these

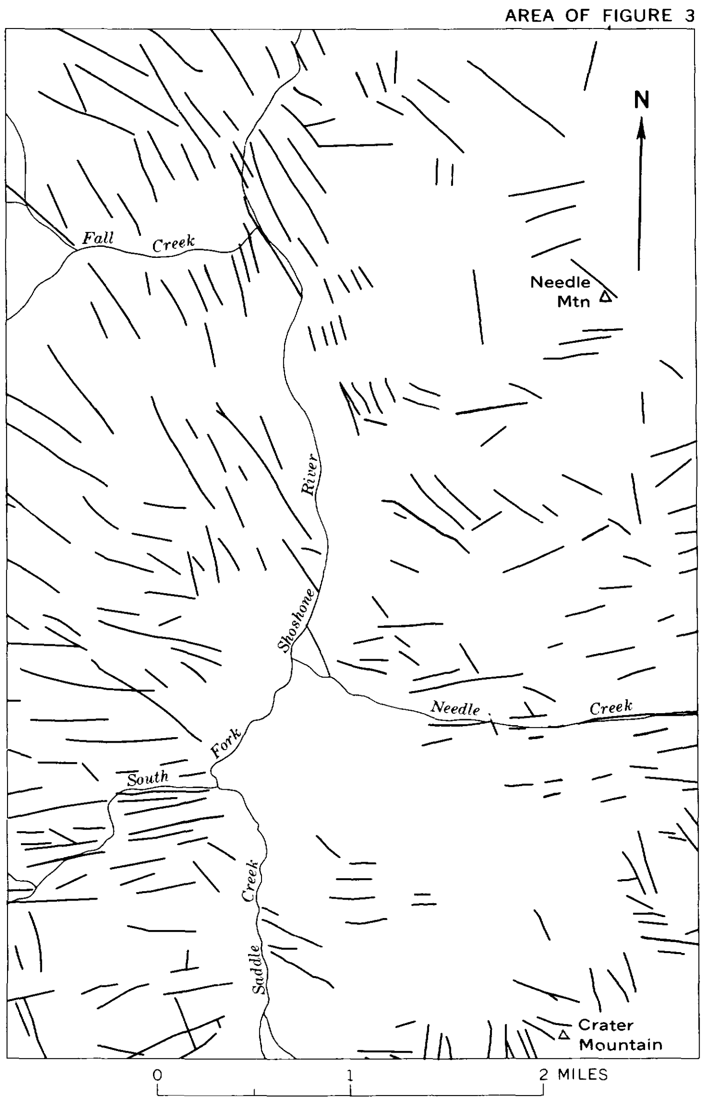

FIGURE 4. — Lineament map of Stinkingwater mining region and vicinity. Data from aerial photographs.

places the streams follow the trends of the major fracture sets—northwest and east to northeast (fig. 4).

Drill hole S–6 (fig. 3) penetrated a fault zone along Needle Creek, as indicated by considerable amounts of fault gouge and breccia in the core between 157 feet and the bottom of the hole at 838 feet. The hole probably was drilled down the dip of the fault zone. Slickensides in the core suggest both strike-slip and dip-slip components of movement. This fault is probably part of the east- to northeast-trending set of fractures. The fault breccia contains some mineralized fragments and also is cut by some thin pyrite veins and stringers, indicating movement during a period of mineralization. In the Cody adit and the D-adit (fig. 3) on Crater Mountain, faults with strikes of about N. 55° W. are present. These fault zones contain mineralized rock fragments in the gouge and are also cut by pyrite and pyrite-quartz veinlets, again suggesting movement during mineralization.

On a broader scale, aerial photographs show the two major fracture sets in the district as well-developed lineaments that trend northwest and east to northeast through the district (fig. 4).

The northwest-trending fracture set is well developed in the vicinity of the junction of Fall Creek with the South Fork of the Shoshone River. The deep canyon (fig. 5) through which the South Fork of the Shoshone River flows is an expression of the northwest fracture set. The fracture set extends northwestward from the canyon, out of the area of detailed mapping (fig. 4). Southeastward this fracture set can be traced in the field approximately to the middle of the mapped area. The northwest fracture set is also expressed in the area of Saddle Creek, mainly as local zones of stream control. The overall trends of Saddle Creek and of the upper part of Needle Creek probably also reflect the northwest-trending fracture set.

The east- to northeast-trending fracture set can be traced entirely across the mapped area. It is well developed in the southwest corner of the area (fig. 3), along the South Fork of the Shoshone River, and is traced eastward to an area of intensely shattered rock on the northwest side of Crater Mountain. Past the shattered zone the fracture set is traced upstream on Needle Creek beyond the mapped area (figs. 3, 4).

The two fracture sets represent major zones of weakness that probably controlled the location of the intrusive complex, which lies near their intersection. The intersection of these zones of fracturing in the underlying basement rocks probably allowed easier access for intrusive magmas, and the continued fault activity of these zones favored longer periods of intrusion and thus a more complex igneous history. The intersection of the zones also allowed access to higher parts of the crust for hydrothermal solutions.

FIGURE 5. — Low-altitude oblique aerial photograph looking north down the South Fork of the Shoshone River. Canyon in left center of photograph is result of stream control by northwest-trending fracture system in the region.

An area of intensely shattered rocks is present on the northwest side of Crater Mountain and extends to the base of the southwest side of Needle Mountain along Needle Creek. The area also lies within the main zone of mineralized rock. The shattered zone may be related to shrinkage of solidified parts of the intrusive bodies after their emplacement, as suggested by Hulin (1945). It is also possible that the shattered zone resulted from the intersection of the two major fracture sets.

ECONOMIC GEOLOGY

GENERAL NATURE

Disseminated copper-molybdenum mineralization occurred in an area, about 1 mile long by one-half mile wide in plan view, that extends from the northwest side of Crater Mountain (fig. 6) to the base of the southwest side of Needle Mountain along Needle Creek (figs. 3, 7). Rocks within this area consist of the Needle Mountain Granodiorite and the Crater Mountain Dacite. Outcrops of these rocks are fairly abundant; however, the lower parts of the mineralized area are obscured in places by landslide debris, soil, talus, and alluvium (figs. 1, 6, 7; Fisher, 1965, 1967). All the outcrops in the mineralized area are highly fractured and bleached and are altered to varying degrees; most of the outcrops are stained with iron oxide. Narrow, steeply dipping veins occur crudely clustered near, and in places as much as a mile away from, the mineralized area.

Remnants of a leached mineralized cap and an underlying supergene enriched zone are present on the northwest side of Crater Mountain. Parts of these zones were removed by Quaternary glaciation and erosion.

