TRIP 1

LEAD - ZINC DEPOSITS OF SOUTHEASTERN BRITISH COLUMBIA

FIELDTRIP GUIDEBOOKS

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JOINT ANNUAL MEETINGS
VANCOUVER B.C., APRIL 1977

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JOINT ANNUAL MEETING, 1977

VANCOUVER, BRITISH COLUMBIA

FIELD TRIP NO. 1: GUIDEBOOK

LEAD-ZINC DEPOSITS OF SOUTHEASTERN BRITISH COLUMBIA

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G.A.C. - S.E.G. Annual Meeting

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F.R. Edmunds, T. Høy, P.W. Ransom, G.F. Warning

PART 1

INTRODUCTION

(Trygve Høy)

An important lead-zinc metallogenic province extends from northern Idaho and Montana through southeastern British Columbia to north of Revelstoke in the northern Selkirk Mountains. Included in this metallogenic province is a variety of sediment- and carbonate-hosted lead-zinc deposits. This field trip will visit the operating Sullivan and H.B. mines and the defunct St. Eugene and Bluebell mines. Emphasis will be placed on the origin, stratigraphic and tectonic setting of these deposits. One day will also be spent studying the Proterozoic and lower Paleozoic succession between Cranbrook and Kootenay Lake.

The lead-zinc metallogenic province lies within the Columbian Orogen, the eastern of two tectono-stratigraphic belts within the Cordilleran Orogen in Canada (Wheeler et. al., 1972). The Columbian Orogen (Fig. 1-1) includes an eastern Foreland thrust and Fold Belt; the central Omineca Crystalline Belt; and a western Hinterland Belt. The eastern belt consists of well-layered miogeosynclinal sediments cut by generally "south-west dipping, concave-upward, locally folded thrust faults" (Wheeler, 1970, p. 155). The Omineca Belt includes the Kootenay Arc and the Shuswap Metamorphic Complex.

The Purcell Anticlinorium is a broad north-plunging structure in Helekian and Hadrynian age rocks between the Foreland thrust and Fold Belt to the east and the Kootenay Arc to the west. It is transected by a number of steep longitudinal and transverse faults. The transverse faults appear to have been active intermittently since at lease Hadrynian time and played an important role in controlling the type, distribution and thickness of late Proterozoic to early Paleozoic sediments (Lis et. al., 1976). The Sullivan ore body (Fig. 1-2) occurs within Proterozoic argillite on the eastern flank of the Purcell Anticlinorium. The anticlinorium is crossed from east to west on the morning of Day 2.

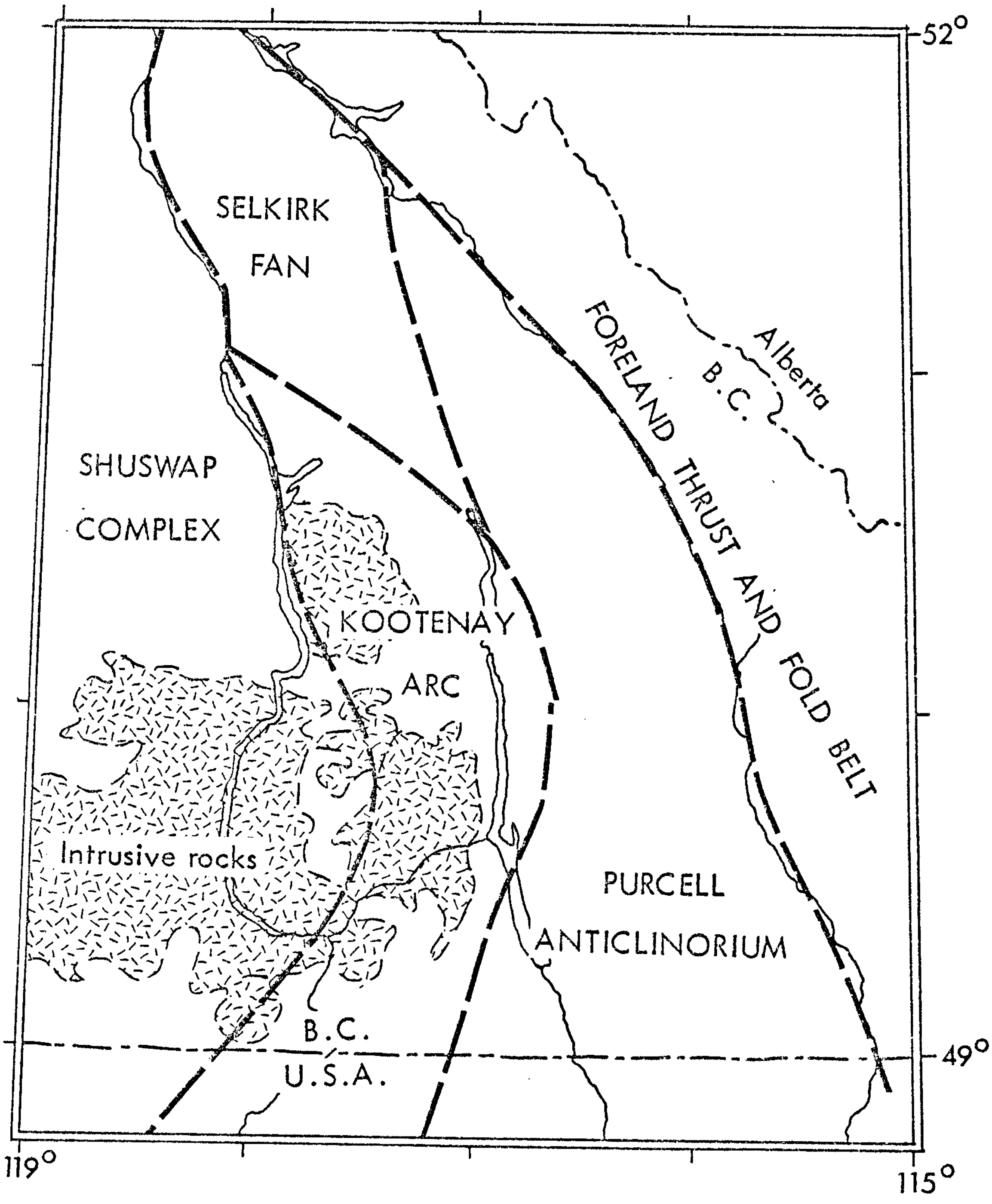


Figure 1-1: Structural elements of the Columbian Orogen in southeastern British Columbia.

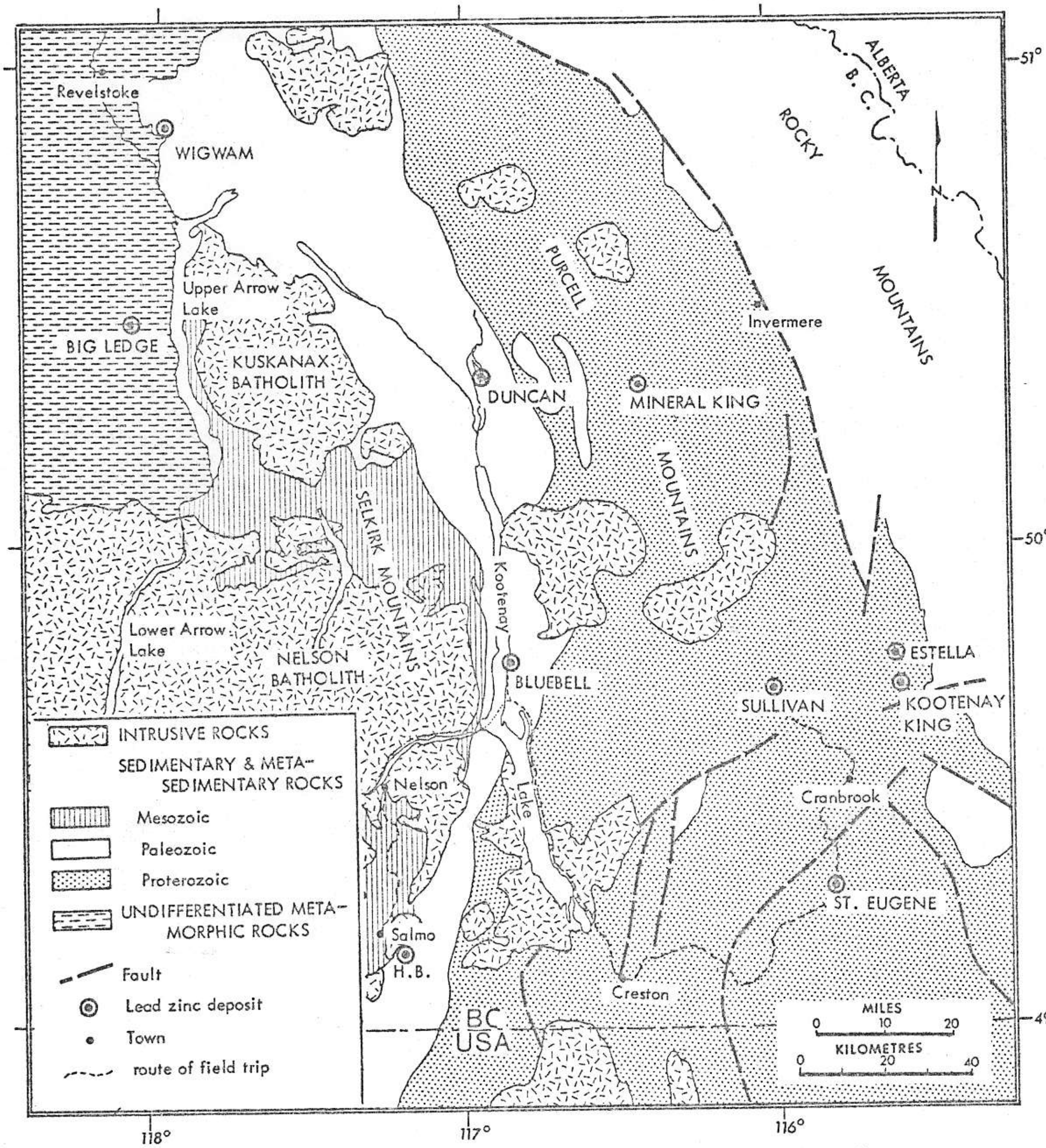


FIGURE I-2: GENERALIZED GEOLOGICAL MAP OF SOUTHEASTERN BRITISH COLUMBIA SHOWING THE LOCATION OF SOME OF THE LARGER LEAD ZINC DEPOSITS.

The Kootenay Arc, a generally north-trending arcuate structural zone developed in a succession of rocks ranging in age from Hadrynian to early Mesozoic, is west of and merges with the Purcell Anticlinorium. In general, the earliest recognized structures in the Arc are tight to isoclinal, north-trending recumbent folds. In the Lardeau area in the northern Kootenay Arc evidence indicates that these structures developed during the Caribooan orogeny in Devono-Mississippian time. Here, a phase 1 syncline in lower Paleozoic rocks is truncated by an unconformity at the base of the lower Mississippian Milford Group (Read, 1976). As well, "a conglomerate at the base of the Milford Group contains clasts of the underlying Broadview Formation with the earliest foliation varying from clast to clast" (Read, 1975, p. 29).

Generally, more open but locally isoclinal, north-trending Phase 2 folds with upright to steeply west dipping axial surfaces are superposed on the phase 1 folds. These folds dominate the structure of the Kootenay Arc and account for the pronounced north-south structural grain, particularly in the south. In the Lardeau area, radiometric dates restrict the second phase of deformation to an interval between 178 m.y. and 164 m.y. The older limit is set by a K-Ar date from the core of the pre- to syn-tectonic Kuskanax Batholith, the younger by both the post-tectonic northern part of the Nelson Batholith and the Mount Carlyle Stock (Read et. al., 1975). The latest discernible deformation in the Arc caused faulting and gentle folding of the earlier structures.

