Massive Sulfide Deposits Near Shellabarger Pass, Southern Alaska Range, Alaska

By BRUCE L. REED *and* G. DONALD EBERLEIN

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A description and discussion of copper- and zinc-bearing sulfide deposits in eugeosynclinal sedimentary and mafic volcanic rocks

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MASSIVE SULFIDE DEPOSITS NEAR SHELLABARGER PASS, SOUTHERN ALASKA RANGE, ALASKA

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ABSTRACT

Copper- and zinc-bearing sulfide deposits near Shellabarger Pass occur mainly as replacement bodies in a north-trending structural trough of marine sedimentary and mafic volcanic rocks of probable Triassic and (or) Jurassic age. The lower part of the sequence is interbedded chert, dolomite, siltstone, shale, volcanic graywacke, basaltic aquagene tuff, sedimentary breccia, and conglomerate. These rocks are overlain by submarine basaltic pillow flows and subordinate interbedded agglomerate, flow breccia, and tuff. This eugeosynclinal assemblage is believed to rest uncomformably upon sedimentary rocks of Paleozoic age.

The sulfide deposits are localized in the lower part of the eugeosynclinal sequence near the keel of the structural trough in sedimentary rocks of favorable lithology and texture. Many deposits also appear to be structurally controlled by subsidiary northwest-trending shear and fracture zones considered part of a larger northwest-striking lineament. The deposits are of three general types: (1) lenticular massive sulfide bodies, (2) sulfide minerals that replace carbonate-rich beds, and (3) fracture fillings, mainly in chert and siltstone. Types 2 and 3 are of relatively minor importance.

Mineralogically, the deposits consist of a very fine grained mixture made of, in order of decreasing abundance, pyrite, marcasite, sphalerite, chalcopyrite, galena, and pyrrhotite. Sphalerite, chalcopyrite, and galena together rarely constitute more than 15 percent of the total sulfide minerals. The gangue minerals are siderite. calcite, quartz, and dolomite. During the first phase of mineralization, favorable host rocks were replaced by pyrite, which locally is altered to marcasite. The resulting replacement texture strikingly resembles that of certain impure sandstones (wackes) in the lower part of the eugeosynclinal sequence. Subsequent fracturing created open spaces that became depositional sites for copper-, silver-, and zinc-bearing minerals and facilitated their replacing early pyrite and marcasite.

The tenor of the massive sulfide bodies averages between 1 and 1.5 percent copper, 0.8 and 1.7 percent zinc, 0.9 and 2.4 ounces per ton silver, and less than 0.5 percent lead. There is a rough direct variation of silver content with lead.

The probable source of the metals was the eugeosynclinal sedimentary and volcanic rocks. Specific controls of the deposits included adequate ground preparation and favorable compositions and permeabilities of host rocks. Fault and shear zones served as feeder channels for mineralizing fluids.

INTRODUCTION

Massive fine-grained copper and zinc-bearing pyritiferous sulfide deposits occur north of Shellabarger Pass in the southern

Alaska Range. Although the deposits may not be commercially exploitable at present, they are considered to be of special significance because such deposits have not previously been known in this little-prospected part of the Alaska Range and they have many similarities with economically important massive sulfide deposits elsewhere in the world. It is hoped that the geologic descriptions and guidelines presented in this report will contribute to the discovery of nearby additional sulfide bodies and stimulate a regional search for new occurrences.

The deposits were discovered in 1967; but because of inclement weather, they could not be examined in detail then. In 1968 the authors spent 10 days sampling and mapping the deposits; they examined them again briefly in late August of 1969 when the snow had melted, better exposing the rocks.

The deposits are in a remote part of the Alaska Range, 2 miles north of Shellabarger Pass, approximately 35 miles east of Farewell and 130 miles northwest of Anchorage (fig. 1). The exposed deposits are between 4,450 and 4,650 feet altitude on the west edge of a small north-flowing glacier (fig. 2) in the SE¼ NW¼ sec. 35, T. 29 N., R. 19 W., Talkeetna C–6 quadrangle. There are no roads or trails in the area. The deposits are best reached by helicopter, although ski-equipped aircraft can land on the glacier adjacent to the deposits when snow conditions are suitable. Properly equipped aircraft can also land in the broad valley at the headwaters of the Dillinger River. The Federal Aviation Agency maintains a 5,000-foot gravel runway at Farewell. The nearest major source of fuel and supplies is Anchorage.

The deposits are in rugged terrain with a relief of 3,500–4,000 feet. Alpine glaciers are abundant in the nearby higher mountains, which rise to an elevation of 6,700 feet. Alluvial deposits mantle the broad valley floors; talus covers the lower parts of steep valley walls. There is virtually no vegetative cover near the deposits.

Geologic maps are not available for this part of the Alaska Range. The only published geologic information on the area is an open-file report giving results of reconnaissance stream-sediment sampling (Reed and Elliott, 1968). The authors acknowledge helpful discussions about the geology of the deposits with James McDougall and Stanley Charteris, of Falconbridge Nickel Mines, Ltd.

GEOLOGY

The Shellabarger sulfide deposits occur near the core of a north-trending synclinorial structural trough composed of a eu-

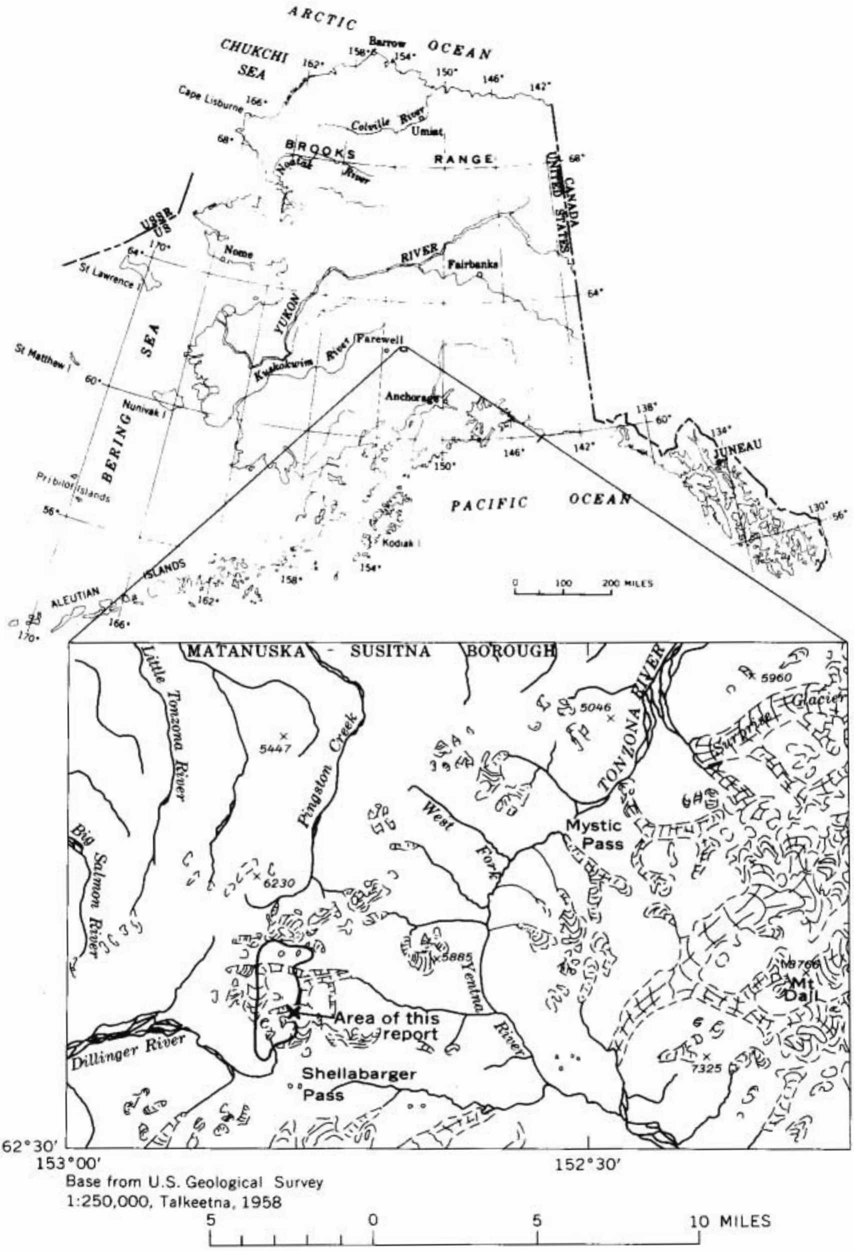

FIGURE 1.—Index map showing location of massive sulfide deposits near Shellabarger Pass. Heavy line is the approximate contact between the mafic volcanic flows and underlying eugeosynclinal sedimentary rocks (M. B. Estlund, oral commun., 1970).

FIGURE 2.—Oblique aerial view of massive sulfide deposits (arrow) beside small unnamed glacier. The high cliffs above the sulfide deposits are chiefly pillow flows. View south.

geosynclinal sequence of marine sedimentary rocks and mafic volcanic rocks believed to be several thousand feet thick. The lower part of the sequence is chert and dolomite, chert, shale, and siltstone, volcanic graywacke, aquagene tuff and breccia, and sedimentary breccia and conglomerate. These rocks are overlain by at least 2,000 feet of basaltic pillow flows which form the central part of the structural trough (fig. 1) ; outside the mapped area (M. B. Estlund, oral commun., 1970), pillow basalts are locally interbedded with the underlying eugeosynclinal sedimentary rocks. The sulfide deposits are localized within a zone of prominent northwest-trending faults and shear zones that may belong to a larger, northwest-striking structural lineament that transects the trough.

