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DISTRIBUTION OF COPPER AND OTHER METALS IN GULLY SEDIMENTS OF PART OF OKANOGAN COUNTY, WASHINGTON

By

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By Kenneth F. Fox, Jr. and C. Dean Rinehart

ABSTRACT

A geochemical exploration program aimed at determining regional patterns of metal distribution as well as pinpointing areas likely to contain undiscovered ore deposits was carried out in north-central Okanogan County, Washington. About 1,000 gully and stream sediment samples were collected from a rectangular area of about 800 square miles. The area includes two contiguous, virtually dormant, mining districts that had yielded nearly $1.4 million in gold, silver, lead, copper, and zinc prior to the end of World War I, mostly from quartz lodes.

The eastern two-fifths of the area is underlain by the Colville batholith, the central two-fifths by metamorphic rocks of Paleozoic and Mesozoic age, and the western fifth by numerous granitic plutons of Mesozoic age. Tertiary volcanic and associated epiclastic rocks are patchily distributed and occupy less than 5 percent of the area.

Samples were routinely analyzed colorimetrically for cold-acid-extractable copper and citrate-soluble heavy metals; these analyses were locally supplemented by semiquantitative spectrographic and atomic absorption analyses. The program consisted of (1) preliminary orientation phase in which drainages below known typical mineral deposits were tested, and (2) a regional sampling phase aimed at representing roughly a square mile with each sample.

Contoured results show a fairly well-defined north-trending belt of above-background-level heavy metal values and anomalously high copper values in the western half of the area. In the eastern part of the area, which is underlain by the Colville batholith, contouring shows an absence of any well-defined belt of heavy metal values— background levels are low and there are no anomalies.

Trend surfaces on copper and on heavy metals considered in conjunction with the distribution and metallic content of known mineral deposits suggest that two or more mineralized belts intersect within the map area. They include (1) a well-defined belt marked by copper deposits containing minor molybdenum and tungsten as well as lead, zinc, silver, and gold and (2) a more diffuse heavy-metal belt marked by deposits containing lead, zinc, silver, gold, copper, and antimony. The copper belt trends north, is parallel to, and in part overlaps a belt of Eocene volcanic rocks. The pattern of the heavy-metal belt is more complex but shows a marked northwest grain, subparallel to the regional lithologic and structural trend.

Five anomalies— four in the west half and one in the northeast quarter of the area— appear to warrant further examination. No copper anomalies were found that are comparable in metal content to the secondary dispersion halos associated with known deposits.

INTRODUCTION

A geochemical exploration program was carried out in the Loomis, Oroville, Conconully, and Tonasket quadrangles of northern Washington (fig. 1), the objectives being to determine regional patterns of metal distribution and to pinpoint areas likely to contain undiscovered ore deposits. This program is a part of a broader study of the geology and mineral deposits of part of northern Okanogan County, sponsored jointly by the U.S. Geological Survey and the Washington Division of Mines and Geology. A report describing the geology and mineral deposits of the Loomis quadrangle has previously been published (Rinehart and Fox, 1972).

The geology of that part of the area encompassed by the geologic map accompanying this report (pl. 1) and not mapped by the authors was compiled from a previously published report by Waters and Krauskopf (1941), theses by Menzer (1964) and by Goldsmith (1952), and unpublished material generously provided by R. J. Roberts and S. W. Hobbs, and by W. H. Nelson. The distribution of the ore deposits shown on the map (pl. 1) and pertinent details of their character and production history were drawn largely from a compilation by Huntting (1956). The authors were very ably assisted in the field by J. Casey Moore. The authors are indebted to Edwin V. Post and William L. Lembeck for guidance during the early phases of the project and for general supervision of the analytical work. The report benefited from careful review and numerous constructive criticisms by R. G. Yates and J. J. Connor.

The area examined is in the northwestern part of the Okanogan Highlands and includes, along its western border, the eastern flank of the Okanogan Range, easternmost of the multiple ranges that compose the Cascades. The topography is moderately rugged, with precipitous peaks along the western side, where summit altitudes range from 5,000 to 7,000 feet above sea

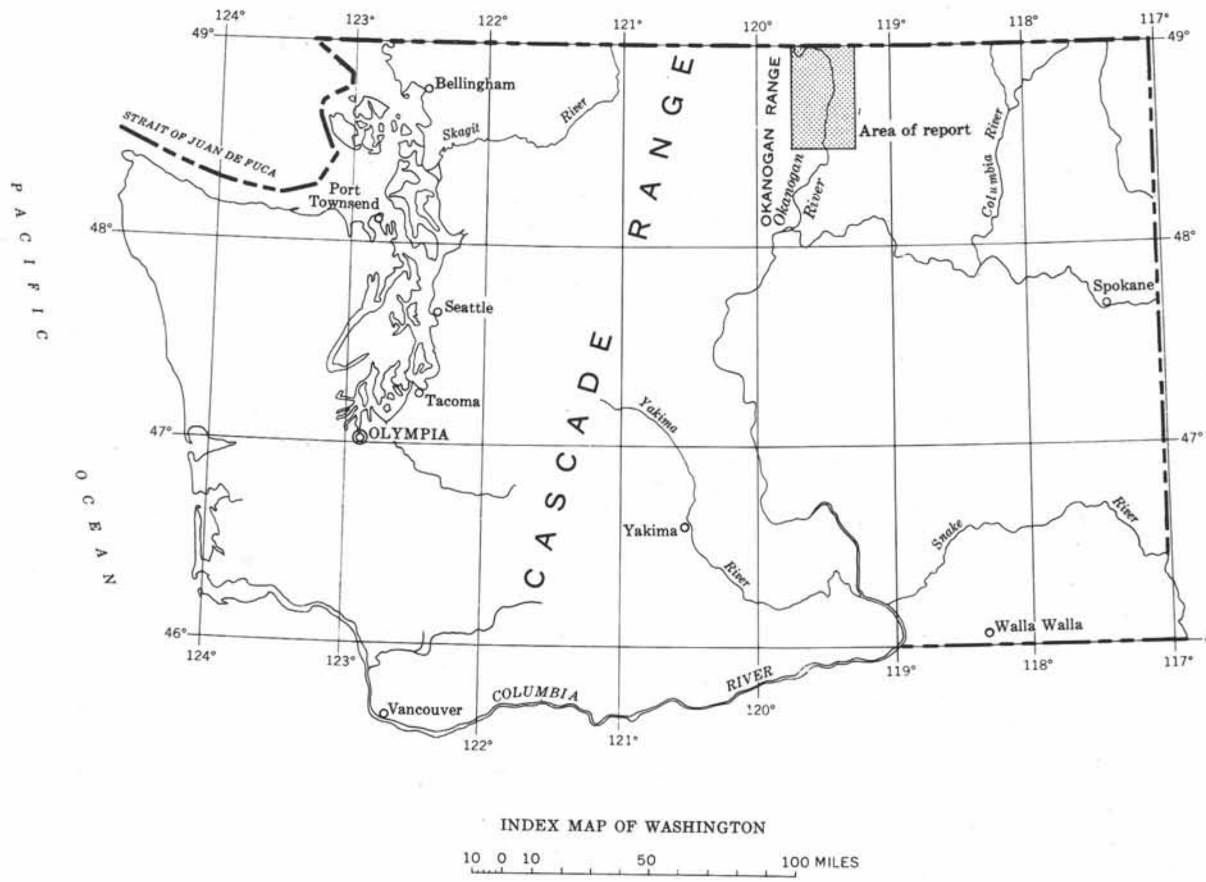


FIGURE 1.—Index map of Washington, showing location of the project area.

level. The terrain slopes irregularly eastward to the deep, north-south-trending valley of the Okanogan River, and the altitudes range from 900 to 1,100 feet. From the river valley the terrain rises eastward to summit altitudes of 4,000 to 5,000 feet. The Okanogan River and its tributary, the Similkameen, enter the area from the north, join near Oroville, and flow southward through a broad, locally alluviated valley to join the Columbia River 50 miles to the south.

The climate is semiarid. Annual streams and springs are few, and the water table is probably low. Drainage is locally deranged, with saline ponds filling low areas during the wet cycles. The vegetation is zoned according to altitude; sagebrush, grass, and scrub timber dominate the lower elevations, giving way to dense coniferous forests above the 2,500-foot elevation on north-facing slopes and above the 4,000-foot elevation on south-facing slopes. The area is serviced by a close network of secondary roads fanning out from highways that follow the major valleys and provide excellent access to back country.

Population is sparse and is concentrated in settlements along the valley of the Okanogan River. Fruit growing (where irrigation is feasible), cattle ranching, lumbering, and tourism are the mainstays of the local economy. The Oroville-Nighthawk and Conconully mining districts, which lie wholly or partly within the area, have lain essentially dormant since the first decade of this century.

SUMMARY OF GEOLOGY

The following paragraphs present a short supplement to the information on the geologic map. Bedrock consists chiefly of metamorphosed rocks of Permian, Triassic, and Jurassic or Cretaceous age, and of plutonic rocks of Mesozoic age. The metamorphic rocks occupy the west-central two-fifths of the area. These rocks consist of a folded succession of weakly to moderately metamorphosed eugeosynclinal deposits, mainly siltstone, sharpstone conglomerate, limestone, dolomite, massive chert, and greenstone, probably aggregating over 30,000 feet in thickness. The metamorphic rocks are flanked to the east by rocks of the Colville batholith and several lesser plutons that occupy about two-fifths of the map area. To the west the metamorphic rocks are bordered by rocks of a number of contiguous plutons that occupy the remaining one-fifth of the map area. The metamorphic and plutonic rocks are locally cut by small plugs of dacite or andesite. They are overlain by lavas of similar composition that are interstratified with epiclastic sedimentary rocks of Tertiary age. The Tertiary rocks are irregularly distributed and occupy less than 5 percent of the area.

METAMORPHIC ROCKS

Anarchist Group

Much of the terrane in the west-central sector of the map area consists of low-grade metamorphic rocks, comprised of complexly folded black slate, phyllite, fine-grained marble, greenstone, and distinctive sharpstone metaconglomerate and metagraywacke, which Daly (1912) named the Anarchist Series and which were redefined by Rinehart and Fox (1972) as the Anarchist Group. Only the finer grained metaclastics of the Anarchist are well foliated, and, where bedding can be detected, it is generally parallel to the foliation; coarser grained rocks are typically massive or only weakly foliated. Individual beds generally have little lateral continuity, either grading to, or interfingering with, other beds on strike, but altogether the Anarchist probably aggregates over 20,000 feet in thickness.

Beds of fine-grained marble (limestone) weather in relief, forming conspicuous light-gray ledges, but the marble is abundant only within the middle third of the Anarchist. The sharpstone metaconglomerates also are restricted in stratigraphic range; they are abundant in the upper third, common in the middle third, and absent from the lower third. Greenstones are common only in the lower third of the Anarchist Group.

Fossils found at several localities within the Anarchist were considered ". . . most likely Permian . . ." by Girty (in Waters and Krauskopf, 1941, p. 1364). Other collections have recently been studied by J. T. Dutro, Jr. (U.S. Geol. Survey Prof. Paper 525-A, 1965, p. A96), who confirmed the Permian age.

Kobau Formation and Palmer Mountain Greenstone

A belt of interlayered green phyllite, greenstone, and metachert in the northern part of the map area is contiguous with similar rocks north of the International Boundary named the Kobau Group by Bostock (1940). The unit, designated the Kobau Formation, by Rinehart and Fox (1972), overlies the Anarchist Group along a gently dipping angular unconformity and is in turn overlain by the Ellemeham Formation along a profound angular unconformity. The thickness of the Kobau Formation in the Loomis quadrangle probably exceeds 12,000 feet.

A thick massive greenstone which crops out locally at the base of, and interfingers with, the Kobau Formation near Palmer Lake in the northwestern part of the map area was named the Palmer Mountain Greenstone by Rinehart and Fox (1972). The Palmer Mountain Greenstone is varied internally, containing small masses of gabbroic to granodioritic hypabyssal intrusives in addition to the fine-grained greenstone that constitutes the bulk of the unit. Where least metamorphosed, the greenstone is basaltic in composition and shows relict vesicles and felty or trachytic texture, suggesting an extrusive origin. The unit is probably at least 7,000 feet thick at Palmer Mountain.

The Kobau Formation is Permian or Triassic in age since it is known to be intruded by Late Triassic plutons and unconformably overlies the Permian Anarchist Group.

Limestone and Dolomite

A sequence of metamorphosed and folded interbedded limestone, dolomite, and minor epiclastic rock overlies the Anarchist Group in the southern part of the map area. Bennett (1944, p. 10) estimated that the unit exceeds 10,000 feet in thickness. Waters and Krauskopf (1941, p. 1365) concluded that the basal contact of the unit was a profound angular unconformity, a view also held by Bennett (1944, p. 10), but Misch (1951) considered it a thrust fault. The sequence is probably Triassic, according to paleontological determinations by Reeside (in Waters and Krauskopf, 1941, p. 1366), and by Muller (in Misch, 1966, p. 118).

Metamorphic Rocks, Undivided

The metamorphic rocks in the southwestern part of the area include gneiss and schist of metasedimentary origin but are much more extensively recrystallized than those described above. Rocks of this unit, immediately south of Sinlahekin Creek, include lithologic types traceable to the north into rocks of the Anarchist Group.

Ellemeham Formation

The Ellemeham Formation (Rinehart and Fox, 1972) includes scattered remnants of a presumably once-continuous deposit that included a basal layer of greenstone or metadiabase overlain by monolithologic breccia and conglomerate. The conglomerate consists chiefly of rubble derived from the underlying greenstone but locally contains identifiable clasts of the Anarchist Group or Kobau Formation. The unit is weakly metamorphosed— distinctly less metamorphosed than subjacent formations. Textures in the greenstone suggest that it was derived from basalt and interbedded pyroclastics. The unit includes the Whisky Mountain spilite of Krauskopf (1938).

The Ellemeham Formation was deposited on a somewhat irregular surface beveled on Anarchist and Kobau terrane.

MESOZONAL IGNEOUS ROCKS

Serpentinite

Several small masses of serpentinite are located within the map area, mostly on or near Chopaka Mountain (T. 40 N., R. 25 E.). The largest, an elongate body on the southeast shoulder of the mountain, is composed of serpentine minerals, tremolite, and diopside, and is veined by chrysotile. The smaller, irregularly shaped, ultramafic bodies in the area are serpentinized peridotites, containing relict olivine and enstatite in addition to serpentine minerals and accessory chromite and magnetite.

Plutonic Rocks

Over half of the map area is occupied by Mesozoic plutons, most of granodioritic and a few of quartz dioritic composition (pl. 1 and table 1). Several exhibit considerable internal range in composition, the Similkameen composite pluton in the northwestern corner of the map area being an extreme example. It ranges from quartz monzonite at its core through monzonite to mafic alkalic rock at its margin.

Internal structure is rare in many of the plutons; that present is usually only a weak subparallelism of phenocrysts or mafic minerals which can generally be attributed to slight movement of the mass prior to final consolidation. The Loomis pluton is exceptional, for it becomes increasingly gneissic toward the southern end, ultimately grading to paragneiss. This gradation suggests that its gneissosity may be, in part, relict. The Colville batholith contrasts with all the other plutons by exhibiting pervasive, strongly developed gneissosity except in its easternmost parts. The Colville batholith must have been forcibly emplaced, judging by the dynamic effects on the wall rock, particularly in the Osoyoos and Whisky Mountain plutons, which grade to cataclastic gneisses near their contacts with the Colville. Colville gneisses also show evidence of internal cataclasis, which Waters and Krauskopf (1941, p. 1414) hypothesized is due to emplacement as a semisolid mass. Much of the mass, however, is layered gneiss of apparent metasedimentary origin (Snook, 1965, p. 760).

A satisfactory detailed chronology of the plutonism has not yet been established. The Loomis pluton is believed to be Middle or Late Triassic (table 1). Most of the other plutons are younger, probably ranging in age from Late Triassic to Cretaceous, but definitive evidence of their chronologic sequence is lacking.

A few generalizations can be applied to most of the plutons (Colville excepted). Contacts with host rocks are not chilled; they are sharp, steep, and generally partly crosscutting and partly concordant. Inclusions are rare, except for local intrusive breccias near contacts. None of the plutons has miarolitic textures, and, except for the Loomis, none grades into zones of migmatite or high-grade metamorphic rock. Granitic dikes (not shown on map, pl. 1) are abundant but seldom can be linked positively to a specific pluton. Plutons studied in detail (those in the Loomis, Oroville, and north half of the Conconully quadrangles) also contain dikes of aplite, alaskite, and locally pegmatite. Potassium feldspar is typically microperthitic microcline. Metamorphic rocks contain mineral assemblages typical of the cordierite amphibolite facies at plutonic contacts, and assemblages typical of the almandine amphibolite facies away from contacts (Winkler, 1965, p. 101). These features suggest that plutonism in the map area has been of the mesozonal type (Buddington, 1959); that is, the intrusion was at depths of 5 to 9 miles.