The Bluebell deposit at Riondel (Fig. 1-2) in the central part of the Kootenay Arc is a replacement deposit in lower Cambrian marble. The H.B. mine at Salmo is one of a number of stratiform lead-zinc deposits in the southern part of the Arc which occur in the same stratigraphic horizon as the Bluebell. The central part of the Kootenay Arc is crossed during the afternoon of Day 2. Bluebell mine is visited late that afternoon and the H.B. mine on Day 3.

The Shuswap Metamorphic Complex (Fig. 1-1) in the core of the Columbian orogen comprises a narrow belt of high-grade metamorphic rocks lying immediately west of the Kootenay Arc. Its eastern boundary is marked by a series of gneiss domes spaced approximately 80 km apart (Reesor, 1970). A number of syn- and post-tectonic batholiths intrude the metasediments of the Shuswap Complex. Shuswap lead-zinc deposits (Fig. 1-2) consist of highly deformed and metamorphosed sulphide layers which occur in calcareous shales of probable lower Cambrian and possibly older age. They generally are found in zones of gneiss mantling the cores of the gneiss domes.

Deposition of miogeosynclinal sediments in the Columbian Orogen in south-eastern B.C. spanned an interval of more than 1,100 million years. The aggregate thickness of these sediments exceeds 14,000 m. They were derived primarily from the North American craton to the north-east and consequently were deposited as a north-easterly tapering sedimentary wedge on the western margin of the continent.

The oldest rocks exposed within the Purcell Anticlinorium are argillites, mudstones, intercalated sandstones and stromatolitic carbonates of the Purcell Supergroup of Helekian age (Fig. 1-3). Coarse clastics and slates of the Windemere Supergroup of Hadrynian age unconformably overlie

	LARDEAU BADSHOT HAMILL	CAMBRIAN
		unconformity
WINDEMERE SUPERGROUP	HORSETHIEF CREEK TOBY	HADRYNIAN
		unconformity
PURCELL SUPERGROUP	MOUNT NELSON DUTCH CREEK KITCHENER SIYEH CRESTON ALDRIDGE FORT STEELE	HELEKIAN
		thrust

Figure 1-3: Table of Formations.

the dominantly fine-grained clastics of the Purcell Supergroup. The Windemere Supergroup includes the Horsethief Creek Group, a thick accumulation of shale, quartzite, grit and quartz-pebble conglomerate, and the Toby Formation, a basal conglomeratic mudstone. A succession of Paleozoic quartzite, carbonates and fine-grained clastic rocks overlies Windemere rocks. Well-sorted Lower Cambrian quartzite of the Hamill Group overlies the Horsethief Creek Group and is in turn overlain by the Badshot Formation, a thin but widespread carbonate unit. The Badshot is the host of virtually all the replacement and stratiform lead-zinc deposits in the Kootenay Arc (Fig. 1-2). Deposits in the Badshot include: the Wigwam deposit south of Revelstoke (Thompson, in press), the Duncan deposit north of Kootenay Lake, the Bluebell Mine, and the H.B. and Reeves Mines in the Salmo area (Fyles, 1959). The Badshot is overlain by the Lardeau Group, a thick accumulation of argillites, shales, calcareous shales and minor quartzites of middle Cambrian and later age.

REFERENCES

Fyles, J.T. and Hewlett, C.C. (1959): Stratigraphy and structure of the Salmo lead-zinc area. B.C. Dep. Mines Pet. Resour., Bull. 41.

Lis, M.G. and Price, R.A. (1976): Large-scale block faulting during deposition of the Windemere supergroup (Hadrynian) in southeastern British Columbia. Geol. Surv. Can., Paper 76-1A, pp. 135-136.

Read, P.B. (1975): Lardeau Group, Lardeau map-area, west-half (82K W½), British Columbia. Geol. Surv. Can., Paper 75-1, Pt. A, pp. 29-30.

———— (1976): Lardeau map-area, west-half (82K W½), British Columbia. Geol. Surv. Can., Paper 76-1A, pp. 95-96.

Read, P.B. and Wheeler, J.O. (1975): Lardeau west-half geology. Geol. Surv. Can., Open File 288.

Reesor, J.E. (1970): Some aspects of structural evolution and regional setting in part of the Shuswap Metamorphic Complex. Geol. Assoc. Can. Spec. Pap. 6, pp. 73-86.

———— (1973): Geology of the Lardeau map-area east-half, British Columbia. Geol. Surv. Can., Mem. 369.

Thompson, R.I. (in press): Geology of the Alkolkolex River area near Revelstoke, British Columbia. B.C. Dep. Mines. Pet. Resour., Bull. 60.

Wheeler, J.O. (1970): Summary and discussion. Structure of the southern Canadian Cordillera. Geol. Assoc. Can. Spec. Pap. 6, pp. 155-166.

Wheeler, J.O., Aiken, J.D., Berry, M.J., Gabrielse, H., Hutchinson, W.W., Jacoby, W.R., Monger, J.W.H., Niblett, E.R., Norris, D.K., Price, R.A. and Stacey, R.A. (1972): The Cordilleran Structural Province. Variations in the tectonic styles in Canada. Geol. Assoc. Can. Spec. Pap. 11, pp. 1-81.

PART 2

DAY 1: GEOLOGY OF THE SULLIVAN OREBODY

(P. W. Ransom)

INTRODUCTION

The Sullivan orebody was discovered in 1892 and after unsuccessful attempts to mine and smelt the ore by various owners it was acquired by the Consolidated Mining and Smelting Co. Ltd. (now Cominco Ltd.) in 1909. The Sullivan Concentrator, the first application of differential flotation to an ore of such complexity, went into operation in 1923 at 3000 tons*per day. Mill throughput was increased in stages until 1941 when the capacity was 11,000 tons per operating day. Current milling rates are 9200 tons per operating day. To date 114 million tons of ore at 6.7% Pb and 5.8% Zn has been mined from the Sullivan. Remaining diluted normal reserves, corrected for extraction losses, are 56 million tons at 4.9% Pb and 6.1% Zn and should last another 25 years under current conditions. Metal production is summarized on Fig. 2-6.

GEOLOGY

REGIONAL SETTING AND STRUCTURE

The Sullivan occurs at the contact of the lower and middle divisions of the Aldridge Formation. The Aldridge Formation is a 4500 m thick stack of flyschoid sediments, possibly a submarine fan type of deposit that formed in an inland sea or in an ocean basin. The sediments are argillites, silts and quartz wackes ranging in thickness from fine laminae to massive units 12 m thick. Most typical are beds 9 to 60 cm thick, generally in clusters 1.5 to 15 m thick separated by thinner bedded and laminated units. Carbonate is present but rare in these sediments. It may have been preserved at depths below the carbonate compensation depth by rapid burial. The sediments are intruded by sills of gabbro 15 to 300 m thick on which accepted age dates range from 1100 to 1500 million years b.p.

The Purcell anticlinorium is the dominant regional structure. It is characterized by open folds plunging gently to the north. The Sullivan occurs on the east side of this structure on the east flank of an open anticline. The orebody itself is some 2000 m in diameter, predominantly a massive sulphide lens 30 to 90 m thick. On the east it consists of a 30 m thick series of massive banded and laminated sulfides separated by beds of argillaceous siltstone. The shape of the orebody is somewhat like that of a tilted inverted saucer. The orebody dips 0^{o} to 10^{o} east on the upper levels (west side of the mine), 10^{o} to 20^{o} east and northeast in the central part, and 30^{o} to 50^{o} east and northeast on the lower levels.