Our reconnaissance and that of M. B. Estlund (written commun., 1970) indicate that these eugeosynclinal rocks rest unconformably (?) upon a "basement" of interbedded green to gray chert, medium- to dark-gray limestone, thin-bedded tan-weathering quartzose sandstone with interbedded siltstone and chert-pebble conglomerate, dolomitic calcarenite, and polymictic conglomerate.

Fossil corals, cephalopods, and brachiopods collected from a thin unit of the gray limestone at Shellabarger Pass are considered to be of Late Devonian age (C. W. Merriam, written commun., 1970).

No identifiable fossils were found in the eugeosynclinal assemblage that contains the sulfide deposits. However, the apparent discordance between these rocks and underlying Paleozoic units, which are markedly different in composition and origin, and their lithologic similarity with parts of other eugeosynclinal sequences in the same province, although many miles distant, suggests that they are of Mesozoic age, probably Triassic and (or) Jurassic.

BEDDED ROCKS

The mapped bedrock units (pl. 1) are described in apparent stratigraphic succession from oldest to youngest.

Chert unit

A sequence of brittle dark-gray thin- to medium-bedded practically carbonate-free chert with an exposed thickness of about 100 feet is probably the oldest stratigraphic unit mapped. The lowermost exposed chert beds are in fault contact with compact gray medium- to thin-bedded siltstone. The chert grades upward into the dolomite-chert unit through a stratigraphic interval of about 10 feet. Individual chert beds range from 4 to 10 inches in thickness and are broken into blocks and slabs along transverse steeply dipping joints.

Very fine-grained pyrite, clearly discernible under the hand lens, is abundantly disseminated throughout the rock and may reflect a euxinic depositional environment. Later primary chalcopyrite and pyrite and secondary malachite and azurite locally coat joint and bedding-plane surfaces.

Dolomite-chert unit

More than 200 feet of unfossiliferous thin- to medium-bedded light-yellowish- to orange-brown-weathering dolomite with thin interbeds of medium-gray chert is exposed in the northern part of the mapped area (fig. 3). The ratio of dolomite to chert ranges from about 3:2 in the uppermost exposed beds to approximately 3:7 at the bottom of the unit near its transitional contact with the underlying chert unit.

Thin veinlets and scattered disseminations of pyrite, chalcopyrite, and sphalerite, together with secondary malachite and azurmapping, we recognize three principal subunits on the basis of relative abundance of the main lithic end members; a chert-shale subunit; a shale-chert-siltstone subunit; and a siltstone subunit.

The chert-shale subunit is composed of dark-gray medium to very thin bedded chert interbedded with dark-gray shale and subordinate siltstone (fig. 4) that makes up 10–60 percent of

FIGURE 4.—Chert-shale subunit showing thin- to medium-bedded chert (resistant) with thin shale partings. Individual chert beds generally pinch out within a few feet along strike.

the unit. Thin interbeds of siltstone and sandy siltstone generally do not exceed 20 percent of the nonchert fraction. Some carbonate minerals, mainly dolomite, invariably are present and tend to be preferentially concentrated in the silty beds. Locally, however, the carbonate minerals are concentrated in thin interbeds and lenses. One sample of chert contains numerous carbonate-rich spheroidal masses that have an average diameter of 1 mm. Microscopic studies reveal crystalline aggregates of calcite set in a micro- to cryptocrystalline groundmass of chalcedonic silica and clay-size particles. These masses are believed to be microconcretions rather than oolites.

A nonfissile variant of the chert-shale subunit (fig. 5) is indurated, very thinly interbedded (down to a fraction of a centimeter) siliceous and calcareous claystone, sandy siltstone, and mapping, we recognize three principal subunits on the basis of relative abundance of the main lithic end members; a chert-shale subunit; a shale-chert-siltstone subunit; and a siltstone subunit.

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The nonfissile chert and shale evidently were significant in localizing the sulfide minerals. Microscopic study of thin and polished sections of the representative sample illustrated in figure 5 suggests that sulfide-bearing solutions entered the host rock through small premineral fractures, selectively replacing chemically favorable carbonate-rich laminae. The relations also suggest that the greater porosity and permeability of certain beds may have controlled sulfide mineral deposition. Figure 5 also illustrates the differential compaction of underlying laminae and depositional thinning over an exotic fragment of intraformational chert.

With an increase in siltstone and a corresponding decrease in chert, the chert-shale subunit grades into a shale-chert-siltstone subunit. Rocks of this subunit contain 30–60 percent shale, 10–35 percent chert, and 10–35 percent siltstone. The shale and siltstone are medium to dark gray and are thickly laminated to thin bedded. The chert is dark gray and occurs as thin beds or lenses. Calcareous phases are locally developed. The presence of aquagene tuff lenses, together with identifiable tuffaceous constituents in the siltstone, suggests a close stratigraphic relation with the basaltic aquagene tuff and breccia unit described below.

The siltstone subunit is compact, light to medium gray, thinly to thickly laminated, and has the general appearance of the banded mudstones commonly identified with molasse assemblages. Lenses and interbeds of chert and shale constitute less than a third of the rock by volume. Some detrital tuffaceous material is generally present.

Volcanic graywacke

The volcanic graywacke rocks are well exposed on the lower bluff south of the massive sulfide bodies, where they are typically massive compact marine volcaniclastics that weather medium dark gray to olive gray and have a greenish chloritic sheen on sheared surfaces. The volcanic constituents are generally 75 percent or more of these rocks by volume.

Fine- to medium-grained graywacke predominates, but beds of loosely packed conglomerate and breccia with angular fragments up to several inches in maximum diameter also occur locally. Fracturing of the fragments has occurred through rather than around the grains.

Petrographically, the graywacke has the fabric of a microbreccia composed predominantly of angular, rather poorly sized, moderately closely packed basaltic mineral and rock fragments

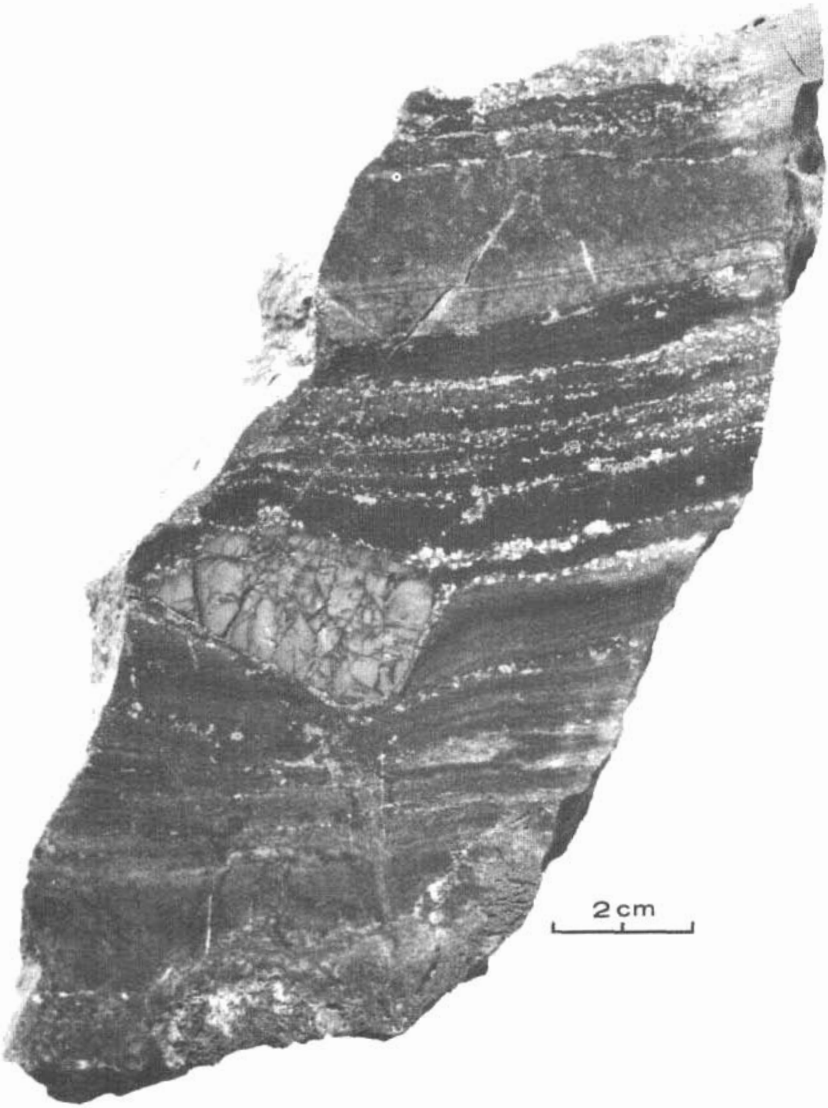

FIGURE 5.—Polished slab of thinly laminated to thin-bedded calcareous siltstone and sandy siltstone of the chert-shale subunit. Sulfide minerals (light) have selectively replaced carbonate-rich laminae. Note exotic fragment of intraformational chert that has not been replaced by sulfide minerals.

chert. The bands in the rock strongly resemble varves. Contacts between individual beds generally are sharp and commonly show scour-and-fill structures. Some laminae show internal or graded bedding.