VOLCANIC AND EPICLASTIC SEDIMENTARY ROCKS

Conglomerate, Arkose, and Graywacke

The metamorphic and crystalline rocks previously described are unconformably overlain by conglomerate, arkose, and graywacke at scattered localities in and adjacent to the Okanogan Valley. Basal beds are generally conglomerate with clasts that are sometimes identifiable as fragments of local granitic and metamorphic rock. The conglomerate beds interfinger with, and are overlain by, lithic and volcanic graywackes, siltstone, and pyroclastics. The unit is cut by Eocene andesitic and dacitic plugs or capped by Eocene andesitic and dacitic flows and includes certain clastic sedimentary rocks known to overlie the flows. The age of the unit as a whole is considered to be grossly that of the andesite and dacite unit, that is, Eocene.

Andesite and Dacite

Andesite, hornblende-biotite dacite, and augite andesite crop out as isolated plugs, flows, and pyroclastic rocks, lying generally in a north-trending belt through the center of the map area. The plugs are clustered a few miles west of Oroville, where they intrude Tertiary epiclastic deposits as well as older rocks. The other masses (pl. 1) probably are mostly flows and subordinate pyroclastics, although feeder dikes and small plugs may be included. The flows, for the most part, overlie Tertiary epiclastics and are locally overlain by more recent sedimentary deposits. The volcanic rocks have been propylitized over extensive areas.

The K-Ar age of hornblende from the flow north of Tonasket (in sec. 21, T. 38 N., R. 27 E.), is 49.1 ± 1.8 m.y.; that from the plug west of Oroville (in sec. 24, T. 40 N., R. 26 E.) is 52.1 ± 2.3 m.y.; and that from the plug northwest of Oroville (in sec. 13, T. 40 N., R. 26 E.) is 51.4 ± 2.6 m.y. (J. Obradovich, U.S. Geological Survey, written communication, 1968). The three ages are inseparable within the limits of analytical error and indicate that the rocks are a southern continuation of the Eocene volcanic province of south-central British Columbia (Mathews, 1964).

METAMORPHISM

Mineral assemblages typical of the metamorphic rocks in areas distant from plutons include albite, actinolite, epidote, chlorite, calcite, and sericite in metamorphosed mafic rocks; and the same assemblage is found in metamorphosed siliceous clastics, with the addition of quartz and biotite. Both assemblages are characteristic of the greenschist facies (facies nomenclature after Winkler, 1965). No general change in mineral assemblages was noted in metamorphic rocks adjacent to the Colville batholith, except for an irregular, narrow belt of biotite hornfels at the contact. In the western part of the map area, oligoclase or andesine occurs instead of albite; hornblende rather than actinolite; and garnet and andalusite are locally present; which suggest a gradual westward transition to rocks of the cordierite-amphibolite and almandine-amphibolite facies (Winkler, 1965, p. 101 and 87, respectively). Rocks of higher metamorphic grade are present within the undivided metamorphic rocks shown in the southwest part of the map area.

Zones of contact metamorphism adjacent to plutons show recrystallization by an increase in grain size or by hornfelsic and spotted textures, but mineral assemblages typically are compatible with amphibolite facies rather than the hornblende-hornfels facies. The conclusion drawn is that pressure (=depth) of metamorphism appears to have been greater than that generally attributed to hornblende-hornfels assemblages.

Metamorphic rocks of Permian or Triassic age are generally of higher metamorphic grade than the younger superjacent Ellemeham Formation, suggesting that the older rocks attained their metamorphic grade prior to burial by the basal greenstone of the Ellemeham. Since most of the major plutons have not been metamorphosed, it is inferred that they were intruded after or during the period of general regional metamorphism, which must therefore have occurred in Middle or Late Triassic time. The effects of later metamorphic episodes are restricted to local areas near contacts of younger plutons.

STRUCTURAL GEOLOGY

Configuration of the Stratified Rocks

The older (Permian and Triassic) metamorphic rocks in the central and northern parts of the map area strike roughly northward, dip steeply westward, but with many local perturbations and undulations. The general trend of the beds is reflected in the somewhat sinuous trace of the mapped carbonate beds (pl. 1). Toward the north, the strike swings eastward, and the beds dip steeply to moderately northward. The structure of the metasediments in the southern part of the map area is not well understood. Although much folded, the carbonates of the limestone and dolomite appear grossly subhorizontal. Whether this observation applies also to Permian strata in the same area is not known.

The rocks of the Ellemeham Formation are homoclinal, dipping moderately east in the area west of Oroville, and dipping shallowly southward on Little Whisky Mountain. The overlying Tertiary epiclastic rocks are warped to a basinlike configuration in the Oroville area but elsewhere are tilted gently to the east.

Folds

Two fold trends are recognized in the Permian and Triassic metamorphic rocks. Axes of folds of the older set trend north-northwest, and the younger, northeast. The older folds dominate the northern part of the metamorphic terrane and, with the elongate plutons, establish the general north-northwest grain of the region. The most prominent fold of this set is the Whisky Mountain anticline, whose axis extends through Whisky Mountain and north-northwest to Ellemeham Mountain. The folds of the north-northwest set are apparently cut off by the Loomis and other plutons, indicating that this deformation was pre-Loomis— presumably Early or Middle Triassic.

The northeast fold set includes crenulations and kink-folds as well as larger folds superimposed on the older north-northwest-trending folds. Fold axes of the minor folds are of diverse strike, although a northeast trend is apparent in a belt trending north through the north-central part of the metamorphic terrane. The northeast folds are older than the Ellemeham Formation and thus are perhaps Jurassic or Cretaceous.

Faults

Numerous faults of varied attitude and type cut the rocks of the map area. North- to northeast-trending normal faults offset the youngest consolidated rocks, the Eocene andesite and dacite unit and the subjacent conglomerate, arkose, and graywacke, and therefore must be of Eocene or post-Eocene age. The age of faults which cut only the older rocks can only be bracketed as Middle Triassic to Tertiary. This latter group includes normal, strike-slip, and thrust faults.

A large thrust fault strikes north and extends from the Wannacut Lake area to Horse Springs Coulee, a distance of about 12 miles (pl. 1). The fault dips 10° to 15° to the west at its southern extremity, steepening to 25° along the northern segment. Offset is probably greatest in the southern part, perhaps as much as several miles. Several subsidiary thrusts have been located east of the main trace, suggesting the existence of an imbricate thrust zone.

Strike-slip and normal faults are of particular interest because of their close geographic and temporal association with the mineral deposits. In this regard the northeast-trending fault that horsetails out on Gold Hill (T. 39 N., R. 25 E.) is worthy of mention because of its mineral content. The fault trace indicates a moderate dip to the northwest along its northeast part, steepening to about 80° west of Sinlahekin Creek. Movement on this fault appears to have been right lateral, with maximum displacement of several thousand feet.

GLACIATION

The map area was overridden by the Okanogan Lobe (Flint, 1935), a piedmont glacier that advanced southeastward from source areas in the mountains of south-central British Columbia, ultimately reaching the vicinity of the Columbia River about 30 miles south of Riverside. The thickness of the ice sheet was great enough to cover even the highest summits within the map area, probably exceeding 6,000 feet in the valley of the Similkameen River and thinning somewhat to the south and east.

The erosive effects of the ice are recorded by the U-shaped valley profiles in the western part of the area and by the rounded summits of the Okanogan Highlands to the east. Melt-water erosion produced the high-level, stair-stepped trenches and notches that cut through ridges and plateau areas. Large volumes of detritus that accumulated on and within the glacier were released by the melting of the ice and were deposited as an irregular drift veneer on the bedrock of the map area. Most of the drift was reworked by the melt water, finally accumulating as terrace deposits, kames, lake deposits, and fans. The general distribution of this material is shown on the accompanying map (pl. 1), but numerous local areas mapped as bedrock are also irregularly mantled with thin deposits of drift.

An integrated drainage network was not reestablished in the highlands of the central part of the map area after retreat of the glacier. The valleys on the western and eastern flanks of the area were enlarged by glaciation, and the drainage pattern, while not deranged by the glaciation, was adjusted to large volumes of melt water. As a result, present-day streams are vastly underfit, except for the through-going Similkameen and Okanogan Rivers.

SUMMARY OF MINERAL DEPOSITS

INTRODUCTION

The metamorphic and igneous rocks of the map area are hosts to numerous mineral deposits. Most are low-grade quartz lodes carrying varying proportions of gold, silver, lead, copper, and zinc, and locally, molybdenum, tungsten, antimony, and arsenic. Disseminated deposits and replacements deposits are rare. Most of the deposits were discovered in the last decade of the nineteenth century and were worked briefly then and during the following ten years. With few exceptions, the mines have since been inactive, except for a brief resurgence during World War I and in the mid-1930's, following the rise in the price of gold. Approximately 150 deposits are shown on plate 1, and they cluster as a loosely defined group of deposits to the north in the Oroville-Nighthawk district, and as the eastern fringe of another group to the southwest in the Conconully district. The total production reported from the mines of the area is valued at about $1,400,000.

VEIN DEPOSITS

The vein deposits, which account for the bulk of the production, are mostly quartz lodes of the fissure-fill type and are rather low grade, except for an occasional rich shoot. Many of the veins occupy shear zones, and commonly show brecciated ore minerals and gangue. The attitudes of the veins display some regularity in local areas, but no preferred orientations or patterns have been recognized for the area as a whole.

A crescentic belt of low to moderately dipping veins crops out at the eastern margin of the Similkameen composite pluton. Several of the veins of this group are exposed in the valley of Lone Pine Creek. The vein at the Submarine mine (Lone Pine mine) (sec. 3, T. 40 N., R. 26 E.), as described by Patty (1921), is an undulating blanket quartz vein, locally dipping up to 10° to the northwest or southeast. The thickness ranges from 1 to 10 feet, averaging 6 feet. It has been traced on strike for approximately 1,000 feet and carries argentiferous galena, pyrite, chalcopyrite, covellite, and bornite. The deposit is explored by a 300-foot tunnel driven N. 50° W. A second tunnel, a thousand feet long, driven 110 feet below the upper tunnel, failed to intersect the ore body. Patty noted that the vein minerals had been shattered by post-mineral movement. Three similar veins were intersected by an adit at the White Knight deposit located one-fourth mile to the north (in Canada) (McKechnie, 1966, p. 166).

A group of steeply dipping, east-northeast-trending auriferous quartz veins, collectively known as the Gold Hill deposit (T. 38 N., R. 25 E.), cuts quartz-diorite and granodiorite of the Loomis pluton. The veins apparently occupy a series of faults horse-tailing away from the southwest termination of an important northeast-trending fault. The quartz veins themselves are considerably brecciated, and slickensides suggest that the displacement was strike-slip. In addition to gold, the veins carry galena, sphalerite, pyrite, and chalcopyrite, and outcrops are stained with malachite and azurite. An oval zone of intensely chloritized and kaolinized host rock, a mile long and half a mile wide, surrounds the veins. Placer gold is present below the vein deposits in the valley of Deer Creek and also in the valley of Toats Coulee Creek below its junction with Deer Creek. The vein deposits were explored by numerous pits and trenches and probably by extensive underground workings, judging by the presence of large dumps and by stopes caved to the surface, but no record of production was found.

The oxidized zone of most of the deposits is shallow, and primary sulfides are present within inches of the outcrop surface. Zones of secondary enrichment are consequently small or entirely absent. The Ivanhoe mine (sec. 16, T. 39 N., R. 26 E.) appears to be an exception, for it contains a zone of secondary enrichment with the high-grade silver ore near the surface. According to Hodges (1897, p. 99), the Ivanhoe deposit is a 20-inch to 7-foot-wide quartz vein with native silver, ruby silver, pyrargyrite, stephanite, and pyrite. An inclined shaft was sunk 500 feet on the vein, and a 4,400-foot-long tunnel was driven southeast, below the outcrop, from an altitude of 2,000 feet on the north-facing slope of Palmer Mountain. The tunnel may have failed to intersect the vein, since we saw no vein material on the dump. Hodges states that an initial shipment of 7,000 pounds of hand-picked ore from a shallow pit at the surface yielded 166 ounces of silver per ton. Subsequent shipments of 15,500 pounds and 25,500 pounds yielded 36 and 39 ounces of silver per ton, respectively.

DISSEMINATED DEPOSITS

Most of the copper deposits clustered immediately west of Osoyoos Lake (pl. 1) are quartz veins and pods located in a series of shear zones cutting the greenstone and metadiabase of the Kobau Formation and equivalent units. The veins exhibit divergent trends but generally dip shallowly to the west and contain chalcopyrite, pyrite, scheelite, and molybdenite. The greenstone and metadiabase are closely jointed, and adjacent to the shear zones the jointing approaches close-spaced fracture cleavage. Copper minerals, revealed by malachite stains, are dispersed along the joint planes. At the Kelsey deposit (sec. 8, T. 40 N., R. 27 E.) the concentration is great enough to constitute a submarginal ore body. According to Umpleby (1911), 18 assays averaged 2.62 percent copper, 0.6 ounce of silver, and 0.04 ounce of gold per ton. The average grade of the deposit is probably considerably less.

A large deposit of disseminated molybdenite (secs. 8 and 16, T. 37 N., R. 26 E.) was investigated by Creasey (1954), who observed that the ore minerals coat fractures and fill interstices in breccia zones in the Aeneas Creek pluton. According to Creasey, the deposit, known as the Starr Molybdenum mine, contained approximately 800,000 tons of indicated ore averaging 0.30 percent MoS_2. He identified two general classes of faults, those that strike N. 10-30° E. and those that strike N. 10-30° W., and hypothesized that the breccia zones controlling the distribution of the ore occur at and near the intersections of faults. The granodiorite wall rock is weakly sericitized and intensely silicified in the vicinity of the deposit. Chief ore minerals include molybdenite, chalcopyrite, pyrite, arsenopyrite, and scheelite.

REPLACEMENT DEPOSITS

Copper

Massive sulfides form en echelon pods within a mineralized zone cutting greenstone and metadiabase on Palmer Mountain (sec. 20, T. 39 N., R. 26 E.). The mineralized zone trends N. 85° W. and dips 40° to the south. Ore minerals include pyrite, chalcopyrite, arsenopyrite, pyrrhotite, magnetite, and sphalerite, and outcrops are stained with azurite and malachite. The mineralized zone is exploited by two mines, the Copper World and the Copper World Extension. The deposit at the Copper World Extension was described by Patty (1921, p. 240-243) as a series of overlapping tabular lenses of sulfide "matte," containing marcasite, pyrite, pyrrhotite, chalcopyrite, and bornite. The wall rock is intensely silicified. Laterals driven from a 300-foot-deep shaft crosscut the mineralized zone at the 100-foot and 200-foot levels, but the lateral at the 300-foot level was not carried far enough, and failed to reach the downward projection of the mineralized zone, according to Patty. Approximately 3,500 tons were shipped from the Copper World Extension between 1918-1919, averaging 3.147 percent copper, 0.42 ounce of silver, and 0.03 ounce of gold per ton (Huntting, 1956, p. 64).

Antimony

A bed of "limestone" (fine-grained marble) within the Anarchist Group is locally replaced by stibnite at the Lucky Knock deposit (sec. 19, T. 38 N., R. 27 E.). According to Purdy's (1951) description of the deposit, the stibnite occurs in pods up to 30 cubic feet in volume, erratically replacing the limestone within a zone of faults and subsidiary fractures that crosscuts the limestone. The stibnite is locally sheared along post-mineral fractures. The limestone is intensely silicified in a zone several hundred feet wide at the deposit. Purdy concluded that the stibnite mineralization was unrelated to the other mineral deposits of the map area because of its obvious epithermal nature, but instead was related to Tertiary volcanic rocks cropping out on Whitestone Mountain 2 miles to the east. Antimony is nevertheless present as a minor metal at a number of lead-zinc-silver deposits in the area, and these deposits, including the Lucky Knock, are rudely aligned north-northwest, suggesting a kinship with the lead-zinc-silver deposits, contrary to Purdy's view.

DISTRIBUTION OF MINERAL DEPOSITS

Metallic mineral deposits are clustered in irregular groups scattered throughout the western half of the map area; their distribution, classified according to the major metal, is shown on figure 2. A well-defined zone of deposits, whose chief values are in

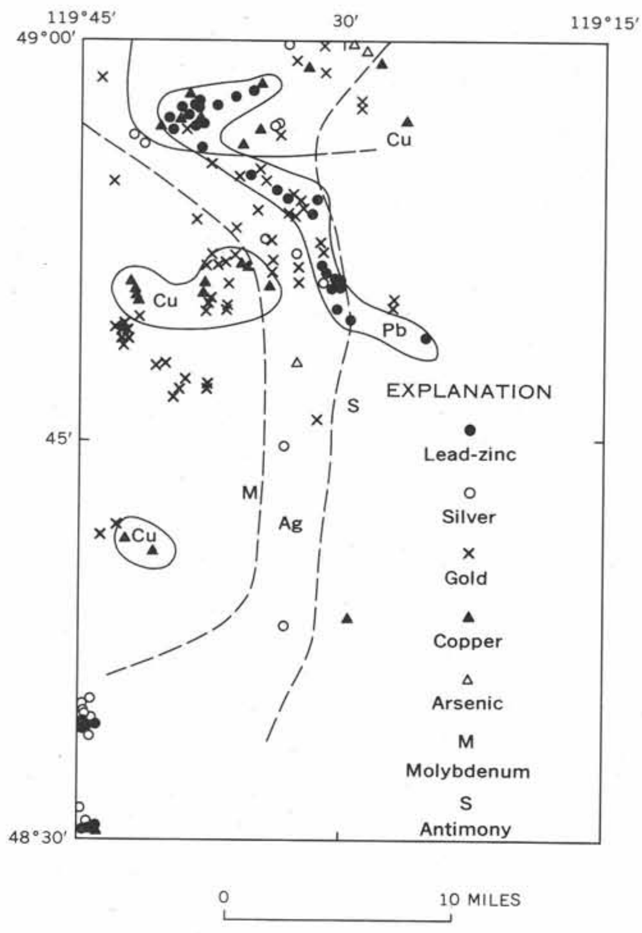


FIGURE 2.—Mines and prospects of the map area classified according to chief metal present, showing metal districts as follows: Cu, copper; Ag, silver; Pb, lead-zinc.

