

inferred from aeromagnetic data to underlie the southern part of the district, may eventually prove to be the parent source of yet undiscovered ore deposits along its eastern, western, and southern borders that conceivably are larger than any yet known in the Tintic area.

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52. Mountain City Copper Mine, Elko County, Nevada

ROBERT R. COATS,* EDWARD C. STEPHENST

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* U.S. Geological Survey, Menlo Park, California

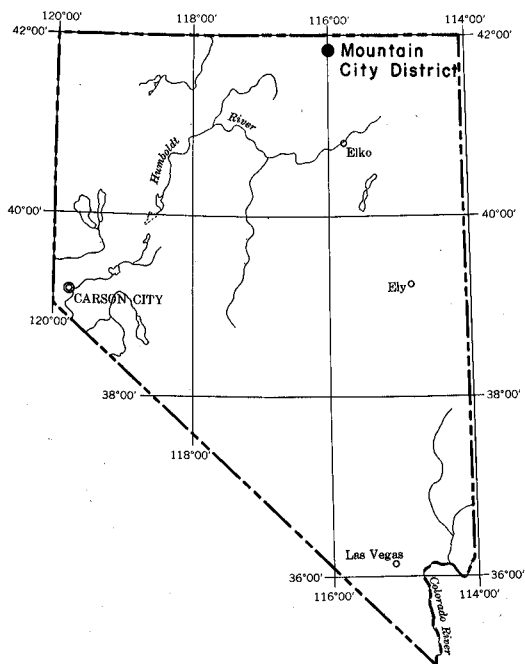
† The Anaconda Company, New York, N.Y.

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ABSTRACT

High-grade copper ore was discovered in 1932 in the long-dormant Mountain City (Cope) mining district, Elko County, Nevada. From 1932 to 1947, the one producing mine in the district, the Mountain City Copper Mine, produced 1,109,878 short dry tons of ore averaging 9.745 per cent copper, 0.274 ounces of silver, and 0.0057 ounces of gold per ton.

The Mountain City Copper Mine is developed in eugeosynclinal rocks of Ordovician age, the Valmy Formation, which is part of the upper plate of the Roberts Mountains thrust. On the Valmy were deposited unconformably first, a clastic formation of Devonian or Mississippian age, the Grossman Formation, succeeded unconformably by a sequence of three conformable formations, the Banner, the Nelson, and the Mountain City. The Banner Formation probably is early Late Mississippian in age; the ages of the Nelson and Mountain City are not known precisely but are believed to be of Late Mississippian and Carbonifer-

ous(?) age, respectively. A thick formation of clastic rocks, limestone, and volcanics, the Reservation Hill Formation, has been thrust over the Mountain City. The age of the Reservation Hill is unknown but is presumed to be Pennsylvanian(?) and Permian(?). Several plutons of Cretaceous quartz monzonite intrude the Paleozoic formations; they and the intruded formations have been laid bare by erosion, and several sequences of volcanic rocks of Miocene and Pliocene age, and perhaps in part older, have been successively deposited on irregular erosion surfaces.

The primary mineralization of the Mountain City Copper Mine is believed to postdate the deposition of the Nelson Formation and to predate the intrusion of the quartz monzonite. The primary ore bodies are lenticular in shape and are composed largely of quartz, pyrite, and chalcopyrite. The ore lenses, in general, strike northwestward and dip northward. They occur in the Valmy Formation within a definite stratigraphic sequence composed largely of shales with associated minor quartzite lenses. The ore is epigenetic.

The principal ore body, the "200," was completely leached to the 200 level. Abruptly beneath the barren gossan was supergene copper sulfide ore, much of which assayed 50 per cent copper. The secondary copper minerals are sooty and massive chalcocite, bornite, and covellite. The supergene enrichment of the ore may have required a large part of Tertiary time.

INTRODUCTION

The discovery of 50 per cent copper ore at the Mountain City Copper Mine, Elko County, Nevada, in 1932 focused geologic attention on this rather isolated part of northern Nevada. Little was known of the geology of the area other than a United States Geological Survey report on W. H. Emmons' visit to the old silver mines in the Mountain City (Cope) mining district in 1908 (1). Detailed geologic mine mapping and reconnaissance work by the geologists of the Mountain City Copper Company staff, from 1932 to 1947 resulted in a generalized concept of the geological setting of the mine. Also in 1932, T. B. Nolan visited the district; but no report was published. Later a comprehensive study of the geology of the Mountain City and adjoining Owyhee quadrangles was undertaken by R. R. Coats and other members of the United States Geological Survey. The objective of this paper is to present a brief description of the mine and district geology.

We acknowledge gratefully the help of many geologists whose work has preceded or supplemented ours. Surface maps by S. K. Droubay and D. C. Gilbert, in association with E. C. Stephens, of International Smelting, and by T. B. Nolan, of the Geological Survey, have furnished a valuable point of departure. The understanding of the mine geology has been furthered by the geologic notes of Reno H. Sales, made during the original examination of the mine; by the maps and stratigraphic correlation charts made by Graydon R. Beechel and Roger Smitten; and by the observations of M. B. Kildale, Tom Lyon, and other officials of the Anaconda Copper Mining Company. The necessarily much-simplified maps of the mine geology scarcely do justice to the detailed underground mapping of W. T. Swenson, James Wilson, Early Whitney, John Baker, Charles Michaels, Earl Stevenson, and other members of Mountain City Copper Company. We absolve all these colleagues of any responsibility for the interpretations in this report.

The writers wish to thank particularly Mr. V. D. Perry, Vice President and Chief Geologist of the Anaconda Company (the parent company of the Mountain City Copper Company) for allowing publication of the Company's maps and information.

R. R. Coats assumes responsibility for the sections on the geologic history and the physiographic history; the other sections were written by E. C. Stephens, but in the absence of Stephens from the United States, Coats has also assumed the responsibility for minor revisions in phraseology in the sections not written by him to eliminate inconsistencies.

The geologic map of the surface was made by Coats; the underground maps and sections were made by Stephens and other members of the mine staff. The drafting of the reduced black-and-white illustrations used in this report from the much larger scale colored maps prepared by mine staff geologists was done by Esther McDermott, of the Geological Survey, to whom we express our profound appreciation.

HISTORICAL INFORMATION

Mining Operations in the Area

Silver veins were first discovered in the Mountain City (or Cope) mining district, Elko County, Nevada in 1869. Up to 1908, when W. H. Emmons (1, p. 80-84) visited the dis-

TABLE I. Mountain City Copper Company Statement of Ore Produced to December 31, 1947 Compiled from Shipments of Ore to Smelters and from Ore Milled as Shown by "Statement of Treatment, Production and Losses at Concentrator"

Year	Ore		Copper		Silver		Gold		
	Wet Weight Pounds	Per Cent H ₂ O	Dry Weight Pounds	Per Cent	Pounds	Ounces Per Ton	Ounces Per Ton	Ounces	
Shipments—Shipping Ore									
1932	1,470,621 ¹	2.281	1,437,076	37.259	535,442	.348	250.19	.005	3.593
1935	31,951,522 ¹	2.564	31,132,285	26.312	8,191,666	.422	6,566.77	.0025	39.310
1936	89,688,440 ¹	2.895	87,091,822	25.989	22,633,846	.435	18,932.24	.0052	226.680
1937	54,037,810 ¹	3.222	52,296,742	27.242	14,246,869	.446	11,651.96	.0060	146.224
1938	13,583,980 ¹	3.968	13,044,937	25.795	3,364,912	.628	4,096.62	.0068	44.518
1939	44,263,560 ¹	3.375	42,769,843	28.319	12,111,996	.515	11,023.53	.0082	175.370
1940	44,458,220 ¹	2.275	43,224,520	27.356	11,824,340	.498	10,764.32	.0091	197.706
1941	34,425,580 ¹	2.435	33,587,271	26.847	9,017,229	.438	7,357.03	.0096	161.149
1942	17,177,360 ¹	2.282	16,785,381	27.695	4,648,739	.348	2,918.70	.0100	83.926
1943	8,788,896 ¹	2.515	8,567,872	25.331	2,170,064	.428	1,833.42	.0095	40.825
1944	12,077,576 ¹	2.743	11,746,264	17.138	2,013,036	.489	2,873.18	.0101	59.252
1945	6,770,160 ¹	2.770	6,582,595	12.673	834,226	.445	1,465.15	.0115	37.953
1946	3,665,840 ¹	3.216	3,547,954	17.226	611,153	.416	737.52	.0153	27.103
1947	2,320,960 ¹	2.239	2,270,942	11.305	256,720	.370	419.56	.0116	13.171
Total Shipments to Dec. 31, 1947									
	364,680,525 ¹	2.905 ²	177,043 Tons 354,085,504	26.112 ³	92,460,238	.457 ³	80,890.19	.0071 ³	1,256.780
Ore Milled—Milling Ore									
1936	54,234,040 ²	2.141	53,072,960	8.531	4,527,464	.2827	7,503.43	.005	132.682
1937	271,716,400 ²	4.149	260,443,600	8.264	21,524,346	.266	34,650.05	.0058	757.689
1938	125,925,400 ²	4.655	120,064,000	8.428	10,119,435	.215	12,919.25	.0054	326.429
1939	234,586,200 ²	4.439	224,173,800	8.071	18,092,495	.261	29,215.67	.0054	607.414
1940	253,410,200 ²	4.340	242,411,600	7.188	17,424,908	.251	30,433.63	.0054	653.733
1941	241,081,400 ²	4.319	230,669,600	6.204	14,311,368	.240	27,717.20	.005	581.012
1942	226,936,400 ²	4.527	216,663,000	5.205	11,277,550	.214	23,155.68	.005	537.881
1943	215,377,600 ²	5.169	204,244,600	4.692	9,583,331	.194	19,857.14	.0049	500.485
1944	148,204,600 ²	5.576	139,941,360	5.386	7,536,799	.261	18,286.08	.0053	372.961
1945	72,770,000 ²	6.731	67,871,600	5.723	3,918,441	.279	9,464.14	.0074	249.447
1946	65,715,600 ²	8.593	60,068,400	5.672	3,407,170	.208	6,234.38	.0068	203.162
1947	49,714,200 ²	7.380	46,045,400	4.653	2,142,515	.173	3,971.93	.0064	148.033
Total Milled to Dec. 31, 1947									
	1,959,672,040 ²	4.797 ³	1,865,669,920	6.639 ³	123,865,822	.239 ³	223,408.58	.0054 ³	5,070.928
Grand Total Production to Dec. 31, 1947									
	2,324,352,565	4.500 ³	932,835 Tons 2,219,755,424	9.745 ³	216,326,060	.274 ³	304,298.77	.0057 ³	6,327.708

¹ These figures are actual smelter weights and assays.² Figures calculated by the mine office from operations of "Poidometer" installed in mill.³ Weighted average.

trict, it is reported to have had a production worth approximately one million dollars. The district then was dormant until 1919, when the adjoining Duck Valley (Western Shoshone) Indian Reservation was opened for

mineral location. Prospectors again rushed to the district, but no silver mines of importance were found. One of the prospectors, Samuel F. Hunt, located a claim on a gossan outcrop that was explored by Hunt and his partners