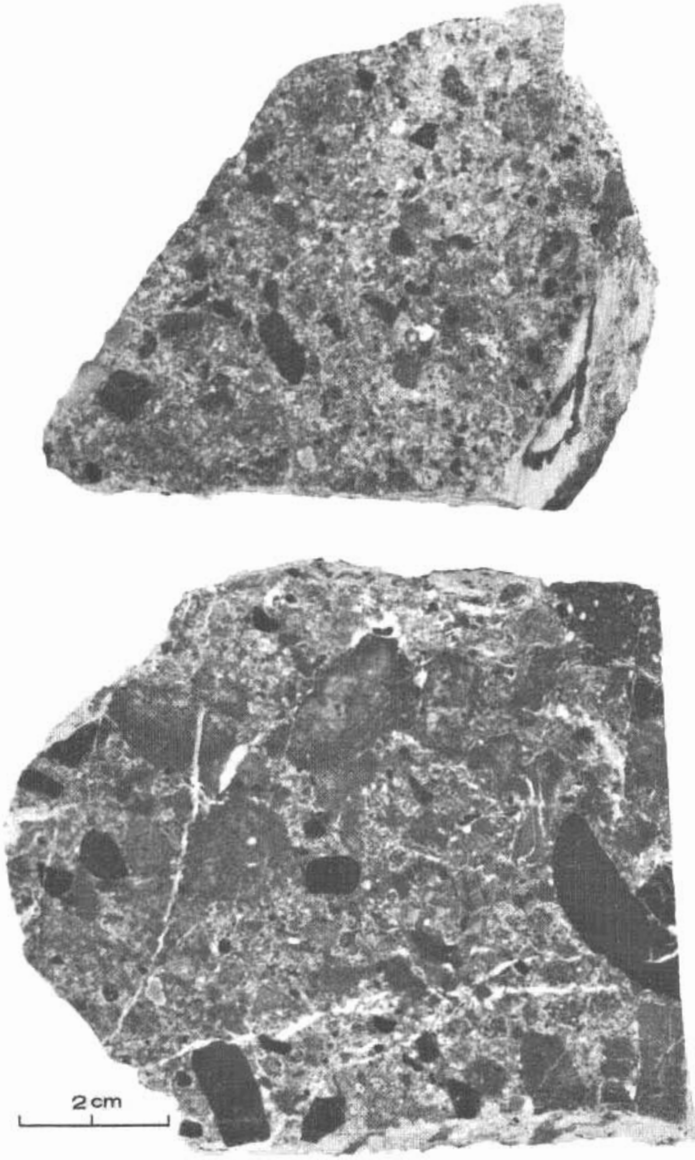

FIGURE 7.—Slabbed sections of basaltic aquagene tuff showing intraformational clasts of chert, basalt, and siltstone in a matrix of comminuted chloritic volcanic detritus and sparry calcite cement.

Carlisle (1963), the formation of the angular vitric clasts and shards may be the result of autocomminution upon quenching. As indicated by the poor size sorting and the tendency of some nonvitric clasts, including quartz and chert, to be rather well rounded, transport by high-energy bottom currents and (or) slumping must have occurred at some time during the deposition of the unit. However, the high angularity of the vitric fragments suggests they formed in situ or were carried very short distances with the other clastic components.

Sedimentary breccia and conglomerate

The youngest sedimentary unit believed present in the area mapped is sedimentary breccia and conglomerate, exposed in the bluff above the upper massive sulfide body in the core of a syncline (pl. 1, section *A–A′*). Breccia predominates and typically consists of a rather chaotic polymictic assemblage of angular to subangular megaclasts in the cobble-to-boulder size range loosely packed in an equally poorly sized greenish-gray calcareous graywacke matrix (fig. 8). With increasing roundness of the larger clasts, the rock becomes more conglomeratic. This is commonly accompanied by an increase in the abundance of megaclasts. However, as the volume of matrix always exceeds that of the megaclasts, the rock has a disrupted framework. Internal primary

FIGURE 8.—Sedimentary breccia exposed in the core of syncline in the southwest part of the mapped area (section A–A′, pl. 1). Larger clasts (white) are medium-gray limestone thought to be correlative with an Upper Devonian limestone at Shellabarger Pass. (Largest clasts are 3 feet maximum diameter.)

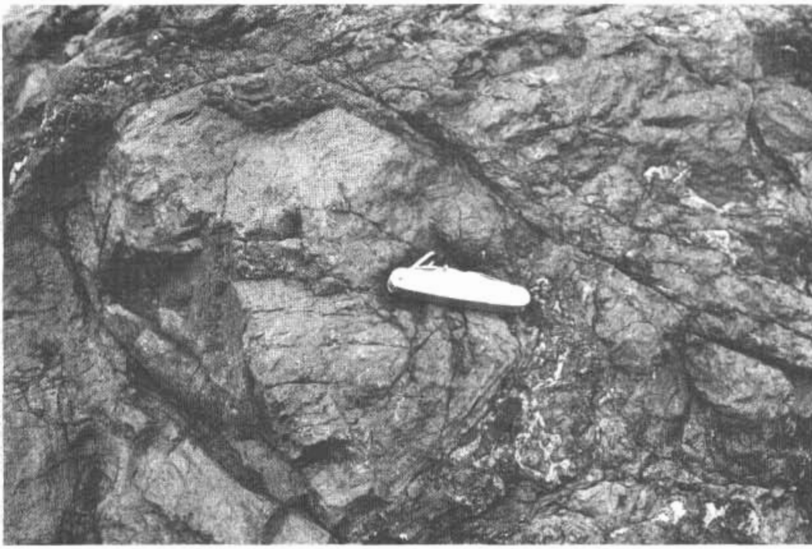

FIGURE 9.—Poorly developed pillow in sheared basalt. The outcrop is in the southwest part of the map area crossed by section A–A′ (pl. 1).

diameter are preserved in exposures of relatively flat-lying flows vertically above the sulfide deposits 800 feet to the west.

The extrusive basalt is typically porphyritic with glomeroporphyritic clots and phenocrysts of normally zoned calcic plagioclase and rare clinopyroxene set in an intersertal to intergranular groundmass of calcic plagioclase microlites, granular clinopyroxene, and minor relict glass that is devitrified and deuterically altered to chlorite, "chlorophaeite," and montmorillinoid clay of undetermined composition. The plagioclase is typically labradorite, but species as calcic as bytownite have been reported (S. N. Charteris, oral commun., 1969). The groundmass feldspar microlites have either a diabasic or trachytic arrangement, depending upon their response to flowage. The clinopyroxene is a nonpigeonitic, nontitaniferous variety. Several specimens examined contain rounded patches and aggregates of crysotile, saponite(?), and delessitic chlorite that suggest the former presence of olivine in amounts up to about 8 percent by volume. Visual estimates of the observed abundance ranges of principal mineral constituents are given in table 1.

Although tholeiitic basalts tend not to be porphyritic, these rocks are tholeiitic on a modal basis, in accordance with the definition of Kennedy (1931, 1933), as broadened by Tilley (1950) upper sulfide body is within the trough of one of the minor open folds. The axis of this minor fold plunges N. 65° W. at about 20°. It is not known whether these minor folds represent disharmonic folding during the same general period of deformation which produced the major syncline, or are part of a later deformation, coeval, perhaps, with formation of the zone of northwest faulting.

The southern part of the major syncline is offset slightly to the east by a fault that trends northeastward. About 40 feet south of this fault, sedimentary breccia, exposed in the center of the syncline, and the underlying aquagene tuff and chert-shale units are truncated by a fault that strikes northwest. South of the latter fault, the gross structural features remain the same as north of the fault (section *C–C′*), but extrusive(?) basalt is exposed in the keel of the syncline. In detail, however, these relations are considerably more complex as a result of movement and crumpling related to numerous shears that dip northeastward at gentle to moderate angles. Figure 10 illustrates the juxtaposition of lithologic units on the southwest limb of the main syncline as exposed at the south end of the prominent bluff.

FIGURE 10.—Southwest limb of the major syncline cut by northeast-dipping faults. The limb of the syncline is composed of chert and shale (cs), aquagene tuff (t), and basalt (b). Basalt also forms the keel of the syncline. The exposure in foreground is approximately 60 feet high and is 40 feet south of section *C–C′* (pl. 1). View north.

a minor syncline, its continuation downplunge would appear to be limited because the limb of the major syncline on which the minor fold is located reverses dip about 300 feet southwest of the outcrop (section *A–A′*, pl. 1). If, however, extensive replacement has occurred in a westward direction along the keel of the syncline and onto its southwest limb, the sulfide body should crop out beneath the surficial deposits approximately 200 feet west of section line *A–A′*. Of potential significance is the finding of two massive sulfide boulders 3–4 feet in diameter in the moraine on the south side of the glacier west of the sedimentary breccia. These boulders could be derived from a continuation of the upper sulfide body that crops out on the west limb of the syncline as suggested above or derived from sulfide bodies located along the south shear zone that may extend northwestward beneath the glacier.

Four chip samples and three grab samples were collected across the upper sulfide body (table 2). The location of these samples is shown on the longitudinal sketch in insert A of plate 1. The chip samples show a range in distribution of copper and zinc from 1.1 to 1.3 and 1.1 to 1.7 percent, respectively, and an average silver content of 1.55 oz per ton.