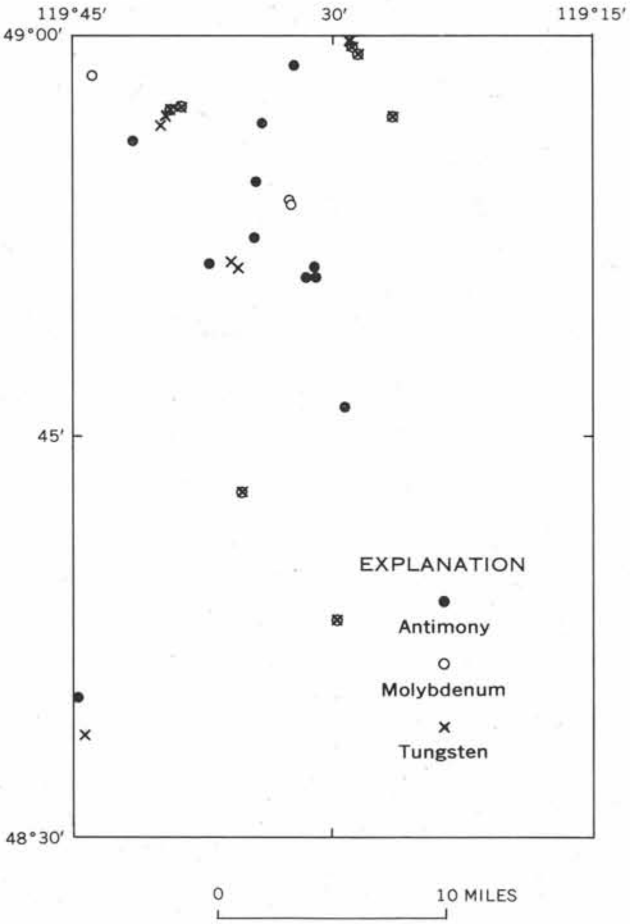


FIGURE 3.—Mines and prospects of the map area classified according to presence of molybdenum, tungsten, and antimony.

lead and (or) zinc, with minor gold and silver, trends north-northwest through the north-central part of the map area. Deposits with a particular dominant metal appear to fall into small clusters, but, with the exception of lead-zinc deposits, the distribution appears random. Distribution of tungsten, molybdenum, and antimony is shown on figure 3, but with the exception of the Lucky Knock antimony and the Starr molybdenum deposits, these metals occur in accessory or trace amounts only. Nevertheless, molybdenum and tungsten occur together at a number of deposits and are antipathetic to antimony. Antimony is present in stibnite at the Lucky Knock and in pyrargyrite or stephanite at the other occurrences. The deposits carrying antimony define a roughly aligned northwest-trending belt. No obvious correlation between the distribution of any metal and the bedrock geology is apparent.

GEOCHEMICAL PROGRAM

INTRODUCTION

The objectives of the geochemical exploration program were to discover and define geographic trends of metallized rock and to locate undiscovered mineral deposits. The most promising exploration targets seemed to be deposits similar to those that are characteristic of the district and of sufficient size to be of economic significance. It was decided that an exploration program capable of accomplishing these objectives, with maximum economy in time and money, would be systematic sampling of gully and stream sediments— chiefly the former because of the scarcity of streams in this dry climate.

Sample locations were chosen by inspection of air photos and topographic maps so that each sample represented a drainage area of about a square mile. The area effectively sampled by this procedure approaches 100 percent in the highlands of the western, north-central, and eastern parts of the area, which are drained by a reasonably well-integrated network of gullies and streams. In portions of the Cayuse Mountains and Horse Springs Coulee (central part of map area, pl. 1), however, where the drainage has been deranged by glaciation, the effective area probably does not exceed 50 percent; and in the undulating karst upland of the "lime belt" (south-central part of the map area, pl. 1) it does not exceed 10 percent.

The samples were taken at depths of 5 to 10 inches, or below the A horizon where it exists, except in boggy or plowed ground in the main valleys where sufficient depth could not be easily attained. Soil profiles were only rarely observed in the gullies and ephemeral drainages. The samples were obtained with a shovel, in amounts equivalent to one or two handfuls each, and were forwarded to either a mobile laboratory based in the vicinity or to the U.S. Geological Survey Field Service Laboratory at Denver. Splits of the -80 mesh fraction, ashed where necessary, were analyzed for cold-acid-extractable copper (xCu), using the method of Canney and Hawkins (1958), and for citrate-soluble heavy metals (cxHm), using the method of Bloom (1955).

Additional tests were employed on selected samples. They include tests for gold (table 4); total lead, copper, and zinc by colorimetric methods (table 6); and semiquantitative spectrographic analyses (tables 2 and 3).

ORIENTATION PHASE

An orientation survey of sediments in streams or gullies draining each of four known mineral deposits was conducted in order to assess the suitability of the exploration technique in detecting halos downslope from the deposits and the down-drainage rate of decay. Background values were chosen somewhat arbitrarily from among analyses of nearby gully and stream sediments derived from similar, but nonmineralized, rock.

Submarine Deposit

The profile of metal values from Lone Pine Creek (fig 4), south of the Submarine deposit (sec. 3. T. 40 N., R. 26 E.), shows anomalously high values, particularly below L-2, with only moderate downstream decline. Samples L-1 and L-2 were collected upgully from known outcrops of the vein, probably accounting for their relatively low values. From the

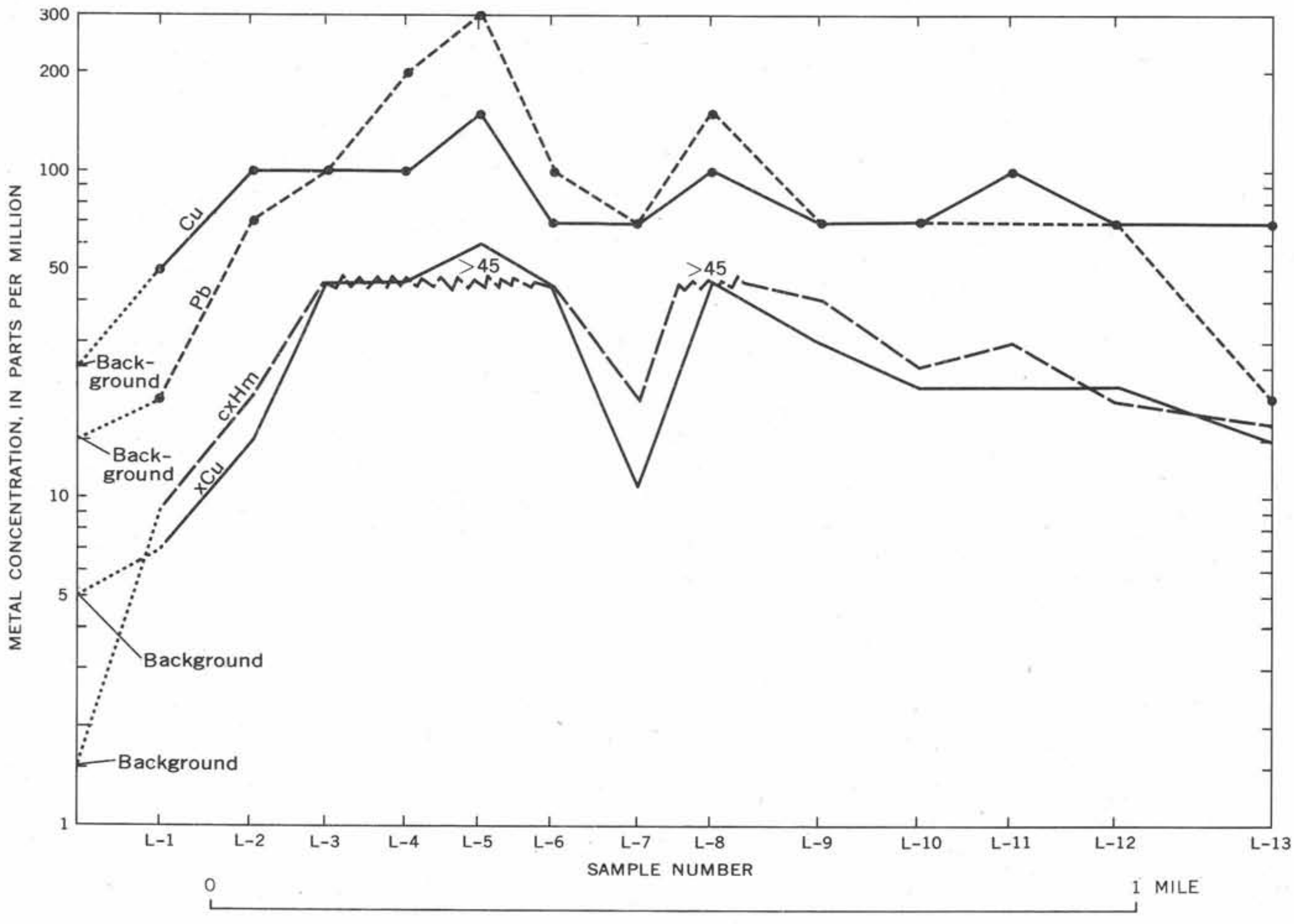


FIGURE 4.—Longitudinal profile of metal values from Lone Pine Creek, which extends south from the Submarine deposit, 4 miles northeast of Nighthawk. Values of Cu and Pb determined by semiquantitative spectrographic analysis; values of xCu and cxHm determined by colorimetric methods cited in text.

examination of plates 2 and 3 it seems safe to conclude that this deposit would have been readily detected in the course of routine areal xCu and cxHm testing.

Ivanhoe Deposit

Unlike the results at Lone Pine Creek, metal values in the gully extending south from the Ivanhoe mine show little more than variation about background levels (fig. 5). Because neither the attitude nor the precise location of the vein is known, any associated halo might lie in the influence of northwestward rather than southeastward drainage. Whatever the reason, it seems likely that this deposit, in contrast to the Submarine deposit, would not have been detected in the exploration program used in this study.

Copper World and Copper World Extension Deposits

The profile of metal values, except for Pb, from the gully draining the west slope of Palmer Mountain exhibits a strong halo (fig. 6). Significantly, values are near background from all samples upstream from L-22, but from L-22 through L-29, values are on the order of 10 to 20 times background— some considerably more— with little suggestion of significant downstream decline. In fact, values at L-368 at the west base of Palmer Mountain, 0.6 miles west of L-29 and on the same drainage, are: Zn, 1,500 ppm; Cu, 300 ppm; xCu, 120 ppm; and cxHm, 45 ppm. These values suggest a downstream halo about a mile and a half in length.

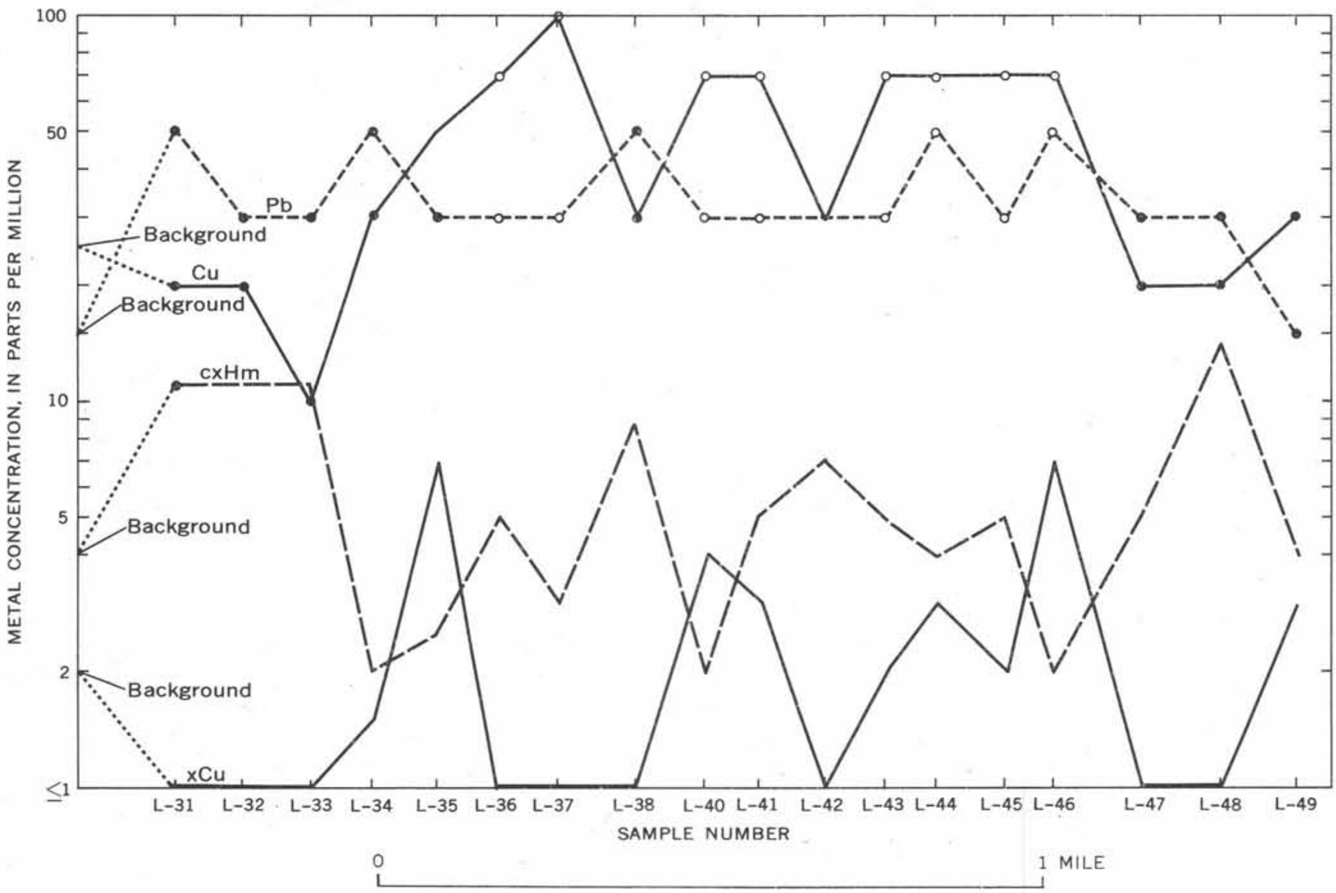


FIGURE 5.—Longitudinal profile of metal values from gully extending south from Ivanhoe deposit on northeast slope of Palmer Mountain. Values of Cu and Pb determined by semiquantitative spectrographic analysis; circled analyses from table 2, others from table 3. Values of xCu and cxHm determined by colorimetric methods cited in text.

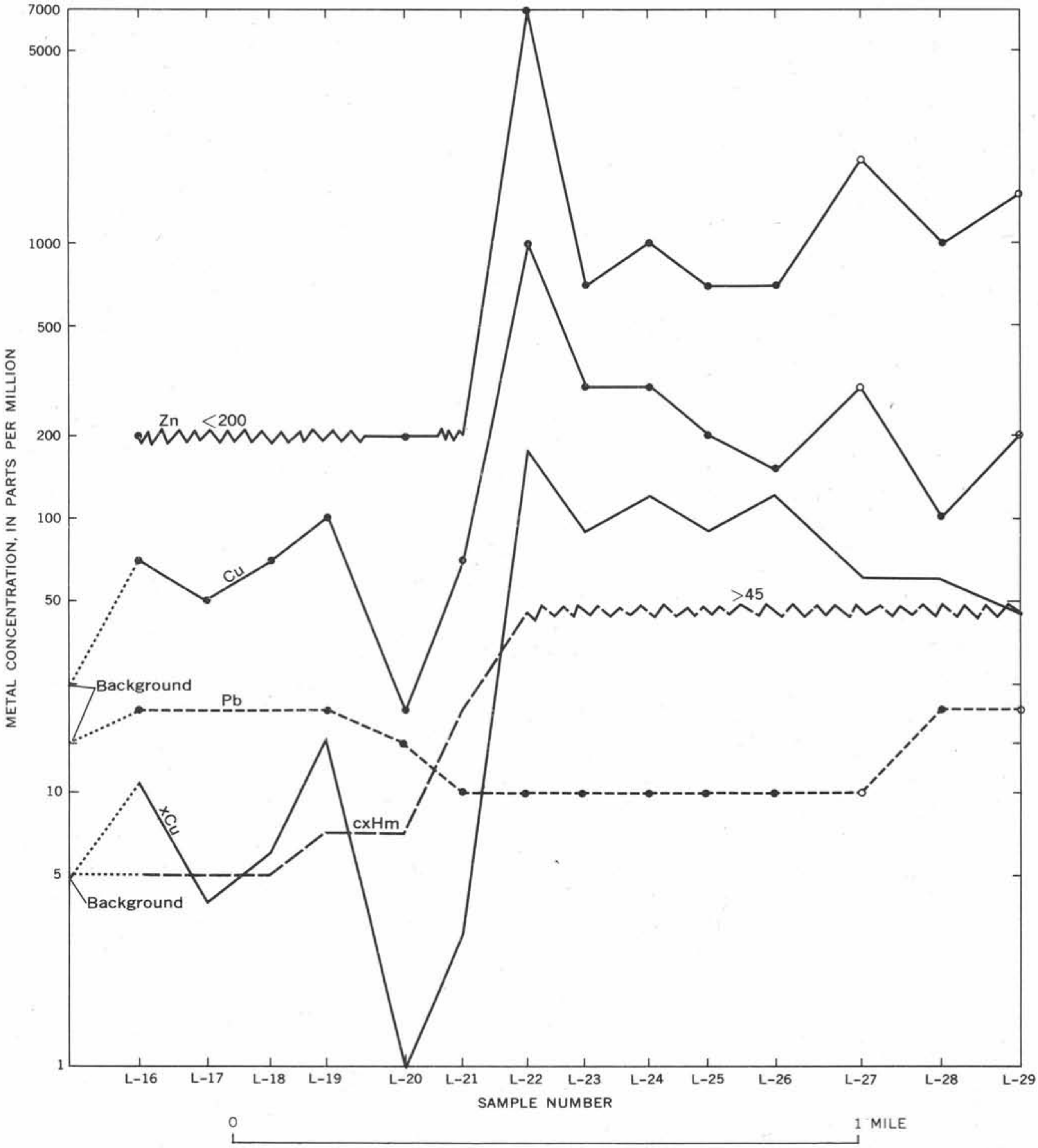


FIGURE 6.—Longitudinal profile of metal values from gully north of Copper World and Copper World Extension deposits on Palmer Mountain. Values of Zn, Cu, and Pb, determined by semiquantitative spectrographic analysis; circled analyses from table 2, others from table 3. Values of xCu and cxHm determined by colorimetric methods cited in text.

