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Copper-Zinc Deposits Associated with Basic Volcanism, Goldstream Area, Southeastern British Columbia

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Abstract

Goldstream and several other small strata-bound copper-zinc deposits occur in the Selkirk Mountains of southeastern British Columbia. Goldstream consists of a thin sheet of massive sulfides in dominantly calcareous and graphitic schists of probable early to middle Paleozoic age. A manganiferous, iron-rich chert unit structurally overlies the sulfide layer. Regional structures suggest that the deposit is inverted and, therefore, that the chert horizon, referred to as the garnet zone, is interpreted to have formed as a siliceous exhalite stratigraphically below the sulfide deposit.

The massive sulfide layer consists primarily of intimately intermixed pyrrhotite, sphalerite, and chalcopyrite, with numerous subrounded inclusions of quartz, carbonate, and phyllite fragments. The sulfides are locally swirled around the gangue inclusions to produce a durchbewegung fabric, a texture common to many deformed and metamorphosed massive sulfide deposits. Contacts with the hanging wall and the footwall range from sharp to gradational over a few meters.

Metal values have a simple and regular distribution in plan, with increasing grades toward the central, thicker part of the massive sulfide layer. The deposit has a pronounced lateral metal zonation, with Zn/(Zn + Cu) ratios increasing to the east. It is suggested that this zonation reflects either an original lateral deposit zonation or is the result of extreme shearing of a vertically zoned massive sulfide lens that had a more copper-rich zone in the stratigraphically lower part of the lens and a relatively zinc-rich zone above. No consistent vertical zonation is apparent.

Goldstream and other copper-zinc deposits in the Goldstream camp are interpreted to be exhalative massive sulfide deposits that formed in an unstable subsiding basin, near the continental margin. Host rocks include thick accumulations of coarse terrigenous clastics, calcareous shale, and basalt. They are similar to the Besshi-type deposits of Japan.

Introduction

A NUMBER of strata-bound copper-zinc deposits occur in metasedimentary and basic metavolcanic rocks in the Selkirk Mountains in southeastern British Columbia (Fig. 1). The largest known deposit, Goldstream, is a thin, laterally extensive sheet of massive sulfides in dominantly calcareous graphitic schists. The Montgomery deposit is in a mixed pelitic and calcareous succession, and the Standard deposit, which consists of a number of lenses of dominantly pyrrhotite and chalcopyrite, is in dark calcareous schist and greenstone. The metasedimentary host rocks of these deposits are roughly correlative and are probably of early to middle Paleozoic age.

Mineral exploration in the Goldstream area dates back to 1865 with the discovery of placer gold in French and McCulloch Creeks, two tributaries of the Goldstream River, and in Carnes Creek, a tributary of the Columbia River 35 km south of the Goldstream River. Interest in lode mining in the late 1800s resulted in renewed exploration in the Goldstream area and discovery, in 1895, of the Montgomery and Standard deposits. The Goldstream deposit was discovered in 1973 and optioned by the Noranda Exploration Company, Ltd., in late 1974. In 1975, 50 holes were drilled on the property, outlining a deposit with reserves of 3.2 million metric tons grading 4.5 percent copper, 3.1 percent zinc, and 20 g silver per metric ton (Reinertson, 1978). The construction of a 1,500-metric ton-per-day concentrator and an underground crushing facility has been completed recently, and production commenced in May 1983.

The first phase of mining consists of a 20,000-met-

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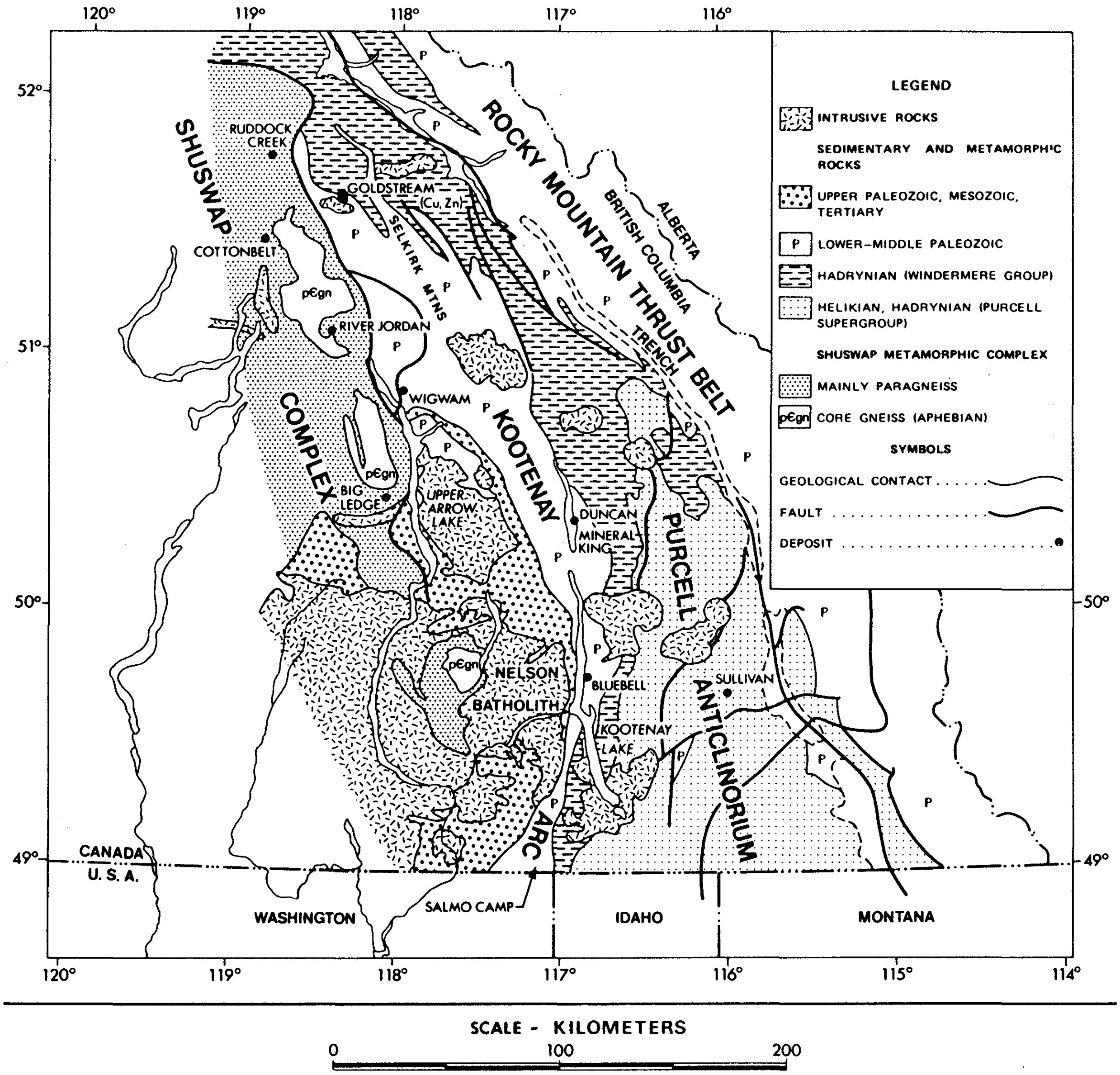


FIG. 1. Regional geologic map of southeastern British Columbia showing the main tectonic belts, location of strata-bound lead-zinc deposits, and location of the Goldstream deposit.

ric ton-per-month open pit with further development of underground stoping blocks to the 655 m elevation. The second phase of mining will involve sinking a shaft to the 400-m elevation and conversion to an exclusively underground operation. A modified step, room-and-pillar mining method will be used to extract the majority of the underground reserves. This method uses a series of strike drifts and ramps that are developed in ore, followed by benching, cut and fill stoping, and pillar recovery.

This paper describes the geologic setting of these strata-bound copper-zinc deposits and details the geology, mineralogy, and geochemistry of the Goldstream deposit. We conclude that these exhalative massive sulfide deposits are associated with basic volcanism and that they are similar to the Besshi deposits of Japan (Kanehira and Tatsumi, 1970) and the Kieslager or bedded cupriferous iron sulfide class of Hutchinson (1980).

Regional Geology

Southeastern British Columbia is subdivided into a number of distinct physiographic belts, each with a unique structural style and characteristic stratigraphic succession (Fig. 1). The eastern Rocky Mountain belt includes dominantly miogeoclinal rocks of middle Proterozoic to Mesozoic age that were deposited on the western cratonic edge of North America and displaced eastward during late Mesozoic and Teritary times. To the west, the Omineca crystalline belt, which includes the Kootenay arc and Shuswap Complex in Figure 1, consists of highly deformed and locally highly metamorphosed Proterozoic to mid-Paleozoic miogeoclinal rocks, younger volcanic and

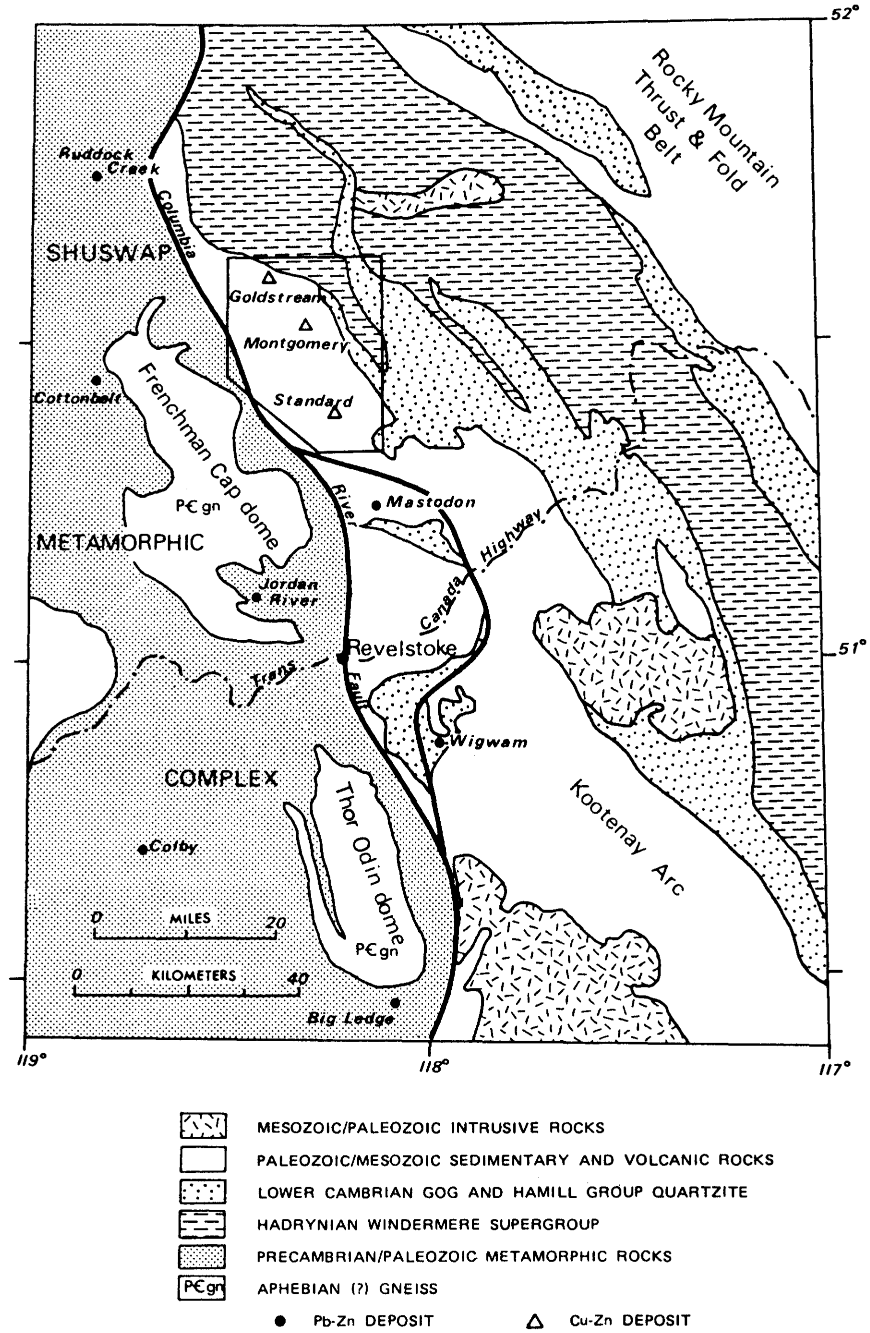
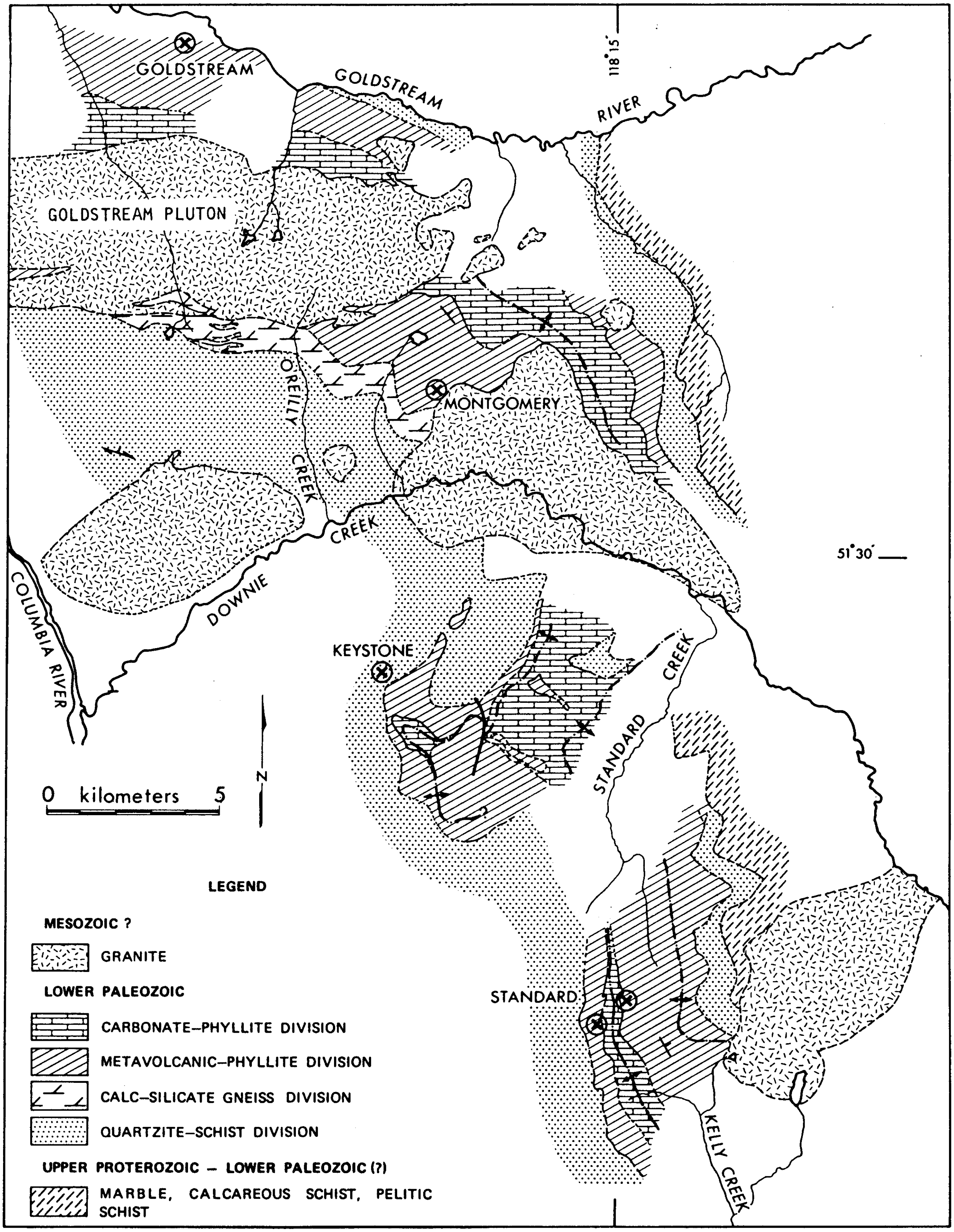