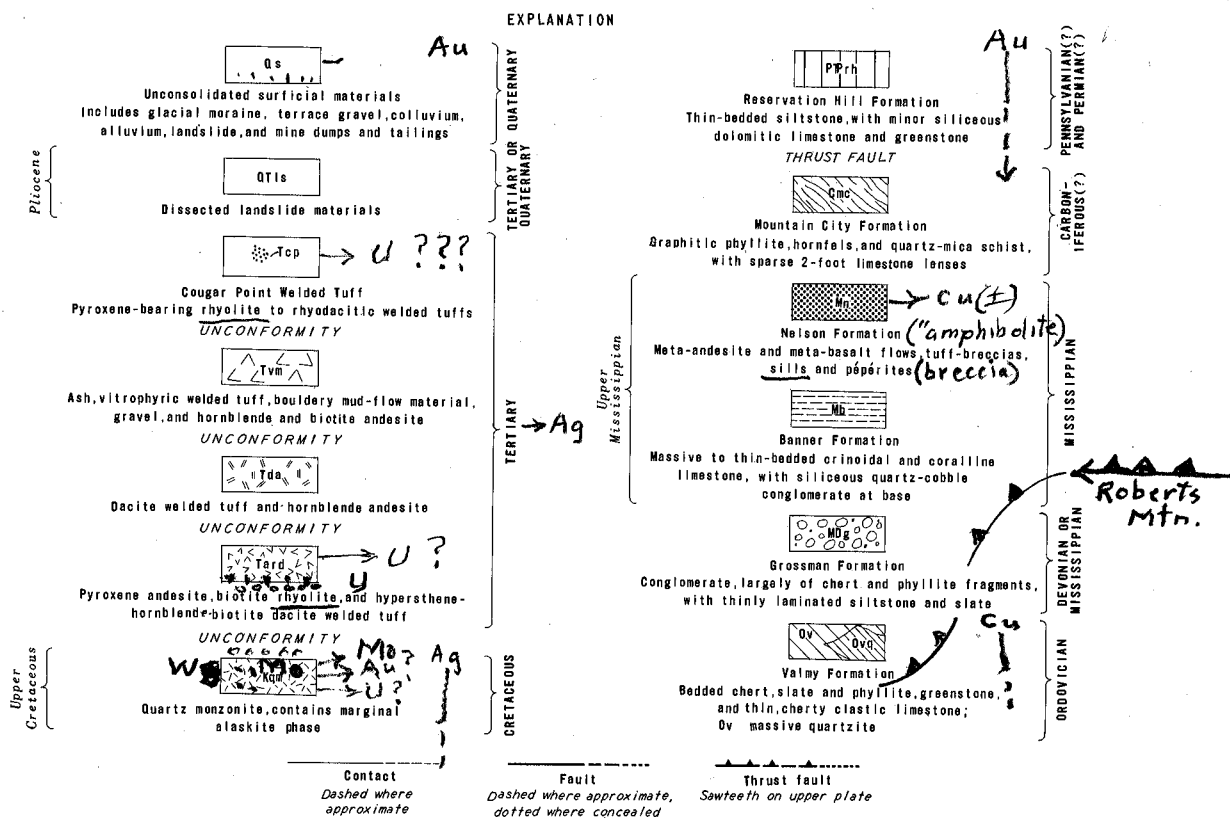


FIG. 1. Areal Geology in the Vicinity of the Mountain City Copper Mine, Elko County, Nevada.

by an inclined shaft which in 1932, at a depth of 242 feet, penetrated a supergene ore body 72 feet wide that assayed 50 per cent copper.

Statistics of Mine Production

From 1932 until operations ceased in 1947, the Mountain City Copper Mine produced 1,109,877.712 short tons of ore averaging 9.745 per cent copper, 0.274 ounces of silver, and 0.0057 ounces of gold per ton. Of this, about 177,042.752 tons averaging 26.11 per cent copper was shipped directly to the smelter in Utah, and the remaining ore was concentrated at the mine. Table I shows the production of the Mountain City Mine by years.

GEOLOGIC HISTORY

Stratigraphic Column

The rocks of the Mountain City Mine area (Figure 1) consist of an Ordovician formation

of the detrital volcanic western assemblage,* overlain by several upper Paleozoic units composed largely of clastics and intermediate to mafic volcanics, all intruded by a Cretaceous quartz monzonite. After a long interval of erosion, volcanic activity began, probably in the late Eocene, and continued intermittently to the Pliocene. Erosion continued throughout the

* In north-central and northeastern Nevada, early and middle Paleozoic rocks have been divided by Roberts and his colleagues (16, p. 2816-2817) into three major assemblages: (1) an eastern, or miogeosynclinal assemblage, largely limestone and dolomite, with minor shale and quartzite; (2) a western or eugeosynclinal assemblage, in which the major elements are shale, coarse clastics, chert, and volcanic rocks, including pyroclastics; and (3) a transitional assemblage, intermediate in character between the other two. In a more recent paper, Silberling and Roberts (23, p. 5) have preferred to substitute the term "detrital-volcanic" for "western" and "carbonate" for "eastern." The older terms will be used here, because they are better known than the newly introduced ones.

period of volcanic activity, and each of the volcanic units accumulated on an irregular surface. The usual diverse array of surficial deposits of Quaternary age helps to obscure the picture.

In the northeastern part of Nevada, the western and eastern assemblages have been brought into juxtaposition by a thrust fault of great displacement, the Roberts Mountains thrust (3, p. 5). The rocks of the eastern assemblage are, therefore, autochthonous and those of the western assemblage allochthonous in this area. The ore of the Mountain City Copper Mine was emplaced in rocks of the Valmy Formation, a part of the western assemblage, as defined above. The Roberts Mountains thrust is not exposed in the mapped area; it crops out several miles to the south, and presumably lies much below any depths reached in mining in this area. It is possible, however, that many of the structures that cut the preorogenic Paleozoic rocks of this area were coeval with the Roberts Mountains thrust.

VALMY FORMATION The oldest rock unit in this area, designated the Rio Tinto Formation by Granger and others (15, p. 116, pl. 14), is reassigned to the Valmy Formation, named by Roberts in the Antler Peak quadrangle of central Nevada (12, 1958). The Valmy Formation in this area consists of fine-grained graywacke, chert, greenstone, argillite, slate, phyllite, quartzite, and thin lenses of clastic, brown-weathering limestone, with minor amounts of secondary black chert. The greenstone includes both pillow lavas and diabasic bodies, presumably sills or thick flows. The chert occurs as small lenticular masses of thin-bedded chert, with slaty partings; it ranges in color from light to dark gray, rarely black, and locally grayish green. Traces of radiolaria are locally present. The phyllite ranges from dark gray to black and weathers to a micaceous soil, generally mantled by fragments of the more resistant quartzite, chert, and greenstone. The phyllite consists essentially of quartz and muscovite, locally with some calcite; goethite, derived from pyrite, is fairly widely distributed. The least metamorphosed of the mafic igneous rocks is a uralitized gabbro, with ophitic texture, that contains relic augite, brown hornblende, plagioclase, and ilmenite. Green uralitic hornblende, chlorite, and leucoxene also are present. Less massive flows, generally metamorphosed in the greenschist facies, consist of aggregates of albite, chlorite, sphene, calcite, quartz, and tremolite. The typical quartzite of the Valmy is fine to

medium grained, glassy, and gray to black in color. It is almost entirely quartz, feldspar being rare; the color is the product of disseminated graphitic material; rare, rounded grains of zircon and tourmaline can usually be found. The typical limestone of the Valmy is essentially a calcarenite in which black chert is secondary. Some of the thin lenses of limestone have furnished excellent specimens of the crustacean, *Caryocaris*, which help to determine the age of that part of the Valmy as Early Ordovician (W. D. Ian Rolfe, written communication, 1964). Because deformation in this area has apparently been repeated, cleavages tend to be nonparallel to the bedding in most samples of the phyllite; hence, graptolites are difficult to find, but a few specimens of graptolites have been found at the base of the bluffs, across the Owyhee River from Patsville, and have been reported on as follows by R. J. Ross, Jr. (written communication, 1960):

"Graptolites are very scrappy and small, but this may not be the result of poor preservation. This fauna may simply be characterized by small and immature specimens. . . . Although identifications are tentative, the forms I believe present include:

Didymograptus? sp. (immature)

Corynoides? sp.

Cryptograptus? sp.

Isograptus cf. *I. dumosus* harris.

Age: Llanvirn or approximately mid Middle Ordovician of U.S. usage."

J. W. Huddle (written communication, 1965) reported on some conodonts from a point at the base of the valley wall on the south side of Mill Creek, about half a mile west of Patsville (Collection 65NC94):

"The specimens in this collection are molds and not certainly identifiable. . . . Probably the rock is Early or Middle Ordovician in age."

GROSSMAN FORMATION The Grossman Formation, named by Coats (31), consists of conglomerate, sandstone, siltstone, and slate; the distinctive lithology is most readily seen in the conglomerate, clasts in which consist chiefly of gray quartzite, black chert, and phyllite. In some places, the clasts have been tectonically flattened. The Grossman crops out in two areas in the Mountain City and adjacent part of the Owyhee quadrangles. One area extends patchily along Mill Creek, from a point about half a mile west of the Grossman place (west of the mapped area) to the south slope of Banner Hill (called California Hill on map), on the east side of the Owyhee River.

The other area is near the south edge of the map area, at the mouths of Haystack Creek and Rocky Gulch, on both sides of the Owyhee River. The stratigraphic base and top are nowhere known to be exposed together; the upper limit is, at some places, an unconformity; elsewhere, a fault surface. The maximum thickness is on the order of 1000 feet.

The Grossman unconformably overlies the Valmy Formation and unconformably underlies the Banner Formation. It was assigned a Devonian or Mississippian age by Coats (31).

BANNER FORMATION The Banner Formation, originally designated the Banner Limestone by Granger and others (15, p. 116, pl. 14), crops out in a narrow belt with a nearly easterly trend, from Banner Hill (also called California Hill on some maps), the type locality, discontinuously westward to the headwaters of Fawn Creek in the adjacent Owyhee quadrangle.

The Banner Formation rests with considerable angular unconformity on the Valmy, or with a slighter unconformity on the intervening Grossman Formation. The lowest part of the Banner is a conglomerate as much as 50 feet thick; the clasts are well-rounded quartzite fragments to 6 inches in diameter, in a tan-weathering matrix of quartz sandstone. This grades upward through well-indurated quartz sandstone to a gray siliceous siltstone that weathers tan. This in turn grades upward into a gray bioclastic limestone in beds up to 1 foot thick, in some places interbedded with 2- to 6-inch beds of siliceous siltstone.

The limestone of the Banner Formation grades upward into volcanic breccia of the Nelson Formation. The age of the Banner is considered to be Late Mississippian.

NELSON FORMATION The Nelson Formation, originally designated the Nelson Amphibolite by Granger and others (15, p. 116), crops out as a west-trending band adjacent to and north of the Banner Formation between Banner Hill and along the north side of Mill Creek. Scattered outcrops of what may be the same formation are found farther west in the Owyhee quadrangle.

The greater part of the formation consists of flows and tuff-breccias of andesitic composition, with minor sills of diabase and one lens of rhyolitic tuff. In the area of the map, it is a green schist, with tremolite-actinolite, chlorite, epidote, calcite, ilmenite, and andesine, in part altered to albite. In the meta-andesite, the amount of amphibole is greatest, and the

composition of the recrystallized plagioclase is most calcic near the eastern end of the belt of exposures, where the rocks are closest to the quartz-monzonite contact. Westward, the amphibole is lighter in color, the new feldspar more albitic, and the rock richer in chlorite. Locally, the rock appears to be a metadiabase.

The greatest thickness in the area mapped appears to be about 800 feet, but the thickness diminishes westward to the vicinity of the Nelson Ranch; farther westward thicknesses appear to be much greater, but there may be unrecognized duplication by faulting.

MOUNTAIN CITY FORMATION The Mountain City Formation was originally named by Granger and others (15, p. 116, pl. 14) from its occurrence at the Mountain City Mine (not named on the map) in the SE¼ of sec. 2, T45N, R53E. It has been recognized only west of the Owyhee River, westward to the headwaters of Fawn Creek, in the Owyhee quadrangle. It forms a belt ranging in width from a few hundred feet to 2.5 miles. The base of the Mountain City rests conformably on the Nelson Formation, and it is limited above by the thrust contact with the overlying Reservation Hill Formation, the intrusive contact of the Cretaceous quartz monzonite, or by overlapping Tertiary volcanic rocks. The total thickness is unknown, but may be as much as 10,000 feet, only the lower part of which is exposed in the mapped area. The Mountain City Formation consists of graphitic quartzose phyllite, with thin beds of siliceous limestone, up to 2 feet in thickness, that make up less than 1 per cent of the total section. The phyllite is thermally metamorphosed to andalusite hornfels and to garnetiferous quartz-mica schist. The age of the formation is unknown, as no determinable fossils have been found in it, but it is presumed to be Carboniferous(?).

RESERVATION HILL FORMATION The Reservation Hill Formation was named by Coats (31) for typical exposures on Reservation Hill in sections 22 and 23, T46N, R53E, just east of the highway from Mountain City to Owyhee and just inside the Western Shoshone Indian Reservation. It rests in thrust contact on the Mountain City Formation and is intruded by the Cretaceous quartz monzonite and overlapped by Tertiary or Quaternary rocks. It extends from the central part of the Mountain City quadrangle westward to the drainage of Fawn Creek, in the Owyhee quadrangle. The total thickness is unknown; the dips are generally steep, the outcrop belt is as much as

1.5 miles wide, but, because many outcrops show tight and intricate folding, the thickness cannot be stated with any degree of precision; it is probably several thousand feet.