PRIMARY SULFIDE MINERALS AND MINERALIZED ROCK

Disseminated Types

Chalcopyrite is the major sulfide ore mineral present in the area of disseminated sulfide minerals, followed in order of abundance by molybdenite and minor bornite. Pyrite occurs throughout and is much more abundant than the other sulfides. The total sulfide content is as much as about 10 percent. The chalcopyrite and molybdenite are present as disseminations throughout the host rocks and also as thin coatings on fracture surfaces. They also occur in very narrow (1–4 mm) quartz veinlets. Molybdenite coats fractures and occurs in veinlets more commonly than do the copper minerals.

The narrow quartz-molybdenite veinlets that occur in the area of disseminated sulfide minerals are very different in mineralogy

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FIGURE 6.—Main zone of disseminated sulfide minerals on Crater Mountain shown by light-colored scars in approximate center of area shown in photograph. Linear aspect of trees in center of photograph is reflection of break in slope near top of landslide material; below this line is landslide debris. View looking east.

FIGURE 7.—Edge of main zone of disseminated sulfide minerals on Needle Mountain is light area (arrow) shown in right-center of photograph. Rocks exposed in the mineralized area shown in the photograph are the Needle Mountain Granodiorite, which has been bleached a white to yellow color. View looking northeast.

and nature of occurrence from other veins in the region. The quartz-molybdenite veinlets are irregular and anastomosing, and they may represent some type of local replacement feature rather than a true fracture filling. Only locally do these veinlets appear to follow a definite fracture. They are composed primarily of quartz, but they also contain molybdenite, pyrite, and minor chalcopyrite.

The disseminated sulfide minerals are generally very fine grained. Chalcopyrite, bornite, and molybdenite grains are commonly 1 mm or less in size; pyrite grains are commonly about 1–2 mm but are as large as 10 mm.

Vein Types

The second type of primary mineralized rock occurs as narrow, steeply dipping veins that are mainly in relatively unaltered country rocks a few hundred yards from the area of disseminated sulfide minerals, although in some places they occur almost a mile from the disseminated zone, and locally they are within the disseminated zone. In most places the veins are only 1–2 inches wide, but in a very few places they are as much as 1 foot wide. Most of the veins can be traced along strike for only very short distances, and in general the veins are poorly exposed. Galena, chalcopyrite, sphalerite, pyrite, and minor amounts of arsenopyrite and tetrahedrite are the major sulfide minerals in the veins.

Quartz, calcite, dolomite, and some siderite are the major gangue minerals. The veins are commonly composed of crustiform and banded material within well-defined wallrocks. In several places the vein material is distinctly vuggy. Little structural displacement is apparent along the veins, and most veins are considered to be simple fracture fillings. Very little wallrock alteration was associated with the veins.

SECONDARY MINERALS AND MINERALIZED ROCK

Oxidized Rocks

A leached and oxidized cap was formed during Miocene(?) and Pliocene(?) time across the area of primary disseminated sulfide minerals. Parts of this leached cap were removed by glaciation and erosion during Pleistocene and Holocene time. The original thickness of the cap is unknown, but drill hole S–4 (fig. 3) penetrated about 109 feet of oxidized material. The area of disseminated sulfide minerals extends southeastward from drill hole S–4 beneath Crater Mountain for an unknown distance. Rock outcrops on the side of Crater Mountain above drill hole S–4 are oxidized in places, indicating that the remaining parts of the oxidized zone may be a few tens of feet to several hundred feet thicker than the zone penetrated in drill hole S–4. The primary ore exposed by glaciation has undergone oxidation; however, the effects of this oxidation are apparently only superficial. Rocks in the oxidized zone are leached, silicified, and stained with iron oxides. Voids relict from oxidized sulfides are very common. Only minor amounts of chalcopyrite are still present, as well as some pyrite and molybdenite. Limonite and jarosite are relatively abundant, and minor amounts of malachite, azurite, and ferrimolybdite occur in a few localities.

Supergene Copper-Enriched Rocks

A zone of supergene copper-enriched rocks was penetrated in drill holes S–4 and S–7. In drill hole S–4 this zone is about 200 feet thick, and in drill hole S–7 it is about 100 feet thick. The supergene copper-enriched zone probably extends southeastward from drill holes S–4 and S–7 beneath Crater Mountain, but its extent beneath Crater Mountain is unknown. This zone was probably more extensive prior to Pleistocene glaciation.

Rocks within the supergene-enriched zone are Crater Mountain Dacite. These rocks are altered, but relict porphyritic texture is commonly present. Chalcopyrite, molybdenite, and pyrite are the major sulfides in the rock. Sooty chalcocite is present as very small disseminations and as rims around grains of chalcopyrite, indicating somewhat incomplete replacement. Occasionally chalcocite rims and replaces pyrite.

ALTERED ROCK

Several types of hydrothermally altered rock are present in the district. They may be broadly grouped, following Creasey (1959, and in Titley and Hicks, 1966), as propylitic, potassic, and quartz-sericite types. Many of the altered rocks, however, do not conveniently fit into these groupings because of the presence of metastable or unstable mineral phases or because of the lack of diagnostic minerals in the sampled rocks.

Propylitization of both the intrusive rocks and the layered volcanic rocks was common throughout the district. The intensity of propylitization was extremely variable, but in general it increased toward the main area of disseminated sulfide minerals; and intensely propylitized rock forms a fringe around the area of disseminated sulfide minerals. Where propylitic alteration was intense, several mineralogical changes from the fresh granodiorite and dacite are evident in thin section. Hornblende and biotite were altered to chlorite, sericite, magnetite, and some calcite. Plagioclase was altered to sericite, calcite, epidote, and some albite(?). Some of the larger plagioclase crystals were altered to quartz, calcite, and epidote. Chlorite, pyrite, calcite, and epidote are generally abundant in the propylitized rocks, scattered through the matrix in small grains (1–2 mm) and occasionally in larger clots. Sericite, quartz, rutile, and leucoxene are also present in variable amounts. The presence of sagenitic rutile in chlorite and of sericitic pseudomorphs in altered rocks is indicative of the former presence of biotite in the rock. In weakly altered dacite, sagenitic rutile, generally altered to leucoxene, is common in biotite phenocrysts. Quartz phenocrysts and the potassium feldspar in the rock were relatively unaffected by the propylitization.

The quartz-sericite-pyrite alteration-mineral assemblage, the most characteristic of the region, is widespread in the central part of the main mineralized area on the northwest side of Crater Mountain and along Needle Creek at the base of the southwest side of Needle Mountain. Rocks within this area were highly altered, bleached, and silicified. In most places the original porphyritic texture is preserved by sericitic pseudomorphs; however, in some places the rocks were totally recrystallized, and all original texture was erased. The sericite is present both as very fine grained flakes in the matrix and as irregular clots depicting former phenocrysts. Quartz is very abundant as small ragged grains in the matrix. Secondary quartz rims some original quartz phenocrysts, and quartz veinlets are common. Pyrite is present as fine disseminations in the matrix and also as larger grains (10 mm) scattered through the rock. It also occurs with quartz in thin irregular veinlets. Commonly the wallrock next to the veinlets shows abundant sericite. Anhydrite in quartz veinlets and as scattered grains occurs in the lower parts of the drill core from the main zone of mineralized rock. Higher in the holes the anhydrite was altered to gypsum.