FIG. 2. Geologic map of the Selkirk terrane, northern Kootenay arc, and Shuswap Complex showing the locations of lead-zinc and copper-zinc deposits; the Goldstream area is outlined and detailed in Figure 3.



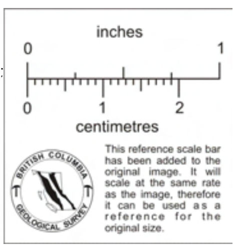


FIG. 3. Geologic map of the Goldstream area. Goldstream, Montgomery, and Standard are copper-zinc deposits described in the text; Keystone is a lead-zinc-copper vein deposit. Axial planes of antiforms are traced with a dashed line (geology after Lane, 1977; Gibson et al., 1977; and Høy, 1979).

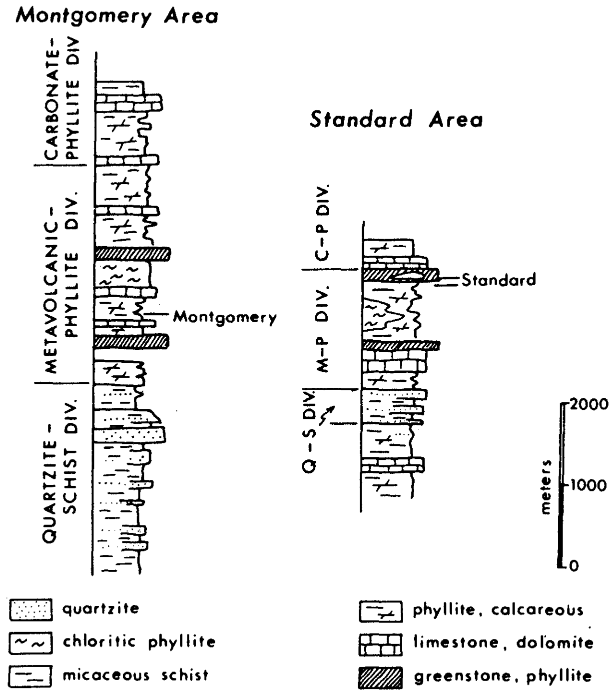


FIG. 4. Composite stratigraphic succession in the vicinity of the Montgomery and Standard deposits. Owing to a lack of outcrop and extent of later intrusive rocks, a composite Goldstream deposit section is not illustrated. Note the stratigraphic positions of the Montgomery and the Standard deposits, either within basic volcanic rocks or in calcareous phyllites within the metavolcanic-phyllite division.

pelitic rocks, and Precambrian crystalline basement that are extensively invaded by Mesozoic and younger intrusive rocks.

The Goldstream area, along the eastern margin of the Omineca crystalline belt, is underlain by a highly deformed sequence of Proterozoic to Paleozoic metasedimentary and basic metavolcanic rocks (Fig. 2). It is contiguous with the northern extension of the Kootenay arc, a generally north-trending arcuate structural zone that developed in a succession of rocks ranging in age from Hadrynian to early Mesozoic. An extensive Lower Cambrian platformal carbonate, the Reeves or Badshot Formation, contains a number of deformed lead-zinc deposits in the Kootenay arc, including Reeves MacDonald, H.B., and Jackpot in the Salmo area just north of the United States border (Fyles and Hewlett, 1959), and the Bluebell (Høy, 1980), Duncan (Fyles, 1964), and Wigwam (Thompson, 1978) deposits farther north (Fig. 1). The Shuswap Complex is separated from the Goldstream area by the east-dipping normal Columbia River fault zone (Read and Brown, 1981). Along the eastern edge of the Shuswap Complex are a series of gneiss domes (Fig. 2) with highly deformed and metamorphosed Aphebian ortho- and paragneiss in their core. Unconformably overlying the core gneisses is a platformal quartzite, marble, and a paragneiss succession of unknown age that hosts a number of large, stratabound lead-zinc deposits, including Ruddock Creek, Cottonbelt, Jordan River, and Big Ledge (Fyles, 1970; Høy, 1982).

The copper-zinc deposits of the Goldstream area are unique in southeastern British Columbia, occurring in basic metavolcanic rocks and in dark calcareous phyllites. This contrasts with the numerous lead-zinc deposits that commonly occur in platformal rocks (Høy, 1982).

TABLE 1. Chemical Analyses of Volcanic Units in the Metavolcanic-Phyllite Division, Goldstream Area (Fig. 3)

Sample	SiO_2	Al_2O_3	Fe_2O_{3T}[1]	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
L62	45.8	12.2	6.8	9.0	9.08	2.0	0.54	2.26	0.27
L99	41.4	12.0	5.2	14.5	10.2	1.6	0.27	1.57	0.25
L129A	47.7	14.2	1.3	9.9	8.18	4.2	0.15	0.76	0.18
L31A	48.5	11.7	2.2	5.6	8.41	2.3	0.11	2.22	0.26
L131B	49.1	16.0	1.9	8.5	10.6	4.1	0.17	0.71	0.15
L141	49.5	12.1	1.0	9.1	9.44	3.8	0.19	1.32	0.21
H76G19-1	45.3	13.3	13.3	9.01	8.75	3.35	0.03	1.25	0.21
H80STD	48.97	14.24	6.86	11.45	12.31	1.666	0.353	0.161	0.132
G0110821	48.4	13.4	13.8	7.04	8.89	3.48	0.05	1.9	0.25
G0110822	48.5	12.10	16.4	5.37	7.92	2.57	0.20	2.5	0.29
G0110823	50.3	13.4	13.8	7.21	6.16	4.37	0.10	1.9	0.22

[1] Total Fe_2O_3

L62 to L141. Collected by L. Lane; XRF analyses by the Geological Survey of Canada (see Lane, 1977)

H76G19-1 and H80STD. Collected by T. Hoy; AAS analyses by the British Columbia Ministry of Energy, Mines and Petroleum Resources

G0110821 to G0110823. Collected by G. Gibson; AAS analyses by the British Columbia Ministry of Energy, Mines and Petroleum Resources

H80STD. A medium-grained subvolcanic intrusive diorite from the Standard area

Local Geology

Copper-zinc deposits in the Goldstream area (Fig. 3) occur in highly deformed calcareous phyllites and basic volcanic rocks that have been intruded by a number of large granitic bodies of probable Cretaceous age. Grades of regional metamorphism range from greenschist facies in the Standard area to the south, to lower amphibolite facies in the region of the Goldstream pluton 20 km farther north.

Stratigraphy

Metasedimentary and metavolcanic rocks comprise five major lithologic packages (Høy, 1979). The stratigraphically lowest consists of dominantly pelitic and calcareous schists and marble exposed east of the Goldstream deposit (Fig. 3) which are correlated tentatively with the late Proterozoic Horsethief Creek Group (Brown et al., 1977). They are overlain by a succession of rocks that consists of four main divisions (Fig. 4): (1) dominantly pelitic phyllite and quartzite of the lower quartzite-schist division; (2) dominantly calcareous rocks of the calc-silicate gneiss division; (3) greenstone, amphibolite, dark calcareous phyllite, and carbonate of the metavolcanic-phyllite division (host to deposits); and (4) limestone, dolomite, marble, calcareous phyllite, and micaceous phyllite of the upper carbonate-phyllite division.

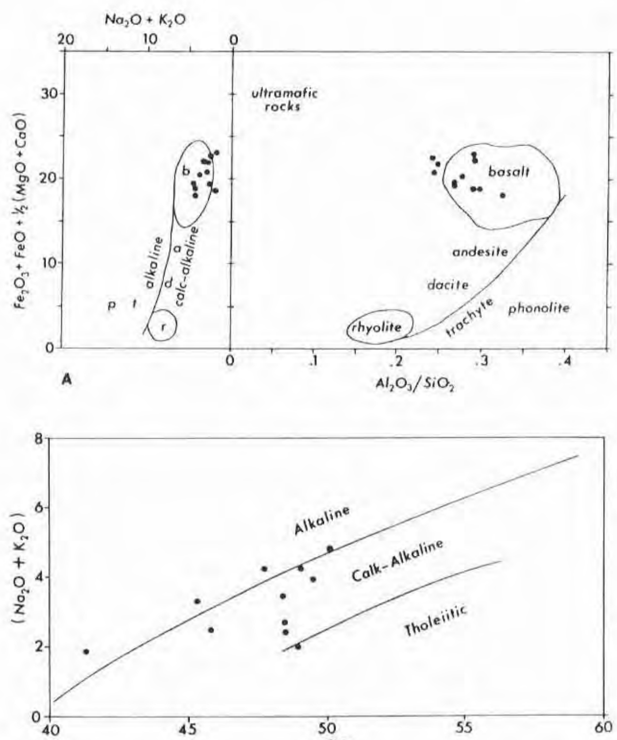


FIG. 5. A. Triaxial oxide plot (after Church, 1975). B. Alkalies-silica plot, showing major element chemistry of metavolcanic rocks in the Goldstream area. The dividing line between the alkaline and subalkaline (calc-alkaline) fields in B is after Irvine and Barager (1971).

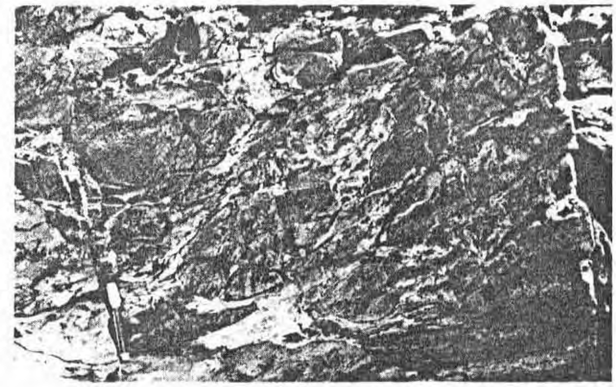


FIG. 6. Deformed pillows in basalt of the metavolcanic-phyllite division on the ridge due east of the Keystone showing (Fig. 3).

A number of stratigraphic tops recognized in the Goldstream area (Lane, 1977; Høy, 1979) suggest that the sequence of rock units outlined above is an original stratigraphic succession. Rocks correlated with the Horsethief Creek Group are apparently the oldest, and the dominantly calcareous rocks of the carbonate-phyllite division, the youngest.

Metasedimentary rocks of the quartzite-schist division comprise at least several thousand meters of interlayered pelitic schist and micaceous quartzite,

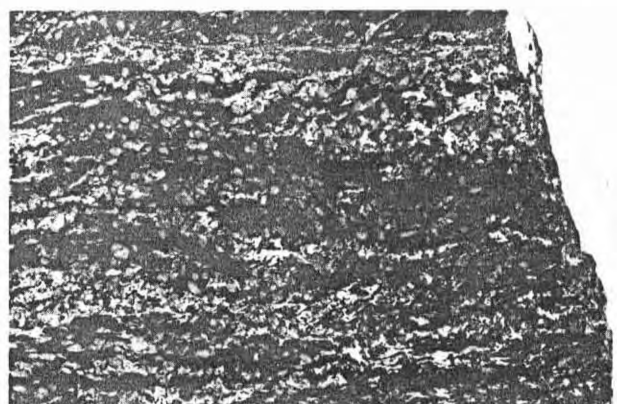


FIG. 7. Dark green chlorite schist with numerous subrounded to angular crystals of plagioclase (gray) and wispy pyrrhotite (highly reflecting) throughout; interpreted to be a deformed crystal tuff; unit V-7, Standard area (Figs. 3 and 9).

FIG. 8. Dark, calcareous, well-layered phyllite deformed by late phase 3 folds. Scale is shown by the small candle holder (ca. 1900) used in underground work on the Standard property (photo width = 60 cm).

massive thickly bedded pure to micaceous quartzite, and subordinate rusty-weathering hornblende gneiss and calcareous phyllite. Thin-bedded, rusty-weathering calcareous phyllite and quartzite, pure to siliceous marble, and biotite gneiss that comprise the calc-silicate gneiss division overlie rocks of the quartzite-schist division. These gneisses are exposed along the southern margin of the Goldstream pluton and are probably contact metamorphic equivalents of calcareous rocks in the lower part of the metavolcanic-phyllite division.