* SHORT TONS

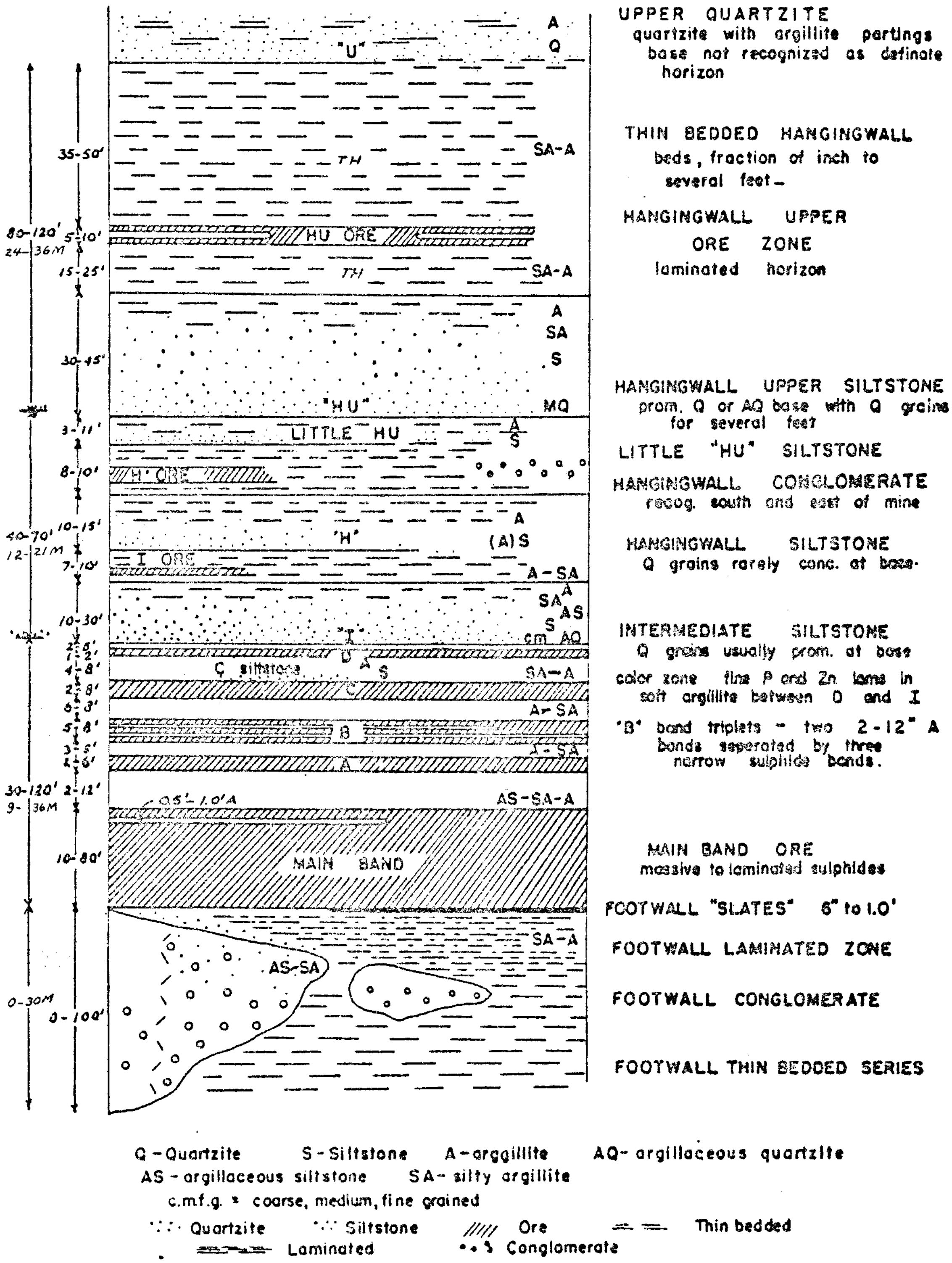


FIGURE 2-1 SULLIVAN MINE IDEAL GEOLOGY SECTION

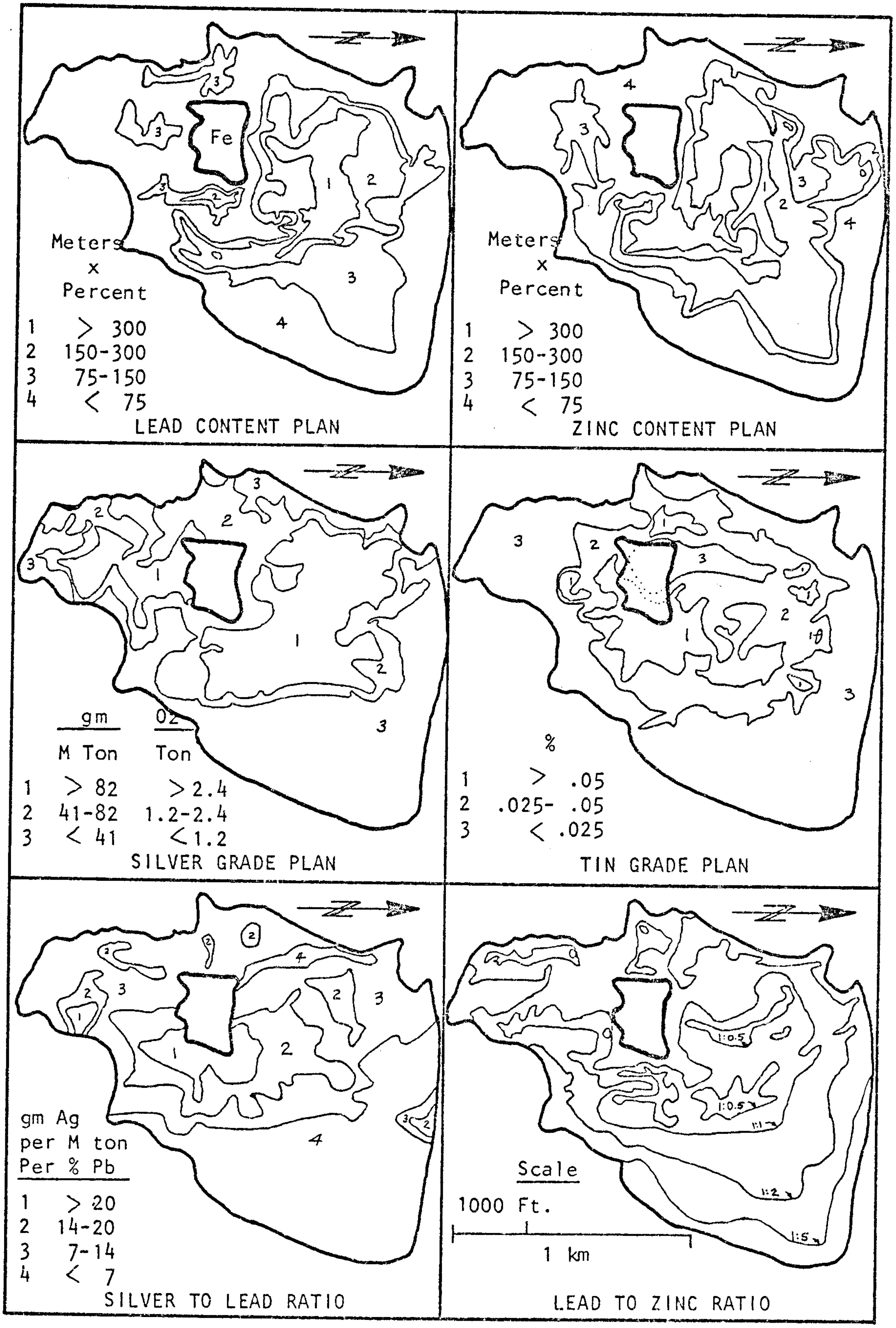


FIGURE 2-2 METAL DISTRIBUTION MAPS

FOOTWALL OF THE SULLIVAN OREBODY

Bedded Footwall Series

This unit occupies at least a 150 m thick interval below the Sullivan orebody. Beds are characteristically 30 cm thick, graded from siltstone of variable argillite content to argillite. Hardness and color both vary with changes in composition and alteration. Cross laminae are rarely observed. The main mineral constituents are quartz, sericite, biotite and carbonate. The interval 6 to 15 m below the sulfide footwall is characterized by pyrrhotite laminations spaced about 1 cm apart near the base and 1 to 3 mm apart near the top. In contrast, the overlying sediments have little or no pyrrhotite. Biotite is often associated with iron sulfides in the footwall.

Interruptions to the Bedded Footwall Series

i) Chaotic Breccia - Figs. 2-3 and 2-4

Areas of chaotic breccia containing fragments and blocks of locally derived sedimentary material from less than 1 cm to 10 m in size have been mapped underground. The largest breccia area is 120 m wide by 900 m long. They are elongate in a north-south direction. Some areas have smaller fragments (less than 0.5 m) that are well rounded; this rounding may have occurred when escaping fluids abraded the fragments during major shifting of material in the breccia areas. Although variably mineralized with pyrrhotite the matrix contains little galena or sphalerite.

ii) Conglomerate - Figs. 2-3 and 2-4

An intraformational conglomerate interrupts the sequence shortly below the footwall of the orebody. It varies in thickness from 0 to 60 m and in plan it occupies an area 900 m by 120 m, about two-thirds the size of the orebody. The conglomerate consists of rounded to angular clasts of argillite, silty argillite, and occasionally quartzite in an argillaceous silty matrix. The proportion of clasts to matrix ranges varies considerably. Pyrrhotite is a typical but variable accessory accentuating either the matrix or the clasts; it occurs as laminations in certain clasts and as rims on other clasts. At some locations clasts are small ragged fragments that indicate near-complete destruction of a pyrrhotite laminated sediment.

iii) Tourmaline and Chlorite Alteration - Fig. 2-4

The tourmaline altered zone also occupies an area about two thirds the size of the orebody. In hand specimen this rock is hard, black to brown in color, and resembles a chert, which it is called locally. Primary sedimentary features such as pyrrhotite laminae, conglomerate clasts, and silty beds are faithfully preserved. In thin-section one sees that the original argillaceous fraction of the sediment has been converted to a fine mush of tourmaline needles, some of which penetrate quartz grains. The bottom limit of the tourmalinized zone is not known. Drilling has shown that it extends down at least to the gabbro sill 450 m below below the orebody. Both transgressive and concordant contact relationships of tourmalinized sediments have been observed.