Potassic alteration in irregular ill-defined zones took place within the quartz-sericite-pyrite areas on the northwest side of Crater Mountain. This type of alteration was characterized by the development of secondary biotite. In general the rocks in the potassic assemblage are highly altered; however, in most places the original texture of the rocks is preserved by sericitic pseudomorphs after plagioclase and by the original quartz phenocrysts. Sericite, quartz, biotite, and remnant plagioclase are the most abundant minerals in the areas where potassic alteration occurred. The plagioclase phenocrysts have all undergone some degree of alteration to sericite. Quartz phenocrysts are commonly rimmed by secondary quartz, and secondary quartz along with flakes of sericite and secondary biotite compose the matrix material of these rocks.

Within areas of supergene enrichment some clay minerals are present in the rocks. These may be the product of supergene processes, for they are apparently restricted to the zone of supergene enrichment and thus possibly represent some form of supergene argillic alteration. The clay minerals are relatively sparse in the sampled rocks, and they normally occur as cloudy brown areas in the vicinity of plagioclase phenocrysts.

In general there appears to be much overlap between the different alteration zones in the region. The presence of chlorite and carbonates in scattered localities within rocks of the quartz-sericite assemblage indicates superposition of the propylitic and quartz-sericite assemblages. This relationship also suggests that the rocks failed to reach equilibrium during the quartz-sericite phase of alteration. In total aspect, the pattern of altered rock in the region is a central quartz-sericite-pyrite zone with included irregular areas of potassium-rich rock. Surrounding the central quartz-sericite-pyrite zone is a fringe of propylitically altered rock. The intensity of alteration in the region was extremely variable, although generally it increased toward the center of disseminated sulfide minerals.

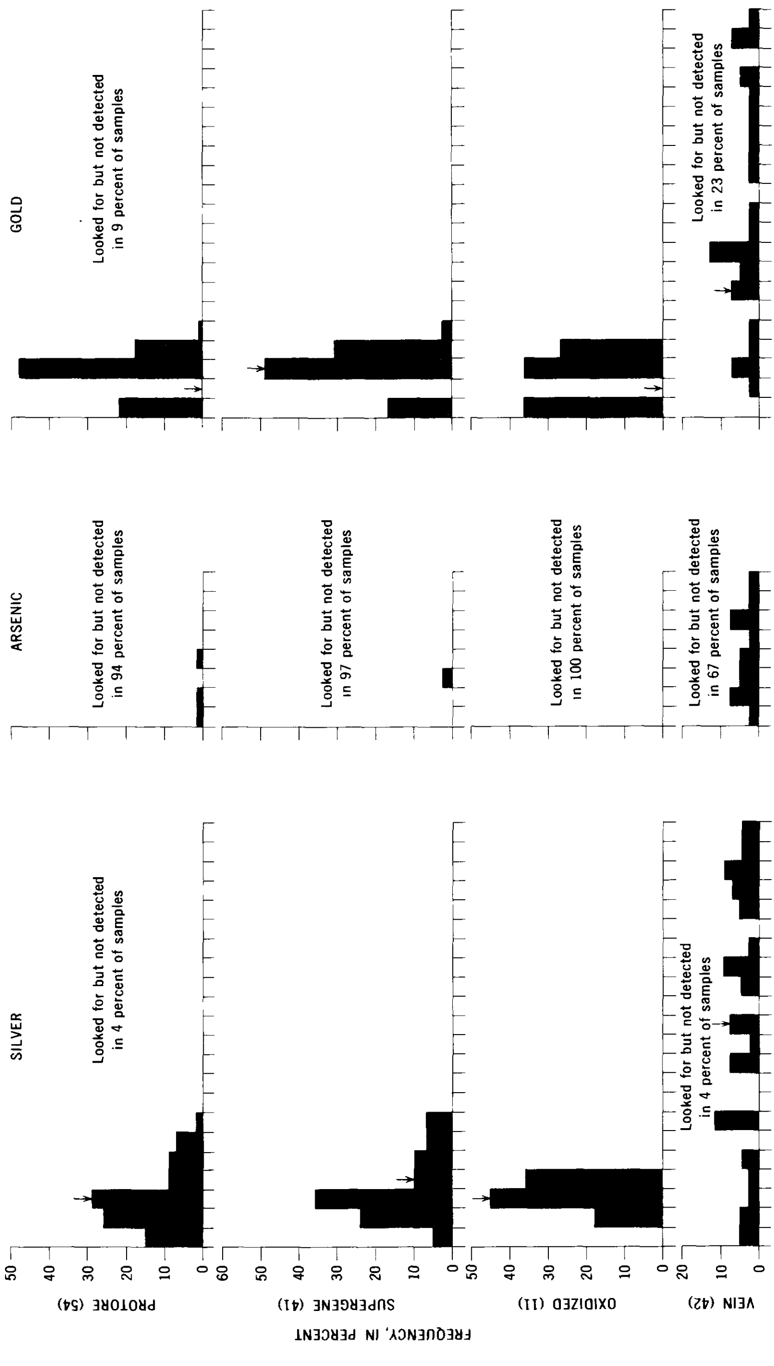
GEOCHEMICAL SAMPLING

To determine the chemical character of mineralized rock in the Stinkingwater region, 650 rock samples were analyzed by semiquantitative spectrographic methods. Most of the samples were taken from outcrops and from 3,503 feet of diamond-drill core; a few were taken from adits in the area. Geochemical summaries of selected elements are presented in figures 8–11; the raw data for all samples used in figures 8–11 were reported previously (Fisher, 1971). The rocks were classified as unaltered, altered, mineralized, vein material, oxidized, supergene, and protore. The unaltered rocks were collected chiefly from outcrops outside the main area of mineralized rock. These rocks contain little or no disseminated pyrite or other sulfides and no sulfide veinlets. They appear fresh in hand specimen and microscopically show no minerals that may be attributed to the effects of hydrothermal alteration. The unaltered rocks are composed mainly of the Needle Mountain Granodiorite and the Crater Mountain Dacite, but they also include some layered rocks. The unaltered rocks were collected not only for comparison with altered or mineralized rocks, but also to help determine the background content of selected elements in the Stinkingwater region.

The altered rocks represent any rock material which has been affected by one or more types of alteration. These rocks commonly contain considerable amounts of pyrite and in some places minor amounts of other ore minerals. They were collected from outcrops, drill cores, and mine dumps, primarily in and near the main area of mineralized rock, and they consist of the Needle Mountain Granodiorite, Crater Mountain Dacite, and a few specimens of layered rock. The altered rocks provide information regarding the distribution of selected elements and the zonational characteristics of the alteration and mineralization that took place in the region.