Sample L-22 is virtually at the intersection of the main gully and a tributary, within the drainage area where the workings of the two deposits lie. Dumps from the deposits may contribute disproportionately to the anomaly; indeed, massive sulfide specimens in the dumps show marked decomposition. Nevertheless the dumps are not large, and considering the relatively short time that the dumps have been contributing metal ions to the drainage, one would intuitively expect to see a fairly abrupt downstream decline in values if their contribution is significant. The markedly high Zn values may be relevant, for there are no reported zinc values in assays or smelter returns. Hence, the source of the zinc should be investigated.

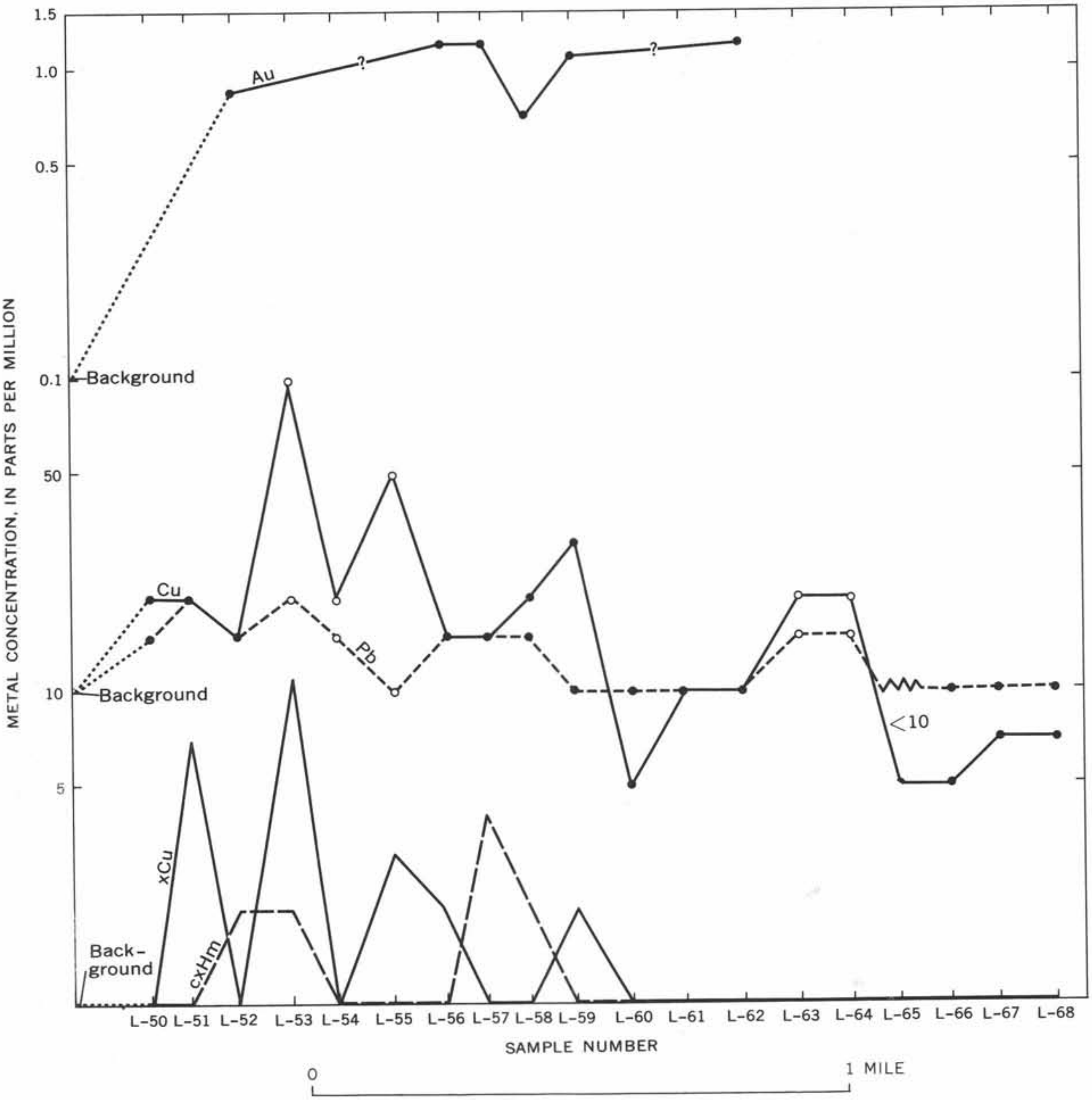
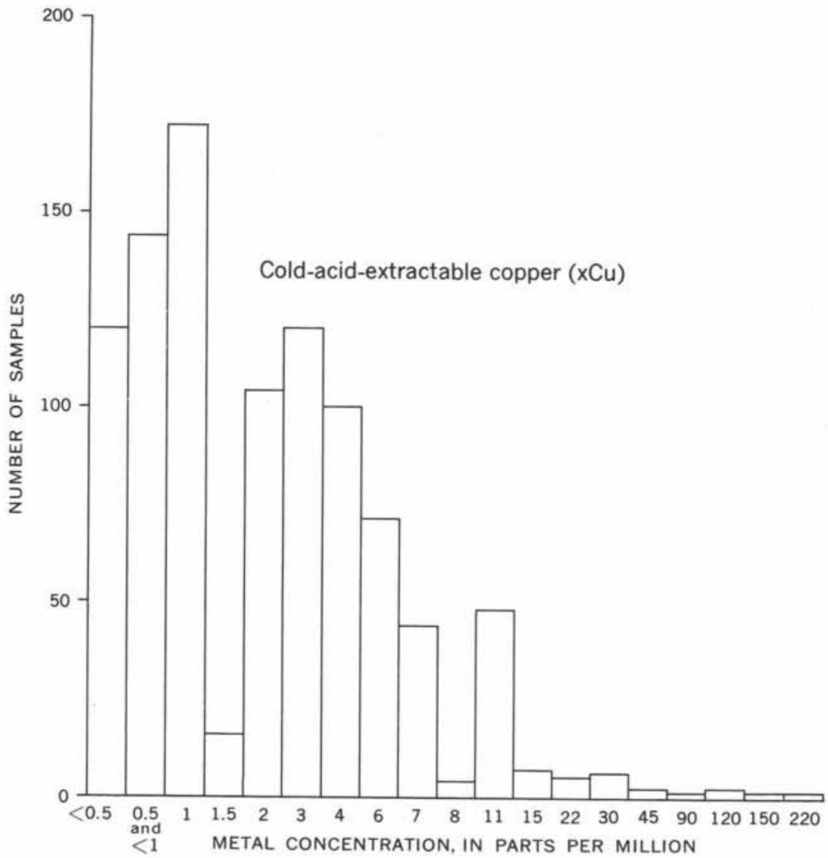


FIGURE 7.—Longitudinal profile of metal values from Deer Creek, which extends northeast from Gold Hill deposits. Values of Au determined by atomic absorption method. Values of Cu and Pb determined by semiquantitative spectrographic analysis; circled analyses from table 2, others from table 3. Values of xCu and cxHm determined by colorimetric methods cited in text.



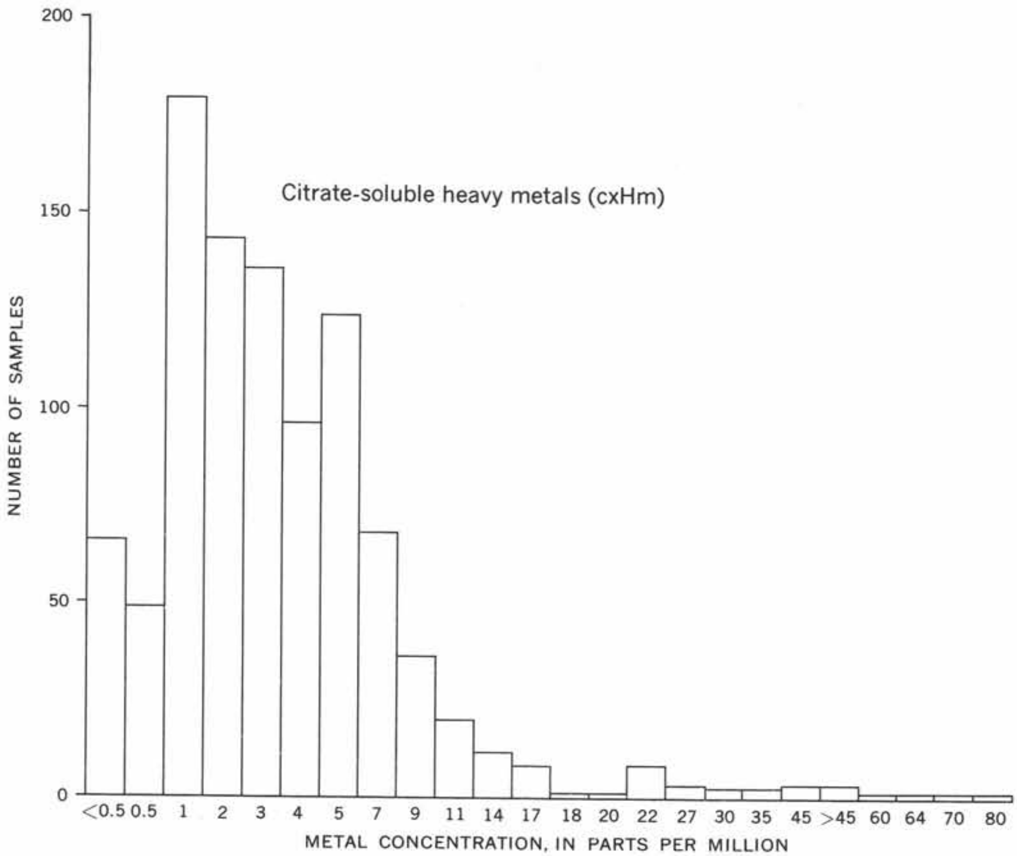


FIGURE 8.—Histograms showing distribution of cold-acid-extractable copper (xCu) values and citrate-soluble heavy metals (cxHm) values within the sample space.

Gold Hill Deposits

The profiles of Cu and xCu values from Deer Creek, which drains northeastward from Gold Hill, exhibit values of 5 to 10 times background in the upstream third. Lead and cxHm values are considerably lower, and most are within an expectable range of background variation (fig. 7). Values diminish downstream so abruptly that the lower half to two-thirds of the creek shows only background levels, suggesting that standard tests for xCu and cxHm alone are inadequate to detect Au deposits of this type. Samples tested for Au, however, show values greatly exceeding background. Further tests for Au are necessary to evaluate downstream decline, but the few Au data shown in figure 7 are encouraging. The metal halo downstream from Gold Hill is complicated by one factor, however—the gully along which the halo is defined is controlled by the same structure (faults) that contains the metalliferous deposits. It is entirely possible that the halo reflects not downstream migration of the metal but rather upward (or sideward) migration from mineralized bedrock.

REGIONAL SAMPLING PHASE

About 1,000 samples were collected during the regional sampling phase of the investigation. All sampling and analytical procedures paralleled those of the orientation phase. All samples were analyzed for cold-acid-extractable copper (xCu) and citrate-soluble heavy metals (cxHm) and the results are plotted on plates 1 and 2 (in pocket). Most of the samples taken during the orientation phase, duplicate samples, check samples, and close-spaced samples taken at specific geologic targets were omitted from the histograms, trend surfaces, and statistical computations in order to achieve an even distribution with minimum bias toward high values. Also omitted were certain values found not to be reproducible on field check or values that were obviously due to contamination. A total of 967 samples remained after excluding those noted above. The distribution of values within the sample space is shown by the accompanying histograms (fig. 8). Copper (xCu) ranges from less than 0.5 ppm to 220 ppm, and heavy-metal (cxHm) content ranges from less than 0.5 ppm to 80 ppm. Mean values are 4.06 and 4.39 for copper (xCu) and heavy metal (cxHm), respectively. Both distributions are highly skewed and appear to be approximately lognormal. Samples showing high values of copper (xCu) or heavy metal (cxHm) were analyzed by semiquantitative spectrographic method; the results are listed in tables 2 and 3. A total of 66 samples were analyzed for gold by the atomic absorption method, with the results listed in table 4. Samples for which analytical data are presented in tables 2, 3, and 4 are numbered on the geologic map (pl. 1).

Regional Pattern

Relatively high concentrations of cold-acid-extractable copper (xCu) in stream and gully sediments are confined to a narrow north-trending belt crossing the west-central part of the map area. The background level of copper (xCu) is low in sediments derived from the Colville batholith and the metamorphic rocks lying east of the Okanogan River. Gully and stream sediments derived from plutons lying west of the Sinlahekin-Fish Lake valley are also low.

The distribution of citrate-soluble heavy metals (cxHm) in stream and gully sediments of the map area (pl. 3), unlike the copper (xCu), fails to define a sharply bounded mineralized belt. In further contrast, sediments derived from the northern part of the Colville batholith and the metamorphic and plutonic terrane lying north of the Colville batholith and east of the Okanogan River, which showed only low background levels of copper (xCu), typically show relatively high values of heavy metals (cxHm). In spite of the dissimilarities in the distribution of copper (xCu) and heavy metals (cxHm) noted above, certain similarities are also apparent. For instance, the sediments derived from the Kruger Mountain area west of Osoyoos Lake and the summit area of Palmer Mountain show high concentrations of both heavy metals (cxHm) and copper (xCu), although the contrast of the heavy-metal content with that in surrounding areas is less than the contrast of the copper content.