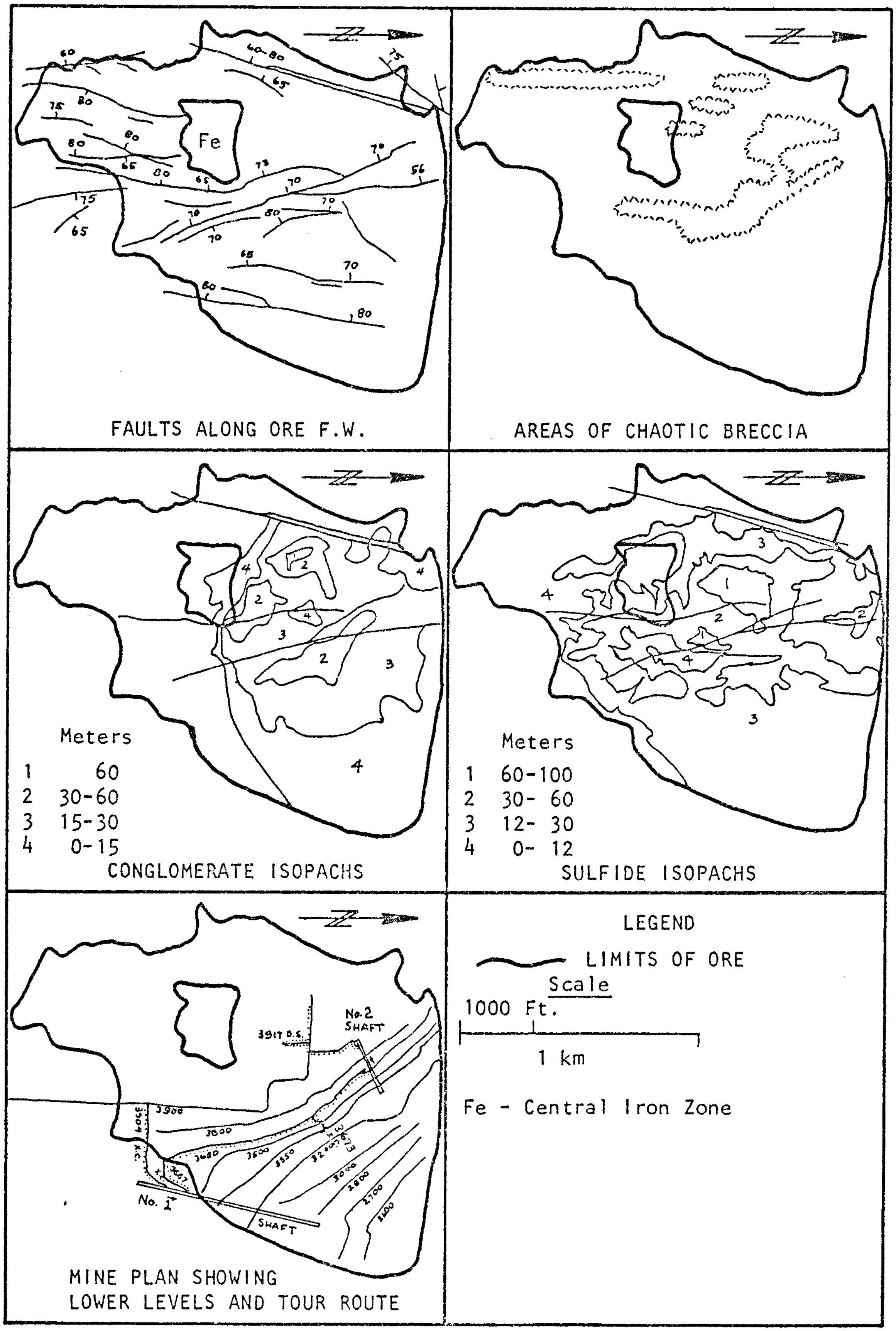


FIGURE 2-3 FAULTS, BRECCIA DISTRIBUTION, CONGLOMERATE AND SULFIDE ISOPACHS AND MINE WORKINGS

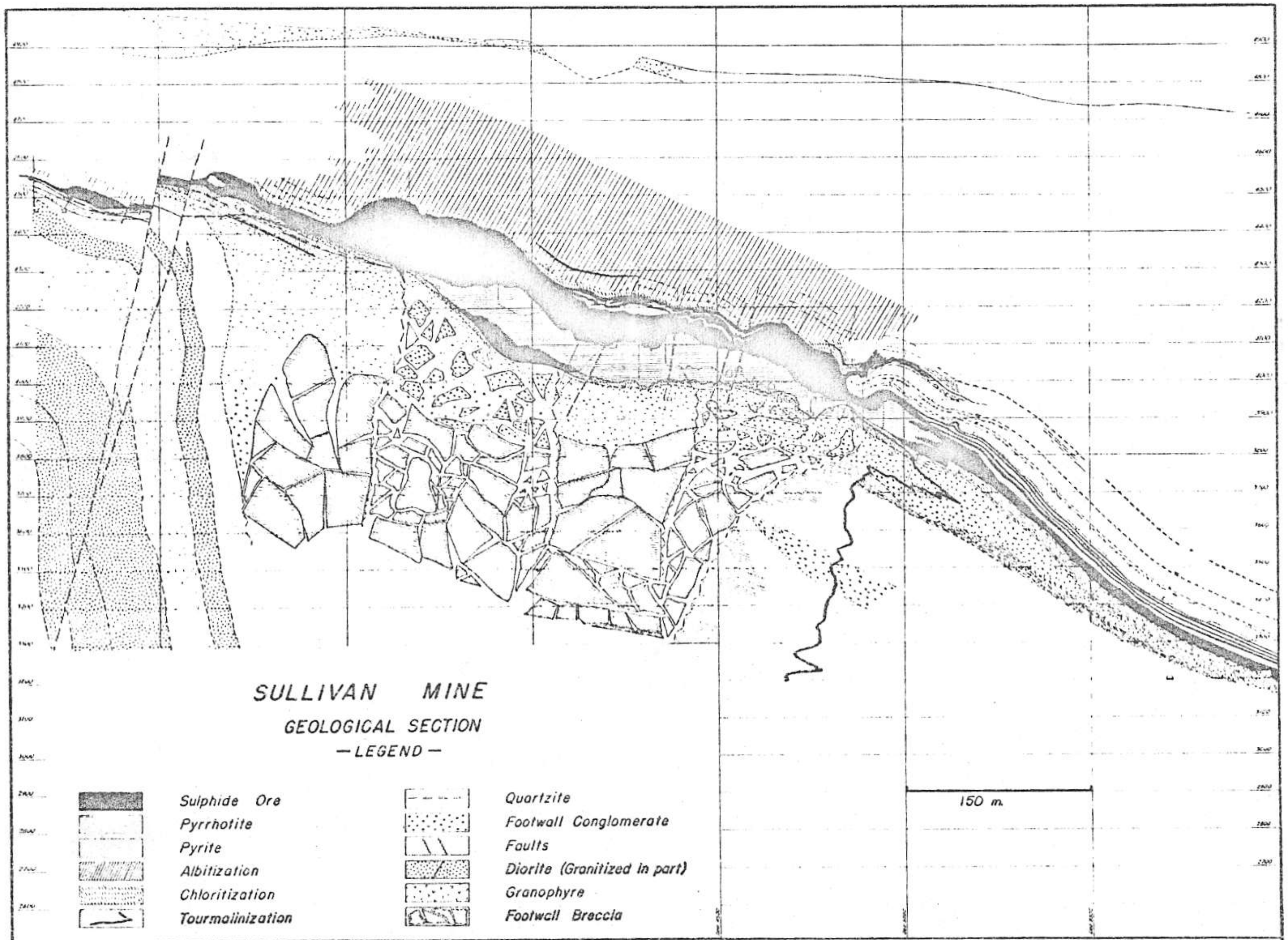

SULLIVAN MINE
GEOLOGICAL SECTION
— LEGEND —
Sulphide Ore
Pyrrhotite
Pyrite
Albitization
Chloritization
Tourmalinization
Quartzite
Footwall Conglomerate
Faults
Diorite (Granitized in part)
Granophyre
Footwall Breccia
150 m.

FIGURE 2-4

Tourmalinization is post-dated by chloritization that occurs both along steep fracture zones well below the orebody and, in places, as an envelope up to 4.5 m thick separated from the massive pyrrhotite ore by a coarse-grained pyrite zone up to 4.5 m thick.

iv) Mineralized Fracture Systems in the Footwall

Recent detailed mapping of fracture systems in the footwall has revealed a number of interesting features which define a paragenetic sequence of events. They are:

1. Boron alteration. This is preserved as tourmalinized sedimentary material. One can observe steep cross-cutting tourmalinized zones that fade rapidly laterally into unaltered sediments. Near the ore footwall, conformable beds of tourmalinized sediment are intercalated with unaltered beds.

2. Pyrrhotite - filled fractures with scheelite (chemical verification pending) and cassiterite.

3. Pyrrhotite - filled fractures with minor chalcopyrite.

4. Sphalerite with minor galena filled fractures.

5. Galena - sphalerite filled fractures.

Evidence of movement of material, such as one might expect from fluid streaming, is well demonstrated in steep fractures in which rounded and aligned tourmalinized fragments occur tightly packed in a sphalerite-galena matrix.

Cross-cutting relationships indicate a system under tension that was periodically shifting, so that existing channelways closed and new ones opened.

v) Gabbro intrusive - Fig. 2-4

A pair of gabbro sills 15 to 60 m thick separated by about 90 m of granophyre intrude the sediments about 450 m below the orebody. The character of the intrusive abruptly changes below the west margin of the orebody where it cuts vertically through the stratigraphy to about the mine horizon, and at that point the intrusive becomes sill-like again.

SULLIVAN ORE ZONE

General

Sullivan stratigraphy is summarized on the Ideal Geology Section (Fig. 2-1). This stratigraphy applies to about one third of the orebody along the east side. The central, north, and central iron zone portions of the orebody do not display good sedimentary types of laminations, except toward the thin margins, but rather display a confused streaking of coarser grained and recrystallized sulfides. The central massive zone consists typically of a greater than 45 m thickness of virtually solid sulfides (Fig. 2-2). A wedge of massive pyrrhotite thickens toward the central iron zone where pyrite begins to predominate. Much of the central iron zone is heavily chloritic (with pyrite) and thins from greater than 30 m to 3 m at one location. To the south, a sedimentary character is recognized again; however, in places the dominant ore bearing horizons are above the Main Band. Further to the south, in the vicinity of the Open Pit, a number of quartzites occur within the section, the ore is much lower in grade and disseminated in character. Increasing amounts of pyrite are observed toward the margins of the orebody and pyrite is the dominant sulfide beyond the margins in the immediate mine area.

Main Band to D Sulfides

The Main Band is composed of massive sulfides, predominantly pyrrhotite, pyrite, galena and sphalerite in varying proportions though pyrrhotite is dominant, forming about 70% of all sulfides. In the obviously stratiform part of the orebody, the Main Band is typically laminated and banded. The main gangue minerals are carbonate, quartz, pale mica, chlorite and garnet.

i) Main Band Fragmental

There are areas in the bottom half of the Main Band that are composed of definite fragments of a variety of types in a fine-grained massive sulfide matrix. The most common fragmental material in this unit is coarse porphyroblastic pyrite consisting of large individual crystals 1 to 3 cm across, or larger masses of coarse-grained pyrite generally less than 15 cm across although as large as 60 cm. The next most abundant types of fragmental material are calcite, quartz, argillite, sphalerite and possibly gabbro. The fragments of argillite are perhaps the best indicators of the disruptive nature of this unit. Argillite fragments of differing color, style, and with or without pyrrhotite laminations, have all been observed within a few meters of each other. Where fragments have been observed in laminated sulfides, the laminae are deformed below the blocks, suggesting the blocks dropped onto a laminated sulfide sediment and were then buried by sulfides, as indicated by the draping of overlying sulfides.

The matrix of the fragmental unit is fine-grained and consists of approximately 40% quartz, calcite, chlorite, and mica, and 60% sulfides. It resembles the coarse fraction in composition. In contrast, normal thin-bedded sulfides contain much smaller quantites of non-sulfide material.

Observations of the fragmental unit suggest that the fragments are introduced and that they are possibly derived from the conduit through which ore-forming fluids passed. Alternatively, slumping of unconsolidated sulfide sediments with underlying sediments could be considered as the mechanism of origin. This fragmental unit is only occasionally recognized in the stratiform portion of the orebody.

ii) Thin-Bedded Ore

The Main Band and the higher A, B, C and D bands are composed of thinly-bedded to laminated sulphides except where the fragmental unit is developed. The thin-bedded ore is characterized by alternating mono-mineralic bands of the main sulfides, pyrrhotite, galena, and sphalerite. The matrix of the thin-bedded ore has variable amounts of silicates and carbonates. The change from one sulfide band to another is rapid, within 1 to 2 mm. Argillaceous bands occur within the uppermost part of the Main Band and in each of the upper bands.

The waste bands below each of the higher ore bands vary from 0.6 to 3.5 m in thickness. Each of these bands consists of one or two beds of silty argillite and argillaceous siltstone in which grading can sometimes be recognized. Pyrrhotite laminations and pyrrhotite nodules are common in these bands and have been observed occasionally to grade along strike into a sulfide band. Distinctive long slabs of pyrrhotitic sediments, possibly rip-ups, also occur.

These thick waste beds represent either rapid deposition of non-sulfide sediment or hiatuses in either sulfide production or sulfide overflow from the area that is now the thickest part of the orebody.

Metal Distribution - Fig. 2-2

The distribution maps for total Pb, Zn, Ag, and Sn show that the greatest amounts of the metals are in the thickest part of the orebody and that they decrease somewhat symmetrically away from this zone. The ratio maps for Pb:Zn and Ag:Pb both show an asymmetrical decrease in ratio away from the central part of the mine to the margins and, for the Pb:Zn ratio, a decrease toward the central iron zone as well. These observations support the idea that metal-rich solutions entered a collecting basin on the sea floor at a location corresponding to that now occupied by the central iron zone or the thickest part of the orebody. The bulk of the lead and iron sulfides precipitated in the deep part of the collecting basin leaving the remaining zinc-rich solutions to spread out further before precipitating. Silver appears to have entered the galena structure preferentially in the area adjacent to the supposed vent where higher temperatures may have existed.

Sulphur Isotope Information

Detailed sulfur isotope studies on the Main Band to D Band sulfides conducted at the University of Calgary have yielded some interesting results. There is a general increase in the relative amount of the lighter isotope going up through the entire sequence. As well, within each band there is an increase in the relative abundance in the lighter isotope going from bottom to top. Cyclical changes in chemical environmental conditions from reducing to oxidizing have been suggested to explain these phenomena.

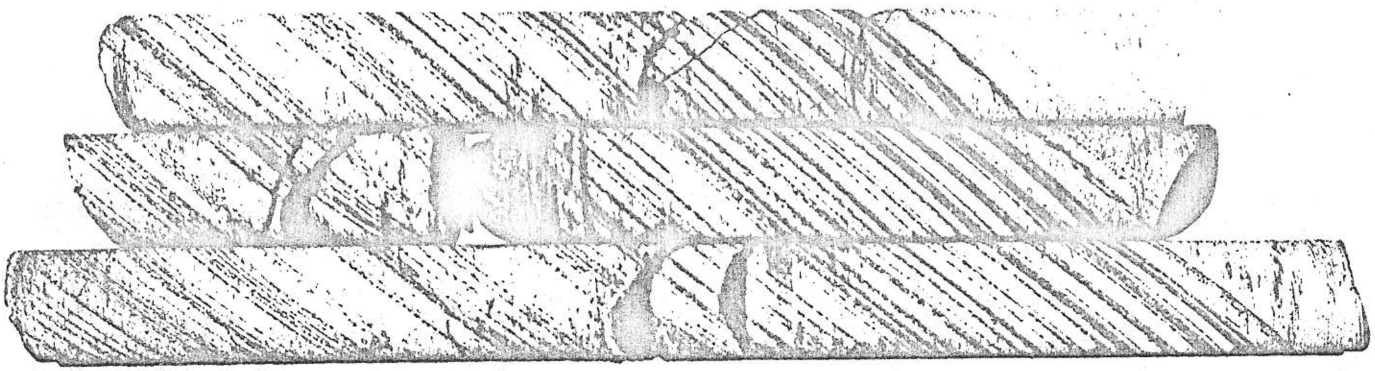


FIGURE 2-5 CORRELATED SETS OF PYRRHOTITE LAMINATIONS IN ARGILLITE

THE HANGINGWALL SERIES

In the 15 to 30 m above the main ore sequence are four distinctive graded series, the I, H, hu and HU marker beds. These beds commonly have clearly visible quartz grains at their bases, followed by 1 to 2 m of argillaceous quartzite that grades into a siltstone, and are capped by a relatively thick argillite top. The overall thickness of these beds is between 2 and 6 m. Each is overlain by an argillaceous unit having pyrrhotite laminations and flakes and which grade into the I, H, and HU ore bands. The thick graded beds are interpreted as turbidites which settled out in the Sullivan area as unusually thick beds because of local topographic features.