The mineralized rocks contain visible ore minerals in significant amounts; samples collected from vein deposits were excluded from this classification. The division between mineralized samples and altered samples is somewhat arbitrary (based primarily on visual estimates of ore minerals, excluding pyrite); however, some broad differences between the two groups can be seen for selected elements. Rocks in the mineralized group were collected from outcrops, drill cores, and mine dumps in the main area of mineralized rock and are composed of the Needle Mountain Granodiorite and the Crater Mountain Dacite. Though they provide data as to the character and intensity of mineralization that took place, and help to show the extent of mineralized material, the data are not adequate for calculating possible ore reserves.

The vein-material rock samples consist of both gangue and ore minerals which occur primarily as fracture-filling veins in and


SILVER
ARSENIC
GOLD
Looked for but not detected in 4 percent of samples
Looked for but not detected in 94 percent of samples
Looked for but not detected in 9 percent of samples
Looked for but not detected in 97 percent of samples
Looked for but not detected in 100 percent of samples
Looked for but not detected in 4 percent of samples
Looked for but not detected in 67 percent of samples
Looked for but not detected in 23 percent of samples
PROTORE (54)
SUPERGENE (41)
OXIDIZED (11)
VEIN (42)
FREQUENCY, IN PERCENT

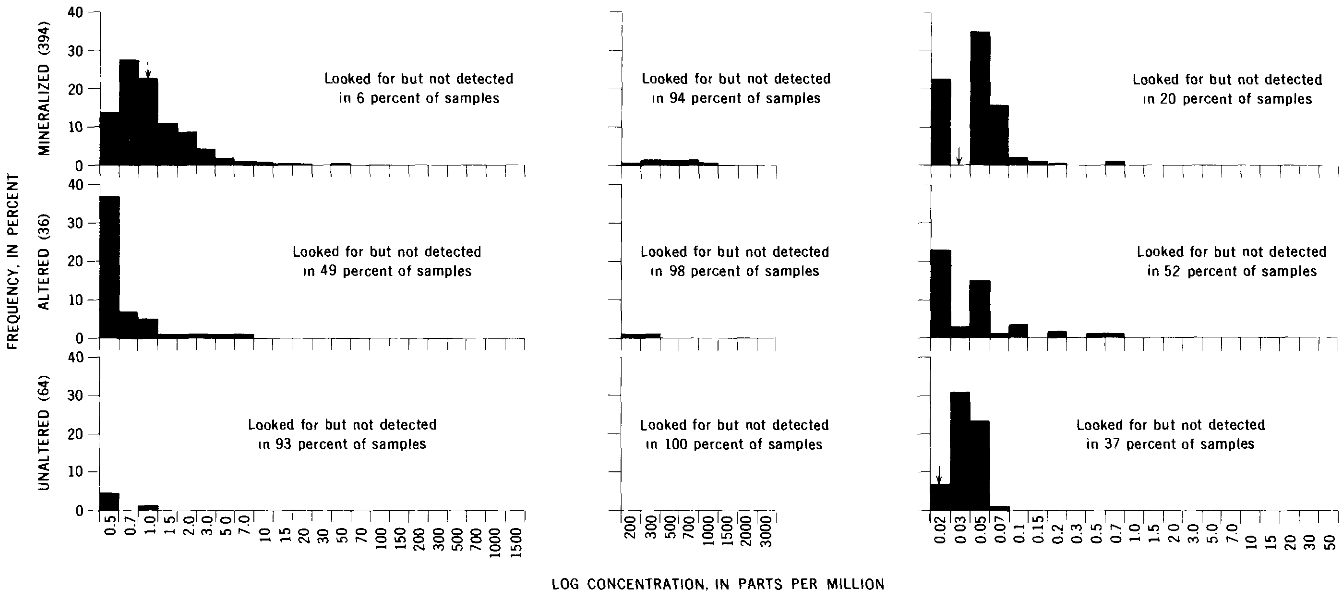
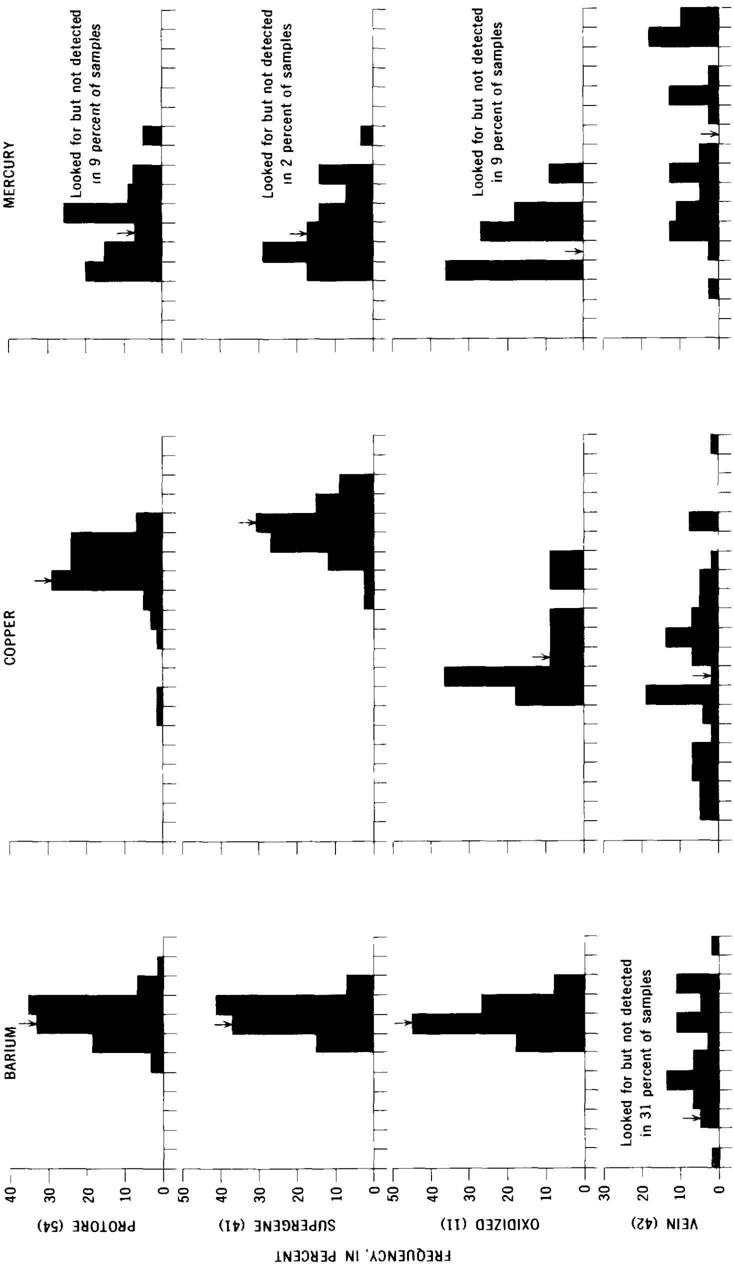


FIGURE 8. — Histograms showing concentrations of silver, arsenic, and gold in samples from the Stinkingwater mining region. Arrow indicates geometric mean. Type of samples indicated at left; number in parentheses is number of samples analyzed.