The principal rock type in the Reservation Hill Formation is a fine-grained dolomitic sandstone or siltstone, pale gray on fresh fracture; it weathers to a color ranging from creamy white to pale reddish brown (10 R 6/4); the latter coloring is quite distinctive. Microscopically, the principal constituents are quartz, orthoclase, oligoclase, and dolomite; metamorphism has resulted in the development of diopside and tremolite. Subordinate to the clastic rocks are lenses of gray siliceous dolomitic limestone, as much as 50 feet thick, and meta-andesite flows, as much as 200 feet thick.

No fossil evidence for the age of the Reservation Hill Formation is available. Lithologically it does not resemble either the known Precambrian rocks of this region or the known Triassic rocks and is therefore assumed to be Paleozoic. R. J. Roberts (oral communication) suggested that it resembles the type Havallah Formation of Pennsylvanian and Permian age; it was therefore designated as Pennsylvanian(?) and Permian(?) by Coats (31).

QUARTZ MONZONITE The quartz monzonite is a light-colored medium- to coarse-grained intrusive rock with visible pinkish orthoclase, white plagioclase, biotite up to 4 mm in diameter, and quartz. Accessory minerals seen in thin section include apatite, magnetite, and zircon; secondary minerals are epidote, chlorite, calcite, and goethite (after pyrite?). Some parts of the pluton are somewhat poorer in K-feldspar, and both sphene and hornblende are present locally. The rock thus changes in composition from quartz monzonite to granodiorite. Locally, especially near the intrusive contact, the pluton is essentially an aplite.

The age of the pluton has been determined by K/Ar method on biotite as 90 ± 5 m.y., and by the Pb- α method on zircon as 110 ± 20 m.y. (28). It is thus Late Cretaceous.

The intrusion of the quartz monzonite was followed by a long period of erosion.

VOLCANIC ROCKS The oldest volcanic rocks from the Mountain City quadrangle that have been dated are about 42 m.y. old; volcanic rocks ranging in age from 36 to 39 m.y. are widespread.

One of the oldest volcanic rocks is a dense lithic reddish-to-yellowish welded tuff, with very sparse phenocrysts of biotite and oligo-

clase. The next and more widespread unit is a dacitic welded tuff. This unit is probably as much as 300 feet thick; it generally is devitrified to pale gray or yellowish tuff in which only biotite and plagioclase are conspicuous. Fresh, glassy basal phases are present locally, and these are very rich in phenocrysts of andesine with green hornblende, brown biotite, hypersthene, and augite; magnetite, apatite, and zircon are common accessories. Quartz grains are sparse.

West of the Owyhee River and sporadically in the valley of Rocky Gulch, and on both sides of the Owyhee River, as far south as the mouth of Trail Creek, widespread flows of pyroxene andesite rest on the welded tuffs and older rocks. The pyroxene andesite is gray or black in color and is characterized by phenocrysts of augite, hypersthene, and plagioclase, ranging in composition from calcic andesine to labradorite, with microphenocrysts of apatite and magnetite, in a partly glassy groundmass of plagioclase and augite microclites. This pyroxene andesite of Rocky Gulch has accumulated in places to a thickness of 200 feet, but its distribution is spotty because of the irregular surface on which it accumulated. All the volcanics described above have been mapped together as pyroxene andesite, biotite rhyolite, and hypersthene-hornblende-biotite dacite welded tuff.

Another volcanic sequence, the relations of which with the pyroxene andesite sequence are uncertain, consists of biotite-dacite welded tuff at the base, overlain by both flows and tuff-breccias of a diverse assemblage of olivine-hypersthene andesite, pyroxene andesite, and hornblende-pyroxene andesite. These rocks, in the mapped Rio Tinto area, are distributed along the east side of the Owyhee River, just above the highway level, from south of the mouth of California Creek to a point north of the edge of the map. They are much more extensive west and north of the mapped area in the Owyhee quadrangle.

The volcanic sequence that is most extensive in the mapped area includes ash, vitrophyric welded tuff, bouldery mudflow, gravel, hornblende and pyroxene andesite, and rhyodacite. This seemingly incongruous assemblage of units has a spacial and genetic coherence, resulting from its mode of origin and relation to the topography of the time of eruption. The lowest unit is a rhyodacitic ignimbrite, with a poorly welded basal phase, a partly welded central zone, and poorly welded top, but not all phases are present everywhere. Petrographically, the material is a rhyodacite

characterized by oligoclase, sanidine, quartz, magnetite, and zircon in a matrix of brown glass. The total thickness is about 30 feet. The sequence next above is a mudflow, nearly unsorted, in which the larger fragments are all nonvolcanic, and, for the most part, quartzite of the Valmy Formation. These fragments are subrounded to well rounded and are characterized by many percussion marks. The surface underlain by the mudflow is now mantled with a carapace of residual boulders of all sizes up to many feet in diameter (the largest seen was 24 feet in longest dimension). Along with the mudflow, and perhaps slightly younger, are a few equally coarse but better sorted gravels; these perhaps represent mudflow material winnowed by streams. The ignimbritic material is found on the stream-cut bluffs west of the Owyhee, opposite the mouth of California Creek and on the north side of Mill Creek Valley, northeast of Rio Tinto Townsite.

The youngest volcanic rocks exposed in the mapped area are those of the Cougar Point Welded Tuff (25, p. M15). The thickness of the formation in the mapped area is probably no more than 100 feet; it is not known what part of the formation is here represented. As in the type area in the Jarbidge quadrangle to the east, the holocrystalline parts of the welded tuff are a dense, compact, cliff-forming rock that is reddish or yellowish brown to brownish gray. The glassy phases, generally confined to the base of moderately thin flows, are gray to black, more closely fractured, and often perlitic. Thinner flows are less densely welded and may have a satiny luster in their most closely welded parts, ranging to dull in the least welded. Much of the welded tuff is vesicular; the dimensional proportions of ellipsoidal vesicles range from nearly equidimensional to flattened, perhaps slightly elongated, or to much elongated and only slightly flattened. The flattening is generally in or near the plane of textural layering, and elongate vesicles display a marked parallelism of their long axes. The Cougar Point in the mapped area is found in small patches, on the crest of the ridge east of the Owyhee River, south of California Creek and north of Haystack Creek, and on a saddle on the ridge just south of the Mountain City Copper Mine.

A single sample of the Cougar Point, taken on the west face of Yellow Rock, in the Owyhee quadrangle, east of the Owyhee River and south of Skull Creek, has yielded sanidine that has been dated by John Obradovich (written communication, 1965), using the K/Ar method. This sample (62NC51, DKA No.

1068) gave an age of 12.2 ± 0.8 m.y., corresponding closely to an age (26, p. 152) of early Pliocene.

Several patches of material that now appear as a surface strewn with large angular fragments of rock evidently derived from some distance are mapped as Tertiary or Quaternary landslide debris. The most conspicuous of these are near the northern edge of the map, and on both sides of Rocky Gulch on the south edge of the map. These occurrences are generally separated from possible sources of the larger fragments by Recent stream valleys of considerable depth.

In a large part of the area, the bedrock structures and lithologies are effectively concealed by unconsolidated surficial materials, locally present to a depth of some tens of feet. These include, roughly in order of age: glacial moraine, terrace gravel, colluvium, alluvium, landslide debris, and material resulting from human activities, such as mine dumps, tailing piles, and the Rio Tinto garbage dump. Glacial moraine is restricted to the heads of some of the valleys that fret the western slope of Bald Mountain, where transverse ridges as much as 10 or 15 feet high, of coarse quartzitic debris, seem best interpreted as glacial moraines. Neither striations nor glacial smoothing have been detected, even on the quartzite. The terrace gravel is generally confined to the valley of the Owyhee River and is found in three conspicuous sets. The highest of these is at about 5850 feet altitude, from south of Dry Creek to north of Mill Creek. A distinctly lower terrace, at about 5750 feet, forms the surface of the Mountain City landing field, and a still lower terrace is about 25 feet above the flood plain of the Owyhee River. The material of the highest terrace is distinguished, with difficulty, from the residual material derived from the mudflow in the volcanic sequence mentioned above; the best criterion is the presence of boulders of the Jarbidge Rhyolite and vesicular olivine basalt, which are not present in the suite of boulders in the mudflow deposit. The boulders of Jarbidge Rhyolite are certainly derived from the body along the southern edge of the Mountain City quadrangle; the source of the vesicular olivine basalt is probably outcrops of this rock, underlying the Jarbidge Rhyolite in the valley of Allegheny Creek, at the southern edge of the Mountain City quadrangle.

In this area, the colluvium reaches a thickness of some tens of feet in many places, particularly on the north-facing slopes of the hills. Such places are apt to have patches of scrub

forest, consisting principally of quaking aspen and chokecherry, that result in a soil accumulation sufficiently thick to obscure completely the bedrock contacts. Where resistant rock, such as quartzite of the Valmy Formation crops out, the colluvial mantle grades into streams of coarse talus.

On the north-facing slopes too, the higher water table tends to favor landslides where resistant rocks, such as the Valmy quartzite and some of the lava flows, overlie more readily weathered material, such as the phyllites of the Valmy, poorly welded tuffs, or quartz monzonite.

Most of the alluvium is in the flood plains of the present streams. The occurrence of scattered outcrops of bedrock within the flood plain of the Owyhee suggests that the alluvium is thin.

General Structure of the Area

The Mountain City Copper Mine is developed in rocks that are in the upper plate of the Roberts Mountains thrust (16, p. 2817). The time of movement on the Roberts Mountains thrust is believed to differ from place to place; it has been assigned to a time interval extending from latest Devonian to the Early Mississippian (16, p. 2817). Evidence available in this area is susceptible to more than one interpretation because no Paleozoic formation has yet been found lapping across the thrust. The coarse, chert-rich clastics of the Grossman Formation, obviously derived from the Valmy, strongly suggest that they result from an orogeny in late Paleozoic time; their greater degree of deformation than the unconformably overlying Banner Formation implies another orogenic pulse, though not necessarily a major one, that predates the Banner. Hence, at or near the site of deposition of the Banner Formation, and the later formations that are conformable with it, the Nelson and the Mountain City, there were two strong orogenic pulses in the late Paleozoic, both pre-Meramec (early Late Mississippian) in age. Unfortunately, some ambiguity still remains as to the proper classification of the Grossman, Banner, Nelson, and Mountain City Formations. That these are postorogenic rocks is plain, but it is not clear whether the original site of deposition was the present location, or whether these formations were deposited a great distance to the west and rode into this area as part of the Roberts Mountains thrust plate. Whereas other sequences of the overlap assemblage in north-central Nevada (16, p. 2844) are poor in volcanic rocks, these are rich in rocks of

andesitic and basaltic type, suggesting that they, like the Valmy, were derived from a source many miles to the west, and came into this area as part of the upper plate of the Roberts Mountains thrust. Another possibility that must be considered is that these formations were deposited near their present site and represent an eastward extension of the belt of volcanic eugeosynclinal conditions not observed elsewhere in this part of Nevada.

The trace of the Roberts Mountains thrust lies several miles to the south of the mapped area; it follows fairly closely the southern border of the Owyhee quadrangle but has a more northeasterly trend from the boundary between the Owyhee and Mountain City quadrangles into the Mountain City quadrangle and disappears beneath the overlapping Tertiary lavas at a point about 2 miles south of the Mountain City Copper Mine. There is no reason to believe that the upper plate is much less than a mile thick at the Mountain City Copper Mine.

As indicated above, the evidence for the age of the thrust faults within the upper plate of the Roberts Mountains thrust, the plate in which the Mountain City Copper Mine is developed, is equivocal. One minor thrust of this category is that which crops out on both sides of Rocky Gulch and brings the Valmy Formation over the Grossman Formation; this thrust must be post-Grossman. The thrust that underlies the plate of quartzite that forms the top of Bald Mountain has brought a quartzite, presumably within the Valmy, onto other Valmy quartzite of slightly different lithology. As the continuation of this plate of quartzite is not found north of Mill Creek and the quartzite boulders in the basal conglomerate of the Banner Formation resemble this quartzite of Bald Mountain rather than the other darker and more widespread quartzites of the Valmy, it is inferred that this thrust also is post-Grossman and pre-Banner in age. The thrust that brings the Reservation Hill Formation on top of the Mountain City Formation must be later than either of these formations, and hence younger than the thrusts described above, but nothing further can be said as to its precise age.