The metavolcanic-phyllite division consists of massive greenstone units, chlorite phyllite, ultramafic pods, and dark calcareous to pelitic schist. Copper-zinc occurrences and deposits, including Goldstream, are within these metasedimentary and metavolcanic rocks. The most prominent metavolcanic unit is a massive, fine- to medium-grained greenstone that is composed of chlorite, actinolite, epidote, plagioclase, and minor amounts of carbonate. Analyzed samples from within the Goldstream area and to the east (Table 1) are within or along the edge of the basalt field of Church's (1975) oxide plot (Fig. 5A); other plots show that the basalts are predominantly calc-alkaline (Fig. 5B). The greenstone is intercalated with chlorite phyllite, with dark calcareous to pelitic schist, and east of Keystone, with greenstone that has deformed but well-developed pillow structures (Fig. 6). The massive greenstone is generally not at a discrete stratigraphic horizon; rather it is a series of lenses that thin and thicken along strike and commonly grade laterally and vertically to chloritic phyllite that may originally have been basic pyroclastic or volcaniclastic rocks (Fig. 7). In the Standard area coarse-grained ultramafic pods (now altered to a chlorite-serpentine-dolomite assemblage) underlie massive greenstone and associated coarse-grained intrusive diorite and are overlain by gray limestone and calcareous and carbonaceous phyllite (Fig. 4). The phyllite is medium to dark gray and commonly is interlayered with thin gray limestone lenses or chloritic phyllite layers (Fig. 8). It is a common unit in the metavolcanic-phyllite division and is the dominant unit in the structural hanging wall of the Goldstream deposit.

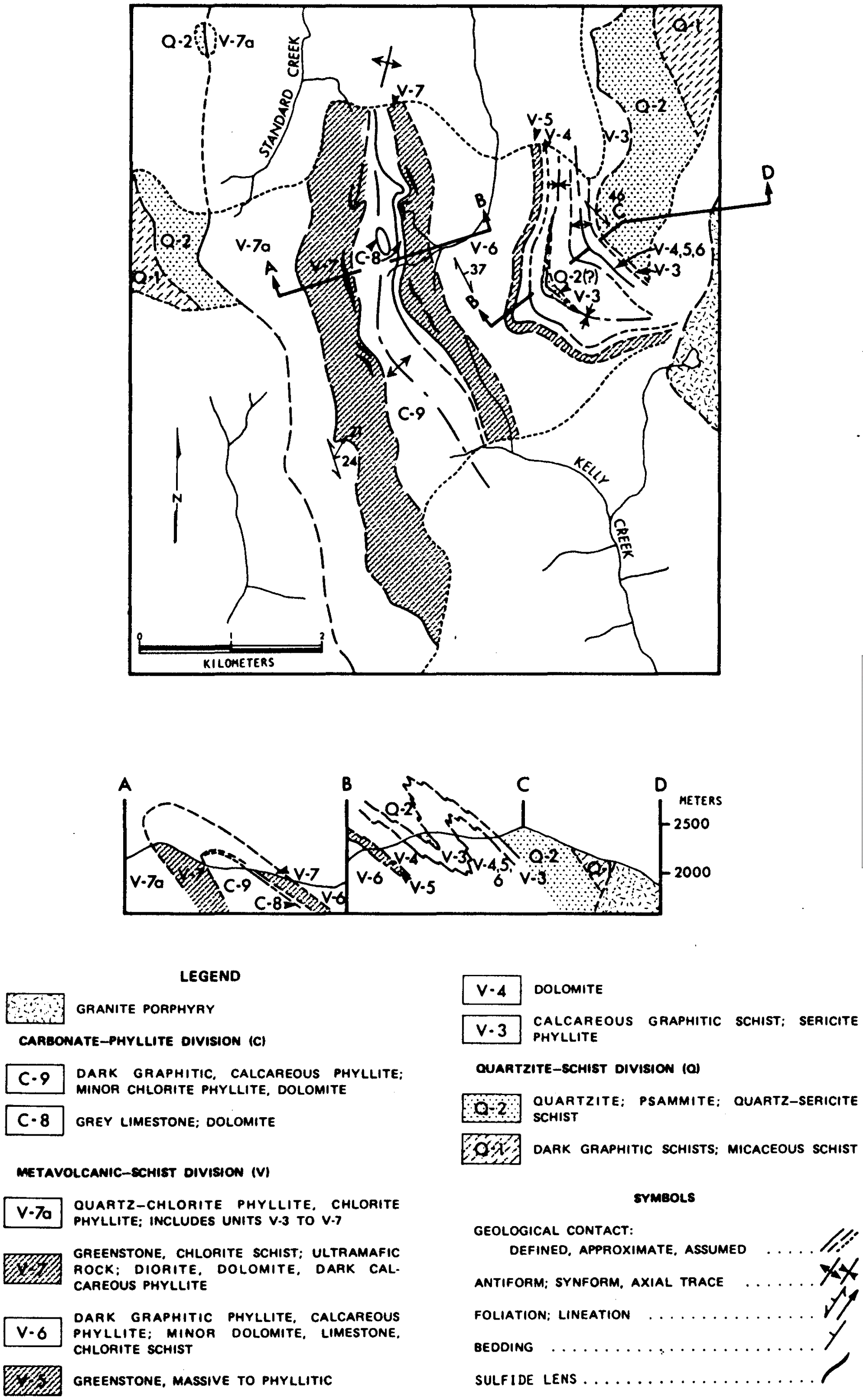
Dolomite, limestone, and calcareous phyllite of the carbonate-phyllite division overlie rocks of the metavolcanic-phyllite division. The carbonates are typically thin-bedded limestone or dolomite interlayered with rusted calcareous schist, biotite schist and, less commonly, chlorite schist.

Depositional environment: The Goldstream area (Figs. 2 and 3) is near the western limit of exposed miogeosynclinal rocks in the northern Selkirk Mountains. The change from deposition of clean massive terrigenous quartzites with interbeds of pelitic shales to thin-bedded, impure carbonates and dark carbonaceous and calcareous shales probably indicates deepening water conditions; rocks of the quartzite-schist division are more typical of a platform or shelf

TABLE 2. Galena-Lead Isotope Analyses from the Goldstream Deposit

Sample number	Pb isotope ratios			Source
	206/204	207/204	208/204	
		(Relative 2 std error as %)		
SP-3535	18.815 (0.11)	15.703 (0.16)	38.547 (0.22)	1
SP-3542	18.791 (0.11)	15.673 (0.16)	38.447 (0.22)	1
		(Relative 1 std error as %)		
GL-O	18.867 (0.09)	15.699 (0.18)	38.645 (0.10)	2
MOP	18.708 (0.12)	15.683 (0.28)	38.302 (0.26)	2

Source: (1) R. Thorpe (pers. commun., 1983); (2) Duncan (1982)



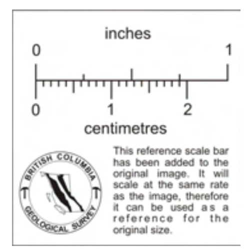


FIG. 9. Geologic map and cross section, Standard deposit area (Fig. 3). Note the distribution of massive sulfide lenses in unit V-7 in the limbs of an antiform. Note also that the entire sequence is inverted, with younger rocks in the cores of the antiforms (geology after Lane, 1977; Gibson et al., 1977; Høy, 1979).

environment, whereas the younger rocks indicate deposition in a restricted basinal environment. Infilling of the basin by dark calcareous shales and coarser clastics was interrupted periodically by basic volcanism in the form of thick massive flows, pillow basalts, and tuffaceous rocks (now preserved as the chloritic phyllites).

An estimated 300 m of massive and pillowed greenstones occur in the Keystone area (Fig. 3). They appear to thin to the north, toward the Goldstream deposit area where they comprise a series of thin (<100 m) flows separated by several hundred meters of clastic and carbonate rocks. In the Standard area to the south (Fig. 3) a larger proportion of metasedimentary rocks is also present, and the proportion of chloritic phyllite appears to increase southward at the expense of the more massive greenstone in the Keystone area.

Our depositional model suggests development of a restricted basin near the western edge of the Cordilleran miogeocline. The voluminous extrusion of basaltic magma may indicate that faulting played an important part in the development of the basin. These features are compatible with the general sedimentologic and tectonic environment of Kieslager or Besshi deposits (Hutchinson, 1980) which are associated with thick accumulations of graywacke and basalt and formed in unstable subsiding sedimentary basins near the continental margin.

Regional correlations and age: Correlation of rocks in the Goldstream area is based on gross lithologic similarities with established stratigraphic successions in the Kootenay arc to the south and the Selkirk terrane to the east and with previously unpublished lead isotope data on Goldstream deposit. The succession along the eastern edge of the map area is right way up and has been correlated with a more calcareous western facies of the upper part of the Proterozoic Horsethief Creek Group (Brown et al., 1977, 1978). Rocks south of the Goldstream River (Fig. 3), which are the host rocks for the Goldstream, Standard, and Montgomery deposits, comprise a highly deformed inverted miogeoclinal stratigraphic panel that may correlate with the Eocambrian Hamill Group and overlying Mohican Formation but more likely correlate with the lower to middle Paleozoic Lardeau Group, as suggested by Wheeler (1965) and Brown et al. (1983). Galena lead isotope data (Table 2) from Duncan (1982) and R. I. Thorpe (pers. commun., 1983) have been interpreted by C. I. Godwin (pers.

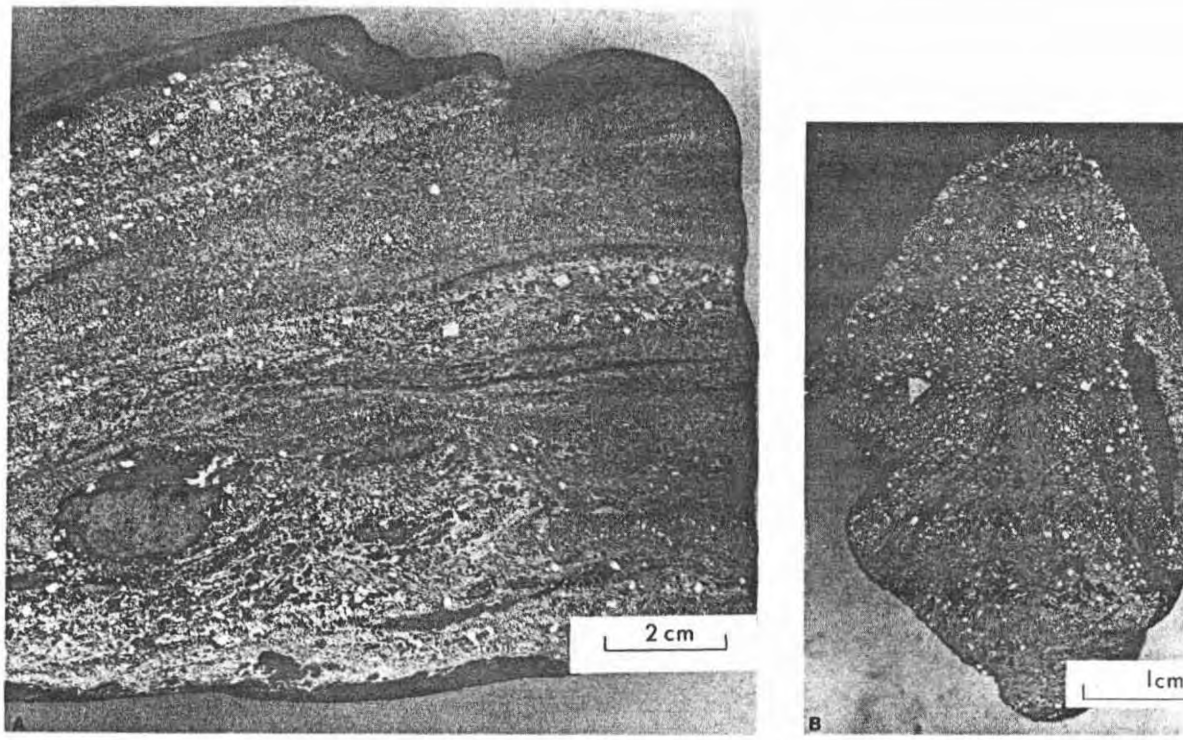


FIG. 10. A. Gneissic sulfide sample from Standard. Fine-grained sulfides are predominantly pyrrhotite with minor chalcopyrite; light-colored (more highly reflecting) subhedral porphyroblasts are pyrite and larger fragments are quartz.

B. Small fold in a sulfide sample from the Standard property. This sample is dominantly pyrrhotite and subhedral to euhedral light-colored pyrite in a quartz (dark) chlorite matrix.