BARIUM
COPPER
MERCURY
PROTORE (54)
SUPERGENE (41)
OXIDIZED (11)
VEIN (42)
FREQUENCY, IN PERCENT
Looked for but not detected in 9 percent of samples
Looked for but not detected in 2 percent of samples
Looked for but not detected in 9 percent of samples
Looked for but not detected in 31 percent of samples
0
10
20
30
40
50

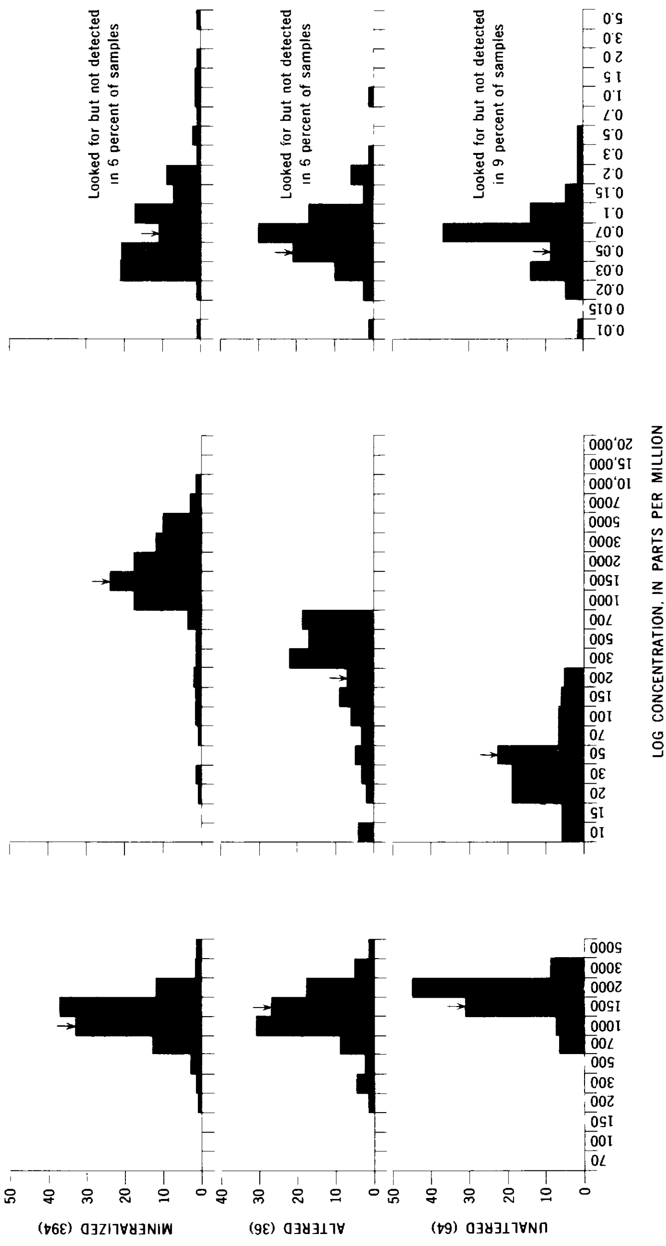
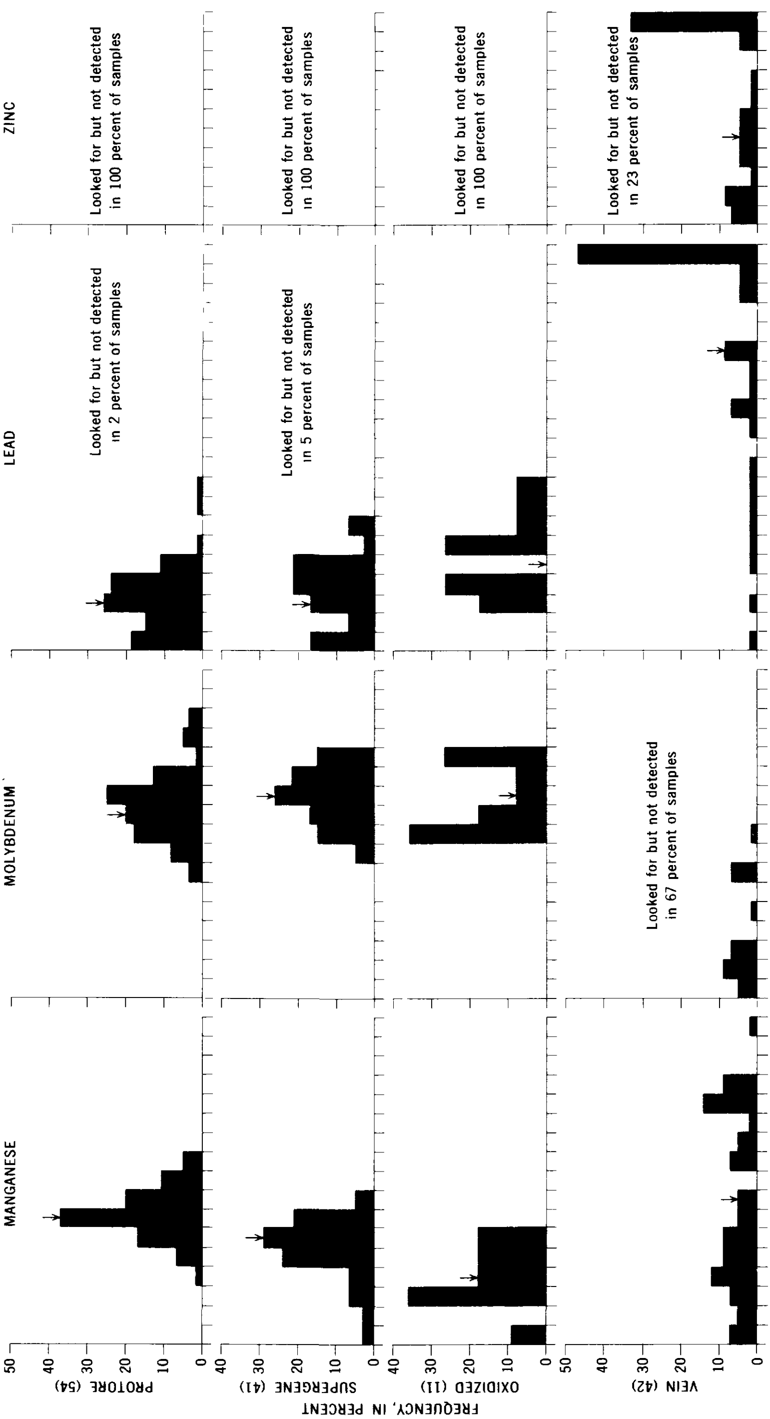


FIGURE 9. — Histograms showing concentrations of barium, copper, and mercury in samples from the Stinkingwater mining region. Arrow indicates geometric mean. Type of samples indicated at left; number in parentheses is number of samples analyzed.