Hangingwall Conglomerate

This unit occurs in the H Series in the southern half of the Sullivan. The conglomerate contains sulfide ore clasts in addition to the usual argillite clasts. This conglomerate is interpreted as a slough from a hump of previously deposited sulfides thickened through slight gravity sliding. The HU series has been traced over the Hangingwall Conglomerate.

HU Ore

The HU ore, if of exceptionally high grade, is consider mineable when only 25 cm thick. It attains more normal thicknesses (1 to 3 m) and grades elsewhere. The HU ore horizon is connected by a vertical zone of sulfides to the underlying Main Band. The HU ore may have formed by remobilization of previously deposited sulfides while they were being subjected to the first stages of diagenesis.

U Quartzites

The HU series is overlain by a series of graded quartzites and siltstones generally regarded as normal middle Aldridge.

Pyrrhotite Laminations - Fig. 2-5

Several sets of pyrrhotite laminations within argillite, that can be matched laterally over great distances, occur within the Sullivan stratigraphy. There are two sets in the footwall, two between the D ore band and the overlying I quartzite, several sets between the I and H quartzites, and one each above the H and HU quartzites. The upper three are stratigraphically equivalent to the I, H, and HU ore bands.

These sets of pyrrhotite laminations consist of 30 to 100 pyrrhotite lamellae over a 10 to 20 cm stratigraphic interval. Variations in spacing between pyrrhotite laminations and perfect uniformity of these variations in a lateral sense has resulted in patterns that are unique. The greatest distance over which one of these markers has been traced is 1500 m.

Albite and Chlorite-Pyrite Alteration

Albite is the main alteration of the hangingwall areas. It is characterized by the partial to complete alteration of original sediments to an albite rock. With increasing intensity, all sedimentary characteristics are obliterated. Chlorite occurs most extensively at the sulfide hangingwall contact over the central part of the orebody. A coarse grained pyrite zone 1 to 5 m thick is encountered typically under the chlorite at the hangingwall, similar to the occurrence at the footwall. Chlorite, accompanied by pyrite, is also found in narrow fractures penetrating the albite alteration zone.

DYKES AND FAULTS

Lamprophyre Dykes

A small number of Cretaceous lamprophyre dykes less than 1 m wide occur at the Sullivan. They are commonly disrupted by low angle and bedding plane faults.

NW Striking Dykes

Three dykes, generally less than 12 m thick, strike north-west across the southern portion of the orebody. Two appear to be offshoots of the main gabbro mass in the footwall. One has been identified petrographically as an albite-chlorite rock and as such may have been a conduit for fluids that formed the albite in the hangingwall.

Kimberley Fault

Stratigraphy on the north side of the orebody is offset at least 3000 m by a normal fault that strikes east-west and dips 55° north. The stratigraphic interval from the base of the Main Band to the I Quartzite remains relatively constant up to the Kimberley Fault. Even though mining limits are 30 m south of the fault, sulfides can be traced to the fault.

Sullivan Type Faults

Faults of the "Sullivan" type displace ore 30 m or less. They are normal faults that strike 10° to 20° east of north and dip steeply west. A complementary set of faults that strikes west of north is not nearly as well developed. (Fig. 2-3).

ORIGIN OF THE SULLIVAN OREBODY

The mode of origin of the Sullivan orebody has long been controversial. Now, however, very few geologists would dispute that the deposit formed as a sediment on the sea floor. If it is assumed that metal-bearing solutions ascended through the fracture system below the Sullivan orebody and combined with sea water sulfate to precipitate as sulfides on the sea floor then a reasonable scenario can be described.

Within a local tensional environment, the formation of the chaotic breccia, the conglomerate (by scarp collapse), a basin suitable for containment of sulfides, and a fracture system suitable for the transport of metal-bearing solutions to the sea floor can all be developed.

Ascending fluids changed in character with time but their effects are very well preserved in the footwall rocks of the mine and in the nature of the ore itself. Initially the fluids were boron rich, the boron entering some of the sediments along steep fractures as well as precipitating as a chemical sediment on the sea floor. Then iron-rich fluids flowed through the system and precipitated onto the sea floor resulting in the formation of the pyrite-chlorite zone in the central part of the mine, and a wedge of massive pyrrhotite having low Pb-Zn values surrounding the pyrite-chlorite zone. Tin and tungsten are known to be associated primarily with this phase. This was followed by the main ore-forming phase of pyrrhotite, sphalerite and galena. With the system waning somewhat, argillaceous sediments were deposited periodically. The hydrothermal system changed, finally, to one which resulted in the formation of the hangingwall albitite during, or shortly after, the hangingwall sediments were deposited. This effectively capped the orebody and the hydrothermal system was closed.

The controversy now confronting us is: What was the source of the metals? Two alternatives are:

1. Scavenging metals from sediments by brines moving within a convection system powered by a heat source at depth.

2. Deriving metals from a potential volcanic or plutonic centre at depth which for some reason got no farther than providing the metals for the Sullivan.

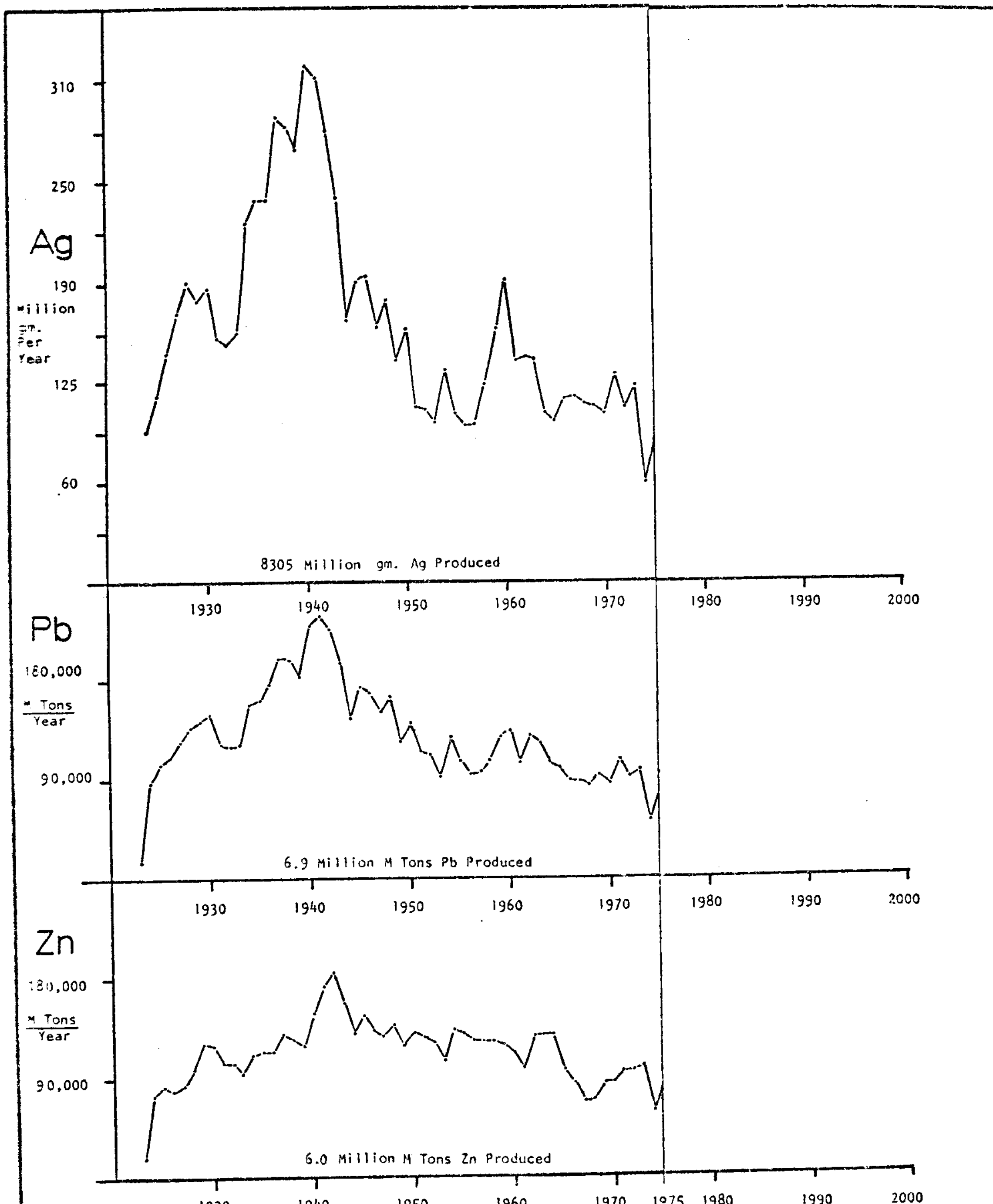


FIGURE 2-6 SULLIVAN MINE

ANNUAL PRODUCTION* OF Ag, Pb, & Zn.

* To 1975. MINING AND MILLING LOSSES DEDUCTED, SMELTER LOSSES NOT DEDUCTED

SELECTED BIBLIOGRAPHY

Carswell, H.T. (1961): Origin of Sullivan lead-zinc-silver deposit, B.C. Unpubl. Ph.D. thesis, Queen's University, Kingston, Ontario.

Campbell, F.A., and Ethier, V.G. (1976): Sulfur isotope studies of the Sullivan and other stratiform lead-zinc orebodies in southeastern B.C. Geol. Soc. Am. (1976) abstract.

Cominco reports (unpublished) by: D.T. Bishop
J.H.H. Heal
G. Mason
O.E. Owens
P.W. Ransom
A.C. Taplin

Freeze, A.C. (1966): On the Origin of the Sullivan orebody, Kimberley, B.C. CIM Spec. Vol. 8, pp. 263-295.

Jardine, D.E. (1966): An investigation of brecciation associated with the Sullivan Mine orebody at Kimberley, B.C. Unpubl. M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba.

LeCouteur, P.C. (1973): A study of lead isotopes from mineral deposits in eastern B.C. and in the Anvil Range, Yukon Territory. Unpubl. Ph.D. thesis, U.B.C., Vancouver, B.C.

Morris, H.C. and Sullivan Mine Staff (1972): An outline of the geology of the Sullivan Mine, Kimberley, B.C. 24th Int. Geol. Cong., Field Excursion Guidebook #A34-C24.

PART 3

DAY 2 (A.M.): KIMBERLY TO CRESTON

STRATIGRAPHY AND LITHOLOGY OF THE LOWER BELT SERIES IN THE PURCELL MOUNTAINS, BRITISH COLUMBIA

(F. R. Edmunds)

The equivalent to the Belt Supergroup in British Columbia, Canada, is the Purcell Supergroup. That portion through which the field trip runs comprises the Aldridge, Creston, and Kitchener-Siyeh Formations (see Fig. 3-1).

The lowest formation encountered is the Aldridge, the equivalent of the Prichard Formation in Montana and Idaho. The base is not exposed in the area of the field trip, but gneiss, interpreted as basement, encountered in wells in the Alberta foothills, has been dated at 1.8 b.y. (Burwash, 1962). Exposed Aldridge Formation is between 4,000 and 5,000 m thick in the Purcell Mountains. It consists of greywacke units interbedded with argillites, with the exception of 210 to 390 m of thin bedded, laminated argillites at the top.

The greywackes are metamorphosed, graded, impure sandstones. They possess sole markings, including grooves, poor flutes, and longitudinal ridges, and the internal sedimentary structures of cross- and convolute bedding, that suggest their similarity to units ascribed elsewhere to turbidity currents (Bishop, Morris, and Edmunds, 1970). Internal stratification of these units permits recognition of the standard Bouma (Bouma, 1962) intervals, although Bouma's B, C, and D layers do not appear to fit a regular pattern of super-position in the Aldridge Formation. Cross-bedding in the C interval indicates a basin axis running in a N-S direction through the centre of the outcrop area.