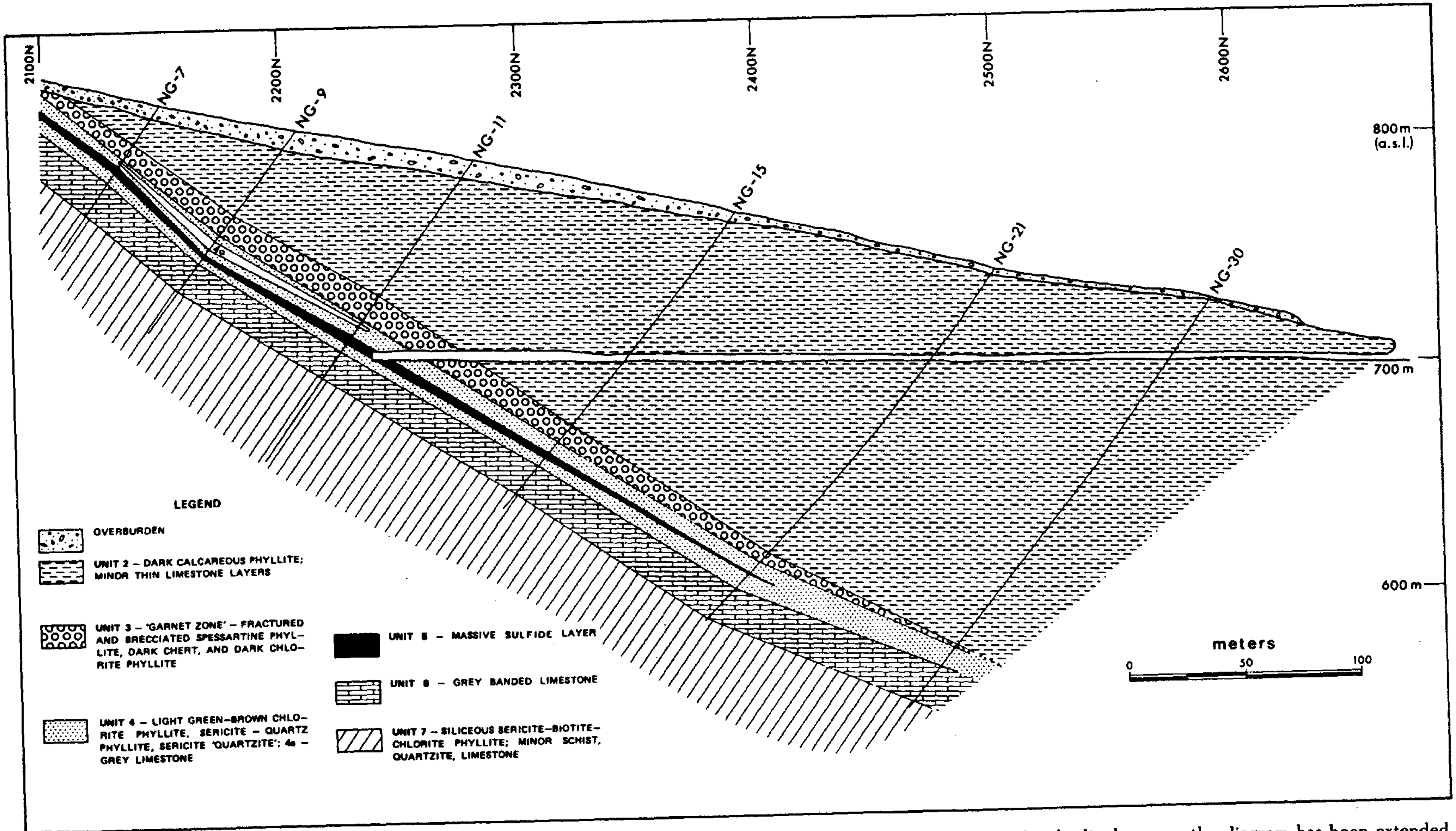


FIG. 11. A north-south vertical section (5300E) through the Goldstream deposit, viewed from the east. The 700-m-level adit shown on the diagram has been extended through unit 6 into the footwall of the sulfide layer (from Høy, 1979). a.s.l. = above sea level.

commun., 1983), using the shale growth of Godwin and Sinclair (1982), to indicate a probable Devonian age for the Goldstream deposit.

From study of these isotopic data and the recent correlation of the Standard succession with the lower Paleozoic Index Formation (Brown et al., 1983), we concur with a lower to middle Paleozoic age for the Goldstream, Standard, and Montgomery deposits and for the host succession.

Structure

Large, tight to isoclinal, east-dipping to recumbent phase 2 folds dominate the structure of the Goldstream area. They have well-developed axial plane schistosities and variable but generally northwest-trending fold axes. A number of graded grit beds throughout the Goldstream area indicate that these phase 2 folds developed in a large inverted stratigraphic panel (Lane, 1977; Brown et al., 1977; Høy, 1979; Read and Brown, 1979), perhaps the underlimb of an earlier (phase 1) recumbent nappe. Minor structures that can be related to phase 1 deformation are not obvious; it is difficult to assess whether many rootless isoclinal fold hinges formed during phase 1 or phase 2.

Late small-scale chevron and kink folds, crenulation cleavage, and small open folds in more competent units are superimposed on earlier structures. They are common in the adit of the Goldstream deposit.

Copper-Zinc Deposits, Goldstream Area

Standard deposit

The Standard deposit property (Figs. 3 and 9) consists of a series of thin, generally discontinuous chalcopyrite-pyrite-pyrrhotite lenses with associated disseminated sulfides in greenstone and dark calcareous phyllite. It was discovered in 1895 and underwent extensive underground development from 1900 to 1906. Noranda Exploration Company, Ltd., optioned the property and in 1976 and 1977 drilled 11 short holes to test underground extensions of surface exposures (Hughes and Bradish, 1976).

The structure of the Standard area is dominated by a tight north-south-trending antiform that plunges at a low angle to the north (Fig. 9). From regional considerations, the antiform is apparently in an inverted stratigraphic panel and younger rocks are exposed in its core. These include limestone and dark graphitic and calcareous phyllite, whereas rocks in the limbs of the antiform are believed to be stratigraphically underlying greenstone, limestone, and phyllite of the metavolcanic-phyllite division. An interpretation of the stratigraphic section is illustrated in Figure 4.

The massive sulfides on the Standard property are most prominent within a distinct stratigraphic interval in the greenstones (unit V-7, Fig. 9), but some also occur within stratigraphically overlying calcareous

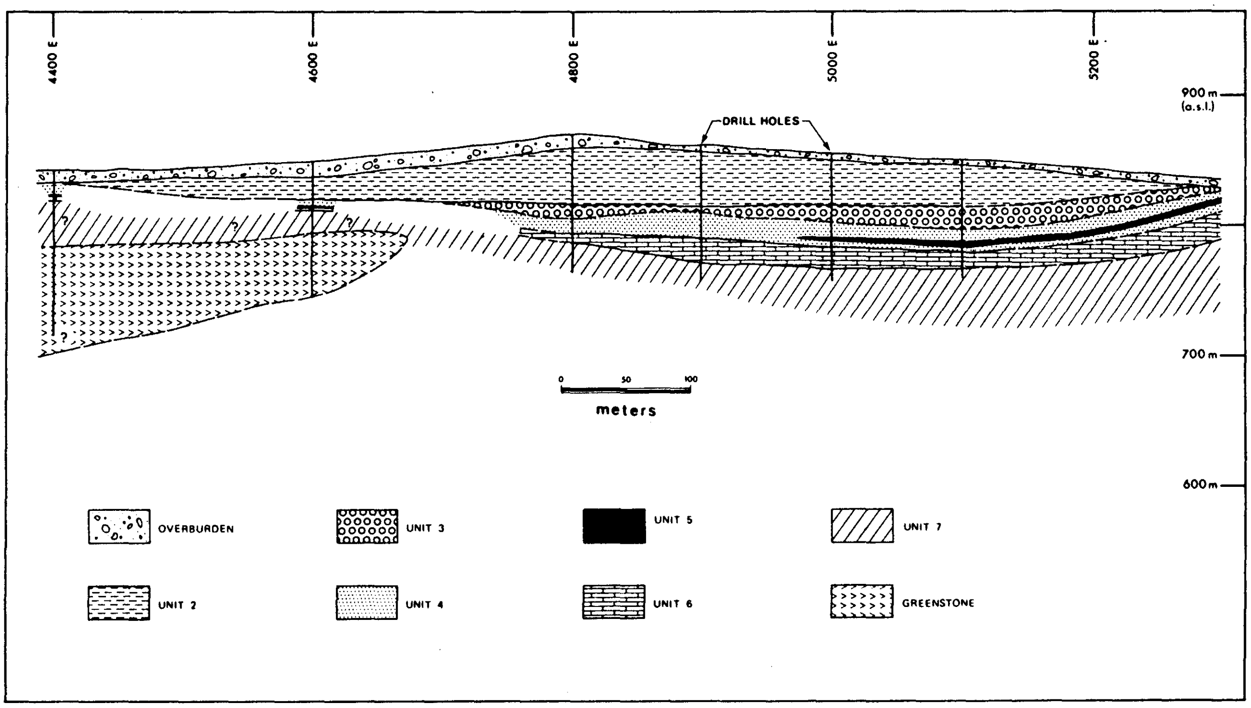
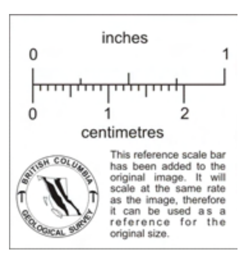


FIG. 12. An east-west vertical section (2100N) through the Goldstream deposit, looking north (see Fig. 11 for lithologies) (from Høy, 1979). a.s.l. = above sea level.



phyllite. They consist of a series of layers and lenses of massive pyrrhotite and pyrite that contain minor chalcopyrite and sphalerite. Sulfides are repeated on the limbs of the Standard antiform, and on the east limb they can be traced intermittently for a strike length of 1,500 m. Copper concentrations in the massive sulfides generally range from 1 to 3 percent and zinc from 0.3 to 1 percent.

The massive sulfides consist dominantly of fine- to medium-grained pyrite interlayered with much finer grained pyrrhotite. Chalcopyrite occurs intimately mixed with pyrrhotite, as irregular blebs and veinlets commonly in dark phyllite or quartz fragments, and as thin discontinuous layers with diffuse boundaries in the pyrrhotite and pyrite. Mylonitization of the massive sulfides has locally produced dull, fine-grained, layered pyrrhotite or gneissic textures (Fig. 10A). Porphyroblasts of euhedral pyrite in the pyrrhotite and complete recrystallization of pyrrhotite layers to coarse-grained pyrite are common. Many small, late, minor folds, augen of clear to micaceous quartz, and angular fragments of dark phyllite are common within the massive sulfides (Fig. 10B). Pyrite also occurs as disseminated grains in calcareous and chloritic phyllite; pyrrhotite and chalcopyrite may occur as thin, intimately mixed, wispy concentrations along foliation planes.

Montgomery deposit

The Montgomery showings (Fig. 3) are a series of lenses of massive sulfides and disseminated sulfides in micaceous chloritic schist and sericitic quartzite of the metavolcanic-phyllite division. Thin limestone and impure dolomite layers, calc-silicate gneiss, calcareous phyllite, and massive to schistose greenstone layers are common in the immediate vicinity of the showings. This succession, believed to be right way up, is immediately underlain by calc-silicate gneiss, calcareous schist, amphibolite, and locally skarn adjacent to the Goldstream pluton, and a thick succession of quartzite and pelitic schist of the quartzite-schist division. To the northeast it is overlain by more calcareous rocks and a thick marble of the carbonate-phyllite division.

The deposits consist of several lenses up to 3 m thick of massive pyrrhotite with minor amounts of pyrite, chalcopyrite, sphalerite, and trace galena in siliceous, sericitic phyllite (Gunning, 1928; Wheeler, 1965). Disseminated and vein sulfides with locally higher copper content (Gunning, 1928) commonly occur in the hanging-wall rocks. A second zone of disseminated pyrrhotite and minor chalcopyrite occurs several hundred meters stratigraphically above the massive sulfide lenses. These strata-bound sulfide zones have been traced intermittently up to 1,000 m along strike (Gunning, 1928).

FIG. 13. A. Unit 3, garnet zone, Goldstream deposit. Note numerous spherical spessartine garnets, thin chert layers, and streaks and disseminations of pyrrhotite.

B. Unit 3, well-layered chert, Goldstream deposit. Note the crosscutting remobilized quartz veins.

Goldstream Deposit

Introduction

The Goldstream deposit is a thin, conformable sheet of massive sulfides in sericitic quartzite and calcareous and chloritic phyllite. It crops out on the heavily wooded southern slopes of Goldstream Valley and plunges to the northeast beneath Goldstream River (Fig. 3). Structures observed underground include a pronounced mineral foliation, crenulation cleavage, small-scale late folds and brecciation, quartz-carbonate veining, and fault gouge in the hanging-wall phyllite.

TABLE 3. Chemical Analyses of Selected Samples of Unit 3 (Garnet Zone) in the Goldstream Deposit
For locations, see Figure 21.

Sample number	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO (%)	Na_2O	K_2O	TiO_2	MnO
NG-D	41.3	3.51	26.7	2.31	12.5	0.01	0.01	0.13	3.77
NG-E	72.9	1.49	14.7	1.27	3.80	0.01	0.04	0.07	1.65
17099	48.3	3.46	23.7	2.71	9.53	0.01	0.02	0.14	3.05
G-14	75.65	8.29	5.26	1.49	2.03	0.88	1.51	0.40	0.382
G-15	69.7	10.79	6.14	1.71	1.97	1.11	2.94	0.73	0.257
G-16	67.11	6.06	13.03	1.04	3.63	0.17	0.54	0.20	1.473
G-17	48.35	8.60	8.42	2.57	13.98	0.29	2.36	1.08	0.789
G-22	70.21	7.58	8.81	1.64	2.87	0.84	1.52	0.35	0.690
G-23	67.20	7.80	8.88	1.89	4.06	0.51	1.15	0.37	1.454
G-38	68.19	8.19	12.32	1.05	2.04	0.51	1.71	0.30	0.438
G-39	70.17	8.87	4.05	1.10	5.17	0.57	1.94	0.32	0.310
G-41	67.62	9.49	3.17	1.31	6.04	1.27	1.60	0.36	0.125
G-42	64.48	4.01	16.22	1.07	4.40	0.01	0.02	0.23	1.315
G-52	49.15	12.22	14.65	1.61	6.47	0.86	2.59	0.75	0.547
G-53	66.51	6.64	5.06	1.17	7.82	0.70	0.97	0.31	0.386

Summary of metal values

Element	Number of samples	Maximum (ppm)	Minimum	Arithmetic average
Ag	14	2.0	<0.7	<0.7
Cu	15	320	40	144
Zn	15	570	13	202
Pb	14	82	18	38
Co	14	22	4	8
Ni	15	110	8	57

Rock units

The Goldstream deposit is within the metavolcanic-phyllite division. Regional structures suggest the succession, illustrated in Figures 11 and 12, is inverted, with the oldest rocks in the hanging wall of the deposit.