MANGANESE
MOLYBDENUM
LEAD
ZINC
PROTORE (54)
SUPERGENE (41)
OXIDIZED (11)
VEIN (42)
FREQUENCY, IN PERCENT
Looked for but not detected in 100 percent of samples
Looked for but not detected in 2 percent of samples
Looked for but not detected in 100 percent of samples
Looked for but not detected in 5 percent of samples
Looked for but not detected in 100 percent of samples
Looked for but not detected in 23 percent of samples
Looked for but not detected in 67 percent of samples

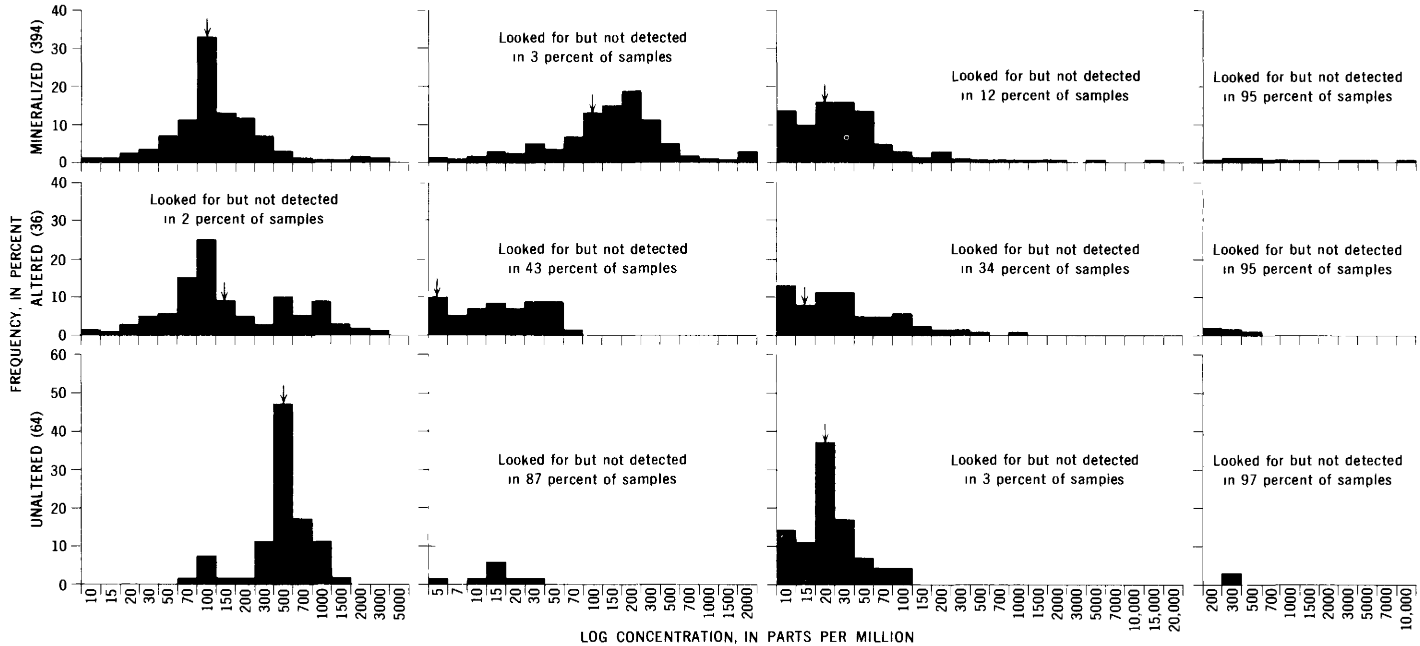
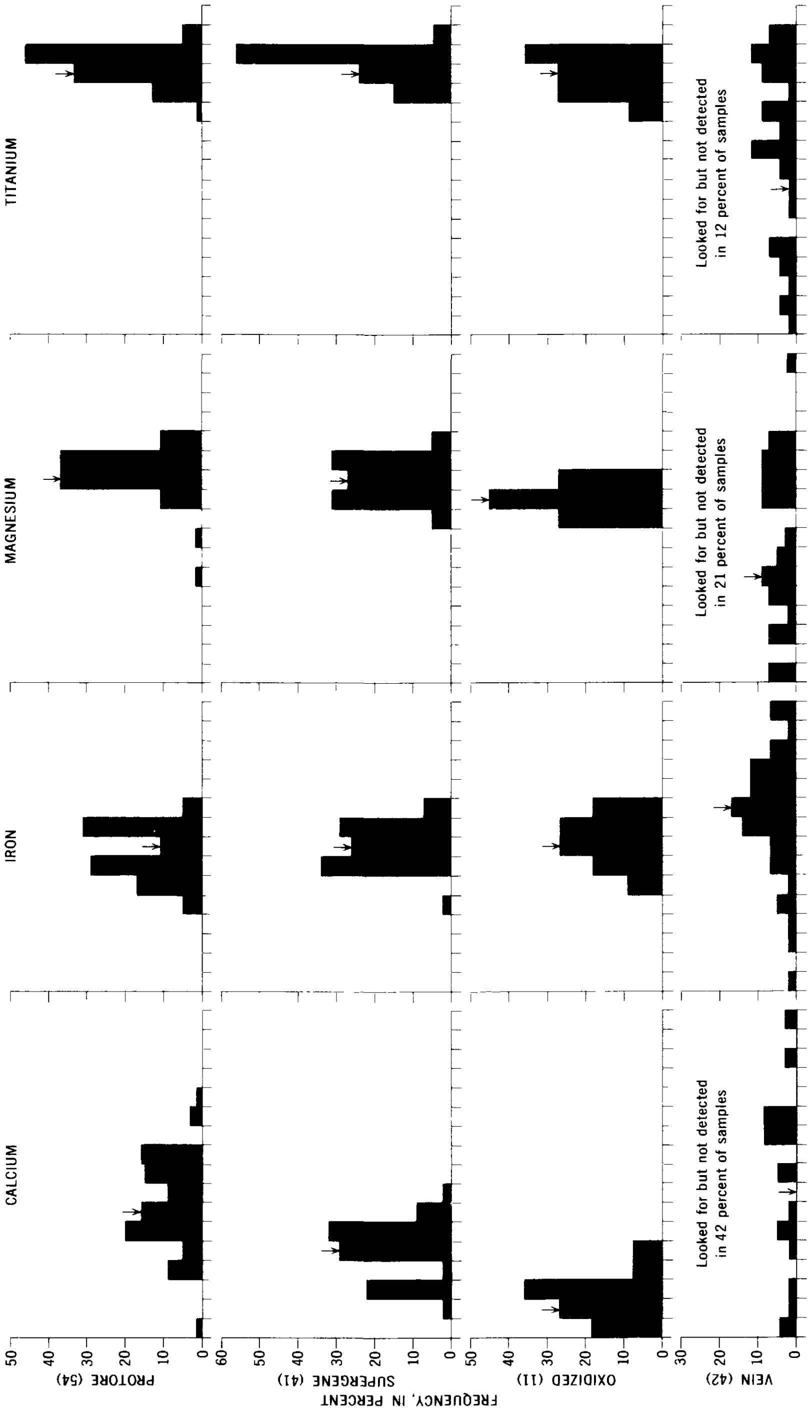