Two of the steeply dipping faults that cut the Valmy Formation and the ore body line up quite well with faults on the north side of Mill Creek that bound bodies of Tertiary volcanic rock, but they have not been traced across Mill Creek. The attitudes of the contacts of the volcanic rocks are not sufficiently well known that the displacement of the Tertiary rocks can be compared, with assurance, with that of the Paleozoic rocks.

*L. Miss.
Roberts
mtn
age*

PHYSIOGRAPHIC HISTORY

The Tertiary volcanic rocks of the Mountain City area give, by their distribution and by their shapes on the surfaces on which they lie, some clues to the development of the physiography of the area. One of the most widespread of the units is an andesite mapped by Bushnell (written communication, 1955) in the Rowland quadrangle (adjacent to the Mountain City quadrangle on the east) and included here as part of the unit of pyroxene andesite, biotite rhyolite, and hypersthene-hornblende-biotite dacite welded tuff. This unit, which is widespread in the southeastern part of the Mountain City quadrangle, has not been recognized in the Mill Creek-Banner Hill area. It is overlain in the valley of Allegheny Creek, southeast of the mapped area, by a sequence of tuffs and tuffaceous sediments that contains lower Miocene mammals (C. A. Repenning, written communication, 1965). These facts suggest that, at least as late as early Miocene time, Mill Creek and California Creek were the headwaters of the East Fork of the Owyhee River, and that the southern part of the map area was drained by an ancestral Humboldt River. The date at which the divide was shifted drastically to the south cannot be established precisely as yet, but the most plausible explanation for the shift seems to be that the eruption of the thick prism of rhyolite through which the present canyon of the Owyhee is cut, north of Wildhorse Reservoir and south of the mapped area, served to divert the headwaters of the Humboldt into the Owyhee drainage. The eruption of the Jarbidge Rhyolite was dated on the basis of sanidine by Geochron, Inc. for Axelrod (25, p. M11) as 16.8 ± 0.5 m.y., and assigned a late Miocene(?) age.

Physical age determinations on younger rocks are not as plentiful as could be wished. Geologically, it is known (E. N. Pennebaker, written communication, 1960) that the base of the vitrophyric welded tuff that underlies the bouldery mudflow deposit is exposed in the Davidson adit, which is driven southward from a point about 0.6 mile east-northeast of the Mountain City Copper Mine and at a level about 50 feet higher than the floor of Mill Creek Valley; this tuff locally dips northward below the adit level. As these volcanic rocks are believed to be older than the Cougar Point welded tuff, to which an age of 12.2 ± 0.8 m.y. (Pliocene) was assigned by Obradovich (see above), it is evident that the base level of erosion has not been substantially lowered in the Mountain City mine area for many mil-

lions of years. However, it should be remembered that many of the younger volcanic rocks, now preserved as remnants on the ridge-tops, like the Cougar Point Welded Tuff, were accompanied by pyroclastics that must have filled up the valleys and produced a quite even surface by the time their eruption ceased. It is probable, then, that during most of the Pliocene and Pleistocene, the Owyhee River and its tributaries have been removing the poorly consolidated volcanic material. And it is highly probable that during most of this time, the water table near the Mountain City mine stood higher than at present, and oxidation and supergene enrichment "took a vacation."

ECONOMIC GEOLOGY — PRIMARY ORE

Forms of the Ore Bodies

The primary ore bodies of the Mountain City Copper Mine are in the Valmy Formation, occurring as disc-shaped lenses in a definite sequence of dark shales having a few minor quartzite interbeds. The longest continuous horizontal dimension of the largest lens (the "200" ore body)* is 1000 feet in strike length, and its maximum width is 92 feet. The lenses strike N65°W to N85°W and dip north, commonly parallel to the bedding, at angles of 65° to 85°. (Figures 2 to 9).

Stratigraphic Relations of the Ore Body

The primary ore bodies occur in a definite shaly sequence locally known as the ore horizon. This occurs approximately 850 feet stratigraphically above the upper contact of the upper black quartzite (the Blackrock quartzite of local usage) and the so-called Rio Tinto Formation.†

The two principal ore bodies, the "200" and the "600" (Figure 11) appear to be faulted

* The first ore discovered was on the 200 level; hence, the orebody became known as the "200 orebody." It extends downward to the 300 and 400 levels, but does not reach the 500 level. The "200 orebody" is shown on Figures 2, 3, and 5 by the cross-hatched areas.

† The name Rio Tinto Formation was applied by Granger and others (15, p. 116, pl. 14) (in local usage) to a phyllitic part of the Valmy Formation of this report in which the ore body of the Mountain City Copper Mine is developed. The name Rio Tinto Formation, therefore, is considered abandoned. The Blackrock quartzite of local usage (15, p. 113) is a black quartzite, also part of the Valmy Formation.

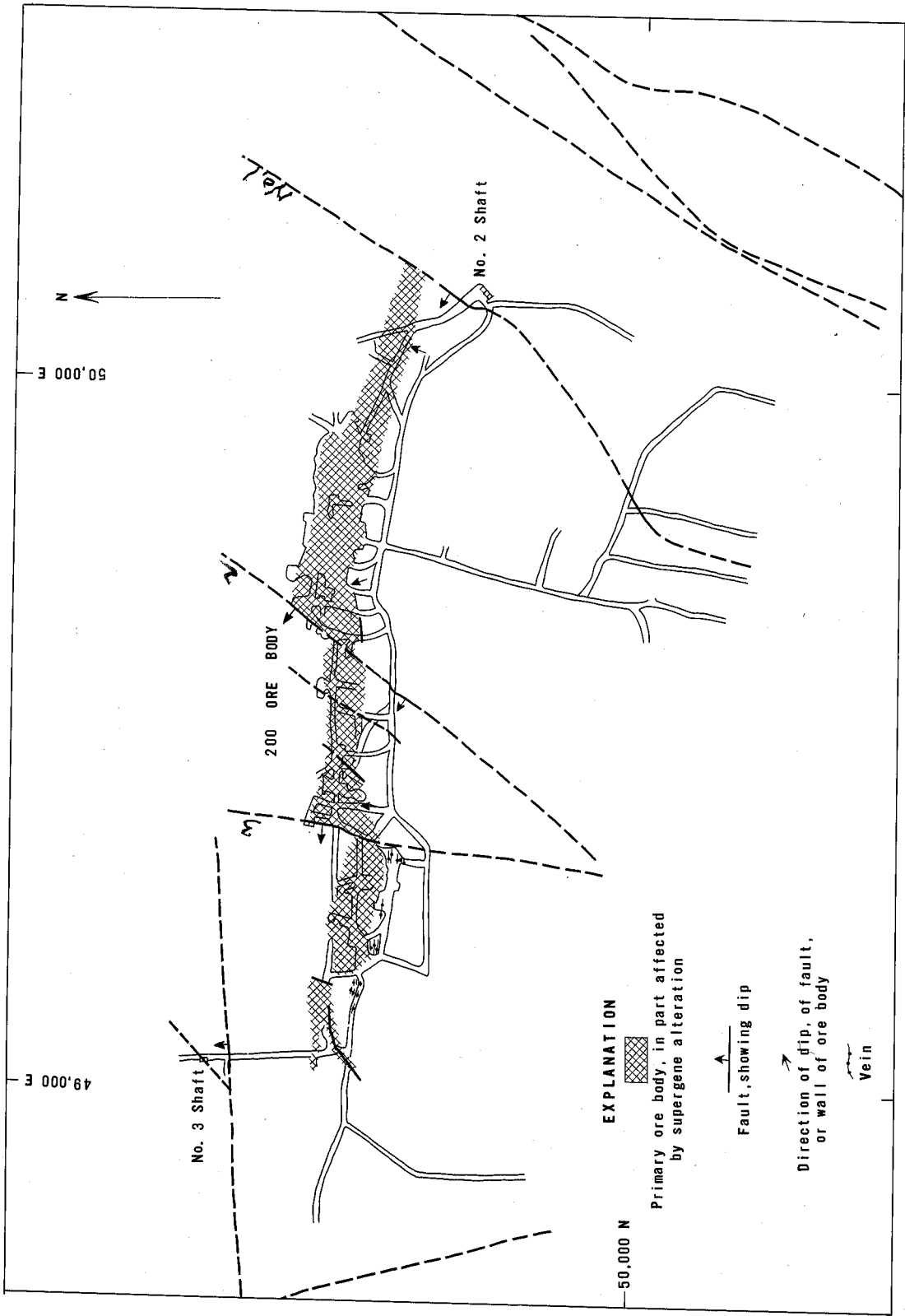


FIG. 2. Geologic Map, showing part of the 200 level of the Mountain City Copper Mine. (The coordinates on Figures 2 through 9 are in feet.)

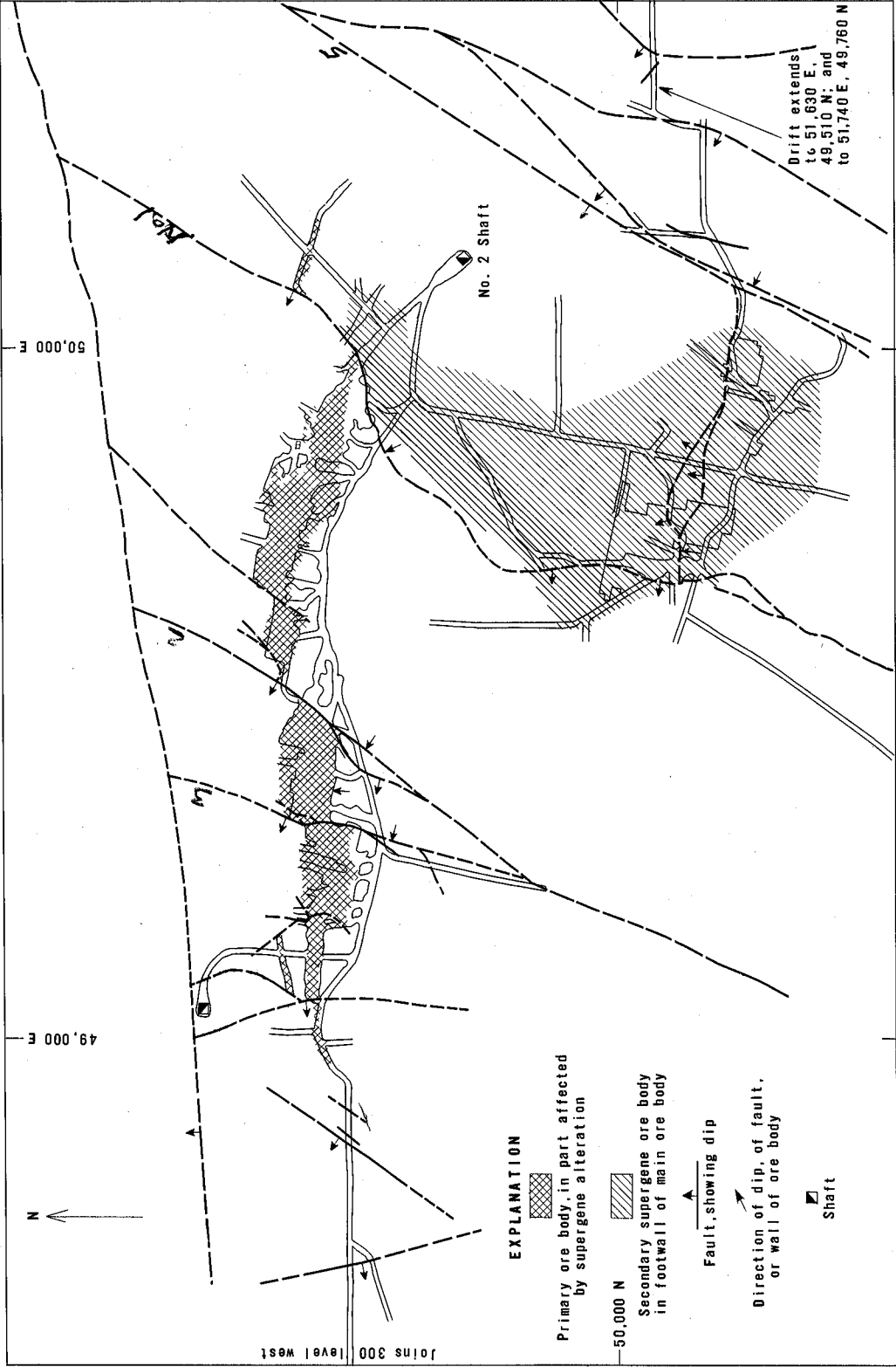


FIG. 3. Geologic Map, showing part of eastern half of the 300 level, Mountain City Copper Mine.