Middle sulfide bodies

The middle sulfide bodies consist of several small, apparently discontinuous sulfide lenses and masses along the south shear zone between 4,500 and 4,550 feet altitude (pl. 1). The largest body is lens shaped in plan view and is exposed for 50 linear feet and a vertical distance of about 20 feet (fig. 14). The long dimension of the lens strikes N. 80° W. This body dips steeply to the north, tapers to the east and west, and probably pinches out within a depth of 50–75 feet. The walls of the lens are smooth and parallel the bedding of the enclosing rocks. Sheared shale on the south side of the lens contains disseminated sulfide minerals which grade outward from the lens into barren country rock. The lens has well-defined banding on its north edge, manifested by both the size and the concentration of sulfide mineral particles. Larger fragments (1–8 mm) are angular, suggesting replacement of original sedimentary rock fragments (fig. 15). In polished section, the largest fragments are pyrite and marcasite in a poorly sized matrix of finer grained pyrite and marcasite grains, carbonate, and other sulfide minerals. Specimens of banded massive sulfide minerals, cut perpendicular to the banding, show textures suggestive of relict graded bedding and scour-and-fill features (fig. 15).

in a matrix of dark-gray carbonate and minor quartz (fig. 13). The close resemblance of this texture to that of the aquagene tuff (fig. 7) suggests that it may represent a partially replaced tuffaceous unit.

The plunge of the sulfide body is about 20° NW. If the sulfide body has selectively replaced a favorable host along the trough of

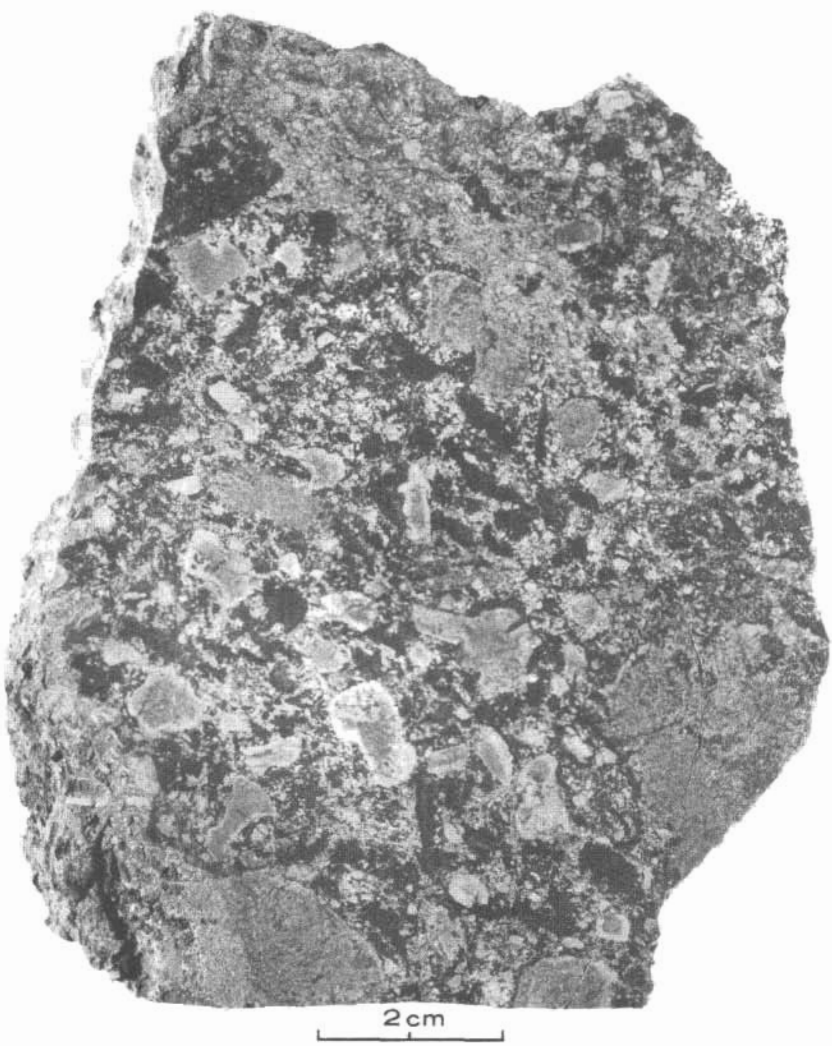

FIGURE 13.—Polished slab showing breccia texture locally developed in the upper sulfide body. Clasts of marcasite and pyrite (light and medium gray) lie in a matrix (dark gray) of carbonate minerals. Note the somewhat similar texture of the aquagene tuff (fig. 7).

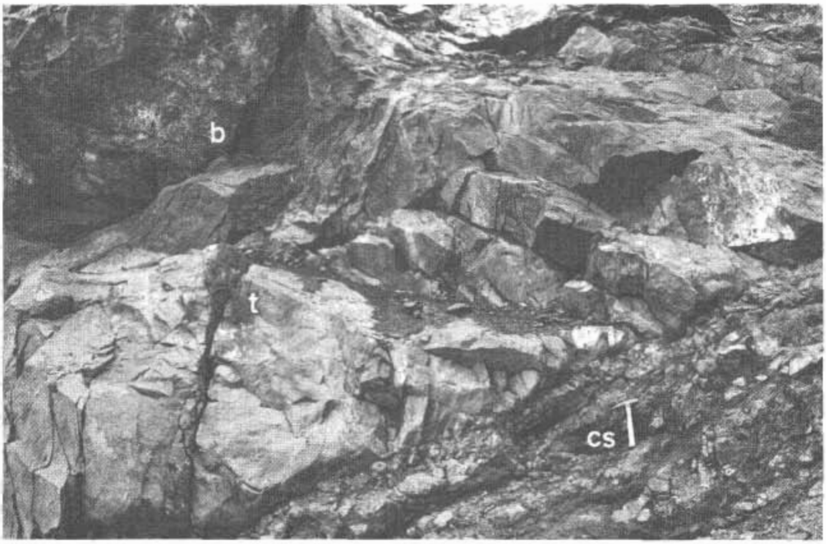

FIGURE 6.—Aquagene tuff (t) overlain by basalt (b) and underlain by chert-shale subunit (cs). View west toward the base of the cliff in the southwest part of plate 1.

of angular pebble-size clasts, the rock grades into breccia with an aquagene tuff matrix.

Petrographic studies show that the vitric fragments range from about 0.10 to 4.00 mm maximum diameter and are highly angular; some retain their original shardlike shapes. Commonly the vitric clasts are molded around grains of other composition and appear to be welded together. Most of the "glass" is palest greenish yellow and in different stages of devitrification and alteration to a poorly crystalline montmorillinoid clay mineral and (or) chlorite of uncertain specific composition. Some samples contain rare vitric fragments that appear to be completely isotropic. In plane-polarized light, such fragments commonly have a deep red-brown color due to clouding by ferric iron oxide crystallites. In addition to an impalpable chloritic mesostasis and carbonate cement, an amorphous greenish material ("chlorophaeite") with a refractive index of 1.58 occurs locally in interfragment areas. Disseminated pyrite is abundant throughout and is probably mostly indigenous.

The aquagene tuff and breccia are probably products of submarine volcanism in a relatively high-energy environment in which calcium carbonate was being precipitated or transported as a mud at the time of eruption and deposition. According to

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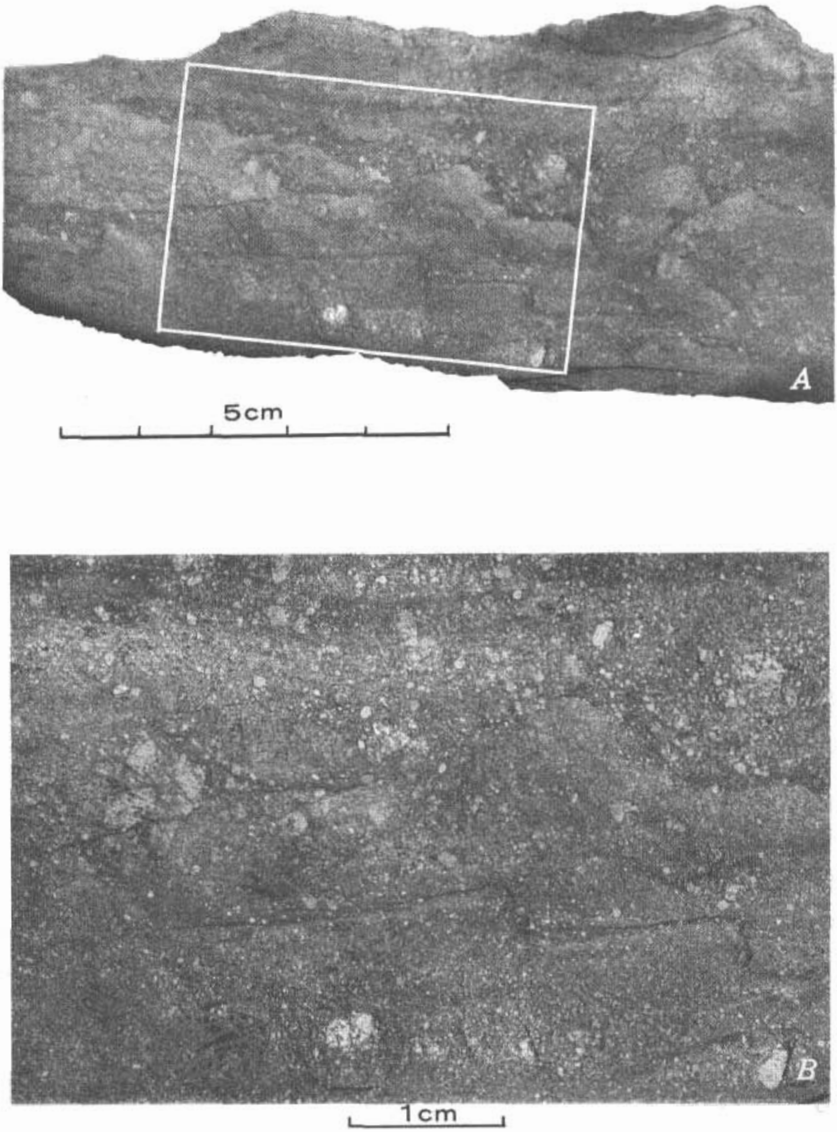