TABLE 2.—Analyses, in parts per million, from Field Services (Denver) and Central (Menlo Park) Laboratories

Sample no.	Colorimetric		Spectrographic (semiquantitative)			
	xCu	cxHm	Cu	Pb	Zn	Ag
L- 10	22	25	150	100	0	0
L- 20	1	7	70	20	0	0
L- 27	60	>45	300	10	2,000	0
L- 29	45	>45	200	20	1,500	0
L- 36	<.5	5	70	30	0	0
L- 37	1	3	100	30	0	0
L- 40	4	2	70	30	0	0
L- 41	3	5	70	30	0	0
L- 43	2	5	70	30	0	0
L- 44	3	4	70	50	0	0
L- 45	2	5	70	30	0	0
L- 46	7	2	70	50	0	0
L- 53	11	2	100	20	0	0
L- 54	.5	1	20	15	0	0
L- 55	3	1	50	10	0	0
L- 63	<.5	1	20	15	0	0
L- 64	<.5	1	20	15	0	0
L- 70	11	2	150	30	0	0
L- 75	<.5	.5	50	20	0	0
L-105	60	14	150	0	0	0
L-108	11	4	100	10	0	0
L-109	11	1	100	15	0	0
L-110	11	3	100	10	0	0
L-200	11	11	100	30	0	0
L-212	15	7	150	20	0	<.7
L-242	3	14	100	15	0	0
L-263	22	9	150	15	0	0
L-267	11	22	150	20	0	0
L-270	7	17	150	15	0	0
L-271	<.5	11	70	10	0	0
L-280	<.5	22	20	20	0	0
L-285	1	17	70	10	0	0
L-292	<.5	45	70	10	0	0
L-293	<.5	11	70	15	0	0
L-299	15	3	70	10	0	0

TABLE 2.—Analyses, in parts per million, from Field Services (Denver) and Central (Menlo Park) Laboratories—Continued

Sample no.	Colorimetric		Spectrographic (semiquantitative)			
	xCu	cxHm	Cu	Pb	Zn	Ag
L-310	11	11	100	70	0	1
L-313	15	22	150	200	0	1.5
L-316	11	30	150	30	0	0
L-368	120	>45	300	0	1,500	0
L-384	11	7	100	30	0	<.7
L-385	11	5	150	20	0	0
L-407	11	11	150	20	0	0
L-432	4	5	70	20	0	0
L-433	6	5	150	20	0	0
L-434	4	2	70	15	0	0
L-435	2	11	70	15	0	0
L-441	3	4	70	15	0	0
L-442	3	4	70	20	0	0
L-443	4	3	70	15	0	0
L-444	6	3	70	10	0	0
L-448	3	17	70	20	0	<.7
L-471	11	1	70	15	0	<.7
L-493	<.5	11	70	20	0	<.7
L-510	6	2	70	30	0	<.7
L-513	<.5	14	70	30	0	<.7
L-516	4	11	70	30	0	<.7
L-517	7	14	100	30	0	1
L-528	7	5	100	30	0	<.7
L-529	6	9	100	30	0	<.7
L-539	11	45	100	70	0	.7
L-558	<.5	14	30	15	0	0
L-564	<.5	17	50	20	0	<.7
L-615	3	11	70	50	0	0
L-616	<.5	17	50	10	0	0
L-617	11	2	70	0	0	0
L-619	3	9	70	15	0	0
L-625	15	2	150	15	0	0
L-647	6	35	70	15	0	0
L-677	11	7	70	10	0	.7

TABLE 2.—Analyses, in parts per million, from Field Services (Denver) and Central (Menlo Park) Laboratories—Continued

Sample no.	Colorimetric		Spectographic (semiquantitative)			
	xCu	cxHm	Cu	Pb	Zn	Ag
L-679	11	5	100	10	0	0
L-680	6	7	100	10	0	0
L-681	8	7	100	10	0	0
L-682	30	17	150	15	0	1
L-695	15	7	100	10	0	0
M- 1	6	3	50	50	0	0
M- 2	220	80	300	30	0	0
M- 3	45	22	150	20	0	<.7
M- 4	90	35	300	20	0	0
M- 5	30	18	150	20	0	<.7
M- 6	4	5	50	20	0	<.7
M- 7	3	7	70	0	0	<.7
M- 8	30	30	150	15	0	<.7
M- 9	150	64	300	10	0	<.7
M-10	22	17	150	15	0	<.7
M-11	45	5	200	10	0	<.7
M-12	2	3	70	10	0	<.7
M-13	3	3	50	15	0	<.7
M-14	120	70	300	0	0	<.7
M-25	1	3	15	10	0	0
M-26	2	3	20	15	0	0
M-30	8	6	70	20	0	0
M-31	4	27	50	15	0	<.7
M-32	2	5	30	20	0	0
M-33	1	5	15	15	0	0

TABLE 3.—Analyses, in parts per million, from Mobile Laboratory

Sample no.	Colorimetric		Spectrographic (semiquantitative)			
	xCu	cxHm	Cu	Pb	Zn	Ag
L- 1	7	9	50	20	<200	<1
L- 2	15	20	100	70	<200	1
L- 3	45	>45	100	100	200	1
L- 4	45	>45	100	200	300	2
L- 5	60	>45	150	300	700	3
L- 6	45	>45	70	100	200	1
L- 7	11	20	70	70	<200	1
L- 8	45	>45	100	150	300	3
L- 9	30	40	70	70	<200	1
L-11	22	30	100	70	<200	1
L-12	22	20	70	70	<200	1
L-13	15	17	70	20	<200	<1
L-14	4	5	30	15	<200	<1
L-15	11	7	30	10	<200	<1
L-16	11	5	70	20	<200	1
L-17	4	5	50	20	<200	<1
L-18	6	5	70	20	<200	<1
L-19	15	7	100	20	<200	<1
L-21	3	30	70	10	<200	<1
L-22	180	>45	1,000	10	7,000	<1
L-23	90	>45	300	10	700	<1
L-24	120	>45	300	10	1,000	<1
L-25	90	>45	200	10	700	<1
L-26	120	>45	150	10	700	<1
L-28	60	>45	100	20	1,000	<1
L-30	<.5	7	20	30	<200	<1
L-31	<.5	11	20	50	<200	<1
L-32	<.5	11	20	30	<200	<1
L-33	<.5	11	10	30	<200	<1
L-34	1.5	2	30	50	<200	<1
L-35	7	3	50	30	<200	<1
L-38	.5	9	30	50	<200	<1
L-42	.5	7	30	30	<200	<1
L-47	1	5	20	30	<200	<1
L-48	<.5	14	20	30	<200	<1
L-49	3	4	30	15	<200	<1
L-50	<.5	1	20	15	<200	<1
L-51	7	1	20	20	<200	<1
L-52	1	2	15	15	<200	<1

TABLE 3.—Analyses, in parts per million, from Mobile Laboratory—Continued

Sample no.	Colorimetric		Spectrographic (semiquantitative)			
	xCu	cxHm	Cu	Pb	Zn	Ag
L-56	2	1	15	15	<200	<1
L-57	<.5	4	15	15	<200	<1
L-58	.5	2	20	15	<200	<1
L-59	2	1	30	10	<200	<1
L-60	.5	1	5	10	<200	<1
L-61	<.5	1	10	10	<200	<1
L-62	<.5	1	10	10	<200	<1
L-65	<.5	1	5	<10	<200	<1
L-66	<.5	.5	5	10	<200	<1
L-67	<.5	1	7	10	<200	<1
L-68	<.5	.5	7	10	<200	<1
L-71	<.5	1	20	10	<200	<1
L-72	6	5	30	10	<200	<1
L-73	4	2	20	<10	<200	<1
L-74	3	.5	15	<10	<200	<1
L-76	<.5	.5	10	<10	<200	<1
L-77	<.5	1	10	10	<200	<1
L-78	6.5	1	10	10	<200	<1
L-79	<.5	.5	20	10	<200	<1
L-80	<.5	<.5	10	<10	<200	<1
L-81	2	1	10	<10	<200	<1
L-82	1.5	1	10	<10	<200	<1
L-83	11	1	30	10	<200	<1
L-84	6	2	20	10	<200	<1
L-85	4	3	30	10	<200	<1
L-86	4	2	20	<10	<200	<1
L-87	3	1	15	<10	<200	<1
L-88	6	2	50	15	<200	<1
L-89	15	2	70	20	<200	<1
L-90	4	2	30	20	<200	<1
L-91	6	7	30	30	<200	<1
L-92	3	5	30	30	<200	<1
L-93	6	1	20	20	<200	<1
L-94	3	1	30	20	<200	1
L-95	4	4	30	30	<200	<1
L-96	4	1	20	15	<200	<1
L-97	11	1	30	15	<200	<1
L-98	4	1	30	10	<200	<1
L-100	1	3	20	15	<200	<1

TABLE 4.—Gold content of selected samples—analysis by the atomic absorption method

Sample no.	Location Sec. (T.R.)	Au (ppm)	Sample No.	Location Sec. (T.R.)	Au (ppm)
L- 10	3(40-26E)	<0.1	L-341	4(38-25E)	.3
L- 12	10(40-26E)	<0.1	L-344	16(38-25E)	.2
L- 52	4(38-25E)	.85	L-345	9(38-25E)	.1
L- 56	4(38-25E)	1.2	L-409	22(37-25E)	<0.1
L- 57	4(38-25E)	1.2	L-410	22(37-25E)	<0.1
L- 58	4(38-25E)	.7	L-411	27(37-25E)	<0.1
L- 59	4(38-25E)	1.1	L-417	35(37-25E)	<0.1
L- 62	4(38-25E)	1.2	L-418	35(37-25E)	<0.1
L- 73	23(38-25E)	<0.1	L-433	7(37-26E)	<0.1
L- 74	26(38-25E)	<0.1	L-434	17(37-26E)	<0.1
L- 87	26(39-25E)	<0.1	L-435	16(37-26E)	<0.1
L- 95	1(40-25E)	<0.1	L-436	21(37-26E)	<0.1
L-116	26(39-25E)	.4	L-441	16(37-26E)	<0.1
L-173	22(38-26E)	<0.1	L-442	9(37-26E)	1.1
L-175	22(38-26E)	<0.1	L-443	9(37-26E)	<0.1
L-176	22(38-26E)	<0.1	L-444	9(37-26E)	<0.1
L-177	27(38-26E)	<0.1	L-448	28(37-26E)	<0.1
L-194	15(38-26E)	<0.1	L-564	27(35-26E)	<0.1
L-200	13(38-26E)	<0.1	L-616	12(35-25E)	<0.1
L-201	24(38-26E)	<0.1	L-617	12(35-25E)	<0.1
L-240	11(39-26E)	.3	L-624	1(35-25E)	<0.1
L-247	10(39-26E)	<0.1	L-625	1(35-25E)	<0.1
L-248	10(39-26E)	<0.1	L-700	16(37-26E)	<.02
L-267	12(39-25E)	<0.1	L-701	16(37-26E)	<.02
L-270	2(39-25E)	<0.1	L-702	16(37-26E)	<.02
L-275	28(40-25E)	<0.1	L-703	9(37-26E)	<.02
L-278	17(40-25E)	<0.1	L-704	9(37-26E)	.04
L-279	8(40-25E)	<0.1	L-705	9(37-26E)	.02
L-284	28(40-25E)	<0.1	L-706	9(37-26E)	.02
L-285	27(40-25E)	<0.1	L-707	9(37-26E)	<.02
L-331	8(38-25E)	.3	L-708	9(37-26E)	<.02
L-332	17(38-25E)	.1	L-709	9(37-26E)	<.02
L-333	17(38-25E)	<0.1			

Trend Surface Analysis

Trend surfaces were prepared by contouring polynomial equations fitted by regression analysis to logarithms of citrate-soluble heavy metal (cxHm) and to logarithms of the cold-acid-extractable copper (xCu) content of those samples taken during the regional sampling phase. The purpose of this procedure is to identify and map the contribution of regional mineralized "zones" or "belts" to the metal content of the overlying surficial deposits, in hopes that the resulting maps will suggest genetic associations of the zones with other geologic features. We hypothesize that in these zones or belts there is a continuum from large deposits to small; that the small are clustered near the large; and that the smallest class of deposit includes disseminations, veinlets, and primary dispersion halos, too low grade to have been of interest to the miner even if detectable. The large deposits are generally few, while those of the smallest class are numerous, and we suppose that the total extent of the zones is considerably greater than the area within which minable deposits are known.

The measured metal content of a sample of surficial material can be considered the sum of two components, a regional and a local. The regional component is presumed to consist largely of the contribution from the hypothetical mineralized belt, although other effects that extend from edge to edge of the map area are included. The local component is regarded as the net effect of the local variations to which geochemical samples are subject; for example, the metal content of unmineralized bedrock, weathering, contamination and analytical error. Within a highly mineralized part of the belt, the contribution to the sample from the belt is obvious. In the less highly mineralized parts, however, local effects may overshadow the effect of the belt. In such circumstances, trend surface analysis may assist in defining the belt by identifying the regional component of the metal content of each sample. At best, however, trend surface analysis can only discover functional relationships that "explain" some part of the measured metal values in terms of their geographic location. Identification of the part so explained with the regional component, and that in turn with mineralized zones or other geologic features, calls for a judgment on the part of the investigator.

A lengthy treatment of the general theory and application of trend surface analysis is given by Krumbein and Graybill (1965), and a somewhat more elementary but informative account is given by Link, Koch, and Gladfelter (1964). Trend surface analysis has been used as an analytical tool in geochemical exploration by numerous investigators, including Connor and Miesch (1964a,b), Nordeng and others (1964), and more recently, Nackowski, Mardirosian, and Botbol (1967).

The trend surface analysis model presupposes that the value of some attribute, which is considered the dependent variable (Z), in this case copper (xCu) or heavy metal (cxHm), can be divided into two parts:

(1) $Z = f(X, Y) + \varepsilon$

where X and Y are the geographic coordinates at which Z is located, f(X, Y) is some functional relationship of Z to X and Y, usually estimated by a polynomial equation of the form:

(2) $\hat{Z} = \beta_0 + \beta_1 X + \beta_2 Y + \beta_3 X^2 + \beta_4 XY + \ldots$ etc.

and ε is the contribution to Z of supposedly local fluctuations unrelated to Z by f(X, Y). In practice, values are found for β_0, β_1, β_2, etc. by regression such that the $\Sigma\varepsilon^2$ ("sum of squared deviations") is a minimum. Equation (2), which is considered the "trend," defines a surface in three-dimensional space whose shape can be shown by contours.

Trend surfaces for this report were fitted to logarithms of the heavy metal (cxHm) values and copper (xCu) values by computer, using the general procedure outlined by Mandelbaum (1963). Metal values below the limit of detection were arbitrarily entered as 0.4 ppm. Heavy metal values reported as "greater than 45 ppm" were arbitrarily entered as 46 ppm. The maps (figs. 9 and 10) have been contoured in parts

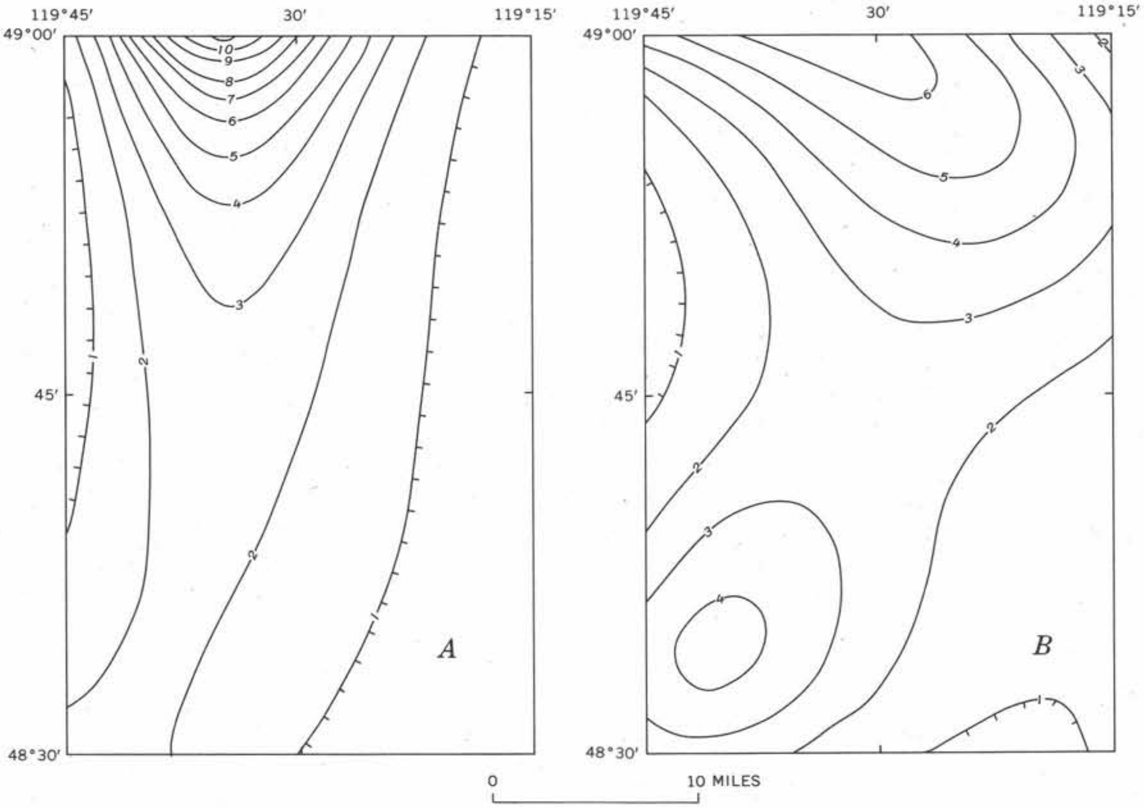


FIGURE 9.—Quartic trend surfaces. A, copper (xCu); B, heavy metals (cxHm).