Unit 1 (above rocks shown in Fig. 11) includes siliceous chlorite-biotite phyllite, phyllitic quartzite, calcareous and graphitic phyllite, and a few impure limestone layers. Unit 2 includes approximately 220 m of dark carbonaceous and calcareous phyllite interlayered with thin gray limestone layers. Calcite and biotite are common within the unit, and pyrrhotite is ubiquitous. The alignment of sericite, chlorite, and graphite (?) grains produces a well-defined foliation and augen of quartz and carbonate, and abundant limy partings give this rock a distinctive layered appearance.

Unit 3, informally called the garnet zone, is generally medium to dark green or gray in color and locally contains abundant spessartine garnets (Fig. 13A). It includes thin dark chert layers, medium green chloritic phyllite layers, and dark gray to black, greasy chlorite-rich graphitic and calcareous quartzite layers (Fig. 13B). Pyrrhotite, concentrated in thin irregular laminations or in discontinuous streaks, is very abundant locally, and grunerite occurs in some dark siliceous layers. Chemical analyses of unit 3 indicate high manganese and iron contents but only traces of copper and zinc (Table 3). A pronounced fault zone coincides, in part, with unit 3, and rocks in many places are sheared, broken, and cut by numerous quartz-carbonate veins. The garnets predate this deformation and predate or are synkinematic with the early stages of phase 2 deformation that produced the prominent mineral foliation in the metasedimentary rocks. This early foliation is bent and warped around the garnet porphyroblasts.

The garnet-rich layer is interpreted to be a metamorphosed, manganiferous, iron-rich chert. It is areally restricted and terminates to the west away from the massive sulfide layer (Fig. 12). Probably, it is an exhalite unit.

The massive sulfide layer is enclosed in an envelope of light green to brown, very siliceous chlorite and sericite phyllite (unit 4) that grades to fine-grained sericite-chlorite quartzite (Fig. 14). Although unit 4 may, in part, represent epiclastic accumulations, it may also include a siliceous exhalative component. A gray limestone layer, 1 to 2 m thick, occurs above the sulfide layer within unit 4. Within the unit pyrrhotite, chalcopyrite, and minor sphalerite increase substantially just above the sulfide layer.

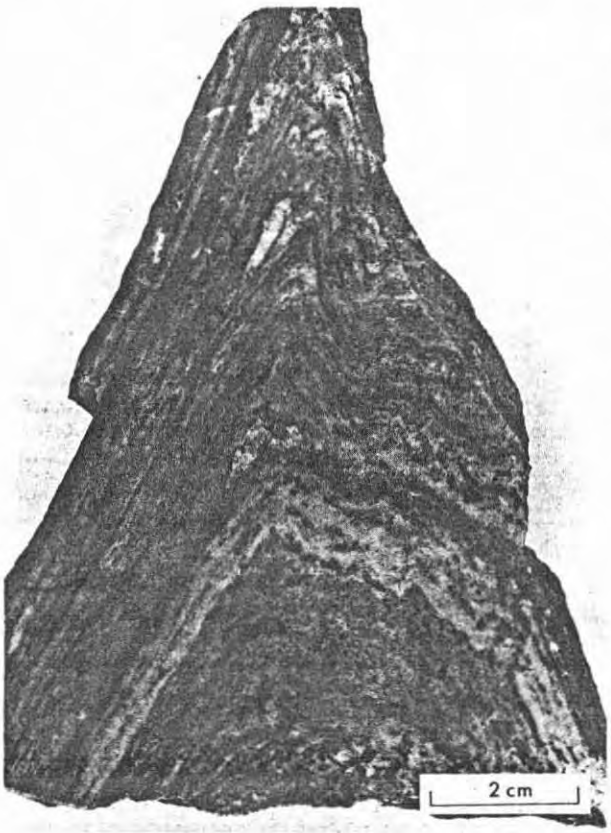


FIG. 14. Unit 4, Goldstream deposit. A fold in fine-grained sericitic and chloritic quartzite in the hanging wall of the sulfide layer. Chalcopyrite and pyrrhotite are disseminated throughout the sample.

A light gray limestone (unit 6), averaging 10 to 20 m in thickness, occurs structurally below unit 4. The limestone is underlain by the interlayered siliceous sericite-biotite-chlorite phyllite, schist, minor quartzite, and limestone of unit 7.

Greenstone was encountered in three drill holes west of the deposit (Fig. 12). A thin gray limestone lying above the greenstone is tentatively correlated with the footwall limestone (unit 6), suggesting that the greenstone lies structurally below the ore horizon. However, it is possible that the gray limestone correlates with the limestone in unit 4, and therefore that the greenstone would be at approximately the same stratigraphic level as the massive sulfide layer. The greenstone varies from fine-grained, massive varieties to chloritic phyllite. It is very altered and composed dominantly of actinolite, chlorite, epidote, and albite. Although the greenstone has not been analyzed, it is correlated with the predominantly subalkaline basalts of the metavolcanic division in the Keystone and Standard areas to the south (Fig. 3).

Structure

The most conspicuous structures in the deposit are late folds and faults. These are related to phase 3 deformation because they deform both the layering and the most obvious phase 2 structures, a penetrative mineral foliation. Phase 1 structures were not recognized underground, but an earlier deformation is inferred from regional considerations because phase 2 structures throughout the Goldstream area are developed in an inverted stratigraphic panel that is pre-

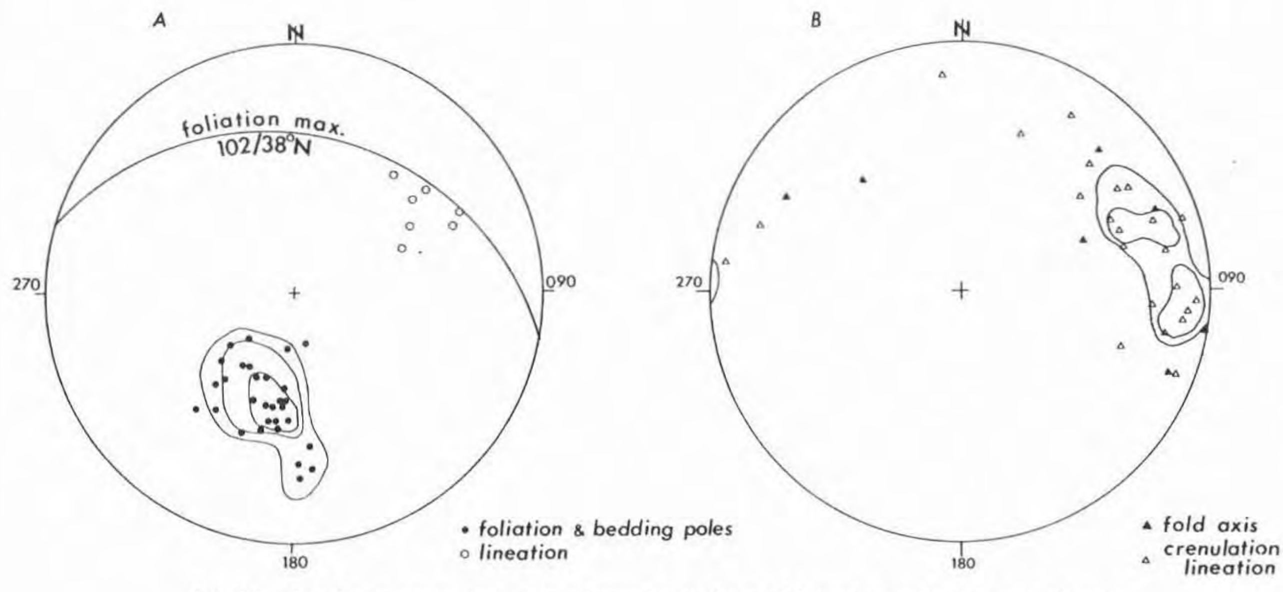


FIG. 15. Equal area projections onto a lower hemisphere of (A) poles to bedding and phase 2 foliation, and phase 2 lineations; and (B) phase 3 fold axes and crenulation lineations, Goldstream deposit.

sumed to be the underlimb of a major, early recumbent nappe (Lane, 1977; Høy, 1979; Read and Brown, 1979).

Phase 3 folds are generally fairly open with rounded hinge zones. Their trends vary from east-west to northeast, and their fold axes, although variable, generally plunge to the east-northeast (Fig. 15B). A crenulation cleavage, with dips varying from approximately 10° north at the adit portal to 30° to 35° north just above the sulfide layer, is parallel to the axial planes of these folds. Phase 3 lineations plunge at low angles generally toward the east and east-northeast. They formed by the intersection of the crenulation cleavage and phase 2 foliation, and plot as a great circle in Figure 15B. Phase 3 structures verge toward the south; that is, they indicate reverse strain in north-dipping surfaces with structurally higher rocks overriding footwall rocks.

Numerous zones of fault gouge and pronounced shearing in the dark phyllites overlying the deposit appear to be related to the phase 3 deformation. Abundant breccias, quartz-carbonate veins, numerous phase 3 minor folds, and a substantial increase in the intensity of crenulation cleavage are associated with these faults. A wide zone of shearing and brecciation is concentrated in the garnet zone above the sulfide layer. The vergence of associated minor folds and numerous slickensides indicate a reverse movement on this fault.

The deposit is on the inverted northern limb of a large phase 2 isoclinal fold. Within the deposit a pronounced phase 2 mineral foliation trends east-west and dips 30° to 40° north, essentially parallel with layering (Fig. 15A), indicating isoclinal to subisoclinal phase 2 folding. A mineral lineation within this foliation plane, presumably related to phase 2 fold axes, plunges 30° to 40° to the northeast. The present sheetlike form of the deposit, its elongation parallel

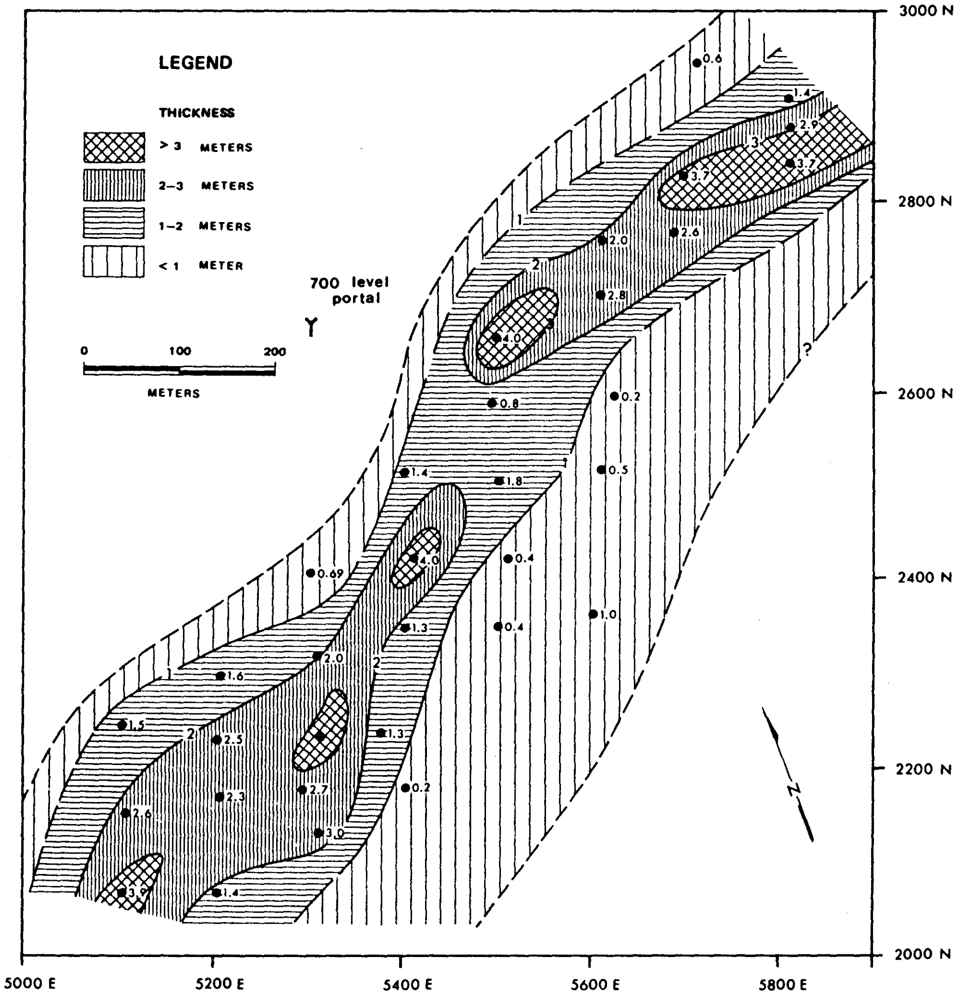


FIG. 16. Isopach map of the massive sulfide layer, Goldstream deposit. Surface projections of sulfide intersections and calculated true thicknesses are shown on the plan (from Høy, 1979).

to phase 2 stretching lineations, and its gneissic textures are due largely to the intense phase 2 deformation. Its position within an inverted stratigraphic panel is due to the earlier phase 1 deformation.

Sulfide layer

The massive sulfide layer averages from 1 to 3 m in thickness, has a strike length of at least 400 meters, and continues down plunge for at least 1,200 m (Fig. 16). Near its western and eastern limits it splits into two layers separated by a narrow zone of quartzitic phyllite that has abundant disseminated sulfide. Only the western and truncated southern boundaries of the deposit have been well defined. It continues down plunge to the northeast at least as far as the Goldstream River, where it is 350 m below the surface. The massive sulfide layer thins gradually to the east and is restricted in extent by a barren hole (at 2562N, 5900E) approximately 300 m east of the last known sulfide intersection (Fig. 16).

The contacts of the sulfide zone with hanging-wall and footwall rocks vary from sharp to gradational and from smooth to highly contorted and brecciated. In general, the structural footwall contact is more sharply defined than the structural hanging-wall contact. Irregular blocks of country rock, ranging up to 1 m in size, are engulfed locally by sulfides to produce megabreccias. Folding and shearing, with irregular sulfide injections into the wall rocks, are also common along the upper and lower margins of the deposit.