FIGURE 15.—*A*, Slab of banded massive sulfides from middle sulfide body. Slab is cut perpendicular to banding and shows angular to subangular fragments of pyrite and marcasite. Poorly sized clastic texture suggests replacement of wacke-type sedimentary rock. *B*, Enlargement of area outlined in *A*. Linear features shown in *B* may represent scour-and-fill features.

Smaller sulfide bodies crop out a few feet east of the main lens (fig. 14). These masses are not well enough exposed to determine their overall shape but are thought to be replacement bodies within the same shear zone.

Analyses given in table 3 for two chip and three grab samples from the middle sulfide body show that the copper, zinc, lead, and silver values for the chip samples are roughly comparable to those obtained for the upper sulfide body. As is common, the amount of cadium tends to vary directly with that of zinc. The low silver content of grab samples 10 and 11 is paralleled by a correspondingly low lead content. The gold content of 0.15 oz per ton for sample 13 is the highest gold value reported for any of the massive sulfide deposits.

Lower sulfide body

The lower sulfide body is surrounded by talus and snow, and its configuration and geologic relations cannot be accurately ascertained. However, it lies on the projected strike of the south shear zone and probably is a lens localized within or adjacent to the shear zone. A small septum of siltstone containing disseminated sulfide minerals occurs within the body.

When the deposits were examined in 1968, about 35 feet of the lower body was exposed in a north-south direction and at a small outcrop surrounded by snow about 15 feet south of the main exposure (as mapped on pl. 1). When the area was reexamined in 1969, the snow had melted and a continuous massive sulfide body was exposed for about 75 feet (fig. 16). The maximum height of the body exposed above the snow was about 12 feet, and an additional 15 feet was exposed below the snow where the ice had melted away from the cliff (this detail is not shown on pl. 1).

Analyses are given in table 3 of chip samples taken along the 35-foot exposure shown on the map. The samples were collected from south to north. There is an apparent consistent range in copper values of 1.0 to 1.7 percent across the body. As in the upper and middle sulfide bodies, the silver content is low and tends to vary directly with lead. Both metals are less abundant at the south end of the exposure. Sample 15c, however, illustrates several exceptions to the general direct variation of silver to lead.

REPLACEMENT OF CARBONATE-RICH BEDS

Sulfide minerals replace carbonate-rich beds in the chert-shale subunit exposed in the central part of the mapped area between 4,500 and 4,600 feet altitude (pl. 1). The bedded rocks dip to the northeast and form a block bounded on the southwest and north-

TABLE 3.—*Analyses of samples from middle sulfide body and adjacent deposits and lower sulfide body*

[Location of samples 8-14 shown in fig. 14, samples 15a-g in fig. 16. Unless noted, chip samples are the sample type. First number is length of chip in feet; second number, interval between chips in feet; that is, 17-1 is a 17-foot chip sample with chips collected at 1-foot intervals. Symbols used: >, greater than; N, detected; L, present but below determination limit or below value shown; H, interference]

Sample	Lab. No.	Field No.	Au	Ag	Cu	Pb	Zn	As	Bi	Cd	Sb	Sample type
			(oz per ton)		(percent)			(parts per million)				
Middle sulfide body												
8	AGC179	69AR116	0.0555	1.61	1.9	0.085	2.0	1,500	20	70	150	11–1
9	183	120	.0496	1.93	.79	.22	1.1	700	L	30	200	15–1
10	181	118	.0380	.12	2.0	<.0005	.17	L	20	N	150	Grab
11	180	117	.0058	.20	.89	.0005	3.7	1,000	L	200	L	Grab
12	182	119	.0613	6.42	1.3	.46	1.6	700	10	L	1,500	Grab
13	184	121	.1460	3.50	3.8	.073	1.7	700	70	30	150	Grab
14	225	161	.0087	1.58	.92	.055	.83	700	N	30	200	17–1
Lower sulfide body												
15a	AGC227	69AR163a	0.0058	0.88	1.3	0.026	0.23	L	H(20)	N	L	5–1
b	228	b	.0058	1.02	1.6	.024	.43	L	N	N	L	5–1
c	229	c	.0029	6.72	1.0	.007	1.6	500	H(20)	70	L	5–1
d	230	d	.0087	1.28	1.7	.053	1.6	700	H(20)	50	L	5–1
e	231	e	.0029	2.28	1.2	.20	1.1	700	H(20)	70	100	5–1
f	232	f	.0087	1.81	1.6	.40	1.5	3,000	H(20)	50	150	5–1
g	233	g	.0292	2.42	1.2	.35	1.0	1,500	H(20)	30	150	5–1

Au: HBr digestion; M.I.B.K. extraction; determination by atomic absorption; sensitivity=0.02 ppm (0.0006 oz per ton); range/(report interval)=0.02–1 ppm/(0.02 ppm), 0.1–1.0 ppm/(0.05 ppm), 1–100 ppm/(1 ppm); R. L. Miller and W. R. Vaughn, analysts.

Ag: fire assay with 150 mg Ag control added; acid digestion of bead; determination by atomic absorption; sensitivity=0.2 ppm (0.006 oz per ton); range/(report interval)=0.2–1 ppm/(0.2 ppm), 1.0–10 ppm/(0.5 ppm), 10–100 ppm/(1.0 ppm), 100–1,000 ppm/(10 ppm); R. R. Carlson and Z. C. Stephenson, analysts.

Cu and Zn: assay by total digestion in HF, HNO_3 and CH_2OClO_3: determination by atomic absorption; sensitivity=50 ppm; range/(report interval)=50–1,000 ppm/(10 ppm), 1,000–10,000 ppm/(100 ppm), 10,000+ppm/(1,000 ppm); J. B. McHugh, analyst.

Pb: assay by total digestion in HF, HNO_3 and CH_2OClO_3; determination by atomic absorption; sensitivity=5 ppm; range/(report interval)=5–10 ppm/(5 ppm), 10–1,000 ppm (10 ppm), 1,000–10,000 ppm/(100 ppm), 10,000+ppm/(1,000 ppm); J. B. McHugh, analyst.

As, Bi, Cd, Sb: by semiquantitative spectrographic analysis in which results are reported in parts per million to nearest number in the series 0.5, 0.7, 1.0, 1.5, 3.0, 5, 7, 10, 15, and so on; precision of reported value is approximately +100 percent or −50 percent; limits of detection (ppm): As=200, Bi=10, Cd=20, Sb=100; K. J. Curry, analyst.

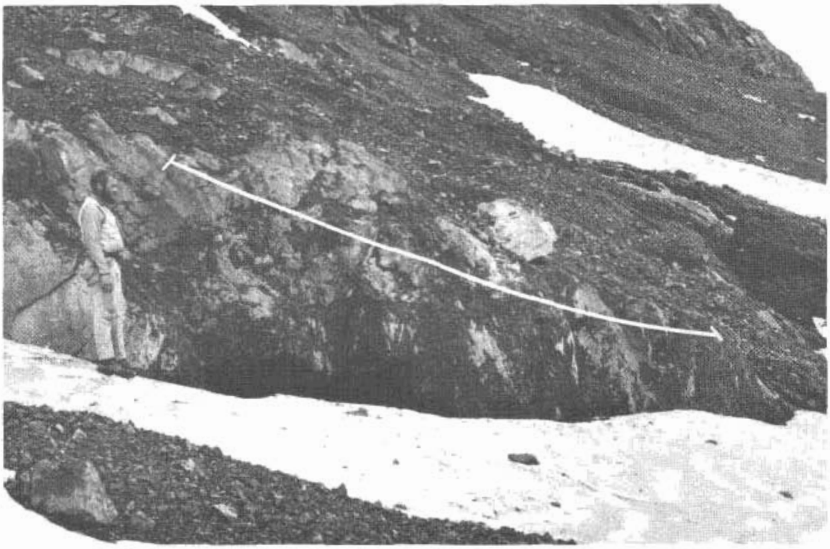

FIGURE 16.—Lower sulfide body as exposed in late August 1969. Massive sulfides are exposed for 15 feet below snowline at dark area near left center of bluff. Line on bluff shows approximate location of chip samples collected in 1968 (samples 15a–g, table 3). View north-northwest.

east by steeply dipping faults that strike northwest (sections *A–A′*, *D–D′*, pl. 1). The block contains many small shears and faults, and the more competent chert and siltstone locally are intensely fractured.