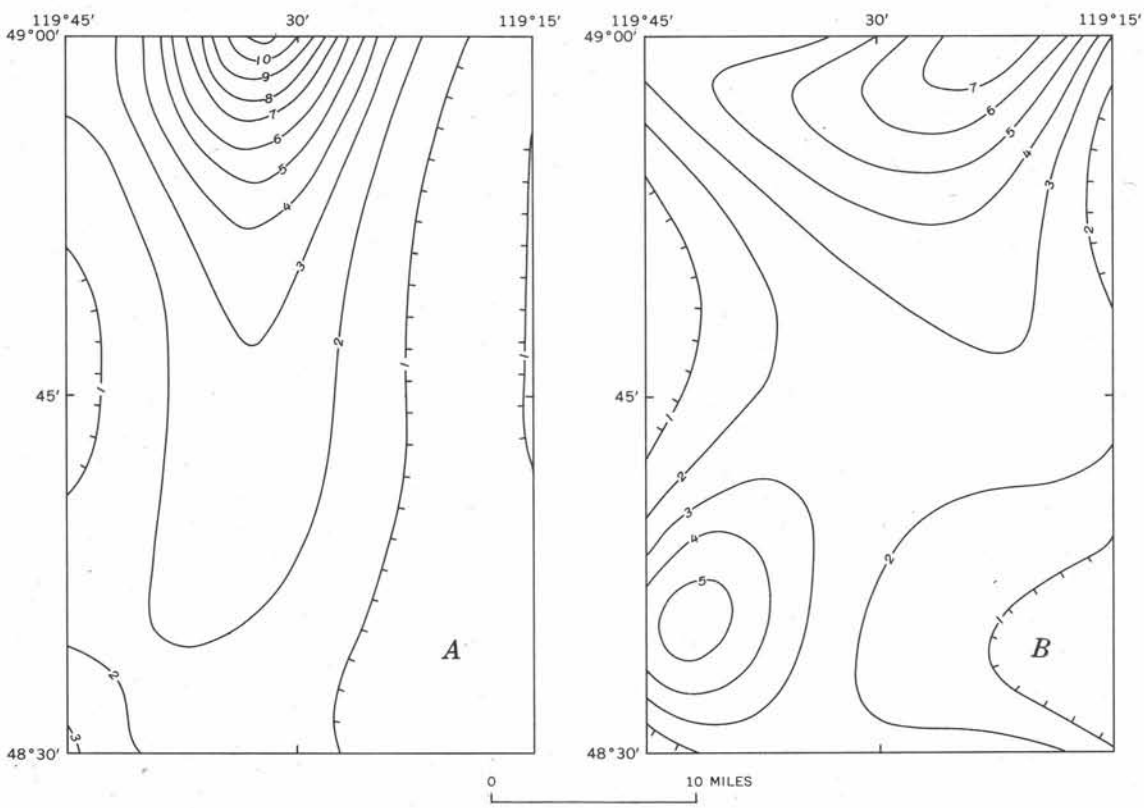


FIGURE 10.—Quintic trend surfaces. A, copper (xCu); B, heavy metals (cxHm).

per million of the respective metals rather than logarithms, however. An analysis of variance, presented in table 5, suggests that all the surfaces would be significant at the 97.5 percent level, provided that the ε's are normally and independently distributed and homogeneous. Although it is likely that these assumptions are not perfectly fulfilled, apparently the analysis of variance is affected little by slight departures from the assumptions (Li, 1964, p. 191). Thus, even though the trends account for only small proportions of the total sum of squares, the regional effects they represent are probably real.

The quintic trends (fig. 10) are considered the best representation of the relationship of metal value to geographic location, although the quartic and other intermediate trends (fig. 9) are so similar that the practical difference is negligible. The quintic trends account only for one-fourth to one-third of the variation in metal content, judging by the percent reduction in the sum of squared deviations (table 5); indicating that most of the variability is due to the sum of the inherent variability in the contribution from the mineralized belts, local effects, and possibly to regional effects where the relationship of metal content to sample location is different than that expressed by the trend.

The quintic trend surface on copper (xCu) (fig. 10) shows a narrow north-trending belt increasing abruptly in value at the north border of the map area. The quintic surface for heavy metals (cxHm) (fig. 10) is more complex, showing a zig-zag pattern with a pronounced northwest grain. The trends of metal content of the surficial deposits cut across bedrock units of diverse composition without deviation. Although most of the samples were taken from surficial deposits beyond the range of influence of known mineral deposits, the location of most of the mineral deposits coincides with the higher parts of the trends. These circumstances suggest that the trends do indeed reflect broad zones or belts of bedrock mineralization.

The quintic trend surface for copper (xCu) is presumed to be a map of a north-trending mineralized belt containing polymetallic deposits in which copper is the dominant metal. The larger deposits of this category include the Kelsey, the Copper World and Copper World Extension. Judging by these deposits, molybdenum, tungsten, gold, silver, lead, and zinc are associated with, but subordinate to, copper. The copper belt generally parallels the zone of Eocene dacitic to andesitic volcanic plugs and flows. The volcanic rocks are locally hydrothermally altered and at one locality (sec. 12, T. 36 N., R. 26 E.) contain copper-lead-molybdenum-silver-(tungsten?) mineralization. These relations indicate that at least some of the copper-molybdenum-tungsten mineralization of the copper belt is as young as Eocene.

The copper (xCu) belt borders the western edge of the Colville batholith throughout most of its length within the map area, although the rocks of the batholith are apparently unmineralized. Since the batholith was emplaced prior to the volcanics, the virtual absence of copper mineralization within it must reflect unfavorable conditions for mineralization if the mineralization is, indeed, post-volcanic in part. Whatever the detailed age relations, the general parallelism of the copper belt with the Tertiary volcanic rocks suggests some sort of relationship, perhaps lower crustal structural control of location, a common source of metal and magma, or both.

The quintic trend surface for heavy metals suggests a somewhat more complex pattern of mineralization than that for copper. The chief elements of the pattern are a northwest-trending zone across the north half of the map area and an oval zone in the southwest corner. The northernmost zone is grossly coincident with the zone containing deposits that are important chiefly for lead, as well as those in which antimony is a minor constituent. The heavy metals trends probably represent deposits such as L-313 (table 6), and the Submarine mine at which lead, zinc, silver, copper, gold, and antimony in varying proportions are present. Judging by the trend surfaces, the zones of high heavy metals values show no obvious spatial relationship with any intrusive rocks.

Since the heavy metals test is sensitive to copper as well as other metals, it is reasonable to

TABLE 5.—Analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Mean square	F	Confidence level percent	Cumulative percent of sum of squares accounted for
	Copper (xCu)					
Linear terms..........	156.37	2	78.19	64.30	99.9+	11.77
Deviations from linear trend............	1,172.25	964	1.22			
Quadratic terms......	19.33	3	6.44	5.37	99.5	13.22
Deviations from quad-ratic trend........	1,152.92	961	1.20			
Cubic terms..........	191.32	4	47.83	47.60	99.9+	27.62
Deviations from cubic trend............	961.60	957	1.00			
Quartic terms........	13.62	5	2.72	2.73	97.5	28.65
Deviations from quartic trend............	947.98	952	1.00			
Quintic terms........	21.14	6	3.52	3.60	99.5	30.24
Deviations from quintic trend............	926.84	946	0.98			
	Heavy metal (cxHm)					
Linear terms..........	31.58	2	15.79	15.35	99.9+	3.09
Deviations from linear trend............	991.38	964	1.03			
Quadratic terms......	93.59	3	31.20	33.39	99.9+	12.24
Deviations from quad-ratic trend........	897.79	961	0.93			
Cubic terms..........	69.74	4	17.44	20.15	99.9+	19.05
Deviations from cubic trend............	828.05	957	0.87			
Quartic terms........	30.48	5	6.10	7.28	99.9+	22.03
Deviations from quartic trend............	797.56	952	0.84			
Quintic terms........	41.87	6	6.98	8.73	99.9+	26.13
Deviations from quintic trend............	755.70	946	0.80			

conclude that the heavy metals trend is influenced by the distribution of copper. Furthermore the heavy metal values include an unknown contribution from the zinc and lead content of the copper deposits. Thus the heavy metal trend surfaces are biased toward the pattern shown by the copper trend surfaces, concealing possible real differences between the distribution of copper-molybdenum-tungsten mineralization and zinc-lead-silver mineralization. Because of these limitations, the heavy metal trends probably only crudely approximate the pattern of the zinc-lead-silver zones.

Anomalies

As herein defined, anomalies include those values that are high enough, when considered in relation to local geologic features, to suggest the presence of significant mineralization but that could not be related to known mineral deposits. This rather loose definition permits inclusion, for instance, of samples from the limestone and dolomite northwest of Riverside showing only moderate levels of heavy metal (cxHm), but also containing detectable silver; or the exclusion of high values where the source is obviously a known deposit. All of the analytical results are recorded on the maps (pls. 2 and 3) and tables (tables 2, 3, and 4) for those who might wish to apply other criteria in the selection of anomalies.

Field checks were conducted at some localities that yielded anomalously high metal values with the limited objective of confirming or refuting the presence of the anomalous level of metallization in the vicinity of the original sample. Samples were generally taken up- and down-gully from the original locality, in order to determine the general down-gully rate of degradation of the metal value. The general vicinity was also inspected for evidence of contamination that might have contributed to the measured value, or of mining activity that might suggest the existence of general mineralization. Customarily no attempt was made to locate the bedrock source of the metal. Approximately two dozen localities were field checked, with the results recorded in table 6. In addition, certain areas considered to have geologic promise were more intensively sampled than the map area as a whole, and these results are summarized in table 6.

The following localities are considered to have above-average promise:

L-316

A strong heavy metal (cxHm) showing on the apex of a fan was confirmed by up-gully check samples. No deposits are on record within the drainage area of the gully, but proximity to L-313 (table 6) and numerous other better known deposits suggests that a lead-, zinc-, and silver-bearing quartz vein is the source of the anomaly. Exposures in the area are good, and it is doubtful that the source, if a vein, escaped the attention of prospectors.

L-564

Sample locality is on a grassy flat at the junction of two dry gullies. Abundant rusting iron and delapidated out-buildings showed that the general area had once been occupied and provided a ready explanation for the high heavy metal (cxHm) content but possibly not the trace of silver detected by spectrographic analysis. Check samples suggest that the source of the anomaly is within the watershed of the tributary gully to the east. The highest metal content, 27 ppm cxHm, was measured in a sample taken about 50 feet west of and down-gully from a concrete-walled cistern that was constructed on the axis of the gully. The cistern may mark the general location of a spring or seep in wetter years. Bedrock in the immediate vicinity consists of metamorphosed limestone, dolomite, and pyroclastic rocks of the "lime belt." A brief reconnaissance suggests that L-564 is located at the grossly conformable contact of metapyroclastics and subjacent carbonates that dip homoclinally to the south. No mineralization was observed, and no prospects are on record in the immediate vicinity.

L-616

A check sample confirmed the presence of high heavy metal (cxHm) content. The sample is from a dry, poorly defined drainage. The area is forested, and bedrock exposure is very poor but probably is metamorphosed limestone and dolomite. The Dunn Mountain pluton crops out 1 mile to the north-northwest.

L-442

The high gold content of the original sample was not verified by the check samples, although traces of gold were detected in several. The heavy metal content in several check samples was quite high, but distribution was erratic. The anomalous locality is in an area where several steep gullies, draining both high-level glacial deposits and bedrock, debouch onto the glacial outwash of Horse Springs Coulee. Bedrock is metamorphosed sharpstone conglomerate, graywacke, and siltstone, which is intruded to the west by the Aeneas Creek pluton and to the northwest by the Loomis pluton. The Starr Molybdenum deposit is located within the Aeneas Creek pluton, about 1 mile west of L-442, and may be within the drainage area of the gully sampled at L-708. The halo suggested by the anomalous heavy metal content of L-703 degrades rapidly up-gully, suggesting that the source lies between L-703 and L-704 or on the slope south of L-703. The weakly anomalous metal content of L-701 and L-702 probably derives from mineralized rock located within a quarter of a mile west of sample locality L-701 in the Aeneas Creek pluton or adjacent metamorphic rock. The above evidence indicates the existence of several areas of mineralization within or peripheral to the east margin of the Aeneas Creek pluton.

M-31

A sample of stream sediment from the bed of Tonasket Creek, a perennial stream, contained high heavy metal (cxHm) content and a trace of silver. Check samples taken upstream confirmed the presence of a low-grade halo. However, the streambed upstream from M-31c and below M-33 was found to be choked with rusting scrap and other debris, which may well be the source of the high heavy metal values. The presence of mineralization cannot be entirely discounted since the stream sediments showing high metal content are at the border of a complex of alkaline igneous rocks containing both massive and brecciated mafic undersaturated plutonic rock (malignite), locally intruded by feldspathic breccia. Although no mineralization was observed within the complex, similar complexes in other areas are commonly mineralized.

Other Areas of Interest

Two deposits (L-105, L-316, table 6) not previously known to us were located by geochemical sampling and, judging by the presence of shallow excavations, they had been discovered by prospectors. One of these, L-313, is perhaps worthy of further mention. A strong heavy metal (cxHm) showing on the apex of an alluvial fan led to the subsequent discovery of a thick (25 ft. estimated) vuggy quartz blanket vein carrying galena and pyrite. The vein is explored by only a shallow prospect pit, suggesting perhaps that the original discoverers obtained discouraging assays. The vein cuts monzonitic rock of the interior phase of the Similkameen composite pluton (table 1 and pl. 1) and is part of a family of veins known near this locality. The strength of the geochemical halo, size of the vein, and favorable location of the deposit near the axial zone of a mineralized belt (indicated by the quintic trend surface on

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples

Sample no. 1/	Location	xCu 2/ (field) (ppm)	cxHm 2/ (field) (ppm)	xCu 3/ (lab) (ppm)	cxHm 3/ (lab) (ppm)	Other 4/ Analyses	Comments
L-48	Sec. 28, T. 39 N., R. 26 E.			<0.5	14	Table 3	Scraps of rusted metal uncovered in sample pits, suggests above background cxHm due to contamination.
L-48b	200 5/ ft. up-gully (north) of L-48.	6	5				
L-48c	500 ft. up-gully (north) of L-48.	6	5				
L-48d	300 ft. N. 62° E. of L-48 in tributary gully.	4	0				
L-48e	At L-48 sample site.	4	7				
L-97	Sec. 4, T. 40 N., R. 26 E.			11	1	Table 3	Source of anomalous xCu probably 2-to-10-inch-long pods of sulfide minerals stained by malachite observed sparsely scattered in bedrock.
L-263	250 ft. south of and down-gully from L-97.			22	9	Table 2	
L-659	700 ft. south-southwest of and down-gully from L-97.			11	2		
L-657	300 ft. north of and up-gully from L-97.			6	1		
L-656	800 ft. north of and up-gully from L-97.			4	1		
L-105	Sec. 33, T. 40 N., R. 25 E.			60	14	Table 2	Source of anomalous xCu and cxHm probably chalcopyrite-bearing quartz vein located 400 ft. west-southwest and up-gully from L-105. Prospect pit on vein.
L-648	200 ft. north of L-105.			22	22		
L-650	At L-105 sample site.			45	32		
L-651	300 ft. south-southwest of L-105.			15	4		
L-212	Sec. 32, T. 39 N., R. 26 E.			15	7	Table 2	Source of above-background xCu not located. Note trace of silver detected in semiquantitive spectrographic analysis (Table 2).
L-212b	2,700 ft. up-gully from L-212.	10	9				
L-212c	At L-212 sample site	12	5				
L-292	Sec. 9, T. 40 N., R. 25 E.			<0.5	45	Table 2	Exact locality of L-292 not relocated during field check. Source of anomalous cxHm not located. Above background level of area suggests mineralization.
L-652	500 ft. south-southeast of L-292.			<0.5	14		
L-653	Same vicinity as L-652.			15	5		
L-299	Sec. 4, T. 40 N., R. 25 E.			15	3	Table 2	Exact locality of L-299 not relocated during field check. Source of weakly anomalous xCu not located.
L-654	300 ft. northeast of L-299.			1.5	2		
L-655	400 ft. southeast of L-299.			4	2		

1/ Localities of samples not indented are plotted on map (pl. 1), indented localities plotted where space permits.

2/ Test conducted at sample site, using 2 gram scoop of unscreened, non-ashed fines.

3/ Test conducted at Mobile lab or Central lab, using 2 gram scoop of -80 mesh sieved fraction of the sample, ashed where necessary.

4/ Ag and Au analyses of samples by atomic absorption; Cu, Zn, Pb, and Mo by colorimetric analysis.

5/ All distances estimated, paced, or from odometer. Elevations by pocket aneroid barometer and inspection of topographic maps.