FIGURE 10. — Histograms showing concentrations of manganese, molybdenum, lead, and zinc in samples from the Stinkingwater mining region. Arrow indicates geometric mean. Type of samples indicated at left; number in parentheses is number of samples analyzed.


CALCIUM
IRON
MAGNESIUM
TITANIUM
PROTORE (54)
SUPERGENE (41)
OXIDIZED (11)
VEIN (42)
FREQUENCY, IN PERCENT
Looked for but not detected in 42 percent of samples
Looked for but not detected in 21 percent of samples
Looked for but not detected in 12 percent of samples

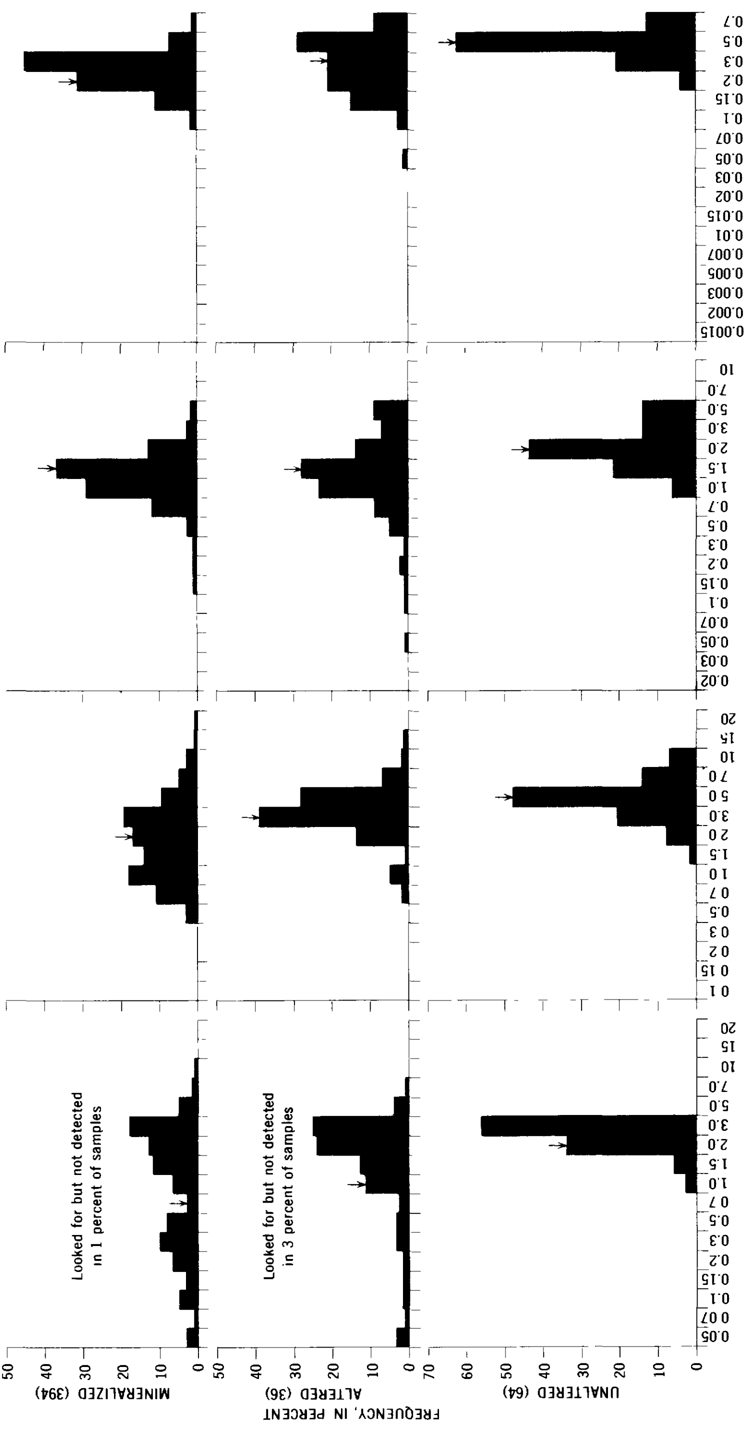


FIGURE 11.—Histograms showing concentrations of calcium, iron, magnesium, and titanium in samples from the Stinkingwater mining region. Arrow indicates geometric mean. Type of samples indicated at left; number in parentheses is number of samples analyzed.

near the main area of mineralized rock. These samples, taken from outcrops and mine dumps, were collected to examine metal distributions in the area and to compare vein-type material with the disseminated sulfides in the region. They, too, are inadequate for estimating possible ore reserves.

The oxidized-, supergene-, and protore-classified samples are all Crater Mountain Dacite from drill cores S–4 and S–7 (fig. 3) and were taken to examine altered and mineralized rock at depth in the area of disseminated sulfides on Crater Mountain. The classification is based on the presence or absence of chalcocite, together with the position of the samples in the drill core.

The oxidized rocks are bleached, stained, and devoid of chalcocite. Most of the chalcopyrite and some of the pyrite have been removed by leaching. Some open spaces and voids relict from oxidized sulfides are lined with iron oxide. These rocks are from the upper 109 feet of drill core S–4.

The supergene rocks were collected from 109 to 310 feet in drill core S–4 and from 130 to 227 feet in drill core S–7. These rocks all contain some very fine grained chalcocite, which is the main criterion for classifying them in the supergene group.

The protore rocks are from 310 to 501 feet in drill core S–4 and from 227 to 500 feet in drill core S–7. These samples are from below the zone of supergene enrichment and are devoid of chalcocite.

METAL DISTRIBUTIONS

The intensity of primary mineralization that occurred in the region is readily seen by comparing histograms and geometric means of unaltered rocks, veins, and protore (figs. 8–11). Geometric means were calculated by using a method developed by Cohen (1959, 1961) for censored distributions. 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 to describe and characterize the abundance of a given element in an individual sample group (Miesch, 1963, 1967).