The southwest part of the fault block is underlain by thinly laminated to thin-bedded calcareous siltstone that contains lenses and beds of limestone and has an exposed thickness of about 25 feet. Sulfide minerals have replaced the carbonate-rich lenses and laminae (samples 16–18, pl. 1, table 4), but the total volume replacement probably does not exceed 10 percent. The thickness of an individual replacement zone is in proportion to the thicknesses of the original carbonate-rich units. These thicknesses range from a millimeter, within which several laminae may be only a few percent of the total rock thickness (fig. 5), to beds up to 2 feet thick that pinch out within a few feet along strike. Such examples of selective and incomplete replacement extend even to the fabric level of the host rocks. Silt-size quartz grains and clasts of chert notably have been unaffected by the mineralizing solutions (fig. 5), and many sulfide lenses contain vestigial embayed calcite or dolomite.

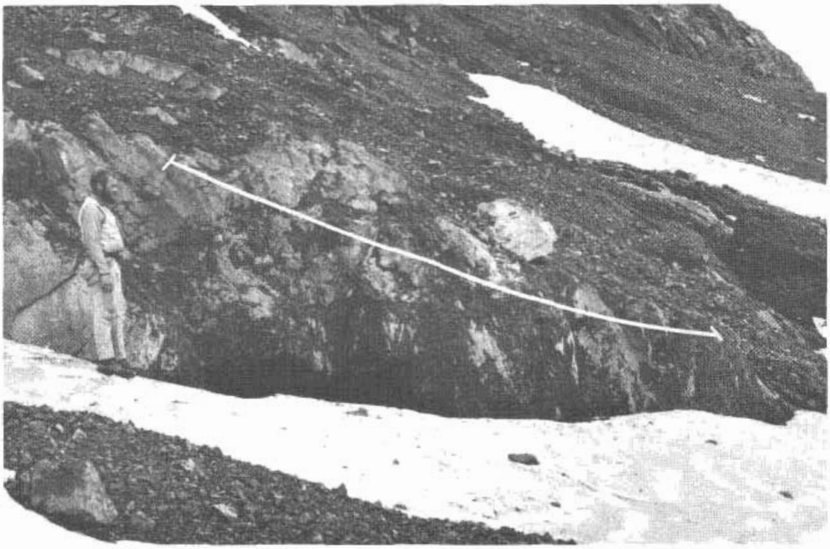

FIGURE 16.—Lower sulfide body as exposed in late August 1969. Massive sulfides are exposed for 15 feet below snowline at dark area near left center of bluff. Line on bluff shows approximate location of chip samples collected in 1968 (samples 15a–g, table 3). View north-northwest.

east by steeply dipping faults that strike northwest (sections *A–A′*, *D–D′*, pl. 1). The block contains many small shears and faults, and the more competent chert and siltstone locally are intensely fractured.

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The siltstone is cut by numerous fractures and small faults, many of which are filled by sulfide minerals. This suggests that mineralizing fluids migrated along the fractures and then outward to replace carbonate-rich lenses and laminae. Perhaps the most important aspect of the deposits is that they represent bedding replacement of chemically favorable units. If these carbonate units are abundant elsewhere in the chert-shale unit and are favorably situated adjacent to feeder channels, then they could be of economic significance.

Two composite chip samples (samples 19 and 20, table 4) were collected across a carbonate-cemented breccia that is irregularly distributed (possibly intertonguing) on the east end of the chert-shale block. Small fragments of chert are cemented by dark-gray carbonate that contains irregular seams and disseminations of sulfide minerals that replace the carbonate.

A prominent fault near the location of sample 21 (pl. 1) has produced 2½ feet of gouge in the chert-shale unit. The gouge contains disseminated sulfide minerals, and a 2-foot-thick limestone bed on the southwest side of the fault is partially replaced by sulfide minerals.

FRACTURE FILLINGS IN CHERT AND SILTSTONE

Within the chert-shale block that contains the replacement deposits are local areas of intensely crushed, compact siltstone and chert. Fractures within these units are in places filled with sulfide minerals. The fractures range in width from a millimeter to about 30 centimeters, are of irregular shape, and pinch out within a few inches. The mineralized fractures are adjacent to faults or shear zones and are best exposed in the chert-shale unit southeast of section *A–A′* (pl. 1). The total volume of sulfide minerals in such fractures is small; but in contrast to the massive sulfide deposits and replacement beds in which chalcopyrite is only rarely visible in hand specimens, the fracture fillings contain notable amounts of visible chalcopyrite. The gold, silver, copper, lead, and zinc content of the single sample collected (sample 22, table 4) is notably higher than that of the massive sulfide deposits.

OTHER OCCURRENCES

Other mineral occurrences of interest within the area mapped are located on the continuation of known mineral-bearing faults or shear zones, and some may be peripheral to unexposed massive sulfide bodies. Two small massive sulfide lenses are enclosed by sheared siltstone in the south shear zone between 4,600 and 4,650 feet altitude (samples 23–24, table 5, pl. 1). The lenses are partially covered by snow, have a maximum exposed length of 5 feet, and are alined parallel to the bedding of the enclosing rocks.

A shear zone in the chert-shale subunit exposed in the southern part of the mapped area contains heavily disseminated sulfide minerals. The zone is 15–20 feet wide, strikes northwest parallel to the bedding, and has a nearly vertical dip. It is marked by a pronounced dark-reddish-brown limonitic color produced by hydrous iron oxide minerals.

Talus on bedrock at the top of the south end of the cliff forms a gossan cemented by iron oxide minerals (sample 28, table 5). Sample 25 (table 5), collected from gouge in a shear zone that roughly parallels the south shear zone, has a relatively high copper content in association with low zinc, lead, and arsenic values. This probably indicates postmineral granulation of chalcopyrite-rich veinlets and disseminations in the host rock rather than proximity to a massive sulfide body or that the shear zone was an auxiliary channelway for mineralizing solutions

Dolomite exposed in the north part of the mapped area contains rare malachite and azurite staining on joint and bedding surfaces (sample 27, table 5) and a few fractures filled with pyrite, chalcopyrite, and rare sphalerite.

On the west side of the main north-flowing glacier approximately 1,200 feet south of the mapped area, a small exposure of massive sulfides 1–2 feet thick occurs in a chert and tuff unit (S. N. Charteris, written commun., 1968).

MINERALOGY AND PARAGENESIS

Study of the minerals was limited to examining polished sections from the midle and upper sulfide bodies and examining single samples from the sulfide lenses and fracture fillings in the chert-shale unit. The mineralogy is not complex, and the same ore minerals occur in varying amounts in each deposit.

From examination of polished sections, the massive sulfide deposits contain, in order of relative abundance, pyrite, marcasite, sphalerite, chalcopyrite, galena, and pyrrhotite. Sphalerite is partly altered to hemimorphite near the surface. Small (<0.05 mm) euhedral grains, tentatively identified as arsenopyrite, were seen in only one polished section, but the arsenic content of some samples (in excess of 1 percent As) suggests that arsenopyrite may be more abundant locally. Although small amounts of gold and silver are present (tables 2–4), no gold or silver minerals were recognized. The massive sulfide deposits contain from 60

TABLE 5.—*Analyses of samples from other mineral occurrences*

[Location of samples shown on pl. 1. Unless noted, chip samples are the sample type. Symbols used: >, greater than; N, detected; L, present but below determination limit or below value shown; H, interfernce]

Sample	Lab. No.	Field No.	Au (oz per ton)	Ag (oz per ton)	Cu (percent)	Pb (percent)	Zn (percent)	As (parts per million)	Bi (parts per million)	Cd (parts per million)	Sb (parts per million)	Sample type
23	AGC215	68AR153	0.0058	6.42	0.74	2.0	6.8	3,000	N	100	700	Grab, massive sulfide minerals
24	218	155	.0058	1.17	.60	.090	1.7	1,500	N	50	700	Do.
25	250	200	.1022	1.69	1.9	.012	.25	N	70	N	L	Grab, gouge zone
26	251	201	.0017	.20	.09	$<.0005$	.017	L	N	N	N	Grab, iron-oxide-stained chert and shale.
27	254	172	.0006	.41	.85	.12	.020	N	N	N	N	Selected; malachite-stained dolomite
28	224	160	.0029	1.11	.09	.19	.057	1,500	N	N	150	Grab, talus cemented by iron oxide minerals.

Au: HMr digestion; M.I.B.K. extraction; determination by atomic absorption; sensitivity=0.02 ppm (0.0006 oz per ton); range/(report interval)=0.02–1 ppm/(0.02 ppm), 0.1–1.0 ppm/(0.05 ppm), 1–100 ppm/(1 ppm); R. L. Miller and W. R. Vaughn, analysts.

Ag: fire assay with 150 mg Ag control added; acid digestion of bead; determination by atomic absorption; sensitivity=0.2 ppm (0.006 oz per ton); range/(report interval)=0.2–1 ppm/(0.2 ppm), 1.0–10 ppm/(0.5 ppm), 10–100 ppm/, (1.0 ppm), 100–1,000 ppm/(10 ppm); R. R. Carlson and Z. C. Stephenson, analysts.

Cu and Zn: assay by total digestion in HF, HNO_3 and CH_3OClO_3; determination by atomic absorption; sensitivity=50 ppm range/(report interval=50–1,000 (10 ppm), 1,000–10,000 ppm/(100 ppm), 10,000+ppm/(1,000 ppm); J. B. McHugh, analyst.