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples—Continued

Sample no.	Location	xCu (field) (ppm)	cxHm (field) (ppm)	xCu (lab) (ppm)	cxHm (lab) (ppm)	Other Analyses (ppm)	Comments
L-313	Sec. 13, T. 40 N., R. 25 E.			15	22	Table 2	Source of anomalous cxHm is probably a thick, vuggy quartz vein carrying galena and pyrite, trending N. 10° E. and dipping 20° to the west, located at an elev. of 2,075 ft. on hillside southeast of L-313. Wall rock is sericitized. Vein is brecciated. Prospect pit.
L-313b	Southwest of L-313 at elev. 1,360 ft. on fan.	6	25				
L-313c	Southwest of L-313 at elev. 1,360 ft. on fan.	2	27	6	45	Ag 0.4	
L-313d	Southwest of L-313 at elev. 1,580 ft. in gully.	3	14				
L-313e	Southwest of L-313 at elev. 1,725 ft. in gully.	6	17				
L-313f	Southwest of L-313 at elev. 2,000 ft. on slope.	6	25				
L-316	Sec. 23, T. 40 N., R. 25 E.			11	30	Table 2	Source of anomalous xCu and cxHm not located. Probably mineralization uphill from L-316c.
L-316b	Southwest of L-316 at elev. 1,275 ft. in gully.	25	30				
L-316c	Southwest of L-316 at elev. 1,400 ft. in gully.	15	40				
L-417	Sec. 35, T. 37 N., R. 25 E.			22	4		Source of anomalous xCu not located. Contamination from farmstead located north of and uphill from L-417 likely.
L-417b	At L-417 sample site, soil sample.	30	7				
L-417c	600 ft. north of L-417b in drainage.	5	7				
L-448	Sec. 28, T. 37 N., R. 26 E.			3	17	Table 2	Note trace of silver detected in semiquantitative spectrographic analysis (Table 2). Scraps of rusted metal found in sample pit at L-448. Trash on bank of gully to north. Disseminated pyrite at outcrop near L-448c. Contamination may be source of anomalous cxHm, but unlocated mineralization not ruled out.
L-448b	1,300 ft. north-northeast of L-448 in gulch on east side of road.	4	9				
L-448c	1,000 ft. north-northeast of L-448 in gulch on east side of road.	2	14				
L-448d	750 ft. north-northeast of L-448. Soil sample from meadow.	0	0.5				
L-448e	At L-448 sample site.	4	14				
L-564	Sec. 27, T. 35 N., R. 26 E., in flat at junction of two drainages, main from north, tributary from east.			<0.5	17	Table 2	Note trace of Ag detected in semiquantitative spectrographic analysis. Sample L-564e taken 50 ft. down-gully from concrete cistern. Source of anomalous cxHm not located.
L-564b	300 ft. east of L-564 in tributary gully.	3	11				
L-564c	750 ft, east of L-564 in tributary gully.	6	27				
L-564d	1,000 ft. east of L-564 at meadow.	2	11				
L-564e	150 ft. north of L-564 in main gully.	3	7				
L-564f	300 ft. north of L-564 in main gully.	4	9				

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples—Continued

Sample no.	Location	xCu (field) (ppm)	cxHm (field) (ppm)	xCu (lab) (ppm)	cxHm (lab) (ppm)	Other Analyses (ppm)	Comments
L-616	Sec. 12, T. 35 N., R. 25 E.			<0.5	17	Table 2	Source of anomalous cxHm not located. Mineralization north of L-616 likely.
L-616b	25 ft. north of L-616 in drainage.	5	11				
L-616c	500 ft. southeast of L-616 in main drainage upstream from its junction with L-616 gully.	7	0				
L-625	Sec. 1, T. 35 N., R. 25 E.			15	2		Anomalous xCu not reproducible.
L-625b	At L-625 sample site.	6	0.5				
L-625c	300 ft. to southwest of L-625 on tributary drainage.	2	0				
L-625d	600 ft. east of L-625 in drainage.	6	2				
L-625e	2,000 ft. S. 61° E. of L-625 in valley.	3	3				
L-677	Sec. 14, T. 40 N., R. 26 E.			11	7	Ag 0.8, and Table 2	Soil samples L-677 through L-695 taken at complex of alkalic igneous rock and intrusive breccias. Note silver detected in L-682 by semiquantitative spectrographic analysis (Table 2). Low-grade mineralization in alkalic complex probable.
L-679	Sec. 14.			11	5	Ag 0.4, and Table 2.	
L-680	125 ft. east of L-679.			6	7	Ag 0.4, and Table 2.	
L-681	Sec. 13.			8	7	Ag 0.4, and Table 2.	
L-682	Sec. 13.			30	17	Ag 1.2, and Table 2.	
L-695	Sec. 13.			15	7	Ag 0.4, and Table 2.	
L-442	Sec. 9, T. 37 N., R. 26 E.			3	4	Au 1.1, Mo 2, and Table 2.	Soil, slope-wash and gully sediment samples. Bedrock source of gold detected at L-442 not located. Anomalous and above background cxHm and xCu suggest widespread low-grade mineralization, perhaps related to Starr Molybdenum deposit to west (in Sec. 8, see text).
L-700	Sec. 16.			3	9	Au <.02	
L-701	Sec. 16.			4	17	Au <.02	
L-702	Sec. 16.			3	14	Au <.02	
L-703	Sec. 9.			19	35	Au <.02	
L-704	Sec. 9.			8	9	Au .04	
L-705	Sec. 9.			3	5	Au .02	
L-706	Sec. 9.			2	7	Au .02	
L-707	Sec. 9.			1	7	Au <.02	
L-708	Sec. 9.			4	17	Au <.02	
L-709	Sec. 9.			4	5	Au <.02	

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples—Continued

Sample no.	Location	xCu (field) (ppm)	cxHm (field) (ppm)	xCu (lab) (ppm)	cxHm (lab) (ppm)	Other Analyses (ppm)	Comments
M-31	Sec. 26, T. 40 N., R. 27 E.			4	27	Cu 20, Zn 100, Pb <25, and Table 2.	Note trace of Ag detected in semi-quantitative spectrographic analysis (Table 2). Source of anomalous cxHm not located, but abundant trash in streambed upstream from M-31c suggests contamination. Nearby complex of alkalic igneous rocks and intrusive breccia (sec. 23) considered favorable structure for low-grade, disseminated mineralization, however.
M-31b	1,500 ft. east and upstream from M-31 at elev. 1,140 ft., stream sediment.	0	17				
M-31c	2,100 ft. east and upstream from M-31, stream sediment.	7	17				
M-417	Sec. 10, T. 36 N., R. 27 E.			1	32	Cu 10, Zn 75, Pb <25.	Corroded waterpipe follows stream at M-417b, suggesting anomalous cxHm due to contamination.
M-417b	At elev. 1,070 ft., near creek on upper part of fan near M-417 sample site.	4	0.5				
M-417c	500 ft. west of M-417 at elev. 960 ft.	2	5				
M-417d	800 ft. northwest of M-417 sample site at elev. 975 ft.	3	3				
M-520	Sec. 31, T. 36 N., R. 27 E.			30	7	Cu 60, Zn 75, Pb <25.	Source of anomalous xCu not located. Copper mineralization reported upstream.
M-520b	Near M-520 sample site. Soil sample from alluvial terrace.	8	7				
M-520c	50 ft. northeast of M-520b, 2 ft. above river level.	7	3				
M-544	Sec. 20, T. 38 N., R. 27 E.			1	14		Trash noted up-gully from M-544. Anomalous cxHm probably due to contamination.
M-544b	Near M-544 sample site.	2	0				
M-552	Sec. 27, T. 38 N., R. 27 E.			22	22	Cu 40, Zn 100, Pb <25.	Source of anomalous xCu and cxHm not located. Area intensely farmed.
M-552b	Near M-552 sample site, soil sample from soil on drift.	5	9				
M-567	Sec. 14, T. 38 N., R.28 E.			4	60	Cu 60, Zn 150, Pb 25.	Farmstead located at M-567 sample site. The cxHm possibly due to contamination.
M-567b	600 ft. southeast of M-567, in ill-defined drainage through grain field.	13	>45	11	25	Ag 0.2	
M-567c	1,000 ft. southeast of M-567, soil sample from flat in aspen grove.	11	3				
M-567d	1,200 ft. southeast of M-567, soil sample in flat at edge of coniferous forest.	10	7				

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples—Continued

Sample no.	Location	xCu (field) (ppm)	cxHm (field) (ppm)	xCu (lab) (ppm)	cxHm (lab) (ppm)	Other Analyses (ppm)	Comments
M-619	Sec. 23, T. 38 N., R. 27 E. on fan.			2	22	Cu 20, Zn 100, Pb 75	Anomalous cxHm probably due to contamination.
M-619b	450 ft. up-gully and east of M-619, above dry spring.	3	7				
M-619c	300 ft. north of M-619 at mouth of tributary above fan.	3	3				
M-619d	300 ft. west of and downstream from M-619, and below area of scattered trash and scrap.	4	11				
M-620	Sec. 14, T. 38 N., R. 27 E., at barrow pit in talus and slope-wash.			11	27	Cu 75, Zn 200, Pb <25	Source of anomalous cxHm and above background xCu not located. Probably due to minor mineralization to east.
M-620b	At M-620 sample site.	12	20				
M-620c	200 ft. north of M-620, sample of slope-wash.	5	0.5				
M-621	Sec. 2, T. 38 N., R. 27 E.			4	27	Cu 10, Zn 50, Pb <25	Source of anomalous cxHm not located. Farmstead located between M-621 and M-621b, suggests probable contamination.
M-621b	300 ft. east and upstream from M-621, where road crosses creek.	4	7				
M-631	Sec. 8, T. 39 N., R. 27 E.			4	17	Cu 40, Zn 50, Pb <25	Source of anomalous cxHm not located.
M-631b	2,900 ft. west of M-631 at elev. 1,700 ft.	15	20				
M-631c	1,100 ft. west of M-631 at elev. 1,500 ft.	12	7				
M-632	Sec. 6, T. 39 N., R. 27 E.			2	14		Source of anomalous cxHm not located.
M-632b	At M-632 sample site.	12	20				
M-632c	600 ft. south of and up-drainage from M-632 at elev. 1,975 ft.	4	5				
M-634	Sec. 12, T. 39 N., R. 26 E.			6	14		Note prospect 300 ft. northeast of and uphill from M-634c. Source of anomalous cxHm and xCu not located, but probably from small, low-grade vein deposits in vicinity.
M-634b	At M-634 sample site.	3	17				
M-634c	1,000 ft. south of and uphill from M-634 at elev. 2,450 ft. in drainage.	15	14				
M-638	Sec. 31, T. 40 N., R. 27 E.			4	14		Anomalous cxHm and above background xCu locally present. Their abrupt down-gully decline suggests contamination.
M-638b	200 ft. west and up-gully from M-638.	3	1				
M-638c	At M-638 sample site.	6	9				
M-638d	300 ft. east and down-gully from M-638.	7	0.5				

TABLE 6.—Results of field checks at localities of anomalous or geologically promising samples—Continued

Sample no.	Location	xCu (field) (ppm)	cxHm (field) (ppm)	xCu (lab) (ppm)	cxHm (lab) (ppm)	Other Analyses (ppm)	Comments
M-646	Sec. 36, T. 39 N., R. 27 E.			<1	17		Source of weakly anomalous or above background cxHm not located.
M-646b	200 ft. north and up-gully from M-646.	2	1				
M-646c	25 ft. south of road and down-gully from M-646.	3	7				
M-664	Sec. 28, T. 38 N., R. 28 E.			1	14		Source of weakly anomalous or above background cxHm not located.
M-664b	150 ft. east-northeast and up-gully from M-664.	1	0.5				
M-664c	500 ft. east-northeast and up-gully from M-664.	1	9				
M-699	Sec. 34, T. 40 N., R. 27 E.			6	22	Cu 30, Zn 50, Pb 25.	Source of anomalous cxHm not located.
M-699b	50 ft. north-northeast and up-gully from M-699.	3	25				
M-699c	50 ft. west of M-699. Sample of soil developed on gravel terrace, with orchard vegetation.	7	0.5				

heavy metals, fig. 10) suggest that the deposit is worthy of further evaluation.

Sediments derived from the rocks of Kruger Mountain, west of Osoyoos Lake, and from the crest of Palmer Mountain contain levels of copper (xCu) that are several orders of magnitude higher than found anywhere else in the map area. The contrast would be more marked if the contour levels on the overlay were carried higher than the present upper limit of 15.5 ppm. High copper (xCu) in sediments from the area west of Osoyoos Lake reflects copper mineralization at the Kelsey and contiguous deposits. The high copper in the stream sediment on Palmer Mountain is evidently generated by mineralization in the area of the Copper World and Copper World Extension deposits. Judging by the results of the survey, it is improbable that other copper deposits commensurate in size to the aforementioned are exposed within the map area.

The strong heavy metal (cxHm) halo on Palmer Mountain is also worthy of consideration, in view of the absence or at least relative unimportance of zinc at the Copper World and Copper World Extension deposits.

CONCLUSIONS

The results of the orientation phase of the investigation suggest that secondary dispersion halos generated by replacement copper deposits, such as those at the Copper World and Copper World Extension, can be detected at distances of 1 to 2 miles downstream by the methods herein applied. The low-grade polymetallic vein deposits such as the Lone Pine (Submarine) deposit, while generating less substantial anomalies, can also be detected at distances of 1 to 2 miles down-gully. Efforts to detect an anomaly below the Ivanhoe mine, which presumably is typical of those deposits important chiefly for silver and which contain a significant zone of secondary enrichment, were largely negative. A number of other known vein deposits were detected in the course of the main phase of the survey, however, suggesting that under favorable conditions the methods used are effective for detecting this type of deposit. Judging by results of tests on the Gold Hill deposits, quartz lodes important chiefly for gold, while generating small anomalies in base metals directly below the deposit, would not normally be detectable at distances as great as a mile, except by testing directly for gold.

Several anomalies were found in the course of the main phase of the survey. Of these, the following localities might be singled out as warranting further examination: L-316, L-564, L-616, L-442, and M-31.

No areas were found showing copper concentrations comparable to those derived from the disseminated deposits west of Osoyoos Lake or the massive replacement deposits on Palmer Mountain. It would appear, then, that the most attractive exploration targets for copper are these previously known deposits, at least as judged by the copper content within the secondary dispersion halos.

The general distribution of mines, if classified by the chief metal (fig. 2), reveals a northwest-trending belt of deposits in which lead is most important. If classified by the presence of molybdenum, tungsten, and antimony, it is apparent that molybdenum and tungsten are associated and are antipathetic toward antimony; and that deposits containing antimony roughly define a northwest-trending belt, which is in part coincident with the lead belt. The mineralogy of the antimony-bearing deposits suggests that they belong to the epithermal class, whereas by the same criteria, those deposits containing molybdenum and (or) tungsten probably belong to the mesothermal or hypothermal class.

The geochemical exploration program revealed a rather sharply bounded north-trending belt of cold-acid-extractable copper (xCu). The belt appears to be of regional scope, cutting across lithologic and structural contacts without deflection, and perhaps significantly, generally coincides with the north-trending belt of Tertiary plugs and flows. No convincing trends are manifest in the contoured values of the citrate-soluble heavy metals (cxHm); but higher order trend surfaces fitted to the heavy metal values suggest the presence of a northwest-trending belt of higher intensity in the northern part of the map area, which is coincident with the lead and antimony belts, and an oval zone of higher intensity in the southwest corner. The hypothesized zones cut across lithologic and structural contacts and show no obvious relationship to any single pluton. In conclusion, the data suggest—not unequivocally, to be sure—that two or more differently mineralized zones intersect within the map area.

No definitive evidence bearing on the age of the mineralization is available. Several silver-, lead-bearing quartz veins in the outer margins of the Similkameen composite pluton are cut by dacitic or andesitic dikes megascopically similar to the Eocene plugs and flows. Thus some or all of the silver-, lead-bearing quartz veins may be pre-Eocene in age. On the other hand, the Eocene igneous rocks themselves are extensively altered and propylitized and locally mineralized, indicating that some mineralization is of Eocene or younger age. These circumstances require that mineralization within the area be of differing ages, but whether the two or more episodes correspond to the two postulated intersecting mineralized zones is conjectural.

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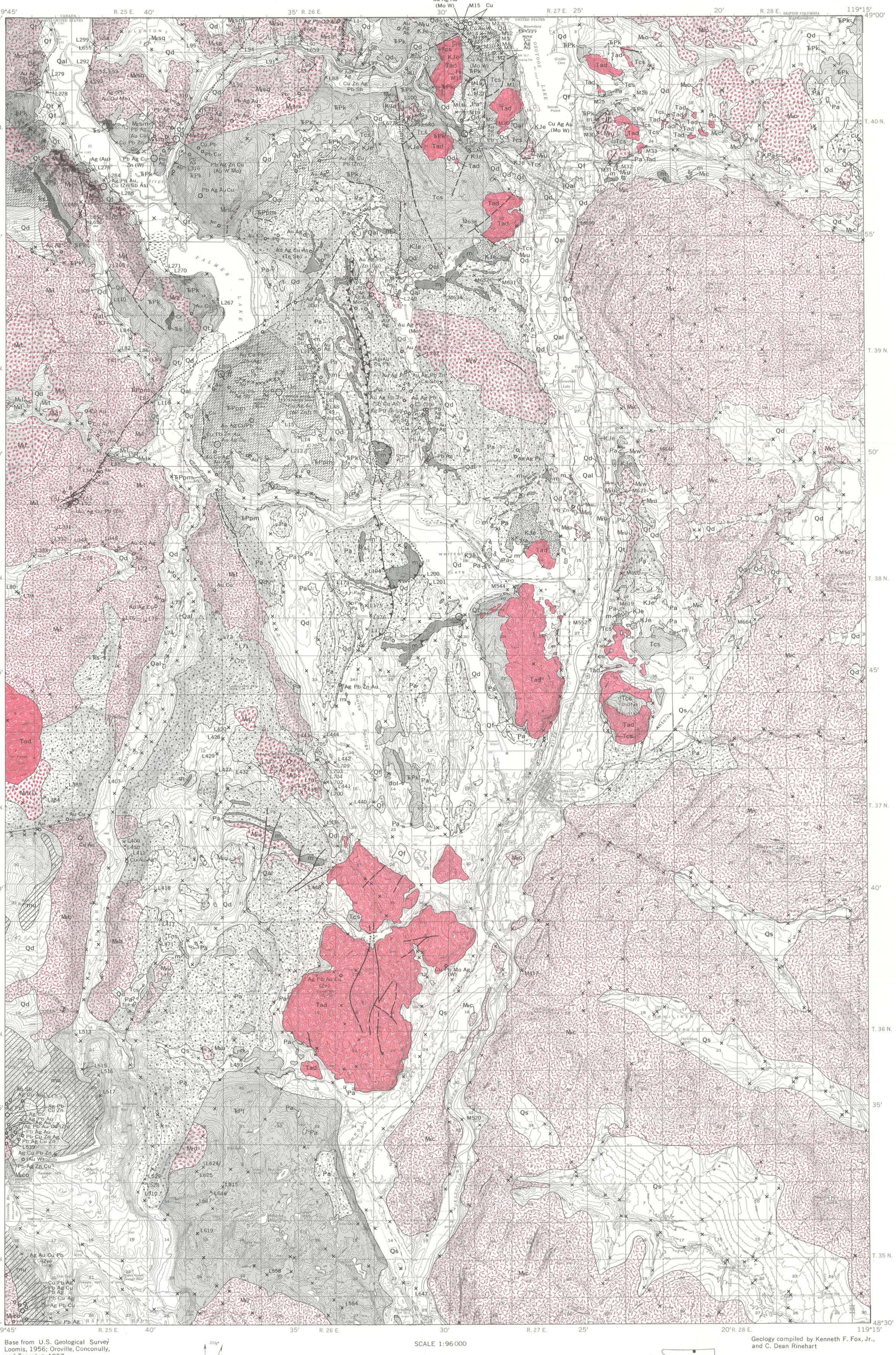
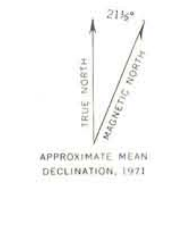