The greywackes are composed of quartz, plagioclase, biotite and sericite, with small amounts of K-feldspar, muscovite, and garnet. The fabric is recrystallized, without being hornfelsic. The metamorphic grade increases from greenschist facies near the International Boundary to amphibolite facies in the core of the Moyie anticline to the north-east (Bishop, D.T., personal communication).

The argillite rock appears to be the end of a series that is transitional with the greywackes, in which sericite and biotite increase at the expense of quartz towards the argillite end. The ultimate end-member is a quartz-sericite (minor biotite, graphite) rock, completely devoid of any current effects, and apparently without a detrital component. This is equated with the pelagic material of the Bouma system. Where this pelagic or interturbidite material is best developed, it provides argillite units of extremely fine, black-white lamination that may be matched, lamination for lamination across distances approaching 300 km. Fourteen of the thicker units are used in this way as stratigraphic markers.

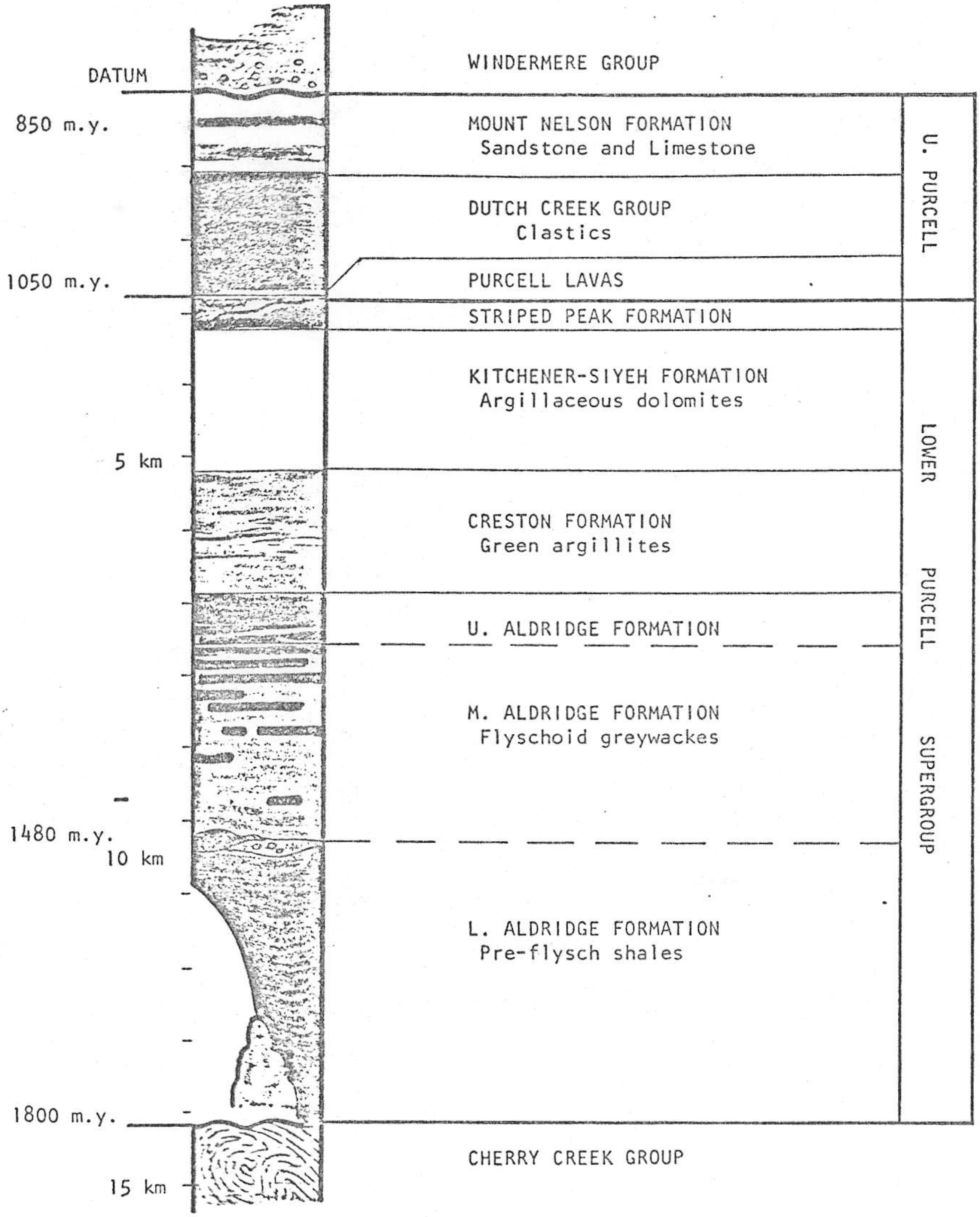


FIGURE 3-1: Summary of the Purcell Supergroup in the Purcell Mountains.

The lower division of the Aldridge formation is poorly exposed. It is composed principally of thin-bedded pyritic argillites in the region of the field trip. No base is visible. The passage from the Lower to the Middle Aldridge Formation is marked by the first appearance of recognizable turbidite units. It also contains a discontinuous sheet of slump conglomerates that are interpreted as the product of the collapse of local submarine fault scarps. The footwall rocks to the Sullivan Mine contain one of these units. The maximum exposure of Lower Aldridge Formation is probably about 900 m.

The Middle Aldridge Formation consists of about 3,000 m of interbedded AE turbidite units and argillites. There is little apparent difference between these argillites and those of the Lower Aldridge except that the development of the marker units is confined to about 1,500 m within the Middle subdivision.

The turbidite units are non-graded, coarser-grained, meta-arenites in general. In most there is minor grading near the top, and in many of these units a thin interval of pelagic material lies upon the sand-sized fraction. The sand fraction commonly contains concretionary bodies of varying composition, generally, however, including carbonate minerals. The soles are characterized by markings indicative of the highest velocities encountered: grooves up to 0.6 m wide and greater than 5 m in length occur. Their directions and sense define a transport direction from the south at about the 49° latitude, swinging to SW a few miles to the north. In other words, they are axial currents, approximately perpendicular to those indicated by the C intervals of the graded units.

The AE turbidites persist through about 2,000 m of stratigraphy. With their termination to the Middle Aldridge Formation strongly resembles the lower subdivision. Between 390 and 210 m from the top of the formation there is a fairly abrupt change into thin-bedded, carbonaceous argillites of the Upper subdivision. Within the Upper Aldridge ripple-marked surfaces and very minor load-casting are the principal primary structures observed.

In most exposures passage into the overlying Creston Formation is transitional across less than 300 m, but in some places it is abrupt. The transition is marked, in Canada, by the simultaneous appearance of cross-bedded quartzite lenses no more than a metre in length, and a slightly greenish appearance to weathered outcrops.

The Creston Formation is the facies equivalent of the Ravalli Group south of the International Boundary. It has a maximum thickness of 2,000 m, and thins to the north (Harrison, 1972) in Canada. It is composed of purple, grey and green coloured argillites and siltstones, with sequences containing thin ($\pm$ 5 cm), cross-bedded meta-sandstone. Subdivisions similar to those named Burke, Revett, and St. Regis Formations in the U.S.A. are probably recognizable, but have not yet been mapped. Ripple-marked surfaces are common; load-casting, and cut-and-fill structures are less so.

A consistent feature of the Creston Formation in the region covered by the field trip is one that may be attributed to creep and/or settling of semi-lithified, layered rock. Pull-apart structures, the micro-intrusion of the silt fraction into and through the claystone layers, and wholescale brecciation of thin argillite beds all indicate the instability of a sequence composed of thin layers of differing viscosities in a semi-consolidated state.

The Creston Formation passes fairly rapidly into the Kitchener Formation. The Kitchener, with a maximum thickness of 2,100 m in Canada, is the equivalent of the much thicker Wallace Formation in Montana and Idaho. It is referred to as the 'middle Belt carbonate member' by Harrison (Harrison, 1972), and in the region covered by the field trip, it is a sequence of grey to buff weathering dolomites, argillaceous dolomites, and grey argillites.

Small scale scour channels and ripple marked bedding surfaces are frequent in the more argillaceous sequences. Structures exist that are reported as stromatolites (Leech, G.B., personal communication; and Ross, 1963), as well as regions of fine, crenulated, calcite veining, named 'molar-tooth structure' (Bauerman, 1884), and regarded by some as having an algal origin (Fenton, 1931).

The Siyeh Formation is a term first used for a limestone unit on Siyeh Mountain, Montana (Willis, 1902). In Canada it is an unfortunate designation because it is applied to whatever sediments, generally argillite, occur beneath the Siyeh volcanics. The lower boundary is impossible to identify in the area of the field trip, and descriptions of lithology generally refer to the Siyeh Formation as from 300 to 600 m of argillaceous dolomites and light grey argillites at the top of the Kitchener (Rice, 1937).

At the north end of Moyie Lake, on Peavine Creek, a few feet of purple marly shales lie above the "Kitchener-Siyeh" Formation. These are so similar to rock of the Striped Peak Formation, 50 miles south on the Montana-Idaho boundary, with the same stratigraphic position, that their correlation appears reasonable.

The intrusives encountered in the region of the field trip are hornblende-quartz metagabbro sills in the middle and lower Aldridge Formation. In the lower Aldridge they may account for well over half of any measured section and are not particularly strata-bound. They crosscut the sediments at low angles to unite in an irregular manner so that the sediments appear as septa or large lenses. Thicknesses up to 450 m may be measured perpendicular to the stratigraphy. In the middle Aldridge Formation the sills may still occur up to 300 m thick, but in ratio to sediments they are less, and their contacts are more nearly strata-parallel. The larger sills are differentiated in a regular manner with respect to Fe and Mg content (Bishop, D.T., personal communication), and usually develop a silicic or 'granophyric' stratum near the top.

Twelve miles southwest of Kimberley a small stock of granodiorite, dated at 1260$\pm$50 m.y. by Rb/Sr methods, intrudes the lower Aldridge. It appears to post-date both the metagabbro sills, and the regional metamorphism (Ryan, and Blenkinsop, 1970).

LEGEND

11	Tertiary and Quarternary cover	
10	Granitic Intrusives	
9	Cranbrook and Eager Formations - Cambrian	
8	Horsethief Creek Formation	Windermere Group
7	Toby Formation	
6	Mount Nelson Formation	Purcell Supergroup
5	Dutch Creek Formation	
4	Kitchener-Siyeh Formation	
3	Creston Formation	
2	Aldridge Formation	
1	Fort Steele Formation	

Major Faults

Geologic Contacts

Highways

Major Rivers

FIGURE 3-2: Regional Geology of Part of Southeast British Columbia: Legend.