Sulfides in the structural hanging wall of the sulfide layer occur as fine-grained disseminations and discontinuous blebs and streaks dispersed parallel to layering in sericitic and chloritic quartzite and siliceous phyllite. They also occur in a complex network of thin, interconnected fractures with parallel layers which are commonly associated with a dark gray to black, greasy, lustrous chlorite alteration. Sulfides are also common in late bull quartz veins that cut foliated hanging-wall rocks. Sulfides are less abundant and restricted to a narrower stratigraphic interval in footwall rocks. They occur primarily as thin discontinuous bands in a dark layered sericitic quartzite or siliceous phyllite.

Mineralogy and textures in massive sulfide layer: The sulfide layer consists mainly of intimately intermixed pyrrhotite, chalcopyrite, and sphalerite with numerous subrounded inclusions of quartz, phyllite, and carbonate. A fine-grained recrystallized matrix of gneissic sulfides, mainly pyrrhotite, is swirled around the gangue inclusions (Fig. 17) to produce a Durchbewegung fabric, as described by Vokes (1969, 1971). Gneissic textures in compact sulfide ore are more characteristic of the margins of the massive sulfide layer; coarse-grained equigranular textures are more typical of the center.

Some massive sulfide samples show a crude compositional layering into chalcopyrite-rich and chalcopyrite-poor units, the latter accompanied by a relative increase in pyrrhotite and decrease in large gangue fragments. Mylonitic textures with crushed and comminuted gangue dispersed in a fine granular sulfide matrix have also been noted.

FIG. 17. Goldstream deposit. Cut slabs from the massive sulfide layer showing a typical durchbewegung fabric. Rounded inclusions of quartz, carbonate, and phyllite are suspended in a granular matrix of pyrrhotite, chalcopyrite, and sphalerite.

A. Inclusion sulfide. Note the swirling of gneissic sulfides about gangue fragments and the partial alignment of elongate phyllite inclusions parallel to gneissosity. Chalcopyrite (pale) is preferentially segregated to interstitial positions within the gangue and to strain shadows adjacent to competent gangue fragments.

Inclusions: Subrounded inclusions of quartz, recrystallized carbonate, and phyllite are ubiquitous (Fig. 17). These vary in size from less than 1 mm to greater than 10 cm and typically make up 40 to 70 percent by volume of the massive sulfide layer. Quartzitic inclusions are subspherical and either clear or opaque-white with smoothly curving margins and undulose extinction in thin section. In mineralogy and texture, phyllite inclusions closely resemble the metasedimentary rocks in the hanging wall and footwall of the massive sulfide layer. The largest of these are markedly elongate in the plane of their foliation

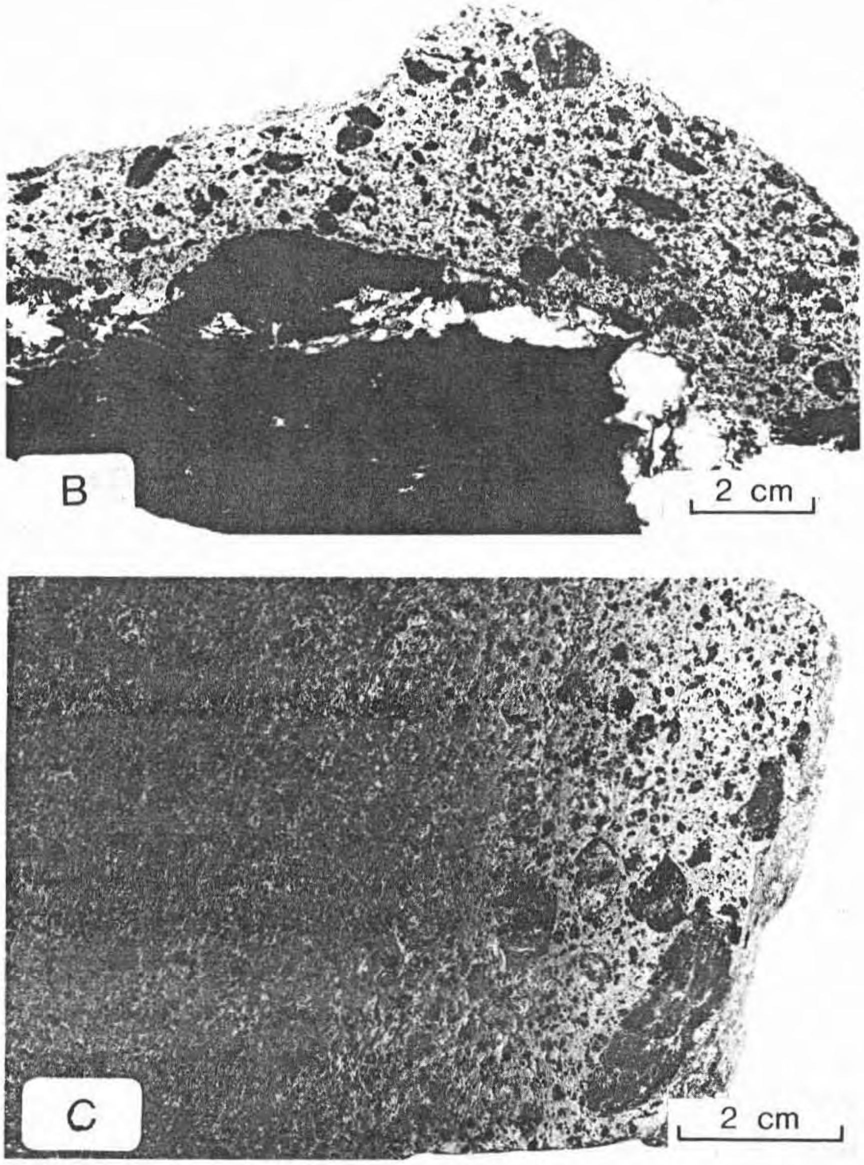


FIG. 17—*(cont.)*

B. The contact of the massive sulfide layer with the structural hanging wall of the deposit; 655.1 ore ramp. Note the coarse chalcopyrite segregations (pale) along fractures and the foliation in the phyllite.

C. Inclusion sulfide. Note the gneissic texture of sulfides, intimate intermixing of chalcopyrite (light colored) and pyrrhotite, and preferential concentrations of chalcopyrite in strain shadows of inclusions.

and tend to be aligned parallel to gneissosity in the surrounding sulfide matrix. Near their margins, many phyllite inclusions are partially disaggregated into their component mineral grains, such that many dislodged mica flakes float in a sulfide matrix (Fig. 18C). Carbonate inclusions consist mainly of fine to coarsely recrystallized calcite with highly irregular margins against matrix sulfides.

Many gangue inclusions in the massive sulfide layer are fractured and brecciated. These often contain chalcopyrite, sphalerite and, rarely, galena as fracture fillings or coarse (up to 5 mm) interstitial or poikilitic grains. Much chalcopyrite also preferentially occupies strain shadows adjacent to brittle gangue inclusions (Fig. 17A). This selective redistribution and coarsening of chalcopyrite into sheltered positions is a positive

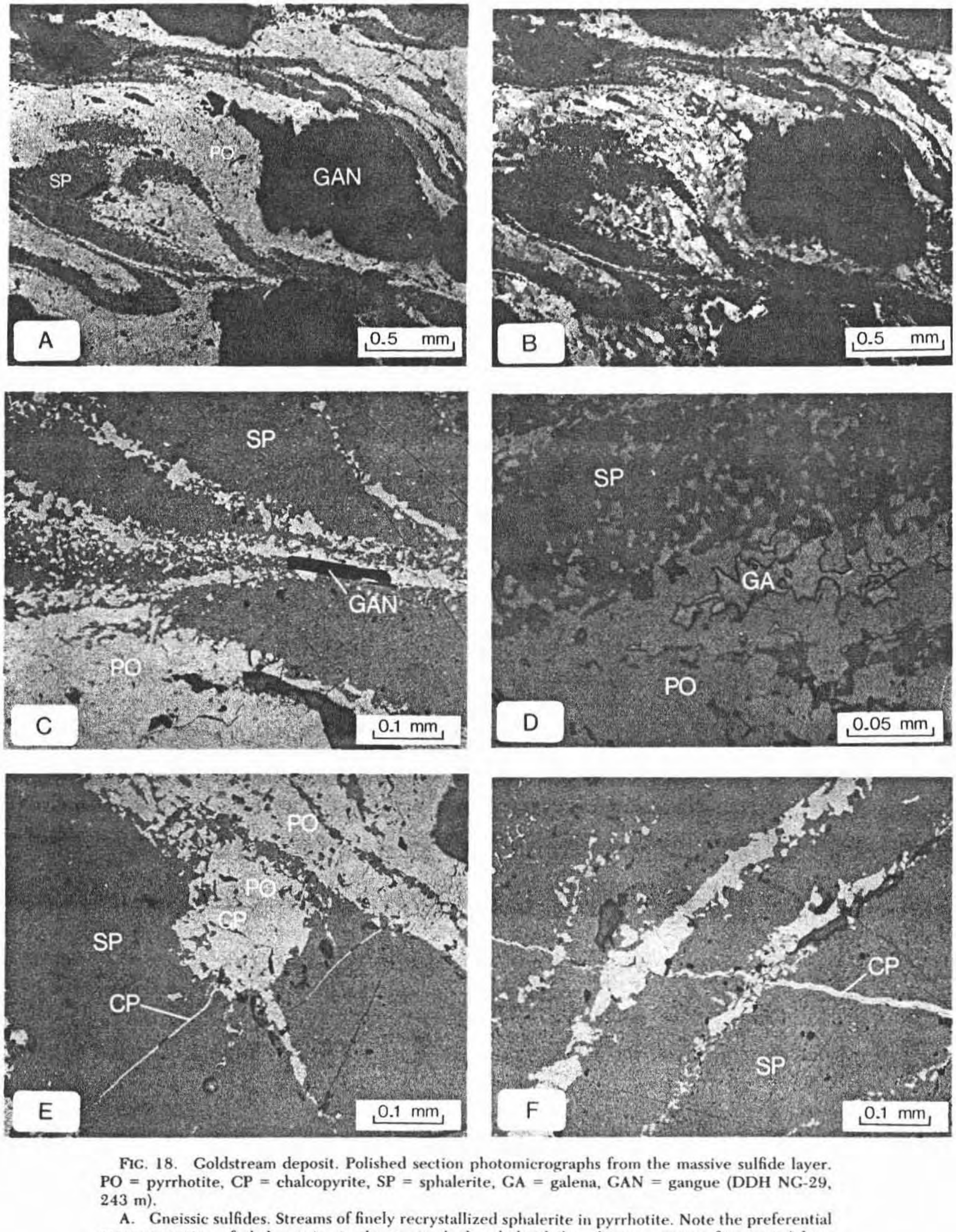


FIG. 18. Goldstream deposit. Polished section photomicrographs from the massive sulfide layer. PO = pyrrhotite, CP = chalcopyrite, SP = sphalerite, GA = galena, GAN = gangue (DDH NG-29, 243 m).

A. Gneissic sulfides. Streams of finely recrystallized sphalerite in pyrrhotite. Note the preferential reconcentration of chalcopyrite in the strain shadow behind the siliceous gangue fragment (plane polarized light).

B. Same field of view as A, but with crossed nicols to illustrate the preferred orientation—parallel to gneissosity—of pyrrhotite grains.

feature of Goldstream ore, enabling more efficient copper liberation during the milling process.

Matrix sulfides: A recrystallized granular mosaic of intimately intermixed pyrrhotite, sphalerite, chalcopyrite, and rare galena forms the sulfide matrix between gangue inclusions. Gneissic textures are well developed in the matrix and are outlined by streams of fine intergranular sphalerite and chalcopyrite in pyrrhotite or pyrrhotite and chalcopyrite in sphalerite (Fig. 18). By contrast, where gangue fragment density is high, matrix sulfides tend to be coarser grained with a more homogeneous granoblastic distribution of the major phases.

Pyrrhotite is the dominant matrix sulfide, occurring as extensive allotriomorphic grain mosaics with chalcopyrite and sphalerite. Individual pyrrhotite grains tend to show preferred optical and form orientation parallel to gneissosity (Fig. 18B). Chalcopyrite, although a major component of the granular sulfide matrix, also occurs as late veinlets cutting gneissic sulfides (Fig. 18E and F) or as minute seriate blebs, rods, and segregations in coarse-grained sphalerite. Larger chalcopyrite grains typically show deformation twins. Sphalerite normally occurs as tiny, cuspate, concave grains that are intergranular to recrystallized pyrrhotite or locally as granular mosaics with subordinate pyrrhotite and chalcopyrite (Fig. 18C–F). Galena is uncommon in the sulfide matrix, occurring as small grains with chalcopyrite, sphalerite, and pyrrhotite (Fig. 18D). Pyrite, although rare, occurs locally as microveinlets in pyrrhotite grains.

Discussion: The observed sulfide textures and fabrics in the Goldstream deposit are interpreted to be largely a product of intense regional metamorphism and deformation. Directed stress induced plastic flowage of sulfides. Competent siliceous bands or discordant quartz veins were stretched, boudinaged, and rounded by rotation and kneading in the incompetent sulfide matrix to produce a durchbewegung fabric. Injection of sulfides into wall rocks along fractures and foliation was followed in part by detachment and incorporation of large wall-rock blocks into the sulfide mass. Inclusions were pulverized, partially disaggregated, and rotated into parallelism with flow lines in the surrounding sulfide matrix. More mobile sulfides, in particular chalcopyrite and galena, were preferentially redistributed into strain shadows and fractures in gangue inclusions.

After the waning of the main metamorphic event, annealing recrystallization of the deformed sulfide matrix produced granular strain-free gneissic aggregates of pyrrhotite, sphalerite, and chalcopyrite. Locally, however, the preferred form orientation of pyrrhotite parallel to gneissosity may reflect grain growth under the continued influence of stress. Unmixing and diffusion of solid solution minerals resulted in intimate sulfide intergrowths and segregation veinlets. Chalcopyrite remained mobile until after at least one major phase of matrix recrystallization, as indicated by irregular veins of chalcopyrite that cut matrix pyrrhotite and sphalerite.