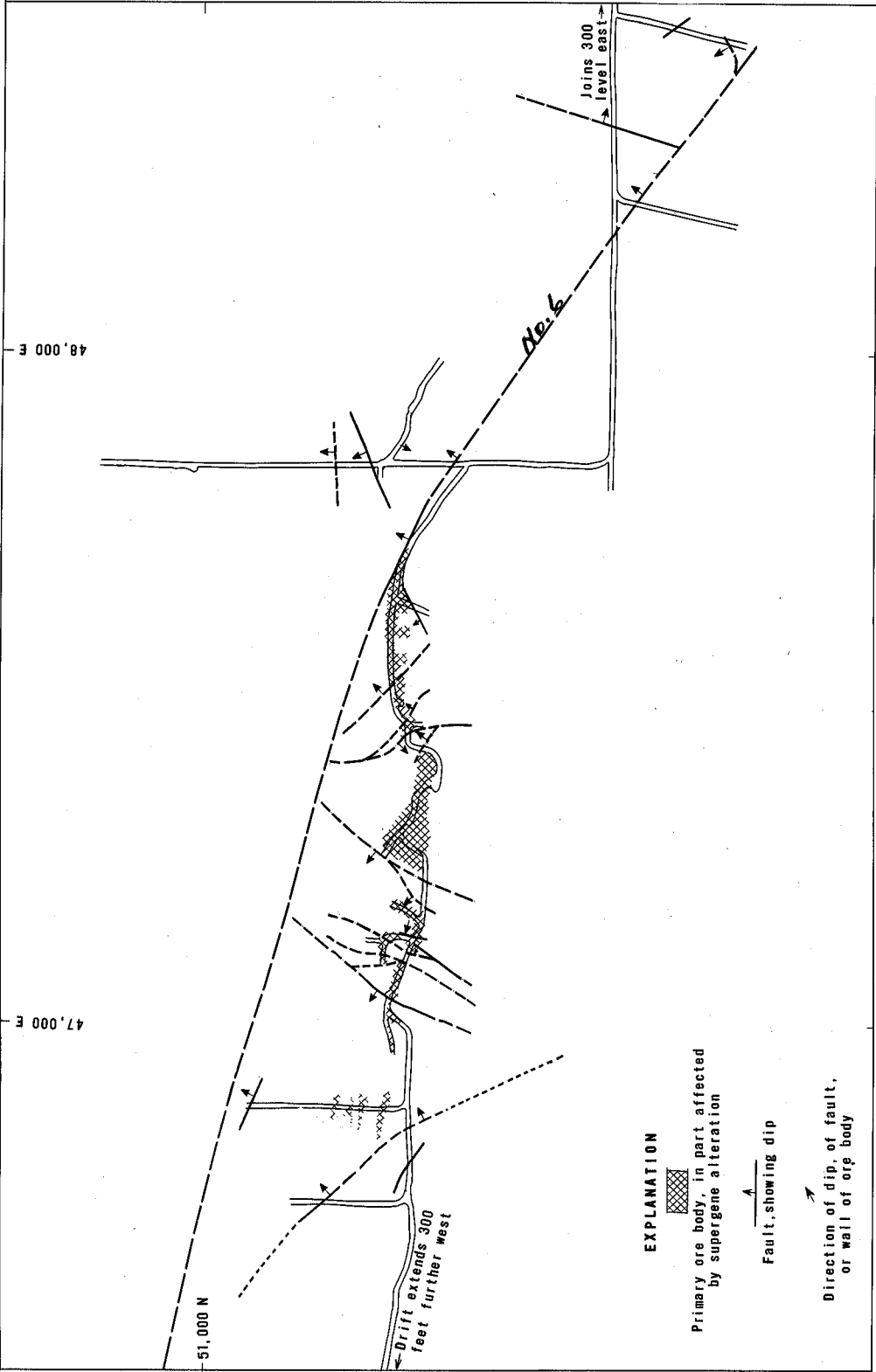


FIG. 4. Geologic Map, showing part of the western half of the 300 level, Mountain City Copper Mine.

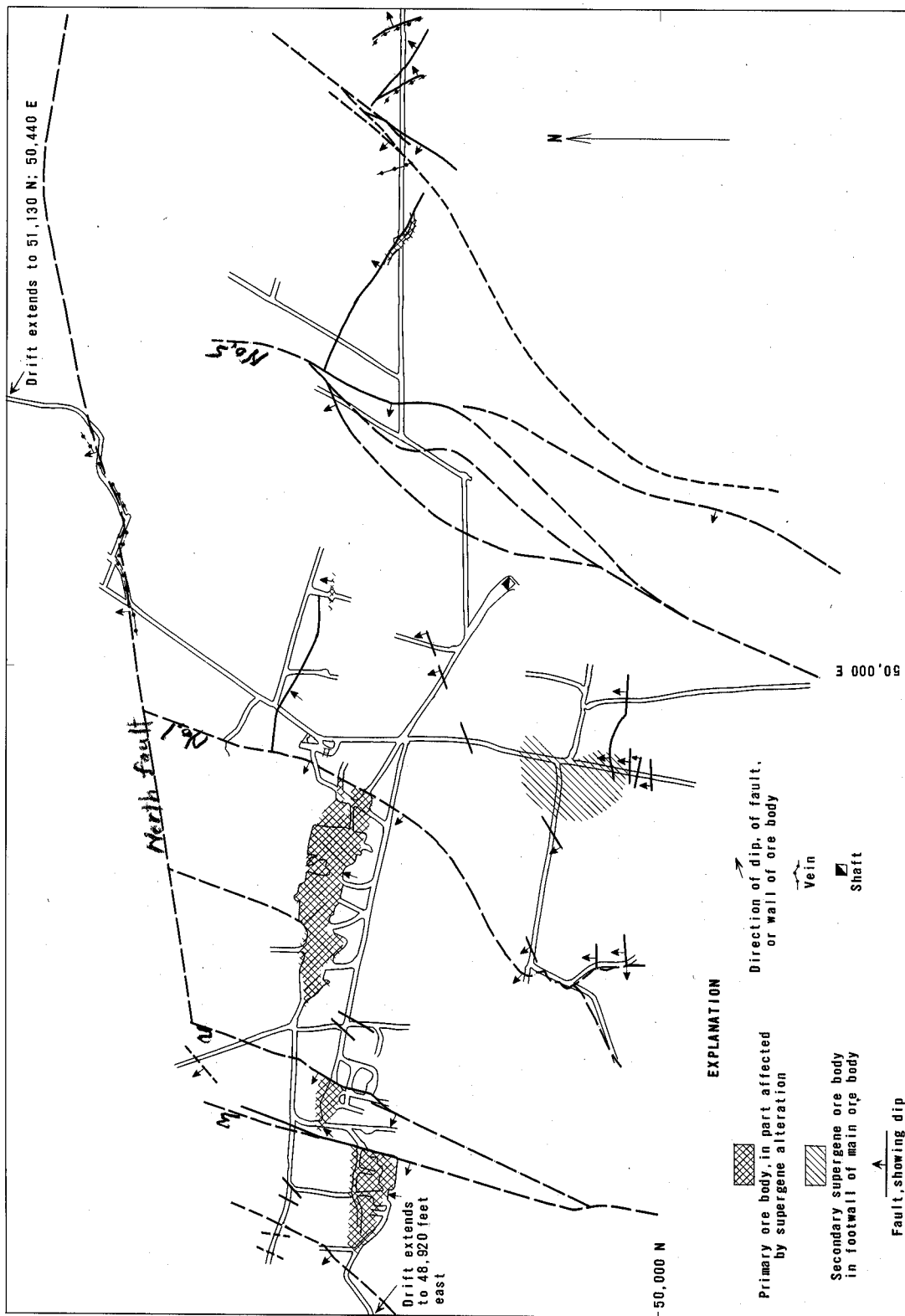


FIG. 5. Geologic Map, 400 level, Mountain City Copper Mine.

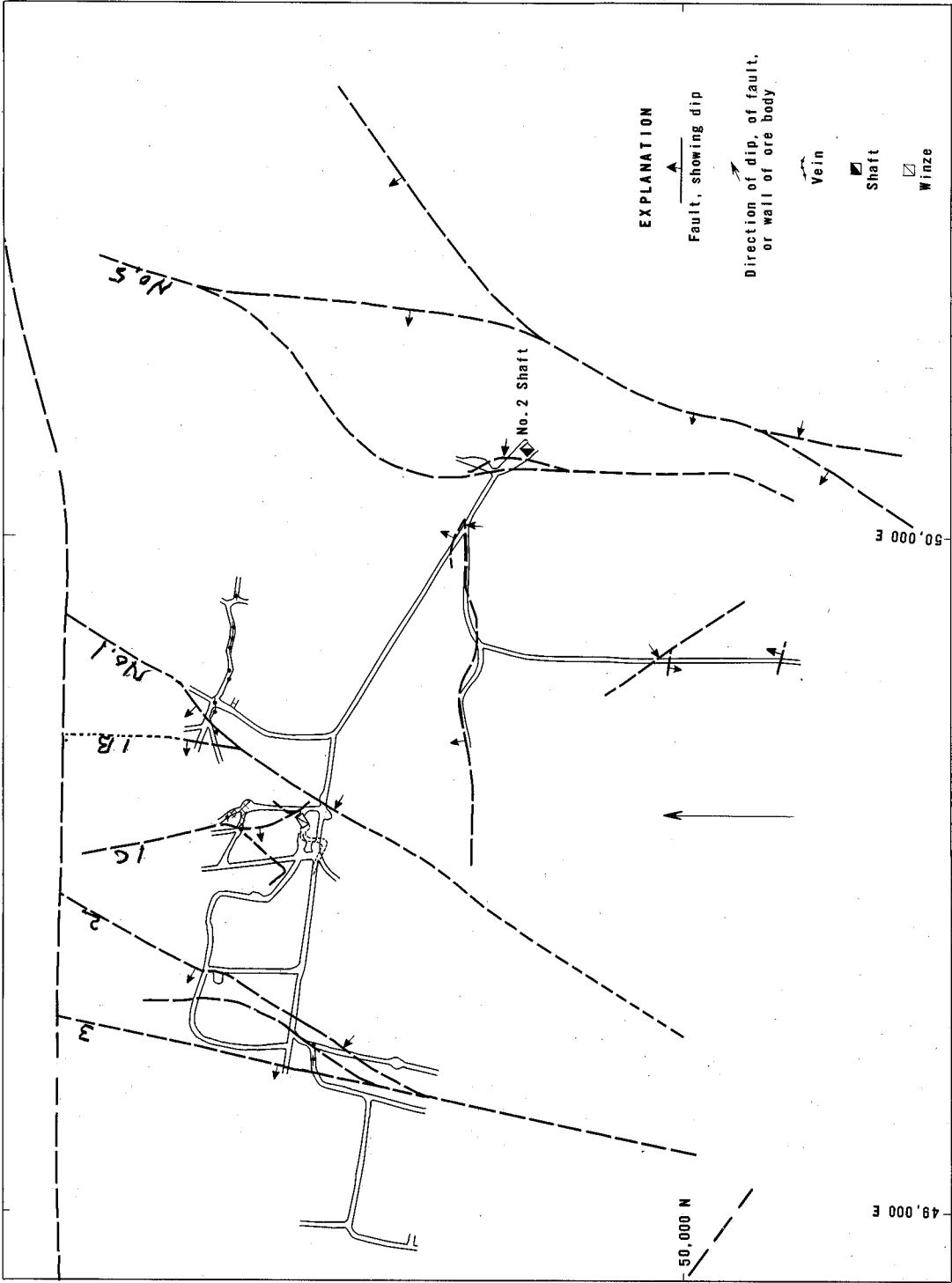


FIG. 6. Geologic Map, 500 level, Mountain City Copper Mine.