Pb: assay by total digestion in HF, HNO_3 and CH_3OClO_3; determination by atomic absorption; sensitivity=5 ppm); range/(report interval)=5–10 ppm/ (5 ppm), 10–1,000 ppm/(10 ppm), 1,000–10,000 ppm/(100 ppm), 10,000+ppm/(1,000 ppm); J. B. McHugh, analyst.

As, Bi, Cd, Sb: by semiquantitative spectrographic analysis; results are reported in parts per million to nearest number in the series 0.5, 0.7, 1.0, 1.5, 3.0, 5, 7, 10, 15, and so on; precision of reported value is approximately +100 percent or −50 percent; limits of detection (ppm): As=200, Bi=10, Cd =20, Sb=100; K. J. Curry, analyst.

to 95 percent sulfide minerals. Sphalerite, chalcopyrite, and galena together rarely constitute more than 15 percent of the total sulfides. Megascopically, the massive sulfide deposits are very fine grained, and chalcopyrite and sphalerite generally are discernible only by careful examination with a hand lens. Galena is visible only in polished section.

Gangue occurs chiefly as microscopic fillings interstitial to larger pyrite grains. Irregular veinlets and clots of medium- to dark-gray gangue up to 2 mm in diameter are not uncommon, however. The gangue consists chiefly of carbonate minerals and sparse quartz. Siderite is the most abundant carbonate mineral, but most specimens contain some calcite, disclosed by a slight effervescence when patches of gangue are treated with cold dilute hydrochloric acid. A minor amount of dolomite, identified by X-ray diffraction, is also present in some samples.

Pyrite is the oldest and by far the most abundant sulfide mineral in the massive sulfide deposits. It occurs as irregular, angular to subangular, closely packed grains which generally range between 0.07–0.5 mm in greatest dimension. Smaller pyrite grains are somewhat euhedral, but euhedral pyrite cubes are common only where pyrite is enclosed by gangue minerals or by later sulfide minerals. Most polished sections show a typical wacke texture in which unsorted angular to subangular grains of pyrite 0.05–3 mm in greatest dimension are in a matrix of finer grained pyrite, gangue, and other sulfide minerals (fig. 17). Such textures are thought to represent replacement of poorly-sized volcanic sandstone or possibly a tuff. Margins of the pyrite grains may be partly replaced and embayed by marcasite, sphalerite, chalcopyrite, and galena. Minor fracturing of the sulfide bodies followed pyrite deposition, locally resulting in brecciation and marginal granulation of the larger grains, with small fractures localizing later gangue and sulfide minerals (fig. 18).

Marcasite is present in most of the polished sections examined and may constitute as much as 40 percent of the sulfide minerals. It most commonly occurs as marginal embayments and as irregular patches in pyrite, suggesting perhaps that pyrite has locally altered to marcasite. In polished section marcasite commonly is pitted and contains inclusions of gangue. However, it may also take a smooth polish like pyrite and can be distinguished from pyrite only by its strong anisotropism. Marcasite, like pyrite, locally has fractures filled by later sulfide minerals and is replaced by the later sulfide minerals. In one polished section, however, marcasite veins pyrite and also appears to replace and vein

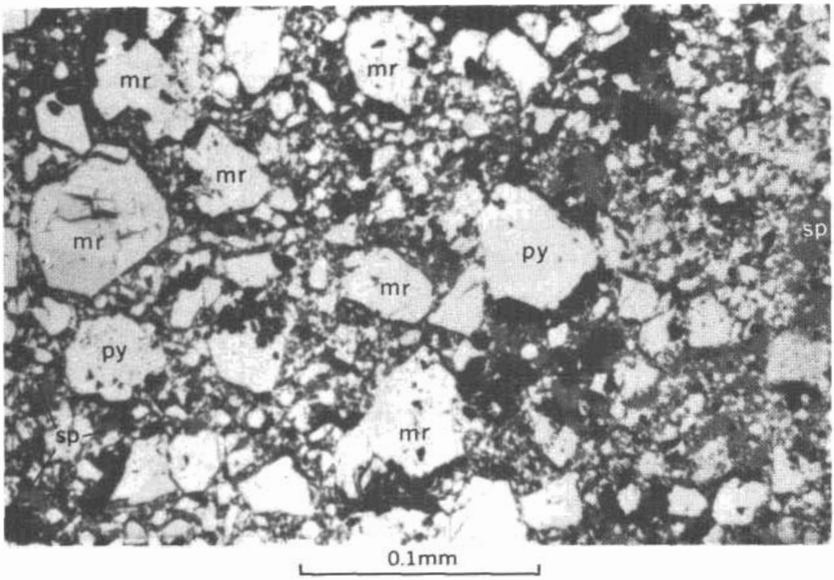

FIGURE 17.—Photomicrograph showing typical wacke texture with angular pyrite (py) and marcasite (mr) grains in a fine-grained matrix of pyrite, marcasite, gangue (black), and sphalerite (sp).

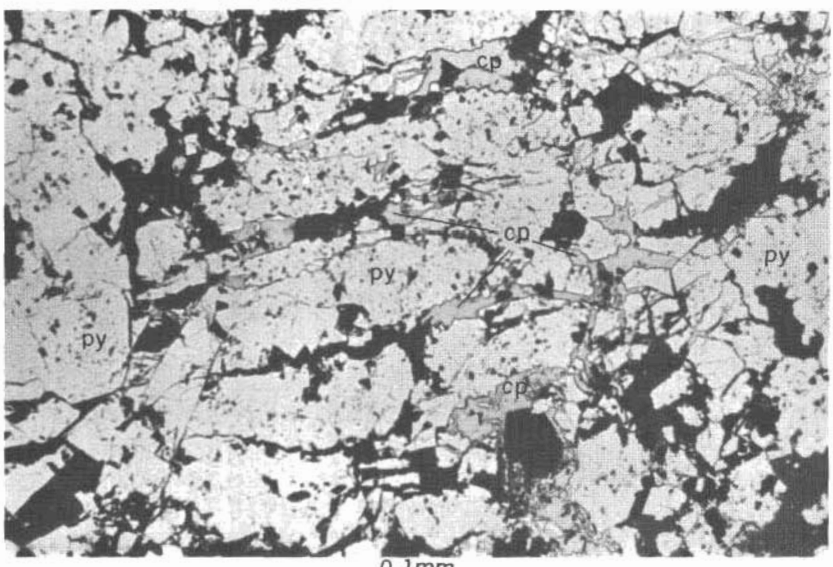

FIGURE 18.—Photomicrograph showing fractures in pyrite (py) filled with chalcopyrite (cp) and carbonate gangue (black). Pyrite is locally replaced by chalcopyrite.

sphalerite and chalcopyrite (fig. 19), indicating that marcasite deposition either continued as an overlapping phase of sulfide deposition following pyrite or was a recurring sulfide phase.

Sphalerite characteristically occurs as an interstitial filling around larger pyrite grains, where it replaces a thin selvage of gangue minerals and smaller pyrite grains. It also corrodes the larger pyrite grains and may occur as small irregular patches in pyrite (fig. 20). Sphalerite patches rarely exceed 0.3 mm in diameter. It is thought to be older than chalcopyrite but may be in part contemporaneous.

Wherever sphalerite is abundant it contains a myriad of chalcopyrite blebs that may show a geometric pattern exsolved along crystallographic directions in the sphalerite (fig. 21). These intergrowths of chalcopyrite in sphalerite can be explained by exsolution or simultaneous deposition of both minerals. (Edwards, 1960, p. 99). The shape and distribution of chalcopyrite blebs in sphalerite may, however, be quite variable even in the same specimen, and some textures suggest that chalcopyrite may not be entirely the result of exsolution but may in part represent an early stage of replacement of sphalerite by chalcopyrite. Sphalerite and chalcopyrite also occur together as small blebs in pyrite. In the chert-shale subunit, where fractures are filled with sulfide

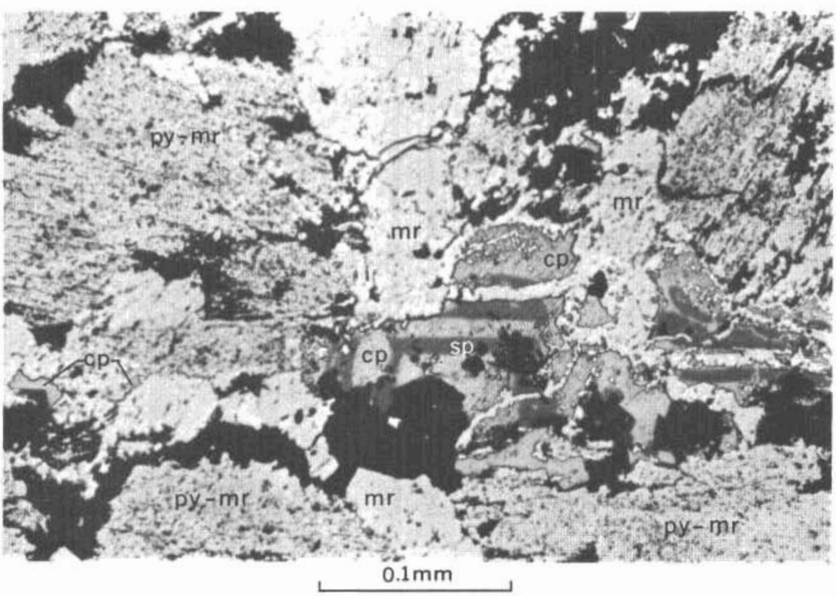

FIGURE 19.—Photomicrograph showing pyrite and marcasite (py-mr) veined by marcasite (mr). Marcasite veins and appears to replace both chalcopyrite (cp) and sphalerite (sp).

the sulfide deposits show compelling evidence for replacement origin; (2) sedimentary and associated volcanic rocks were hosts for the sulfide deposits; and (3) shear or fault zones provided channels for mineralizing solutions and favorable structural settings for massive sulfide deposits.