Base from U.S. Geological Survey Loomis, 1956; Oroville, Conconully, and Tonasket, 1957



SCALE 1:96 000

2 0 2 4 6 MILES

2 0 2 4 6 KILOMETERS

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

Geology compiled by Kenneth F. Fox, Jr., and C. Dean Rinehart

EXPLANATION

QUATERNARY

Holocene

Qal | Qf | Qt

Alluvial and colluvial deposits
Not separately shown in south part of map area
Qal, *alluvium*
Qf, *large fan deposits*
Qt, *talus deposits*

Pleistocene

Qd

Glacial drift

Qs

Surficial deposits
Includes alluvium, talus, and glacial drift

VOLCANIC AND EPICLASTIC SEDIMENTARY ROCKS

TERTIARY — Eocene

Tad

Andesite and dacite
Includes lava flows, pyroclastic rocks, and plugs

Tcs

Conglomerate, arkose, and graywacke
Includes small amount that is probably younger andesite and dacite

MESOZONAL IGNEOUS ROCKS

MESOZOIC

a | b

Plutonic rocks

Relative age unknown except where noted below. Quadrangles occupied by plutons shown by letters: L, *Loomis;* O, *Oroville;* T, *Tonasket;* C, *Conconully. Contrasting patterns,* a *and* b, *used to aid delineation of individual plutons*

Pattern a:

Mzsm, *Similkameen composite pluton border phases—malignite, pyroxenite, and syenite gneiss.* L
Mzt, *Toats Coulee pluton: quartz monzonite, granodiorite, diorite; intrudes Loomis pluton.* L, C
Mza, *Anderson Creek pluton: granodiorite; intrudes Loomis pluton.* L
Mzo, *Osoyoos pluton: gneissic quartz diorite; older than Colville batholith.* O
Mzw, *Whisky Mountain pluton: porphyritic granodiorite; older than Colville batholith.* L, O
Mzac, *Aeneas Creek pluton: quartz monzonite, granodiorite.* C
Mzd, *Dunn Mountain pluton: granodiorite.* C
Mzu, *Undifferentiated plutonic rocks: composition unknown; mostly in small bodies*

Pattern b:

Mzsq, *Similkameen composite pluton interior phases: quartz monzonite, granodiorite, and monzonite.* L
Mzc, *Colville batholith: gneissic granitic rocks—leucocratic biotite granodiorite, porphyritic granodiorite, quartz monzonite—gneissic amphibolite, and layered paragneiss; younger than Osoyoos and Whisky Mountain plutons.* O, T
Mzl, *Loomis pluton: granodiorite and quartz diorite; older than Toats Coulee and Anderson Creek plutons.* L, C
Mzb, *Blue Goat pluton: medium-grained, locally porphyritic granodiorite.* C
Mzco, *Conconully pluton: granodiorite.* C
Mzj, *Johnson Creek pluton: porphyritic granodiorite common but composition highly varied, ranging from quartz monzonite through diorite.* C

TRIASSIC(?)

TRs

Serpentinite

METAMORPHIC ROCKS

JURASSIC OR CRETACEOUS

KJe

Ellemeham Formation
Weakly metamorphosed spilitic lavas, pyroclastic rocks, conglomerate, and breccia

PERMIAN OR TRIASSIC

dol | TRPk | TRPpm

Kobau Formation and Palmer Mountain Greenstone
TRPk, *Kobau Formation: interbedded greenstone, green phyllite, and metachert*
dol, *dolomite bed east of Horse Springs Coulee*
TRPpm, *Palmer Mountain Greenstone: derived from lava flows and hypabyssal intrusives. May include greenstones of other ages*

PERMIAN(?) AND TRIASSIC

TRPl

Limestone and dolomite
Chiefly recrystallized carbonates, locally fossiliferous, with lesser amounts of interbedded metamorphosed clastic rocks. These rocks constitute the colloquially known "lime belt" that lies between Conconully and Riverside

mu

Metamorphic rocks, undivided
Chiefly gneisses and schists. In extreme southwestern part of map

PERMIAN

m | Pa

Anarchist Group
Mostly interbedded phyllite, phyllitic siltstone, graywacke, slate, greenstone, and marble; also includes minor but highly distinctive chert-bearing conglomerate
m, marble

Contact
Dashed where approximately located

Fault
Dashed where approximately located, dotted where concealed

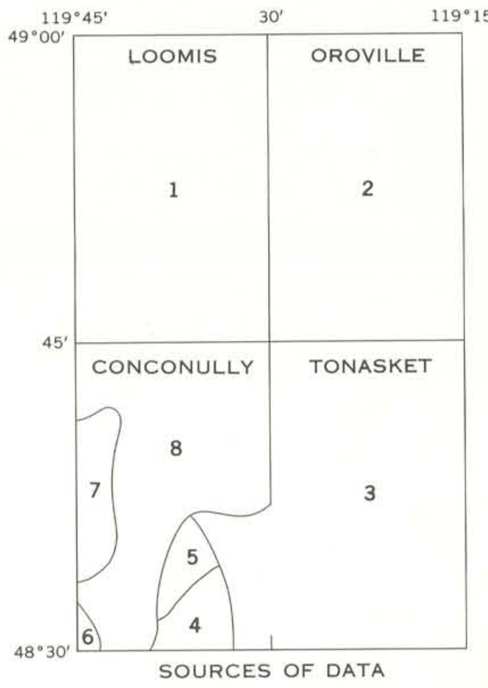
Thrust or low-angle reverse fault
Dashed where approximately located, dotted where concealed. Sawteeth on upper plate

Prospect — Some production reported — Substantial production reported for sustained periods

Mine or prospect
Name shown where known. Metals, observed or reported, listed in presumed order of value

L368

Geochemical sample locality
Number indicates additional analytical data cited in text or listed in tables 2, 3, 4, or 6



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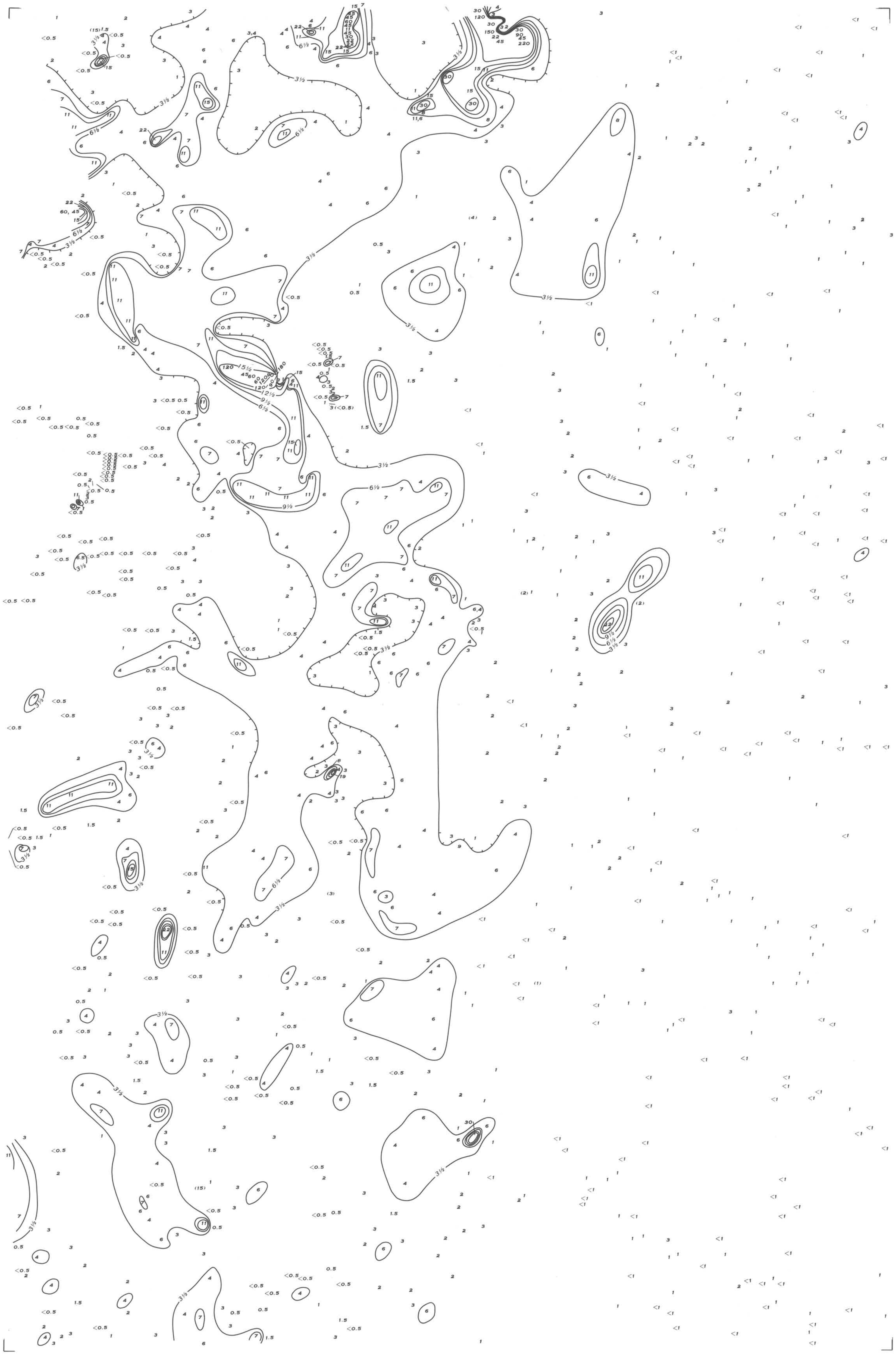
GEOLOGIC MAP OF PART OF OKANOGAN COUNTY, WASHINGTON

PREPARED COOPERATIVELY BY THE
U.S. GEOLOGICAL SURVEY



3½ — Contour showing concentration of cold-acid-extractable copper (x Cu)

Hachures toward direction of declining values. Contours at 3½, 6½, 9½, and 15½ parts per million

7 — Measured concentration of cold-acid extractable copper (x Cu), in parts per million

Bracketed value indicates analysis unreproducible on field check and therefore disregarded

SCALE 1:96 000

2 0 2 4 6 MILES

2 0 2 4 6 KILOMETERS

COLD-ACID-EXTRACTABLE COPPER (xCu) IN GULLY AND STREAM SEDIMENTS

Overlay to geologic map (Plate 1)

2½ — Contour showing concentration of citrate-soluble heavy metals (cx Hm)

Hachures toward direction of declining values. Contours at 2½, 6½, 15, and 45 parts per million

6 — Measured concentration of citrate-soluble heavy metals (cx Hm), in parts per million

Bracketed value indicates analysis unreproducible on field check and therefore disregarded

SCALE 1:96 000

2 0 2 4 6 MILES

2 0 2 4 6 KILOMETERS

CITRATE-SOLUBLE HEAVY METALS (cxHm) IN GULLY AND STREAM SEDIMENTS

Overlay to geologic map (Plate 1)

TABLE 1.—Plutonic rocks

Name	Composition	Internal structure	Contact metamorphism	Age	Mineral deposits
Similkameen composite pluton, border phases	Thin discontinuous outer shell of syenite gneiss, inner zone of hastingsite-augite-biotite malignite, locally grading to augite-hastingsite-phlogopite pyroxenite. Grades inward to monzonite rock of interior phase.	Gneissosity of syenite parallels outer margin of pluton. Malignite locally weakly gneissic.	Local zones in Kobau Formation as much as $\frac{1}{4}$ mile wide showing coarser than typical recrystallization characterized by granoblastic and lepidoblastic textures, but with almandine-amphibolite facies mineral assemblages.	Probably middle or late Mesozoic, since the Ellemeham Formation near Shankers Bend (sec. 12, T. 40 N., R. 26 E.) has been metamorphosed, presumably by the Similkameen. The Ellemeham is also intruded by malignite (sec. 13 and 14, T. 40 N., R. 26 E.) correlated with Similkameen. Occurs as detritus in basal Eocene conglomerate, arkose, and graywacke unit.	Subhorizontal to moderately dipping fissure-fill veins, Ag, Pb, Zn, Cu minerals common. Disseminated copper minerals locally present in contact metamorphic deposits. Steeply to moderately dipping veins in metamorphic rocks marginal to pluton.
Similkameen composite pluton, interior phases	Zoned; monzonite grades inward to granodiorite and quartz monzonite.	Locally weakly gneissic.	------do--------	Dikes of interior phase crosscut the exterior phase but elsewhere contacts gradational, indicating essentially contemporaneous emplacement.	Subhorizontal to moderately dipping veins similar to those described above present in outer parts.
Toats Coulee pluton	Border phase: fine-grained hornblende-augite diorite; interior phase; biotite-hornblende-augite granodiorite to quartz monzonite, locally porphyritic. Accessory allanite, tourmaline.	Pluton probably comprises a number of shallow west-dipping layers of slightly contrasting texture or composition.	None.	Cuts Loomis pluton. K-Ar age of coexisting hornblende 170 ± 5 m.y. and biotite 151 ± 5 m.y. (Rinehart and Fox, 1972).	None.
Anderson Creek pluton	Granodiorite; cuts locally developed fine-grained diorite border phase. Resembles Toats Coulee pluton.	Massive.	Metamorphic wall rocks almandine-amphibolite facies mineral assemblages; no aureole, either superimposed or relict, recognized.	Cuts Loomis pluton.	Narrow quartz veins associated with shear zones; carry Au, Ag, Pb.
Osoyoos pluton	Epidote-biotite-(hornblende) quartz diorite.	Cataclasis extreme along southern contact; but everywhere at least slightly gneissic.	Metamorphic aureole not apparent in amphibolite(?) facies wall rocks.	Progressive increase in cataclasis toward Colville batholith suggests that Osoyoos is the older.	None.
Whisky Mountain pluton	Porphyritic biotite-hornblende granodiorite mafics chloritized, plagioclase saussuritized.	Cataclasis extreme at western edge of pluton (east of thrust fault) east of Okanogan River.	Narrow ($\frac{1}{4}$ mile wide) albite-epidote hornfels aureole with spotting locally developed.	Progressive increase in cataclasis toward Colville batholith suggests that Whisky Mountain is the older.	Moderate to shallow dipping quartz veins, carrying Au (Ag, Pb), present at western edge of pluton.
Aeneas Creek pluton	Quartz monzonite to granodiorite.	Massive.	Spotted hornfels.	---	Large, low-grade deposit containing disseminated Mo developed in breccia zone (Creasy, 1954, p. 53).
Dunn Mountain pluton	Fine- to medium-grained granodiorite.	Massive.	Weak or none.	---	A few malachite-stained quartz veins.
Colville batholith	Gneissic granitic rocks—leucocratic biotite granodiorite, porphyritic granodiorite, quartz monzonite—gneissic amphibolite, and layered paragneiss.	Ubiquitous gneissosity parallels layering in paragneiss, northwest lineation. Zone of cataclasis at margin in country rocks.	Narrow zone of biotite-sericite hornfels.	Probably younger than Osoyoos and Whisky Mountain plutons.	None.
Loomis pluton	Biotite-hornblende quartz diorite grading to biotite-hornblende porphyritic granodiorite on west.	Locally gneissic near contacts.	Andalusite hornfels locally developed near contact, otherwise contact metamorphic aureole not apparent in almandine-amphibolite facies wall rocks.	K-Ar age of coexisting hornblende 194 ± 6 m.y. and biotite 179 ± 5 m.y. (Rinehart and Fox, 1972).	Quartz veins associated with shear zones, carry values in Au, Ag, Pb.
Blue Goat pluton	Medium-grained, locally porphyritic granodiorite.	Locally gneissic near contacts; zones of weak gneissosity sporadically distributed through pluton.	Spotted hornfels locally developed.	---	A few quartz veins, and at least one disseminated deposit in adjacent wall rocks, carry values in Cu, Au, Ag.
Conconully pluton (Very small amount in map area but occupies several tens of square miles to the west)	Granodiorite(?).	Massive.	Sillimanite, andalusite, and cordierite locally found in wall rock (Menzer, 1964).	---	Veins northwest of Conconully and west of map area carry Ag, Pb, (Au) both in pluton and in metamorphic rocks marginal to it.
Johnson Creek pluton	Porphyritic granodiorite common, but composition highly varied, ranging from quartz monzonite through diorite.		Metamorphic aureole known to be present, but grade and extent not determined.	---	None.