The following elements were looked for and either were not found or were found in amounts normal for the rock type sampled and thus were not included in the statistical summary: B, Be, Co, Cr, La, Nb, Ni, Sc, Sn, Sr, V, W, Y, Zr.

The character of metal distributions between the veins and the area of disseminated-mineralized rock is indicated by histograms and geometric means for the vein and protore groups. These show that the samples from veins are enriched in silver, arsenic, gold, mercury, lead, and zinc as compared with the samples of protore. Bismuth, cadmium, and antimony, which are not shown in figures

8–11, are restricted to the veins. The bismuth is generally found in samples from galena-rich parts of the veins, and the cadmium values are invariably associated with sphalerite. Copper and molybdenum are more abundant in the protore group of samples than in the vein group. The distribution of the veins around the area of disseminated sulfide minerals and the relative enrichment of the previously mentioned elements in the veins give a broad zonational pattern to the metal distribution in the region.

The behavior of selected metals and other elements in the oxidized and supergene zones is shown by figures 8–11. Copper, as expected, shows the most marked enrichment in samples from the supergene zone. Some copper, however, is still present in the oxidized zone. Gold and silver may have been slightly enriched by the oxidation-supergene process, but more samples are needed to provide a better basis for comparison. Barium, molybdenum, iron, titanium, mercury, and magnesium show no apparent enrichment as a result of oxidation and supergene processes. The slight depletion of mercury in oxidized rocks probably represents a loss of mercury vapor to the atmosphere. Calcium and manganese both apparently are progressively depleted by the weathering process and show a continued decrease in abundance from protore to supergene to oxidized material. Lead appears to be slightly enriched in the oxidized rocks, which may be reflecting the development of some lead oxide minerals. It should be reemphasized that the small number of samples of oxidized material could bias the results.

Broad gains and losses of various elements in unaltered and altered rocks, indicating the overall characteristics of the alteration in the region, can be seen in figures 8–11. The mineralized group of samples should also be considered here for comparative purposes, because all the mineralized samples are normally more altered than even the altered group. No attempt has been made to compare chemical changes among the different alteration assemblages. Silver, copper, and molybdenum all show slight increases, and arsenic and zinc may have increased some with progressive alteration. Calcium, iron, and manganese are all depleted to some extent in the altered and mineralized groups. Magnesium, titanium, and barium show slight depletion with increasing alteration. The concentration of lead appears to have been unchanged by the alteration process. Potassium was not analyzed for; however, it probably would show some increase with progressive alteration as suggested mineralogically by the development of secondary biotite and by sodium cobaltinitrite staining, which indicates potassium enrichment next to quartz-pyrite veinlets.

The metal zonation in the region is characterized by a central copper-molybdenum zone surrounded by a fringe of silver, gold, lead, zinc, arsenic, and possibly mercury. In terms of actual tonnage present, probably more gold and silver are concentrated in the lower grade disseminated-sulfide zone than in the higher grade border-zone veins. Thus, gold and silver could also be grouped in the assemblage that resulted from central-zone mineralization. In terms of prospecting, however, it is more desirable to group the gold and silver in the assemblage that resulted from the fringe mineralization because their higher grade in the fringe veins makes them more amenable to discovery. In addition, the wider distribution of the veins provides a somewhat larger target for prospecting, even though the veins aggregate a much smaller volume than does the disseminated-mineralized rock.

PROSPECTING GUIDES

Local

Metal zonation in terms of areal occurrence now known provides only a framework for prospecting. Several additional guides should be made available for further prospecting in the Stinkingwater region. First, a detailed outcrop map should be prepared of the main area of altered and disseminated-mineralized rock to provide more information on the distribution of and relation between the hydrothermal alteration types and mineralization. Particular attention should be paid to both mineral and metal zonations, because these may further define the most favorable targets for prospecting within the region.

Second, additional diamond drilling should be done in the area southeast of drill holes S–4 and S–7, higher on the side of Crater Mountain. The detailed mapping suggested in the preceding paragraph should be a help in locating the best positions for holes that will delineate the extent of mineralized rock beneath Crater Mountain. Some diamond drilling in this area has already been completed, but the results of this work are not available.

Third, the possible presence of replacement mineral deposits in sedimentary rocks at depth should be investigated. Replacement ores have been found in sedimentary rocks in the Cooke City district farther north in the Absaroka Range (Lovering, 1930). That sedimentary rocks may occur relatively close to the surface in the Stinkingwater region is suggested by the fact that Paleozoic sandstone and limestone crop out in an area about 4 miles southwest of the region, along the east side of the South Fork of the Shoshone River. Regional mapping and structural interpretations should provide estimates of the depths of sedimentary rocks in the Stinkingwater region. If the depths are reasonable, then diamond drilling for replacement mineral deposits may be feasible.

Regional

The mineralized rocks in the Stinkingwater region are intimately associated with an igneous center which had a relatively long and intense history of intrusive and probably extrusive activity. Examination of other intrusive bodies in the Absaroka Range suggests that plutons with only one phase of emplacement of intrusive material are devoid of mineralized rock, whereas all the known mineral deposits in the Absaroka Range are associated with areas of complex multiple intrusive and probably extrusive activity (Pedersen, 1968; Fisher, 1967; Dreier, 1967; Wilson, 1964a; Rubel, 1964; Parsons, 1937; Lovering, 1930).

The Stinkingwater region is located on a roughly defined northwest-trending belt of intrusive bodies. This belt probably represents a zone of weakness or fracturing in the underlying basement rocks. In the Stinkingwater region, northwest-trending fracture zones are intersected by other fracture zones which trend northeast to east. Similar relations may be observed in other mineralized districts in the Absaroka Range. The mineral deposits in the Absaroka Range thus may be situated above areas where a northwest-trending basement weakness is intersected by northeast- to east-trending fracture zones. Regional mapping of lineaments on aerial photographs may outline broad structural patterns from which favorable targets for further study may be located.

The streams in the vicinity of the Stinkingwater region are transporting small amounts of gold (½–1 part per million in pan concentrates of stream alluvium) that was probably derived from the vein system clustered around the area of disseminated sulfide minerals. The veins extend several hundred to a few thousand feet outward and upward from the area of disseminated sulfide minerals. Effects of wallrock alteration near the veins are generally lacking, and the veins are very inconspicuous in outcrop. Similar vein systems are associated with other mineralized areas in the Absaroka Range. The location of the noneconomic veins may suggest potential target areas for further exploration for blind porphyry copper-type deposits in the Absaroka Range. The areas of vein outcrop can probably be located by chemical analyses for gold in pan concentrates taken from stream sediments.

Some mercury is present in the Stinkingwater region, both in the disseminated-mineralized rock and in the surrounding border-zone veins. Selected target areas for mercury could be further investigated by methods suggested by McCarthy, Vaughn, Learned, and Meuschke (1969).

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