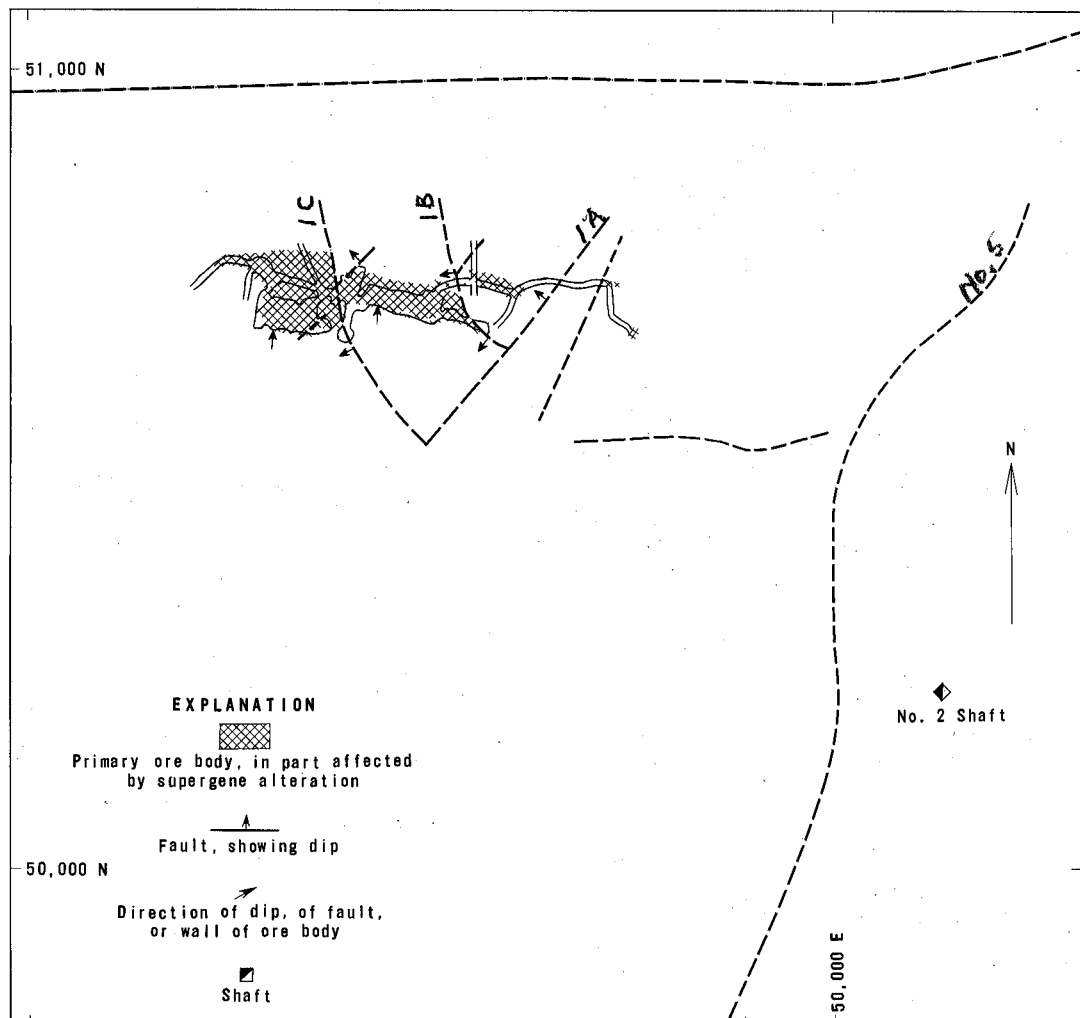


FIG. 7. Geologic Map, 600 level, Mountain City Copper Mine

segments of the same lens. Other, smaller lenses occur both laterally and below the principal ore bodies.

The ore "horizon," which attains a maximum thickness of 200 feet, consists largely of dark, thin-layered shales. The primary ore lenses, which are restricted to the "ore horizon," commonly parallel, but also cut across, bedding.

Mineralogy of the Deposit

The two principal hypogene sulfide minerals are pyrite and chalcopryite (4). A little sphalerite is associated with the "massive" ore types (quartz-pyrite-chalcopryite), and one minor occurrence of galena was found close to one

of the principal ore lenses. There are only minor local differences in the ratio of the various sulfides to one another in each ore type. There are no significant changes of the hypogene sulfide mineralization laterally or vertically within an individual ore type. The spatial relationship of the various ore types has been plotted in great detail on maps and sections of which Figures 10 and 11 are representative.

Detailed descriptions of the textures of the several ore types are given under "Mineral Textures" (below).

The supergene copper sulfide minerals, chalcocite, bornite, and covellite, which largely replace primary sulfides, are the most abundant in the 50 feet immediately beneath the present top of the ground-water table in the "200"

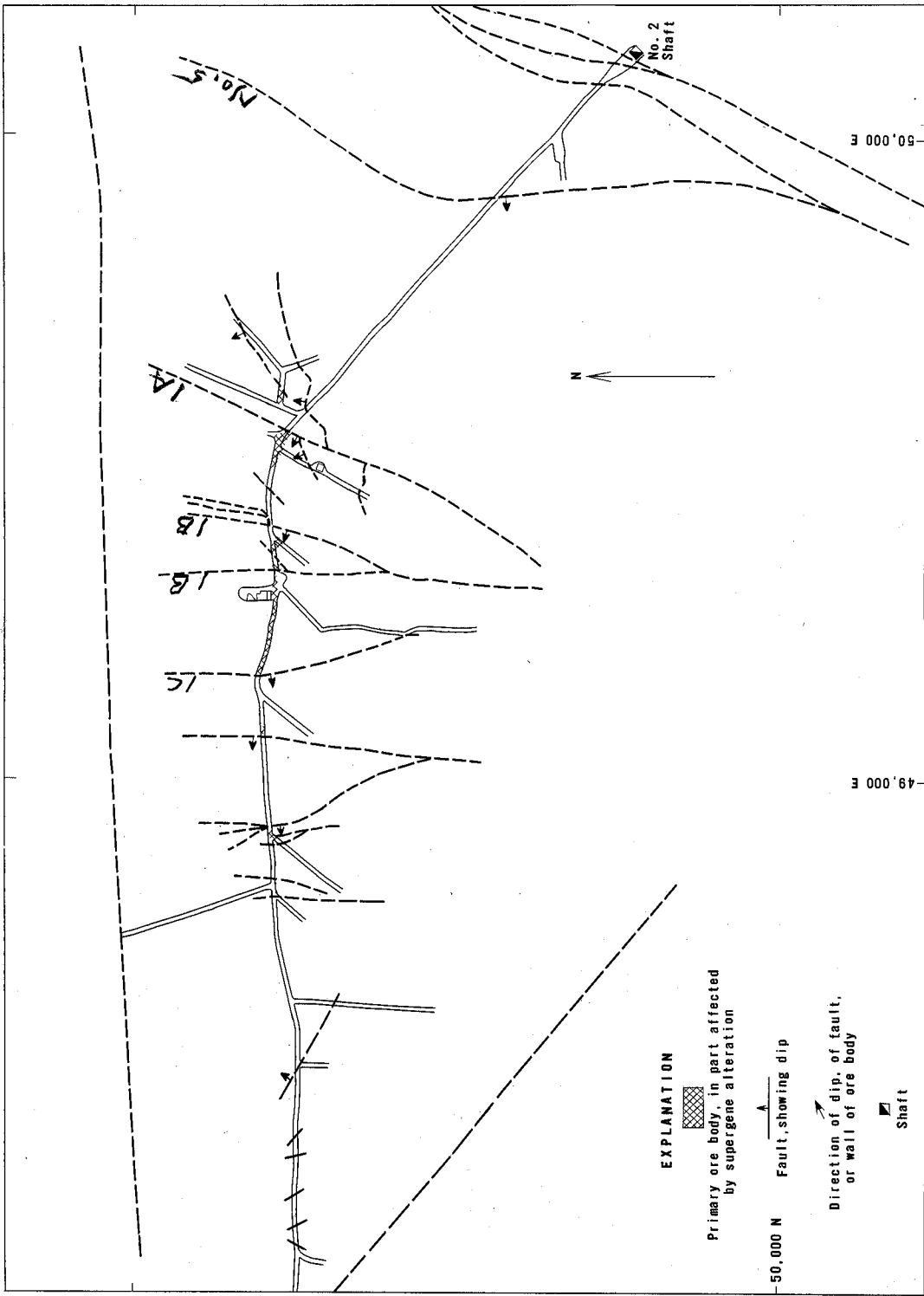


FIG. 8. Geologic Map, 700 level, Mountain City Copper Mine.

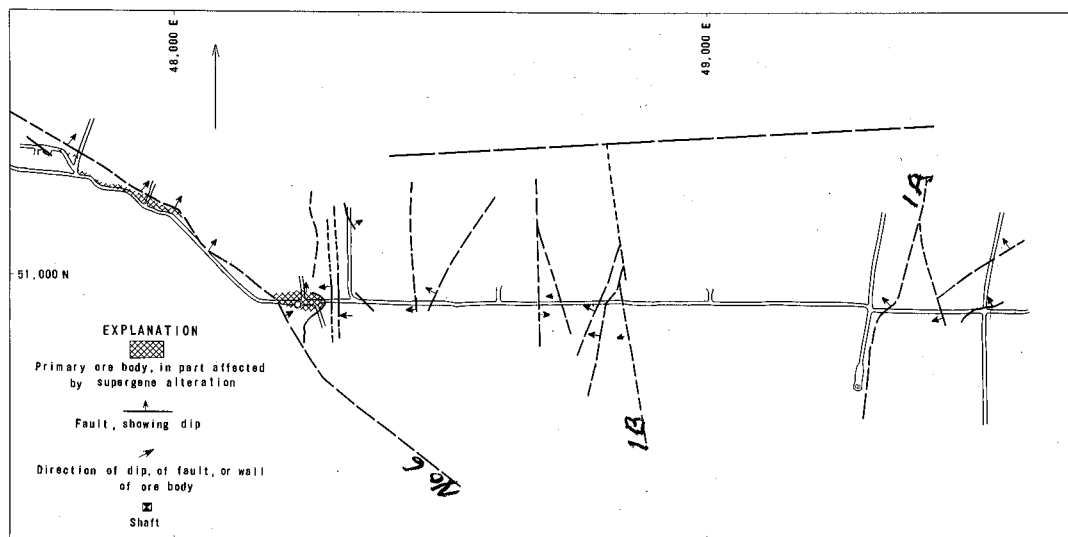


FIG. 9. Geologic Map, 1000 level, Mountain City Copper Mine.

ore body (Figure 11). In general, the supergene minerals become less abundant in direct proportion to the depth beneath the ground-water table. There are, however, deep prongs of secondary mineralization extending more than 200 feet below the top of the ground-water table along loosely consolidated permeable zones in the primary ore.*

The shales in the footwall of the "200" ore body in the east end of the mine contain secondary copper minerals that replace pyrite, and a large proportion of the chalcocite appears to have filled openings in carbonaceous shales. The chalcocite also occurs in rods of dark-gray quartz that are a common feature of these particular dark shales.

The nonsulfide copper minerals, cuprite,

* The irregularity of the lower surface of the supergene ore body may seem anomalous but is a consequence of the laws of ground-water flow and the great differences in permeability in the ore and the enveloping rock. The depth to which oxygen-bearing water can penetrate before reaction is dependent upon the length of path, the rate of flow, and the availability of reactive material. The path followed by any given element of oxygenated water is not necessarily a simple one, limited to the ground-water table and controlled as to direction and rate by the gradient of that table. It is rather to be thought of as a complex path, controlled by local differences in permeability so that a given amount of water may descend, along a particularly favorable zone, well below the ground-water table, move laterally, and rise to the surface again at the local stream-way level.

native copper, malachite, and azurite, which resulted largely from the oxidation of supergene copper sulfides, are found with chalcocite in "footwall shales" (the shales underlying the ore horizon). The rock thus mineralized forms the so-called "footwall supergene ore body," which extends to a horizontal distance of more than 600 feet south of the primary "200" ore body from which the copper originated. The secondary copper minerals in the "footwall shales" occur where the impervious "footwall" clayey alteration did not exist in the extreme eastern part of the "200" ore body or where transverse faults broke the seal and allowed the secondary solutions access to the shales in the footwall of the "200" ore body.