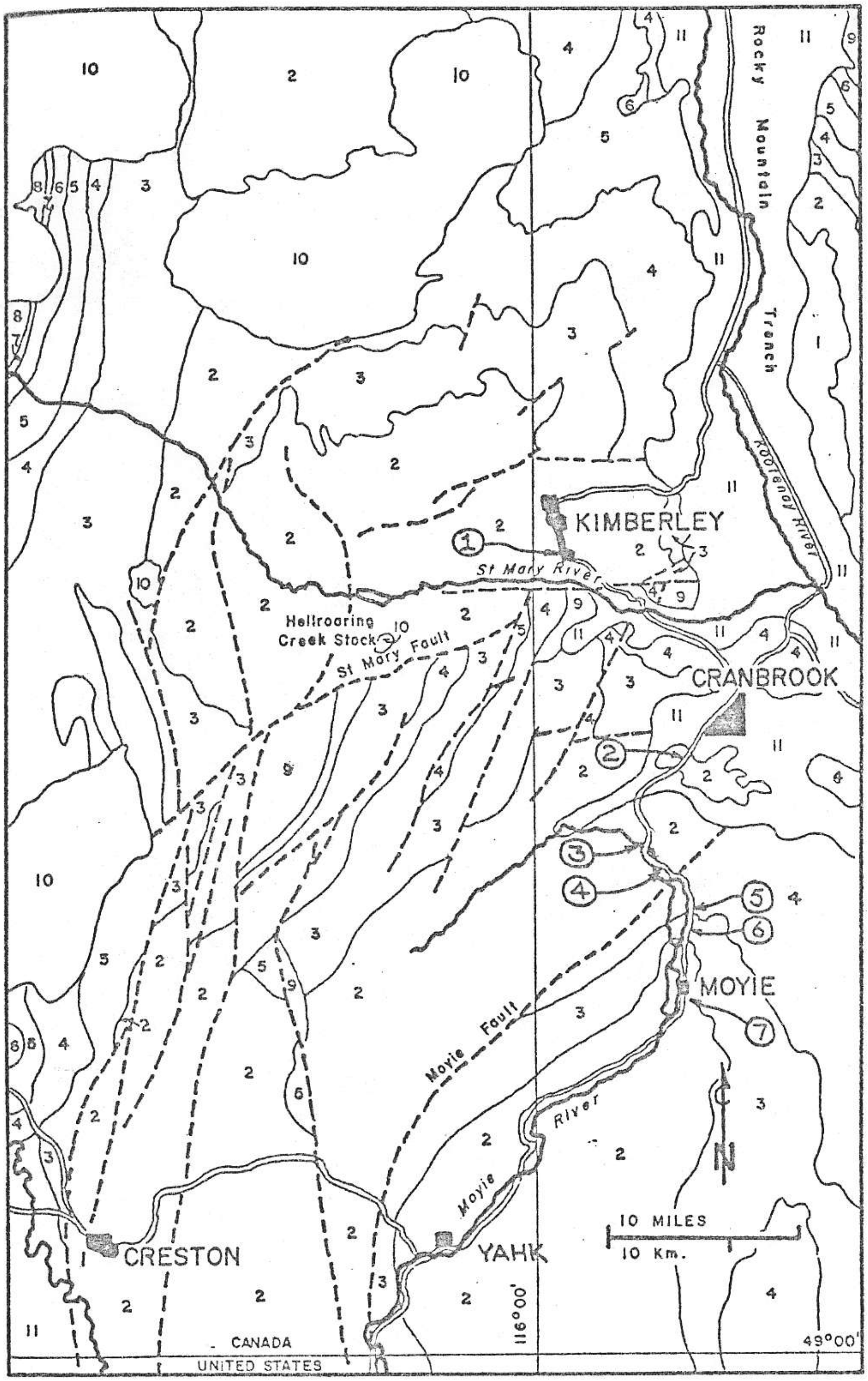


FIGURE 3-2: Regional Geology of Part of Southeast British Columbia.

(1) Field trip stops.

ROAD LOG: KIMBERLEY TO CRESTON

Hwy 95A to Cranbrook, Hwy 3/95 Cranbrook to Yahk, and Hwy 3 Yahk to Creston.

The trip starts in the Sullivan Mine horizon at Kimberley and passes down-stratigraphy as it runs southwest to Yahk. As it crosses both the St. Mary and Moyie faults it passes back into relatively higher stratigraphic levels: these faults drop the sequence on the south side.

Mileage

0.0 Kimbrook Inn, Kimberley.

2.5 Mark Creek and Marysville.

2.5 STOP 3 - 1 - Lower Aldridge sediments within a few feet of the Sullivan Mine horizon are exposed in the gorge below the bridge. These are thin-bedded and argillaceous in general, although meta-sandstone units occur. The main purpose of the Stop is to permit comparison with the turbidite-bearing Middle Aldridge Formation at STOP 3 - 2.

4.2 The trace of the St. Mary Fault. Cambrian sediments in the trees on the east lie unconformably upon the Kitchener Formation (top of the lower Belt).

8.1 Village of Wycliffe and junction with Cranbrook Airport road.

8.6 St. Mary River. Outcrops of Kitchener Formation occur along the river bank.

9.0 to 17.0 - The route runs on glacial gravels. The underlying units pass down through the Kitchener Formation, the Creston Formation, and the Upper Aldridge Formation, into flat-lying Middle Aldridge west of Cranbrook.

17.3 Junction with Hwy 3/95 from Radium and Fernie.

17.5 Northern city limits of Cranbrook.

21.5 Western city limits of Cranbrook.

The route continues through flat-lying, poorly-exposed lower Middle Aldridge Formation. Cliffs visible occasionally on the north side of the highway are metagabbro sills.

28.7 STOP 3 - 2 - A sequence of turbidite units and interbedded argillites is exposed on the east side of the highway. It lies in the Middle Aldridge Formation 10,000 m above the base. The presence of AE turbidites up to 1 m thick may be contrasted with the lithology of STOP 3 - 1 and rocks encountered in the Sullivan Mine.

The turbidites are graded only in their tops. They possess concretionary bodies and rip-up clasts. One unit is internally laminated in a manner attributed to a flowing-grain-layer process. Within the fine sand and silt-sized material convolute laminae, fine cross-bedding, and flame structures occur. The flame structures are attribtued to load-casting because they incline in a variety of directions. Indistinct sole marks may be seen on the undersides of the beds. The more argillaceous sections contain large crystal casts with the swallowtail form of selenite.

31.2 STOP 3 - 3 - A metagabbro sill outcrops on both sides of the highway and in a railway cut 50 m to the north.

31.7 Moyie River Bridge.

32.9 Moyie River Bridge.

32.9 STOP 3 - 4 - Exposures of Middle Aldridge Formation include a Marker Argillite in the cliffs east of the road and south of the river. The Marker Argillite occurs at the base of the cliff towards the north end. It is about 3.5 m thick, but includes up to a metre of non-laminated sediments. The corroded condition of the unit is due to the weathering of a relatively high proportion ($\pm$4%) of iron sulphides.

33.7 Trace of Moyie Fault. Outcrops of top lower Belt stratigraphy on the far side of the fault indicate a stratigraphic displacement in excess of 6,000 m.

35.3 Cross Peavine Creek and enter the steep north-plunging nose of the Moyie Anticline. Moyie Lake lies on the west and the top units of the Kitchener-Siyeh Formation lie on the east.

36.1 STOP 3 - 5 - Lower units of the Kitchener Formation occur on both sides of the road. They are interbedded argillaceous dolomites and dolomitic argillites. Of particular interest here is a structure referred to as "molar tooth". Small crenulated veinlets of calcite, approximately perpendicular to the bedding, weather in negative relief. Their form is quite varied, in some places being almost tubular. In addition, ripple-marked surfaces and scour-and-fill structures can be found in the more argillaceous units. Elsewhere in the Kitchener (and Kitchener-equivalent) Formation stromatolites have been identified. Although algal-like structures have been found 5-10 m to the north, no positive biogenic forms have been found in this sequence. The transitional contact with the underlying Creston Formation occurs about 100 m south of the debussing point.

37.2 STOP 3 - 6 - Cliffs on the east side of the road are from the top of the Creston Formation. On the whole they are of interbedded siltites and argillites in different shades of green and dull grey-green. One purplish sequence can be seen, with minor green lenses and blebs. These rocks are best examined down the bank on the west side of the road where large blocks that slide onto the road have been deposited by the bulldozer. Load-cast features and internal textures may be seen, as well as a great variety of surface markings strongly resembling mud-cracks. Many of the blocks present cross-sections showing that these "mud-cracks" extend above, as well as below, the bedding plane, and that they are associated with small scale silt intrusions.

38.1 Transition between the upper Aldridge Formation and the Creston Formation. The Aldridge is a dark, carbonaceous, thin-bedded, argillite succession. The Creston is a green coloured alternation of thin argillites and siltites, weathering rusty (Aldridge characteristic), but slightly green on relatively fresh surfaces. Some sand lenses can be found, as well as silt "intrusions" and penecontemporaneous pull-apart structures.

For the next 1.5 miles the highway runs over recessive weathering Upper Aldridge Formation carbonaceous argillites.

40.4 Highest exposures of the Middle Aldridge turbidite units.

40.6 Town of Moyie.

41.0 STOP 3 - 7 - The entrance to the St. Eugene Mine is on the east side of the highway. Adits and associated dumps can be seen up the hillside to the east. On the far shore of Moyie Lake to the west the Aurora Mine dump is visible.

The St. Eugene Mine lies about 2,000 m above the base of the Middle Aldridge Formation. It was discovered in the late 1890's by a Kootenay Indian and acquired by the owners of the Trail smelter in 1905 to supplement diminishing supplies of concentrates. The mine is a ladder-vein, striking WNW and dipping steeply south. The ore is essentially galena and silver. By 1916, when reserves were exhausted at 620 m below the headframe, production had amounted to 1,026,435 tons grading 12% Pb, 1% Zn and 6 oz./ton Ag.

The following description of mineralization is taken from a Cominco Report:

> "Lead, silver and zinc are the most important metals of the St. Eugene vein system and are mainly derived from argentiferous galena and sphalerite. Tetrahedrite is present in some areas, and small amounts of chalcopyrite are generally common in occurrence. Gangue minerals of the productive veins include quartz, biotite, chlorite, garnet, amphibole, pyrrhotite, pyrite and magnetite. Some epidote, grunerite and fluorite is found locally.

Commercial concentrations of these minerals occur in tabular ore shoots within steep-dipping veins and in multiple orebodies within extensive cymoid structures. The average width of mineable material, in both vein-type and cymoid-type deposits, is in the order of 2 to 3.5 m.

The main break in which the vein-type shoots form is generally uniform in trend but irregularly refracted in detail. The break is sometimes wide and other times narrow, and may be either filled with gangue minerals or barren.

The cymoid structure is bounded by two main breaks with parallel veins ('parallels') and cross veins ('avenues') transecting the inter-area. The structure is generally well-mineralized throughout and larger deposits sometimes reach 10 m in width with one or more bands of near-massive galena up to 1.3 m thick.

All the shoots tend to be longer down their dip than along their strike. The Lake Shore and St. Eugene shoots of the St. Eugene mine are apparently of the cymoid type and appear to pitch moderately to the east, whereas the Moyie shoot, which occurs in a warped area of the North vein, is of the vein-type with a near-vertical pitch. The Aurora shoots, across the lake at the Aurora mine are in the same vein system and are also related to a warped break, but apparently pitch moderately west.

The overall vein system, including ore shoots and barren sections, can be traced for some 3,500 m along its strike and some 1,400 m down its dip."

No more stops are planned for this leg of the trip. For the next 25 miles the route along Hwy 3/95 descends through Middle Aldridge stratigraphy as it passes obliquely through the western limb of the north-plunging Moyie Anticline. By the town of Yahk, the route has reached its lowest elevation in the stratigraphy of the block south of the Moyie Fault - just 100 m above the top of the lower Aldridge Formation.

45.3 Midway Mine lies on the north side of the road. This is a small quartz vein deposit operated for gold. Associated metallic minerals are arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite. The earliest records are from 1933 when the property was acquired by the B.C. Cariboo Goldfields Limited. Although the grade is reported to be 0.3 oz./ton Au the tonnage is negligible. Only a few ore shipments have been made.

60.1 Yahk

62.4 Junction between Hwy 3 and Hwy 95. The route continues along Hwy 3 to Creston for 26 miles.

REFERENCES

Bauerman, H. (1884): 49th parallel of north lattitude west of the Rocky Mountains. Geol. Surv. Can. Rept. of Prog., pt. B, pp. 1-4.

Bishop, D.T., Morris, H.C. and Edmunds, F.R. (1970): Turbidites and depositional features in the lower Belt-Purcell Supergroup (abs.). Geol. Soc. Am. Program, Boulder, Colo., 1970, p. 497.

Bouma, A.H. (1962): Sedimentology of some flysch deposits. Elsevier, Amsterdam, 168 p.