The sulfide laminae and lenses which contain relict clots of corroded calcite and stringers of unreplaced quartz appear to be valid replacement bodies. A replacement origin for the middle sulfide body is strongly indicated by (1) sulfide banding parallel to bedding of enclosing rocks and which may represent replaced original sedimentary structures; (2) the decrease in concentration of disseminated sulfide minerals in the enclosing sheared shale away from the sulfide body; (3) the relict poorly-sized wacke texture defined by angular pyrite-marcasite grains in a matrix of finer grained angular pyrite-marcasite grains, gangue, and sulfide minerals; and (4) the paragenetic sequence of sulfide mineral deposition. The close similarities in texture between the breccia of the upper sulfide body and the aquagene tuff suggest that the sulfide mass may represent a partially replaced tuffaceous bed. A coarse sedimentary tuff could presumably have had sufficient permeability to allow migration of metal-bearing fluids, during either diagenesis or orogenesis, resulting in sulfide mineral deposition. It is difficult to explain the selective replacement of clasts, and Clark (1968) has proposed another hypothesis for the genesis of the Kuroko deposits of Japan: that the deposits represent pyroclastic accumulation of sulfide fragments blown to their deposition sites by volcanic explosions.

As there is no geologic evidence for subjacent granitic rocks in the immediate area, it is difficult to appeal to the traditional buried granitic source for hydrothermal mineralizing solutions to replace chemically favorable rocks along favorable structures. Rather, it seems that the volcanic and sedimentary rocks of the eugeosyncline were the source of the metals and mineralizing fluids. Such a source is appealing because many large deposits of sulfur and iron sulfides are directly associated with volcanic processes. Examples are the deposits of Japan (Japan Geological Survey, 1960, p. 167), Taiwan (Tan, 1959), and Cyprus (Hutchinson, 1965). According to the source-bed concept for the formation of massive sulfide deposits, syngenetic beds of iron sulfide were deposited under near-surface conditions by a volcanic exhalative process, and during diagenesis the iron sulfide crystallized to pyrite. It is believed that water trapped in the sedimentary and volcanic rocks and heated by increased heat flow carried

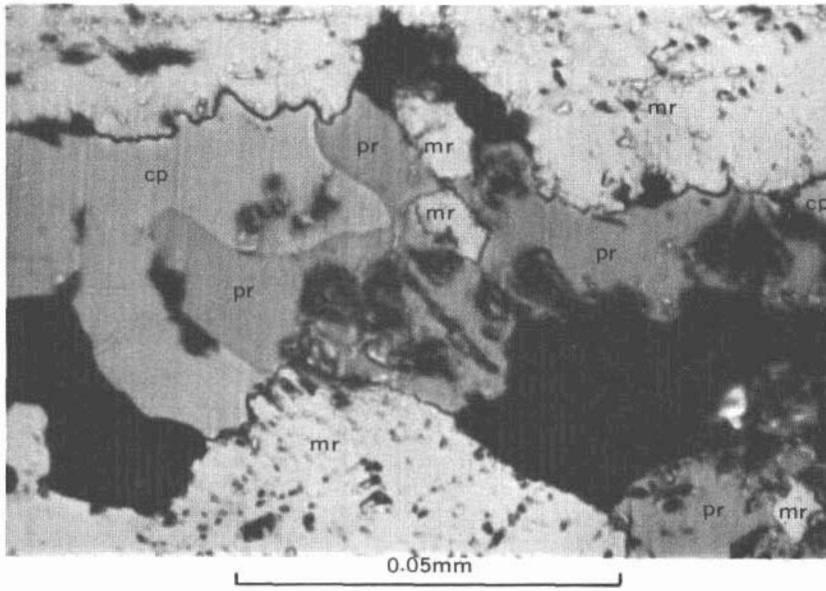

FIGURE 22.—Photomicrograph showing mutual boundary relation between pyrrhotite (pr) and chalcopyrite (cp), which are interstitial to marcasite (mr) grains. Chalcopyrite and pyrrhotite appear to corrode marcasite.

more than 1 percent arsenic, as much as 1500 ppm antimony, and as much as 70 ppm bismuth. No silver minerals were seen in polished sections. If separate silver-bearing mineral phases are present they must be restricted to a size range below the limit of resolution of conventional reflected light microscopy. The silver-lead trend suggests that some of the silver may be in solid solution in galena, but without analyses of the separate ore minerals no definite statement can be made on the distribution of the silver.

In summary, although overlaps in sulfide mineral deposition occurred, there were periods in which deposition of one or more sulfide minerals predominated. Widespread pyrite replacement was the first phase of mineralization. Locally, pyrite appears to be altered to marcasite. A minor period of fracturing following pyritization locally fractured the pyrite-marcasite grains. These fractures are filled by the later sulfide and gangue minerals. Sphalerite and chalcopyrite were deposited simultaneously, but chalcopyrite probably continued as an overlapping phase with galena deposition, as both minerals transect and replace sphalerite. The later sulfide minerals show a preference for occurring

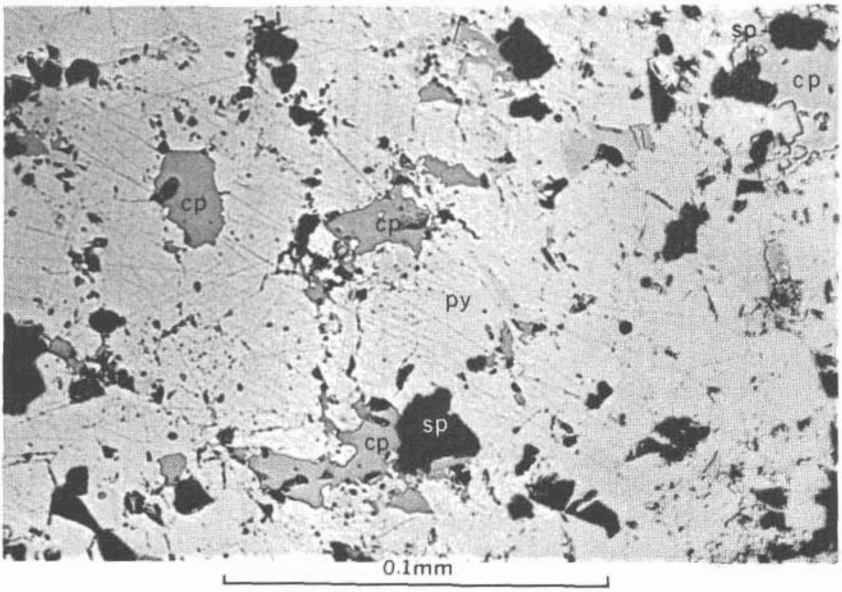

FIGURE 20.—Photomicrograph showing part of pyrite grain (py) with irregular patches of chalcopyrite (cp) and sphalerite (sp). Sphalerite locally contains blebs of chalcopyrite.

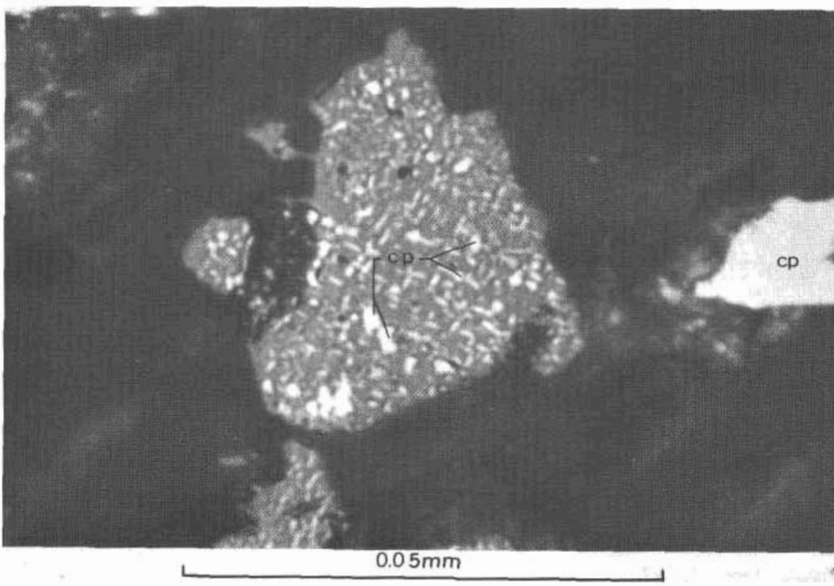

FIGURE 21.—Photomicrograph showing grain of sphalerite (medium gray) surrounded by calcite (dark gray). Sphalerite contains oriented intergrowths of chalcopyrite (cp, white), suggesting that the chalcopyrite has in part formed along crystallographic directions in the sphalerite.