Microveinlets or coatings of pyrite on pyrrhotite have ragged, replacement-type embayments along their edges and may indicate late-stage retrogressive alteration of pyrrhotite to pyrite.

Metal distribution

Massive sulfide layer: The distribution of copper, zinc, and silver in the massive sulfide layer, based on weighted averages of 31 drill intersections, closely parallels the massive sulfide isopachs (compare Figs. 16 and 19). These metal grades have a simple and regular plan distribution, with increasing values toward the central, thicker parts of the layer. Furthermore, a decrease in grades at approximately 2600N is coincident with a thinning of the sulfide layer. The plan distribution of lead is not as well known because it was not assayed for routinely during exploration and preproduction drilling. However, underground sampling (Table 4; Fig. 20) indicates a tendency toward higher lead grades near the center of the deposit. Furthermore, this sampling shows a strong positive correlation between lead and copper, zinc, and silver (Table 5), which suggests that the distribution of these elements is similar in the massive sulfide layer.

The sulfide layer has a pronounced lateral zonation, with Zn/(Zn + Cu) increasing to the east (Fig. 21). This zonation is independent of the thickness of the sulfide layer or copper or zinc grades. Results of the limited underground sampling show that Cu/Ni ratios increase from between 0.5 to 1.0 in the west to between 2.0 to 3.0 in the east; Pb/(Pb + Cu + Zn) ratios also tend to increase to the east.

A consistent vertical zonation within the massive sulfide layer is not apparent. Eight drill intersections have slightly enriched Zn/(Zn + Cu) values near the footwall, but nine intersections, as well as a series of chip samples (NG-1 to NG-5, Table 4), show no enrichment patterns. The variability in assay values and metal ratios is illustrated in Figure 22.

Hanging wall and footwall: The metal contents of

C. Granular streams of pyrrhotite in sphalerite; the enclosed mica flake is oriented parallel to the gneissosity (plane polarized light).

D. Detail of recrystallized sulfides. The average grain size is typically less than 20 μm (plane polarized light).

E and F. Gneissic sulfides. Late veining of sphalerite by chalcopyrite (plane polarized light).

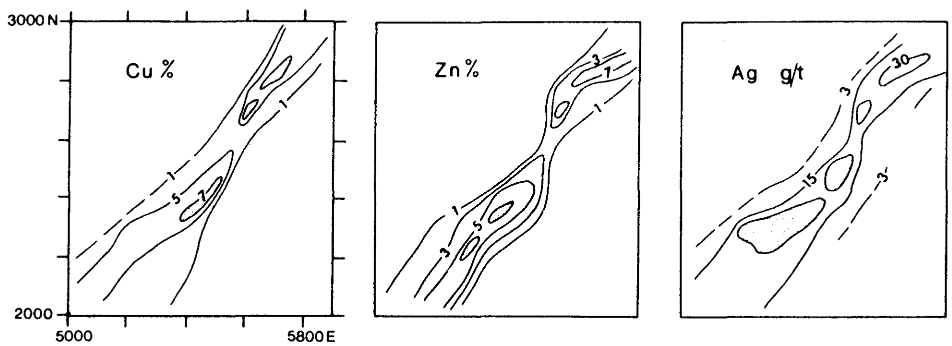


FIG. 19. The distribution of copper, zinc, and silver in Goldstream deposit.

hanging-wall rocks within a few meters of the sulfide layer are variable (Fig. 22; Table 6). Copper and zinc values range from less than 0.1 to 2.5 percent, with averages of 0.6 to 0.7 percent. Silver averages from 2 to 7 g per metric ton. Grades are lower in footwall rocks (Table 7), and the average thickness of mineralized footwall is less (Table 8). The pronounced lateral zoning in the massive sulfide layer is not apparent in footwall or hanging-wall rocks. Rather, an irregular distribution of higher Zn/(Zn + Cu) ratios (0.5 to 0.7) appears to be concentrated in the footwall approximately beneath the thicker central part of the sulfide layer, with lower values (<0.3) toward the margins of the deposit. Ratios in the hanging wall are very irregular, with no consistent zonation pattern. The weighted average Zn/(Zn + Cu) ratio in the hanging wall is somewhat more than that in the massive sulfide layer and in the footwall (Table 8).

Discussion: The two most noticeable features of metal distribution in the Goldstream deposit, a pronounced lateral zonation of zinc vs. copper and high metal values in the central, thicker portion of the sulfide lens, are probably due to an original depositional configuration. They may simply reflect an original high-grade core in the deposit with a superposed lateral zonation with higher Zn/(Zn + Cu) values along the eastern margin (Fig. 23A). Alternatively, they may be due to intense shearing of a massive sulfide lens also with a high-grade core but with an original vertical zonation, an extreme example of shear deformation of a massive sulfide deposit as described by Sangster (1972). The deposit is on the

TABLE 4. Analyses of Selected Sulfide Samples, Goldstream Deposit
See Figure 20 for sample localities.

Sample number	Sample type	Cu (%)	Zn (%)	Pb (%)	Fe (%)	Ag (ppm)	Au (ppm)	Ni (ppm)	Co (ppm)	Mn (%)
G-6	grab	7.26	8.13	0.87	27.5	49	0.145	60	67	0.33
G-10	1-m chip	4.64	5.69	0.49	23.5	29	0.057	45	56	0.31
G-12	0.6-m chip	0.27	0.01	0.01	20.5	0.5	0.02	104	38	0.04
G-18	grab	0.66	1.58	0.15	27.0	7	<0.02	112	44	0.14
G-27	0.6-m chip	3.40	5.21	0.67	28.5	28	<0.02	71	67	0.31
G-30	2-m chip	3.23	5.18	0.75	25.0	25	0.107	35	71	0.40
G-34	1.2-m chip	5.74	6.20	0.81	38.0	49	0.337	47	114	0.13
G-36	grab	3.33	2.16	0.03	27.0	15	<0.02	48	100	0.19
G-44	grab	0.11	0.07	0.03	28.0	2.1	<0.02	125	41	0.67
G-46	grab	1.12	3.66	0.46	21.0	13	<0.02	103	57	0.53
G-48	grab	3.10	2.50	0.02	23.5	10	0.054	51	51	0.16
NG-1	0.6-m chip[1]	1.96	1.08	0.10	6.0	14	n.a.	32	28	0.15
NG-2	0.6-m chip[1]	4.53	5.98	0.72	17.8	48	n.a.	71	86	0.50
NG-3	0.6-m chip[1]	4.07	4.97	0.57	16.7	19	n.a.	70	78	0.44
NG-4	0.6-m chip[1]	5.20	5.10	0.73	22.1	24	n.a.	85	96	0.33
NG-5	0.6-m chip[1]	5.52	7.01	0.89	32.7	19	n.a.	133	144	0.39
NG-A	grab	5.21	7.95	1.03	35.0	<10	n.a.	60	76	0.33
NG3-27	grab	2.69	2.39	0.03	33.7	<10	n.a.	45	100	0.29
NG3-28b	grab	5.13	4.53	0.52	22.4	<10	n.a.	20	53	0.33

[1] Samples NG-1 to NG-5 are successive 0.6-m chip samples from the hanging wall through to the footwall of the sulfide layer
n.a. = not analyzed for

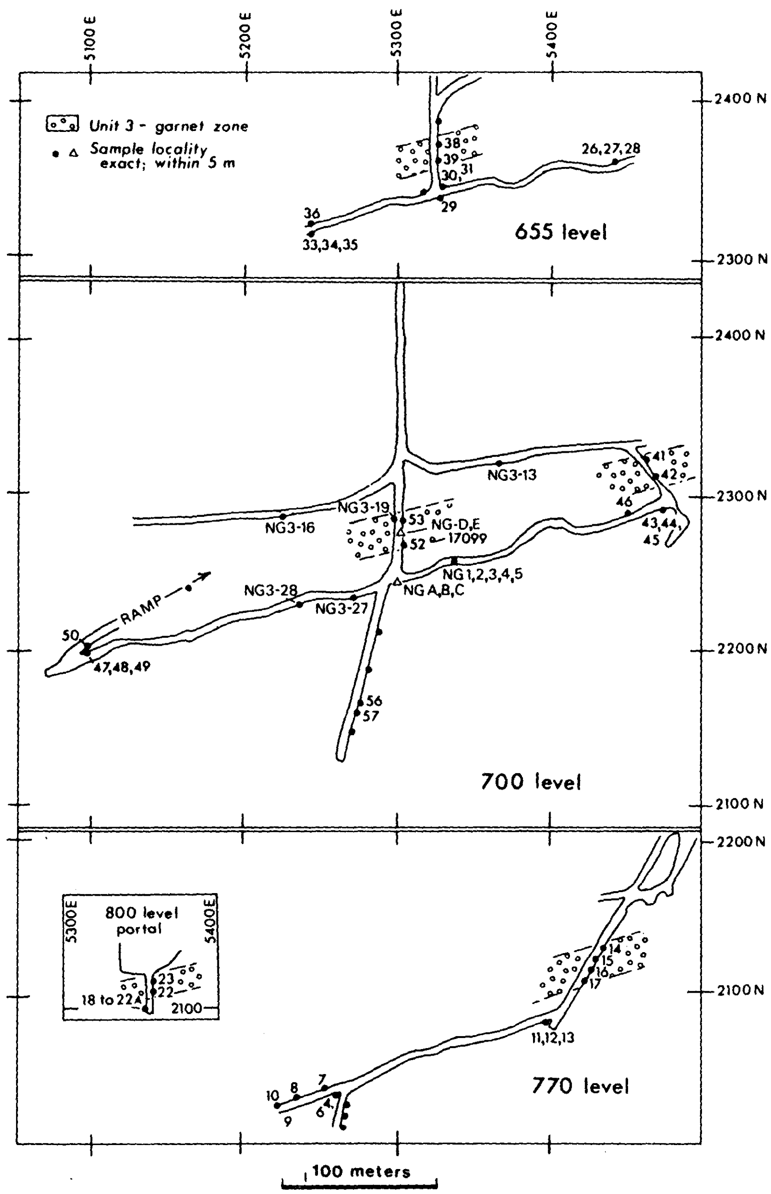


FIG. 20. Extent of underground workings (September, 1982) and location of samples listed in Tables 3, 4, and 6, Goldstream deposit.

northern inverted limb of a major isoclinal fold and, :herefore, was undoubtedly subjected to intense si- ıistral (viewed downplunge to north) shear. Such hear strain, concentrated in the incompetent massive ulfide lens, could shift the upper part of the lens to he west and eventually result in a very attenuated ılfide layer with pronounced lateral zonation (Fig. 3B). In this model, the higher grade core zone would so retain its position in the central, thicker part of e lens during the deformation. However, it does ıt explain metal ratios in the hanging wall or footwall the deposit. It is possible that less intense shearing of more competent footwall rocks allowed approximate retention of relatively high zinc in these rocks.

Summary and Discussion

A number of small massive copper-zinc sulfide deposits and the major Goldstream deposit occur in geosynclinal rocks in the northern Selkirk Mountains of southeastern British Columbia. Host rocks include either basic metavolcanic or dark carbonaceous and calcareous phyllites, associated with thick accumulations of impure quartzite, graywacke, and calcareous rocks. Locally they are associated with ultrabasic rock.

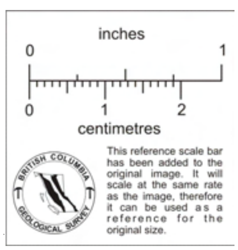
TABLE 5. Correlation Coefficients for Elements in the Massive Sulfide Layer
From data listed in Table 4 (n = 19).

Element	Fe	Cu	Pb[1]	Zn[1]	Co[1,2]	Ni	Ag[1]
Fe		0.314	0.310	0.361	*0.564*	0.146	0.104
Cu			**0.771**	**0.889**	**0.575**	0.385	**0.827**
Pb				**0.943**[2]	*0.492*	−0.047	**0.787**
Zn					*0.546*	0.201	**0.826**
Co						−0.090	0.461
Ni							−0.443
Ag							

[1] Coefficients in bold type = 99 percent significance
[2] Coefficients in italic type = 95 percent significance

The deposits resemble Besshi-type bedded cupriferous iron sulfide deposits. They are bedlike or lenticular in form, are composed primarily of pyrrhotite (or pyrite), chalcopyrite, and sphalerite, and are within or associated with basic volcanic rocks. Their regional tectonostratigraphic setting, in metamorphosed and highly deformed geosynclinal rocks, is also similar to Besshi deposits. In contrast, some of the typical features of polymetallic or Kuroko-type volcanogenic deposits are absent, only poorly developed, or perhaps difficult to recognize owing to metamorphism; these include the association with acid volcanic rocks, a clearly defined crosscutting alteration pipe, association with sulfates, and obvious vertical metal and ore-type zoning (Sangster, 1972; Hutchinson, 1973).