The copper in the footwall supergene ore-body is believed to have been derived entirely from the main ore body of the mine, presumably from the present oxidized zone, or from now-eroded parts of the ore body. It has been suggested in the past that this ore body represents the oxidation in place of primary copper minerals that formed a disseminated ore body, but all attempts to find, directly below the footwall supergene orebody, primary pyrite-chalcopyrite ore from which the supergene ore could have been derived have been unsuccessful. Sulfide, as well as nonsulfide minerals, are present in this ore body. The nonsulfide minerals are prevalent in the upper part of the ore body, but decrease downward as chalcocite increases. Nevertheless, nonsulfide minerals are still present in substantial amounts on the 300 level, and no absolute

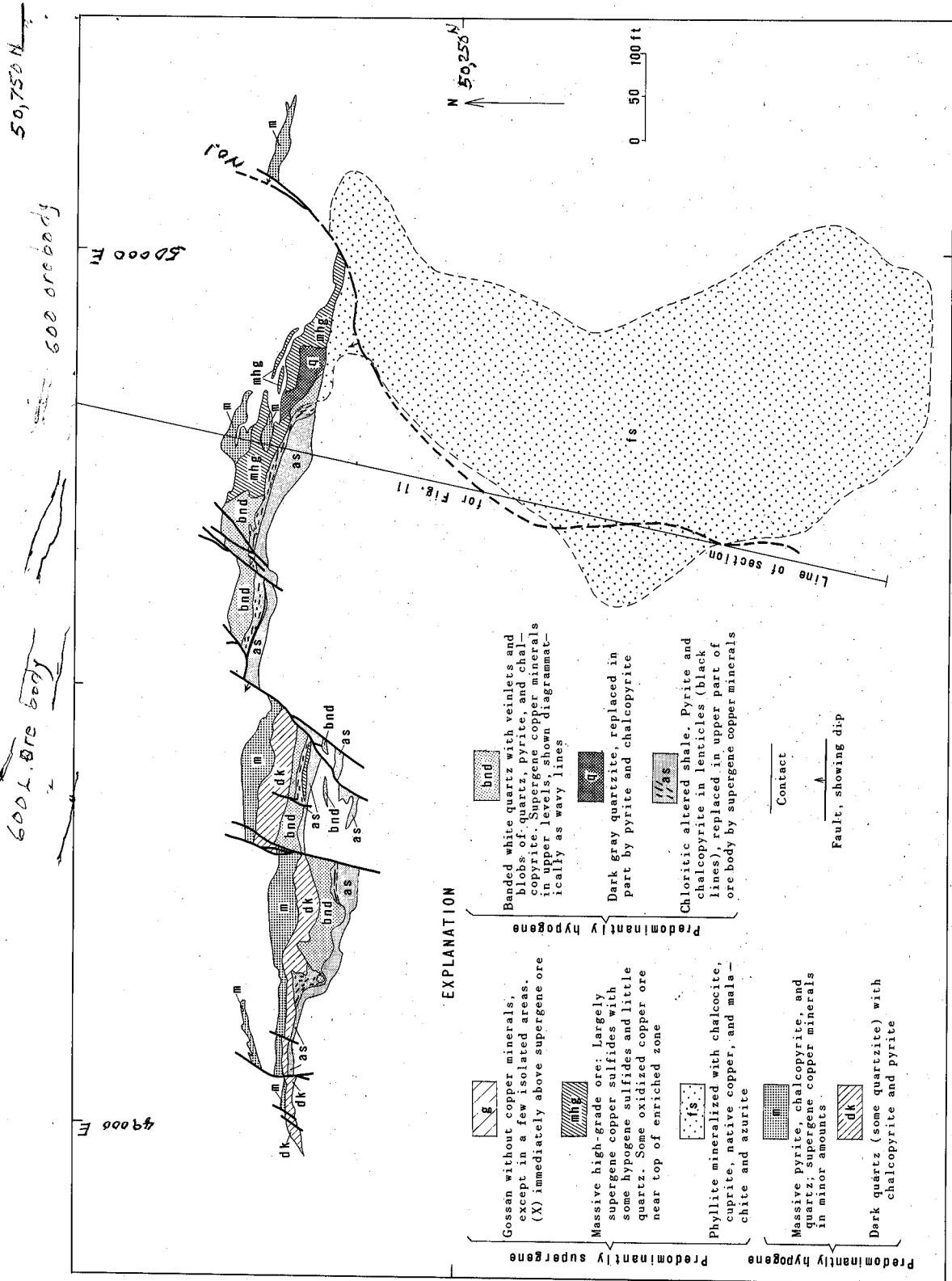


FIG. 10. Horizontal Section on 300 Level, Mountain City Copper Mine, showing distribution of ore types and location of section (Figure 11).

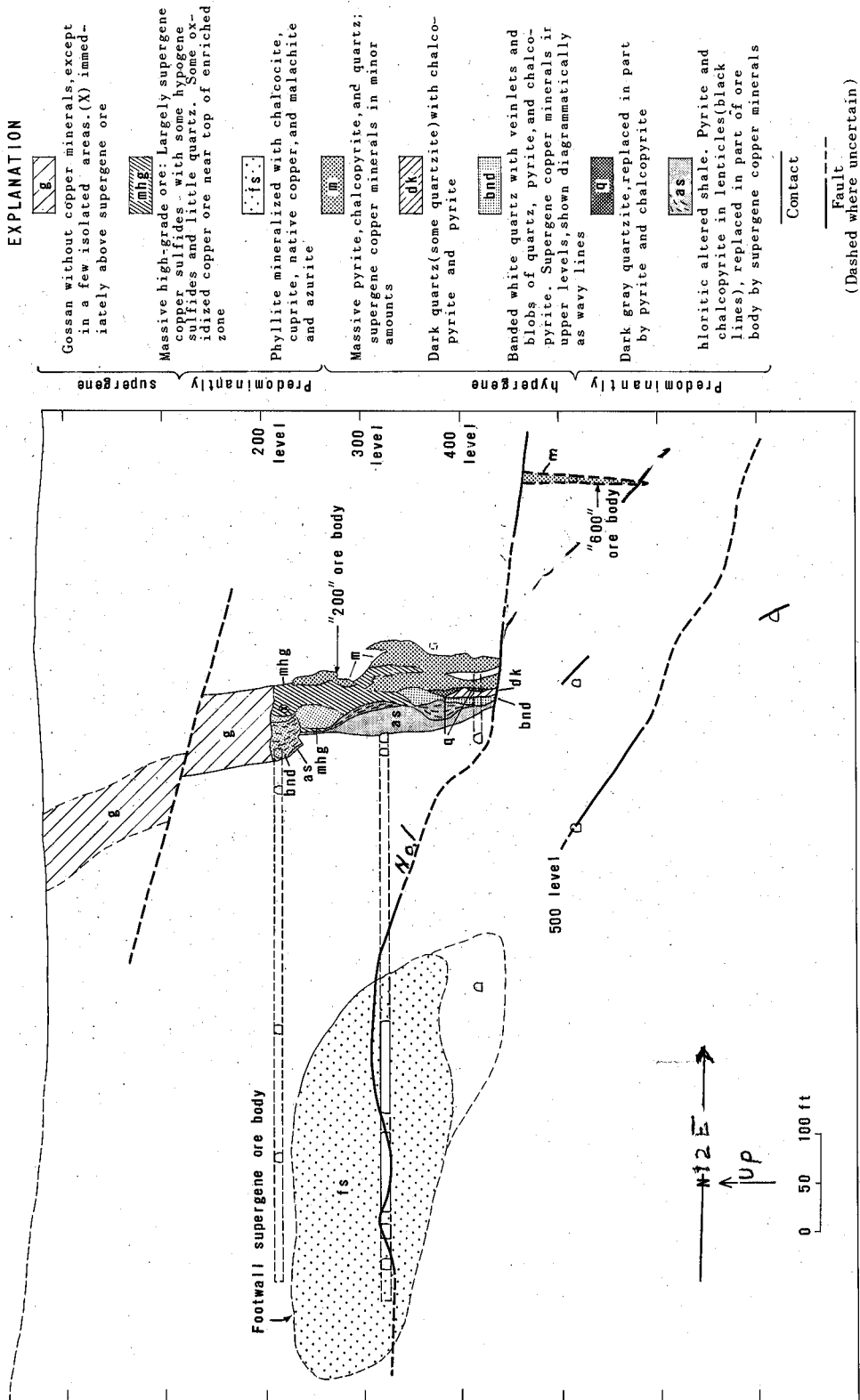


FIG. 11. Vertical Cross Section 2-10, looking N78°W, showing distribution of ore types.

lower limit was found. Some native copper was found as low as the 400 level. The total tonnage of the footwall supergene ore body is on the order of 600,000 tons containing approximately 1 per cent copper. Some of this ore body has been mined, but the mined areas are beyond the limits of the level maps presented herewith. The presence of supergene sulfide ore raises the question of the nature of the precipitant that has reacted with the supergene oxygenated solutions. For this we can suggest two sources: the widespread carbonaceous material in the Valmy phyllites and, probably more important, the disseminated pyrite that is present in small quantity, even in rocks remote from the ore body.

Oxide copper minerals also developed in a few restricted local areas directly above the supergene ore in the "200" ore body. In most instances, the oxide and secondary copper sulfide minerals constituted a "mixed" ore type that was shipped directly to the smelter.

WALL-ROCK ALTERATION OUTWARD FROM ORE BODIES The intensity of wall-rock alteration surrounding the hypogene ore bodies ranges over broad limits. The most intense alteration associated with the "200" ore body is in the shales immediately in the footwall of the hypogene sulfide lens. The chloritic and clayey alteration, however, does not exist around the extreme east end of the "200" ore body. Other than the highly altered shale mentioned above, which attains a thickness of more than 25 feet, the greater proportion of the carbonaceous shales of the ore horizon have a black, greasy appearance. They are described as being "woody" or "schisty." The shales in the hanging wall commonly, but not always, are less altered than those in the footwall. The alteration of the "ore horizon" rocks is more intense near sulfide lenses, but it persists for hundreds of feet along both strike and dip, beyond the ore lenses.

MINERAL TEXTURES Each hypogene ore type has its characteristic textures. The "massive" ore type is a hard rock that consists of an intimate mixture of quartz, pyrite, chalcopyrite, and rarely sphalerite. The "dark-gray quartzite" ore type is erratically silicified, and the sulfides, of which chalcopyrite is more abundant than pyrite, cut the quartzite in random directions. The "dark quartz" ore type is the result of complete silicification and is coarsely banded. The sulfides occur as streaks and blobs and only rarely are accompanied by later glassy white quartz, except near the gradational contact with the "banded white

quartz" type. The "banded white quartz" ore type has distinct layers that range from 0.25 inches to 1 inch in thickness. The attitude of the layering seldom is parallel to the attitude of the ore lenses. It has been suggested that the bands represent bedding planes, but this is debatable. The initial silicification of the "banded white quartz" ore type was completely pervasive and unaccompanied by sulfides. Subsequently the "banded quartz" was cracked, and glassy quartz, pyrite, and chalcopyrite were introduced, in that order. This "later surge" is represented by a myriad of tiny criss-cross veinlets in which any one or any combination of the three minerals may be present.

In the massive secondary ore, which occurs to a depth of approximately 50 feet below the water table, the original hypogene ore textures have been largely obliterated by the replacement by sooty and massive chalcocite. 130'
(Fig. 11)

MINERAL PARAGENESIS The "banded white quartz" ore type well demonstrates the mineral paragenetic sequence. The initial pervasive silicification stage was followed first by crackling of the rock, then by the mineralizing stage, with the successive introduction of quartz, pyrite, and chalcopyrite.

GRADES OF ORES IN VALUABLE METALS The average silver and gold content of the ores, which is quite low, is given in Table I. The silver and gold content of the ores apparently differs only from one ore type to another. There is no appreciable vertical or lateral change in gold and silver content within individual ore types. The grades for the direct-shipping and milling ores are shown in Table I.

Factors Controlling Form and Location of Ore Bodies

The known hypogene copper ore bodies have a definite stratigraphic control. They lie within a particular sequence of sediments consisting of largely black and gray shales containing minor quartzite lenses. There are many tight "Z" folds in the area of the ore bodies and the "ore horizon" sequence appears to be somewhat more pervasively deformed than other units of the Valmy Formation. Suggestions as to why this particular sequence is favorable for ore deposition, whereas adjoining shales are not, range from a structural explanation of greater distortion of the ore horizon to the possibility of the mineralization being controlled along an unconformity. No evidence of an unconformity, however, was recognized

in the mine area. The principal feature of the ore deposition is that it was restricted to a specific definite stratigraphic unit at a locus of pervasive intense deformation, *ie bedding fault*.

Replacement of the shales and quartzites, first by silica and later by a quartz-sulfide surge, left no recognizable evidence of paths of ore-solution introduction. *except for alteration?*

Effects of Metamorphism (Regional or Dynamic) on the Ores and Their Immediate Environment

Regional metamorphism in the mine area appears to be entirely pre-ore. No evidence of any effect from the quartz monzonite pluton has been found.