The Goldstream deposit is on the inverted northern limb of a major isoclinal fold. Features within the deposit that tend to support structural inversion include a more gradational massive sulfide–hanging-wall contact than footwall contact, a thicker, mineralized hanging-wall section, extensive disseminated pyrrhotite in hanging-wall rocks, and pronounced dark chlorite alteration in the immediate hanging-



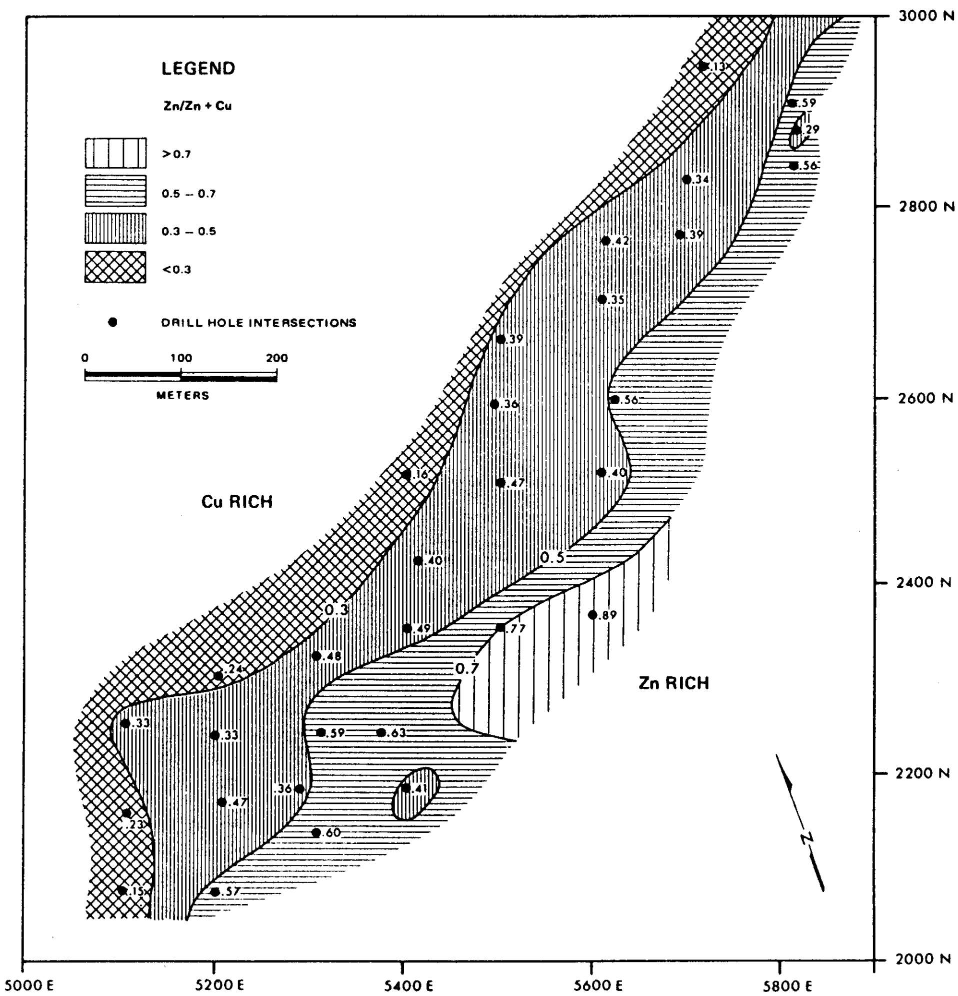
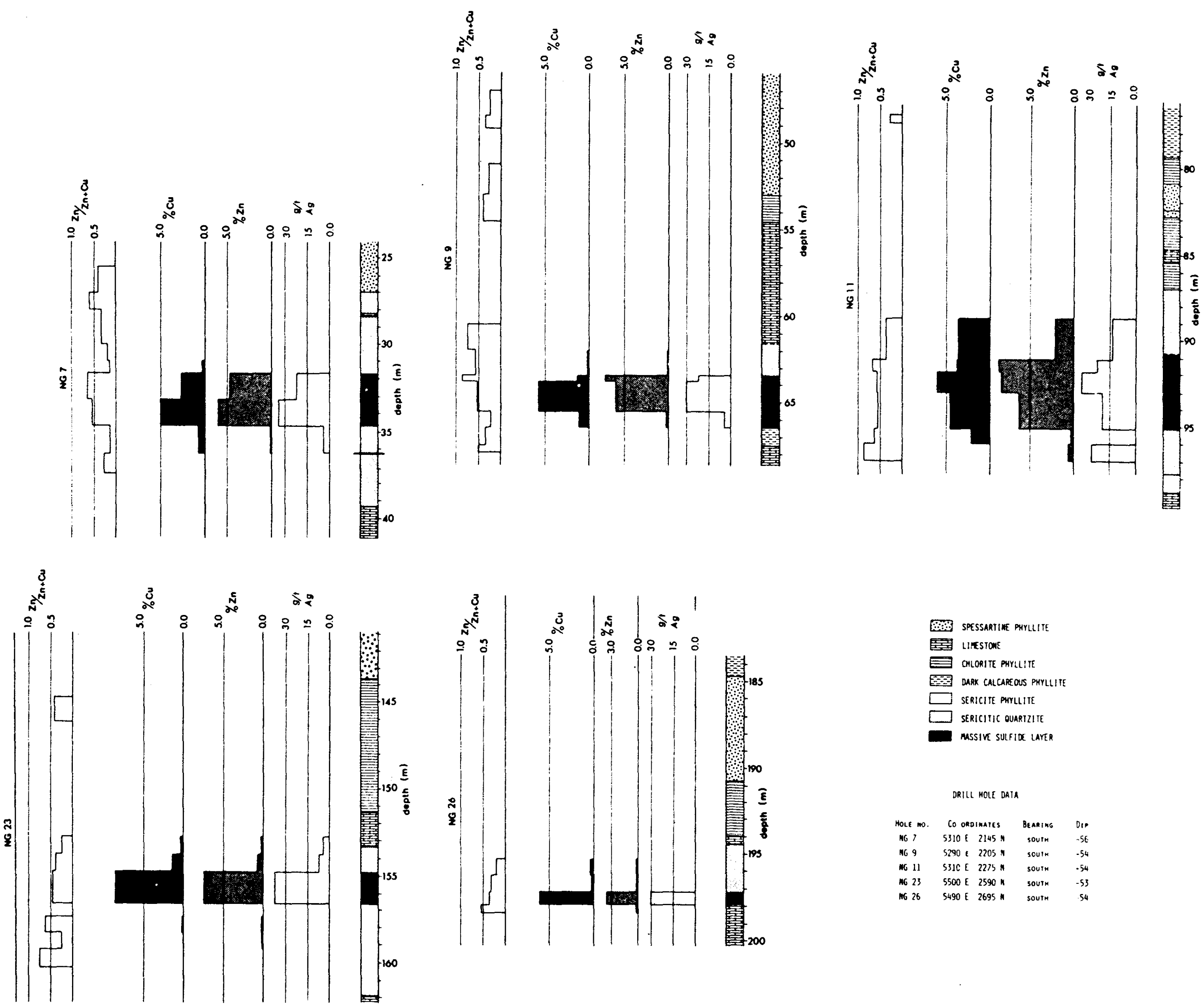


FIG. 21. Weighted Zn/(Zn + Cu) ratios in the massive sulfide layer, Goldstream (from Høy, 1979).



DRILL HOLE DATA

Hole no.	Co ordinates		Bearing	Dip
NG 7	5310 E	2145 N	south	-56
NG 9	5290 E	2205 N	south	-54
NG 11	5310 E	2275 N	south	-54
NG 23	5500 E	2590 N	south	-53
NG 26	5490 E	2695 N	south	54

FIG. 22. Selected drill intersections through the Goldstream sulfide layer illustrating the main lithologies, absolute Cu, Zn, and Ag values, and the variable Zn(Zn + Cu) ratios in the sulfide layer, footwall, and hanging wall. Coordinates and bearing refer to the grid in Figure 16.

TABLE 6. Analyses of Selected Samples of the Hanging Wall of the Goldstream Deposit
See Figure 20 for sample localities.

Sample number	Sample type	Cu (%)	Zn (%)	Pb (ppm)	Fe (%)	Ag (ppm)	Ni (ppm)	Co (ppm)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	MnO (%)
G-7	grab	0.88	0.10	174	2.74	6.6	22	12	80.26	4.42	4.45	0.30	3.58	0.60	0.64	0.266	0.103
G-8	grab	2.56	0.66	32	5.84	<0.7	16	36	58.65	9.19	11.96	4.88	2.24	2.52	0.77	0.611	0.150
G-22a	1.5-m chip	0.18	0.04	60	1.86	2.8	34	10	82.43	5.89	4.14	1.71	0.81	0.74	1.28	0.530	0.042
G-28	grab	5.01	1.14	360	6.12	18	14	28	53.46	3.00	15.14	2.08	7.13	0.42	0.28	0.379	0.302
G-31	2-m chip	0.06	0.013	96	1.20	<0.7	8	4	46.49	3.69	1.86	1.83	23.39	0.64	0.54	0.225	0.176
G-43	20-cm chip	0.34	0.19	475	10.66	3.0	60	18	57.02	7.46	15.92	1.96	6.74	0.45	1.17	0.393	0.303
G-49	grab	0.014	0.019	22	3.12	<0.7	52	22	46.34	15.78	7.37	12.93	4.90	0.49	2.47	0.733	0.251

G-7. White, fine-grained granular sericitic and calcareous quartzite
G-8. White, fine-grained quartzite
G-22a. Dark gray to black lustrous chlorite schist; interlayered with chert
G-28. Light gray, laminated sericitic quartzite
G-31. Light gray, massive sericitic limestone
G-43. Quartz-veined sericite-chlorite phyllite
G-49. Gray-green altered talcose-sericite schist

TABLE 7. Analyses of Selected Samples of the Footwall of the Goldstream Deposit
See Figure 20 for sample localities.

Sample number	Sample type	Cu (%)	Zn (ppm)	Pb (ppm)	Fe (%)	Ag (ppm)	Ni (ppm)	Co (ppm)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	MnO (%)
G-4	grab	0.49	700	144	11.51	4.4	42	40	62.06	6.61	17.77	0.86	2.45	0.569	1.240	0.455	0.083
G-9	1-m chip	0.06	263	121	2.72	0.8	32	12									
G-11	1-m chip	0.03	257	51	3.89	0.3	34	14									
G-19	1-m chip	0.09	93	52	3.26	0.7	40	18	61.34	15.30	7.82	1.90	1.77	0.898	3.682	1.250	0.093
G-26	2-m chip	0.95	375	49	7.91	3.4	42	16	56.35	9.93	12.64	2.46	6.10	0.624	1.946	0.596	0.664
G-26a	0.5-m chip	0.65	422	110	3.49	2.8	24	12	73.23	10.76	5.82	0.67	0.74	0.268	3.025	0.821	0.036
G-29	2-m chip	0.19	217	30	3.86	0.7	30	12	60.95	16.62	6.19	1.64	2.37	0.831	3.989	1.297	0.092
G-33	1-m chip	1.40	2.29%	0.46%	9.72	19	29	46									
G-45	0.8-m chip	0.26	620	134	15.52	<0.7	91	22	67.41	2.28	22.38	0.24	1.89	0.036	0.413	0.136	0.088
G-50	2-m chip	0.014	193	22	3.12	<0.7	52	22	52.44	17.91	7.11	2.68	5.09	1.186	4.418	1.111	0.098

G-4. Dark, fine-grained siliceous chlorite phyllite
G-9. Gray, sericite-chlorite phyllite
G-11. Gray, sericite-chlorite phyllite
G-19. Light gray, sericite-chlorite phyllite
G-26. Medium gray, pyrrhotite-rich siliceous phyllite
G-26a. Light gray, siliceous sericite phyllite
G-29. Dark gray, carbonaceous and calcareous phyllite
G-33. Quartz-veined phyllite
G-45. Pyrrhotite-rich phyllitic quartzite
G-50. Dark gray, carbonaceous phyllite

TABLE 8. Comparison of Hanging-Wall, Footwall, and Massive Sulfide Mineralization
Data from 33 drill hole intersections.

	Maximum thickness (m)	Average thickness (m)	Average[1] copper (%)	Zn/(Zn + Cu)
Hanging wall	9	2.3	0.62	0.47
Sulfide layer	5.5	1.4	5.2	0.40
Footwall	5	1.6	0.58	0.33

[1] 0.1 percent cutoff

wall rocks that might be the remnants of a sheared sulfide-rich footwall stringer zone. The massive sulfide layer has a well-defined lateral zonation. It is suggested that this zonation is due either to an original lateral zonation or to extreme shearing of a vertically zoned deposit. The iron-rich, manganiferous chert horizon in the hanging wall of the deposit records a period of silica exhalation that preceded sulfide deposition.

Massive sulfide deposits such as Goldstream are a new type of exploration target within the eastern Canadian Cordillera. They are distinct in their form, composition, and setting from polymetallic volcanogenic deposits of the more western terranes, such as Western Mines and Tulsequah, but are somewhat similar to deposits such as Anyox and perhaps the recently discovered Windy-Craggy deposit (MacIntyre, 1983) which are associated with basic to intermediate volcanic rocks (Thompson and Panteleyev, 1976). Exploration for high-grade deposits similar to Goldstream is extremely difficult. They are small, have minimal primary alteration halos, and occur in highly deformed terranes. Exploration requires a strategy involving, in its early stages, recognition of favorable terranes with basic volcanic rocks, followed by detailed geologic mapping and prospecting.

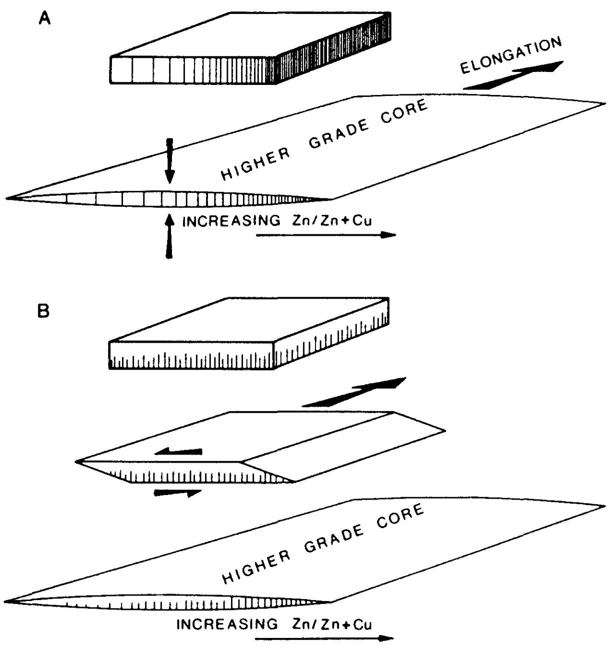


FIG. 23. Two models that illustrate flattening and elongation of a massive sulfide lens during extreme deformation. Both models can account for the pronounced lateral zonation of Zn/(Zn + Cu), the retention of a high-grade core zone during deformation, and the thickening of the central part of the sulfide layer. Model A assumes an original Zn/(Zn + Cu) zonation; model B produces lateral zonation by simple shear in a lens that was originally zoned vertically. (Note that the vertical hatching indicates higher Zn/(Zn + Cu) ratios.)

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