Summary of the Sequence of Geologic Events Required for the Formation of the Primary Ores

The geologic events began with the accumulation and consolidation of the sediments, followed by structural deformation into a north-dipping homoclinal structure, the intrusion and extrusion of andesitic and basaltic rocks (now represented by amphibolites), intrusions of porphyry dikes in the mine area, first-stage silicification and alteration, and second-stage mineralization consisting of glassy quartz, pyrite, and chalcopyrite.

ECONOMIC GEOLOGY—SECONDARY ORE

Supergene Sulfide Enrichment

Following the deposition of the primary ore, the region was extensively intruded by batholiths of quartz monzonitic to granodioritic composition. A long period of erosion, occupying part of the Cretaceous and most of the Paleocene, followed. Volcanic eruptions began in late Eocene (29, p. 32) and continued to the middle Pliocene. Intermittent gravity faulting and continuing erosion prevented the development of any erosion surface of low relief throughout the Tertiary.

The climate during the Tertiary, in this area, is best indicated by the nature of the flora of the Dead Horse Tuff, of late Eocene age (25, p. M7), intensively studied by Axelrod (29, p. 24-26), who concludes that the precipitation at that time was near 50 to 60 inches and that the climate was cool and temperate.

Axelrod also concluded that the altitude in Copper Basin (25 miles to the east) was about 3000 feet lower than at present.

The fundamental conditions evident in the supergene enrichment of the Mountain City copper ore body are that the wall rocks of the ore body were argillaceous and quartzitic; the primary ore body consisted of quartz and abundant sulfides, but no carbonates; and there was an impervious clayey layer developed during the alteration stages along the greater part of the footwall of the "200" ore body, thereby confining most of the copper-rich supergene solutions to the ore body itself. Ample precipitation permitted complete flushing of the copper-bearing solutions to the water table, and abundant pyrite in the ore body resulted in highly acid solutions. The level of the nearest drainage channel to the mine, Mill Creek, is about as deep as that to which downcutting has reached since the hypogene ore body was deposited. These conditions resulted in a complete leaching of the ore body in the oxide zone, and, consequently, the gossan showed negligible copper.

Oxide Enrichment or Residual Concentration

No residual nonsulfide minerals were left in the gossan except in a few isolated spots immediately overlying the chalcocite ore. There are, however, nonsulfide copper minerals overlying the secondary ore body which occurs in the "footwall shales" south of the east end of the ore body. Some of these nonsulfide copper minerals are found in surface excavations.

Paragenesis of the Secondary Ore and Gangue Minerals

Sooty and massive chalcocite apparently preferentially replaced chalcopyrite before pyrite (4). The chalcopyrite commonly was replaced by bornite and covellite before chalcocite was developed, particularly in the deeper parts of the supergene zone.

Bornite and covellite also occur with chalcocite immediately beneath the top of the water table, and the paragenesis here is ill-defined.

Physical and Chemical Controls Affecting the Formation of Secondary Ores

- (1) A quartz-sulfide primary ore enclosed in argillaceous rocks.
- (2) An abundance of sulfides.

- (3) Reasonably consistent and copious annual precipitation.
- (4) Complete leaching of the copper minerals in the oxide zone and abrupt change of environment at water table.
- (5) Loose, permeable zones in the hypogene ore that allowed the secondary solutions to penetrate and copper to be deposited as supergene minerals more than 200 feet beneath the top of the water table.

SUMMARY AND ORE GENESIS

The features of geologic evidence most significant to any discussion of the genesis of the Mountain City ore body may be summarized: the ore deposits of the Mountain City Copper Mine occur in a stratigraphically restricted zone of black and gray phyllite and associated minor quartzite lenses of the Valmy Formation. In this zone there is, in the mine area, more intense deformation than in the Valmy Formation elsewhere. The ore deposits have a broad alteration envelope. Ore lenses both transect and parallel bedding within the restricted stratigraphic unit. A few narrow altered porphyry dikes of uncertain affinity (not shown on the mine maps and sections) have been found in the mine, although none is in contact with the hypogene ore.

Some chalcopyrite-pyrite mineralization is present in the metavolcanic rocks of the Nelson Formation, a few thousand feet west of the mine.

Practically, the primary metallic minerals of the Mountain City Copper Mine ore are limited to pyrite and chalcopyrite; spalerite is very minor and galena rare; gold and silver are exceedingly minor, even economically; no silver minerals have been recognized.

The texture of the ores, the structure of the ore body, and the relation to epigenetic structures in the country rock all indicate the epigenetic nature of the ore deposit. The principal question that arises is the nature of the controls, other than structural ones, that localized the deposit. Conventionally, epigenetic ore deposits are commonly attributed to genetic connections with bodies of igneous rock, if any are available within reasonable distance. Few, of course, would suppose the ore to be derived from the magma now represented by the exposed body of igneous rock but rather that the two are collaterally related to derivation from a common ancestor. Igneous rock bodies younger than the Valmy Formation in this area fall into two groups: one includes

the late Paleozoic greenstones and minor di-basic intrusives associated therewith, principally exposed northwest of the mapped area; the other includes the Cretaceous quartz monzonite pluton in the Mountain City area.

As direct means for determining the genetic relation of the ore deposit to one or the other series of igneous rock are lacking, indirect means by comparison with deposits in other areas must be resorted to, inconclusive though such comparisons must be.

Consideration of the nature of other ore deposits in this region, clearly associated with one type of igneous rock or the other, shows that the ore deposit of Mountain City Copper Mine has no close family resemblance to ore deposits clearly associated with either the quartz monzonite or the greenstones. Copper minerals are negligible in known ore deposits that are clearly related to the quartz monzonite pluton; most of these are either gold-quartz veins with minor galena, sphalerite, pyrite, and chalcopyrite or contact metasomatic scheelite deposits in calcareous country rocks with very minor amounts of copper sulfide minerals. No other workable copper deposits such as the Mountain City Copper Mine have been found in the Paleozoic rocks in this area.

There remains, therefore, only the expedient of comparing this ore deposit with other deposits, in other areas, where the genetic relations are clearer. It has not proved difficult to find descriptions of deposits resembling the Mountain City Copper Mine in many particulars.

One of the principal types of copper deposits described by Schneiderhöhn (22, p. 121, 125), the "Kata- to mesothermal pyrite stocks as replacements and impregnations of silicates (Rio Tinto Type)" includes, according to Schneiderhöhn, several ore deposits that seem to resemble this one closely. The Rio Tinto pyrite deposits in the province of Huelva, Spain, however, differ in one important particular, in that they are closely associated with bodies of rhyolite porphyry and keratophyre. This association may, however, be accidental; Finlayson (2) considered that the ores are later than diabase dikes and sills, the latest important intrusive bodies. Williams (7, p. 607) pointed out that the diabase rocks interdigitate with the slates and are slaty toward the margins, but he arrived at no conclusions concerning the relative age of ore and mafic rocks. Elsewhere in the province of Huelva, both pre- and post-mineralization diabase is recorded. Williams (24, p. 492) recognized that some of the quartz porphyries are rhyolitic

lava flows and pyroclastic deposits. Kinkel (21, pp. 1078–1079) agreed that the rhyolite is in part pyroclastic and thought that the iron sulfide and other metallic elements were deposited in the pyroclastics toward the end of the period of volcanism and the beginning of marine sedimentation. The copper is thought to have migrated during Hercynian time. Kinkel points out that many massive pyrite deposits in the Philippines, Japan, Alaska, Shasta County, and the West Belt in California, most of the deposits in Canada and Scandinavia, and many of the deposits of central Europe, Cyprus, Turkey, and the Urals are in sodic felsic or mafic volcanics with much pyritic material and associated eugeosynclinal sediments. Callaghan (30) regards the cupreous pyritic ore of Cyprus as a replacement of a favorable zone in a volcanic environment.

Other deposits placed in a similar class by Schneiderhöhn are those of the Urals. These have been subdivided by Zavaritsky (3, p. 145–151) into several classes having somewhat different mineralogy. All are emplaced in mafic volcanic rocks and tuffs. The type Pymnisko-Klutchevsky seems to resemble the Mountain City occurrences most closely. Zavaritsky believed that all are related to quartzose albitophyres. A number of somewhat similar pyritic deposits, some of great importance, have been described from Japan (5, p. 155–160). All of these are associated with mafic igneous rocks and were formed by replacement or fissure filling. Granitic rocks are absent or are later than the ore deposits, as at the Makimine mine (13). Imai (19) regarded one such deposit (the Okuki mine) as formed by hydrothermal metasomatism genetically related to the intrusion of mafic igneous rocks and associated folding. The associated chloritic alteration shows the gradational relation of these deposits to Schneiderhöhn's (22, p. 125) "Mesothermal chlorite bearing chalcopryrite veins and mineralized shear zones in metamorphic basic rocks ('Chloritic copperformation')." Deposits placed in this class by Schneiderhöhn include those of the Foothill Copper Belt in California, but most of these are characterized (9, p. 20) by abundant sphalerite as well as by pyrite and chalcopryrite; substantial amounts of gold and silver are present in many. A few mines of this belt, notably the Newton Mine (10, p. 49–60), consist of lenses of massive pyrite and chalcopryrite, with little zinc, gold, or silver, replacing low-rank schists and greenstone. Pyroxenite and quartz-porphyry are found in the general area; the ultramafic body is post-metamorphism.

A somewhat similar deposit of massive sulfide is that of the Island Mountain Mine in Trinity County, California (17, 1957), where quartz, pyrrhotite, chalcopryrite, and cubanite, with rare sphalerite, galena, arsenopyrite, and bornite replace graywacke of the Franciscan Formation, associated with andesite and diabase. No granitic rocks are found anywhere in the vicinity. Schneiderhöhn also places in this class the copper deposits of Prince William Sound, Alaska, the geology of which has been summarized by Moffit and Fellows (11, p. 47–77). These are more or less massive sulfide replacements of greenstone and graywacke by pyrite, pyrrhotite, chalcopryrite, and cubanite. Sphalerite and galena are much rarer, and the content of gold and silver quite low.

Saksela (20) has described economically unimportant veins in extrusive or intrusive mafic rocks, now metamorphosed, in Fennoscandia. These are characterized by chalcopryrite, cubanite, and valleriite, locally by pyrrhotite and pyrite. Galena and sphalerite are very rare, and the gold and silver content is low. Saksela agreed with Eskola that these deposits were the product of post-volcanic exhalations. No intrusives younger than the greenstones are found in the area.

Wells (14, p. 104) recognized this type of massive pyritic copper deposit as belonging to his "ensimatic geosynclinal" suite. He believed that the hydrothermal solutions and metals were "sweated out" of the rocks in the geosyncline when these rocks were transformed to green rocks or amphibolitic gneiss or even into granitic rocks.

Borchert (18, p. 18) also regards the "Chloritic copper-formation" as one of the types of ore deposits that are connected with "geosynclinal juvenile-basaltic magmatism."

Gümüş (27) has described the relations of Ergani Maden, a Turkish deposit of cupreous pyrite that bears strong resemblance to deposits at the Mountain City Copper Mine. De Wijkerslooth (8) has described mineralogical relations, however, that would seem to put it in a class transitional to high-temperature hydrothermal deposits.

We, therefore, consider that the weight of probability is on the side of the hypothesis that the Mountain City copper deposit is genetically connected with the late Paleozoic mafic vulcanism rather than with the Cretaceous quartz monzonite pluton, although it is unlikely that absolute proof can ever be offered. This hypothesis may have practical consequences in guidance of future prospecting, as it suggests that other deposits of this

type may be found in eugeosynclinal terranes of the west, whether or not they are associated with younger plutonic masses. Deposits of this type that are transitional to hypothermal may have pyrrhotite as the principal iron sulfide and be favorable for prospecting by magnetometer; those that are of lower-temperature origin and lack pyrrhotite may be sought by conductivity, self-potential, or induced-potential methods. The copper-iron ratio is generally low enough that only the massive sulfide bodies are minable.

The primary ore is estimated to have averaged between 6 per cent and 7 per cent copper before being enriched by supergene processes. The siliceous high-sulfide ore deposits and argillaceous wall rocks, the abundant precipitation in the Mountain City area, the confining impermeable altered shale on the footwall of the greater part of the "200" ore body, which restricted most of the enriching solutions to the ore body itself, all combined to make a textbook example of a completely leached gossan and the development of an extremely rich supergene ore.

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53. Ore Deposits of the Park City District with a Contribution on the Mayflower Lode

MARVIN P. BARNES,* JOHN G. SIMOST†

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* United Park City Mines Company, Heber City, Utah.

† Hecla Mining Company, Heber City, Utah.