Burwash, R.A., Baadsgaard, H. and Peterman, Z.E. (1962): Precambrian K-Ar dates from the Western Canadian sedimentary basin. Jour. Geophys. Research, v. 67, no. 7, pp. 1617-1625.

Fenton, C.L. (1931): Algae and algal beds in the Belt Series of Glacier National Park. Jour. Geol., v. 39, pp. 670-686.

Harrison, J.E. (1972): Precambrian Belt basin of northwestern United States. Geol. Soc. Am. Bull., v. 83, no. 5, pp. 1215-1240.

Rice, H.M.A. (1937): Cranbrook map area, British Columbia. Geol. Soc. Can. Mem. 207, 67 p.

Ryan, B.D. and Blenkinsop, J. (1971): Geology and geochronology of the Hellroaring Creek stock, British Columbia. Can. Jour. Earth Sci., v. 8, pp. 85-95.

Willis, B. (1902): Stratigraphy and structure, Lewis and Livingstone ranges, Montana. Geol. Soc. Am. Bull., v. 13, pp. 305-352.

Ross, C.P. (1963): Belt Series in Montana, U.S. Geol. Surv. Prof. Paper 346.

PART 4

DAY 2 (P.M.): CRESTON TO RIONDEL

STRATIGRAPHY AND STRUCTURE OF HADRYNIAN AND CAMBRIAN ROCKS, EAST SHORE OF KOOTENAY LAKE

(Trygve Höy)

Between Creston and Riondel the route crosses obliquely the transition from the western margin of the Purcell anticlinorium to the Kootenay arc, and continues to the central part of the arc in the Riondel area (Fig. 4-1). The transition is marked by an increase in the grade of regional metamorphism and by a noticeable change in structural style, from the broad, open north-plunging folds characteristic of the Purcell anticlinorium to the overturned, isoclinal folds typical of this portion of the arc. The metasedimentary units through which this portion of the field trip runs includes the Toby Formation, Horsethief Creek Group, Hamill Group, Badshot Formation and Lardeau Group (Fig. 1-3, p. 4), as well as the discordant, post-tectonic Bayonne Batholith.

STRATIGRAPHY

The Toby Formation at the base of the Windemere Supergroup unconformably overlies argillites, limestones, and quartzites of the Dutch Creek and Mt. Nelson Formations. It is a conglomeratic mudstone (diamictite) unit generally consisting of boulder to pebble-sized clasts of dolomite, quartzite, and argillite that are derived from the Dutch Creek and Mt. Nelson Formations. The clasts are supported by a fine argillaceous, dolomitic or rarely, silty matrix. Deposition of the formation has probably taken place by mudflows, although Aalto (1971) suggests that the formation is a tillite. Elsewhere, the Toby Formation consists of well-sorted and closely packed clasts within a sandy mudstone matrix, suggestive of fluvial deposition (Lis et. al., 1976).

The overlying Horsethief Creek Group consists of up to 8500 m of pelite, slate and grit, with several quartzite and polymict units (Lis, op. cit.). The similarity of the polymict conglomerate units in the Horsethief Creek with the Toby Formation suggests that they as well were deposited as mudflows and fluvial gravels, derived from the upper part of the Purcell Supergroup. Lis (op. cit.) suggests that these units are fanglomerates which accumulated adjacent to a fault scarp that separated the uplifted source area south of the scarp from a deep structural basin on the north. Northward within the basin, the Horsethief Creek Group thins from greater than 9 km thick at the south end of Kootenay Lake to only a few kilometres thick. Southeast of the fault scarp (now marked by the St. Mary Fault, a northeast dipping reverse fault), lower Cambrian quartzites of the Cranbrook Formation lie unconformably on Upper Purcell rocks (Fig. 4-1). The Upper Proterozoic Windemere Supergroup is missing completely and 4 km of Middle Proterozoic strata, exposed farther to the northeast, has been eroded away.

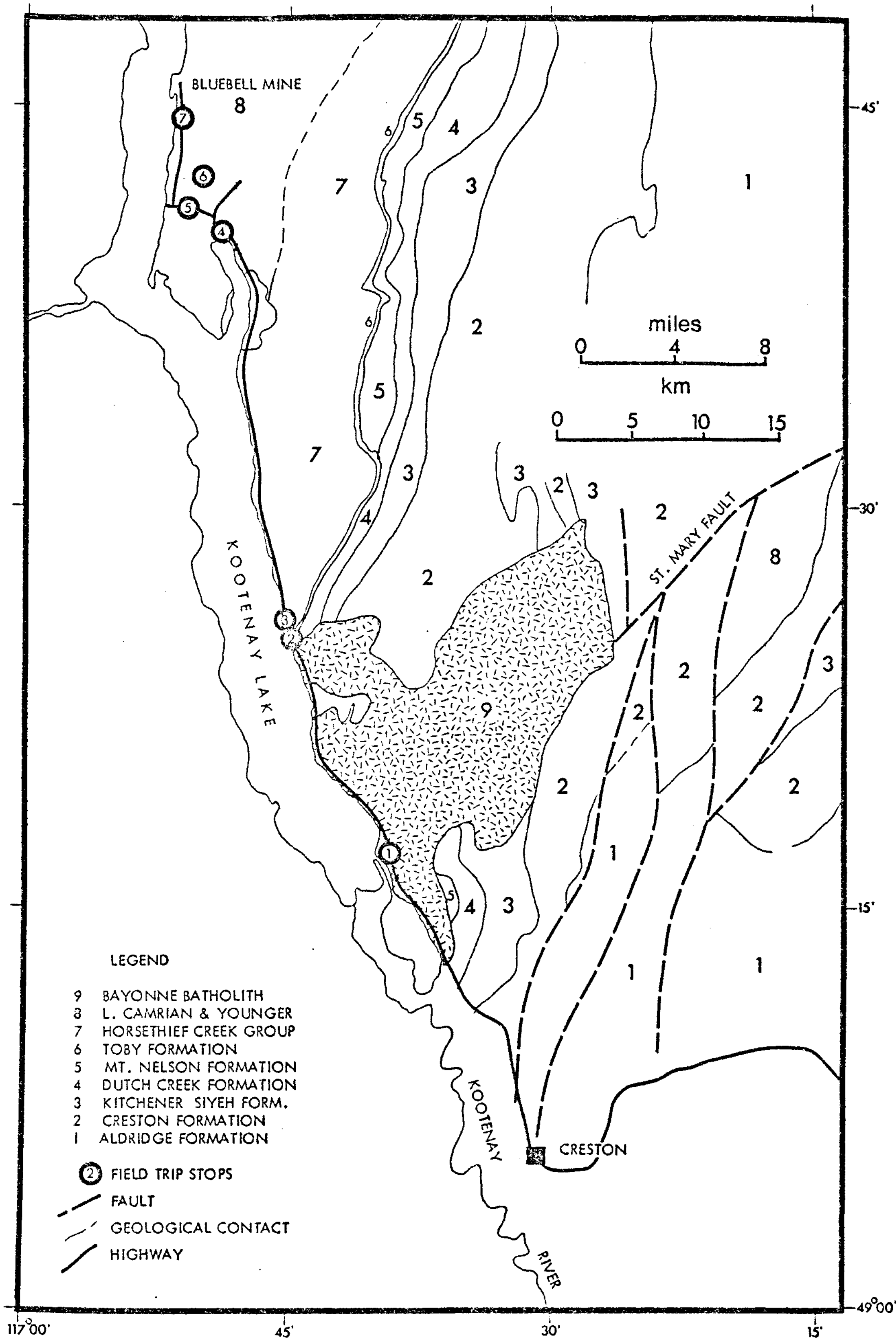


FIGURE 4-1: GENERALIZED GEOLOGY OF THE CRESTON-RIONDEL AREA SOUTHEASTERN BRITISH COLUMBIA (after Rice, 1956).

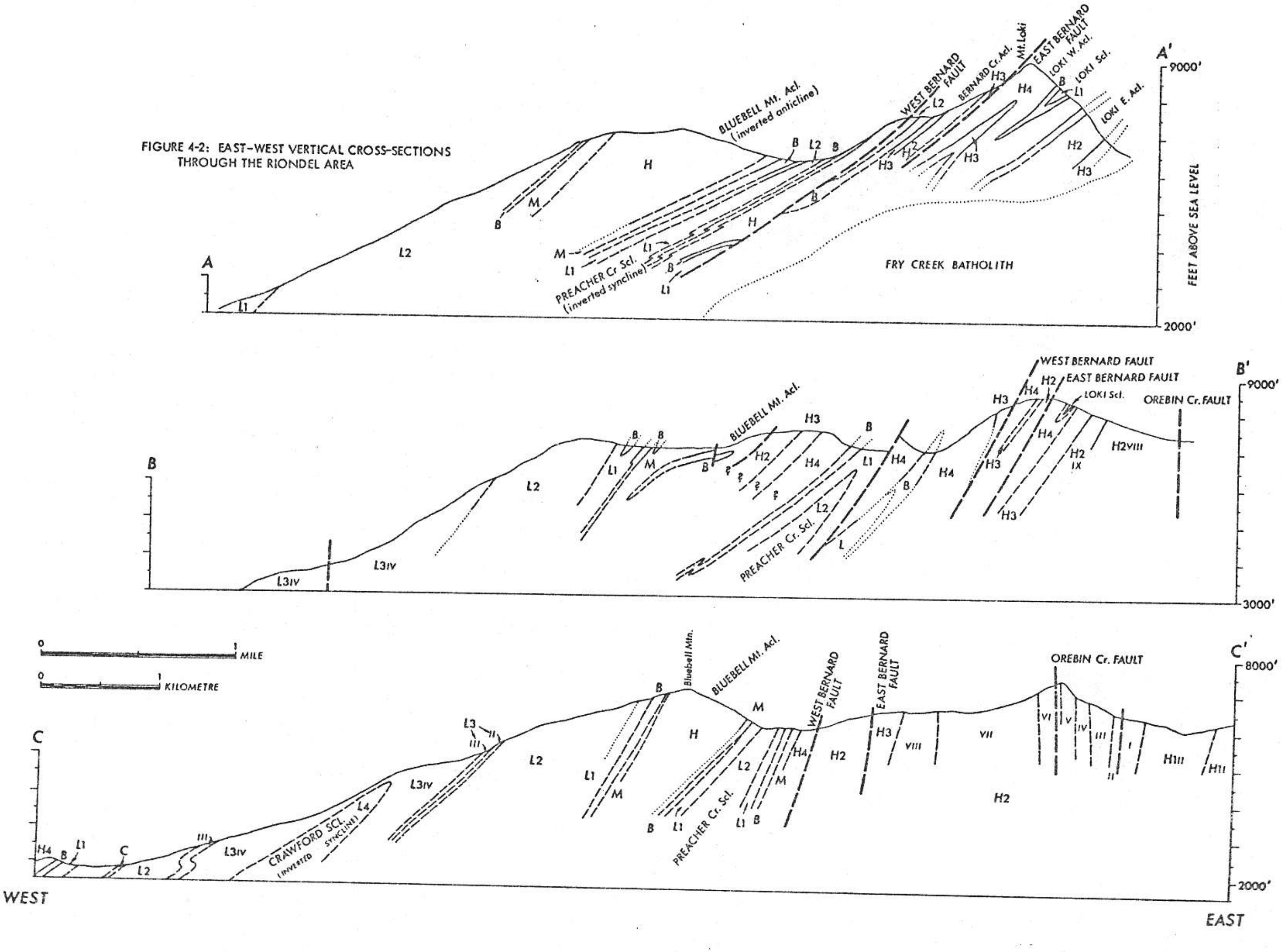


FIGURE 4-2: EAST-WEST VERTICAL CROSS-SECTIONS THROUGH THE RIONDEL AREA

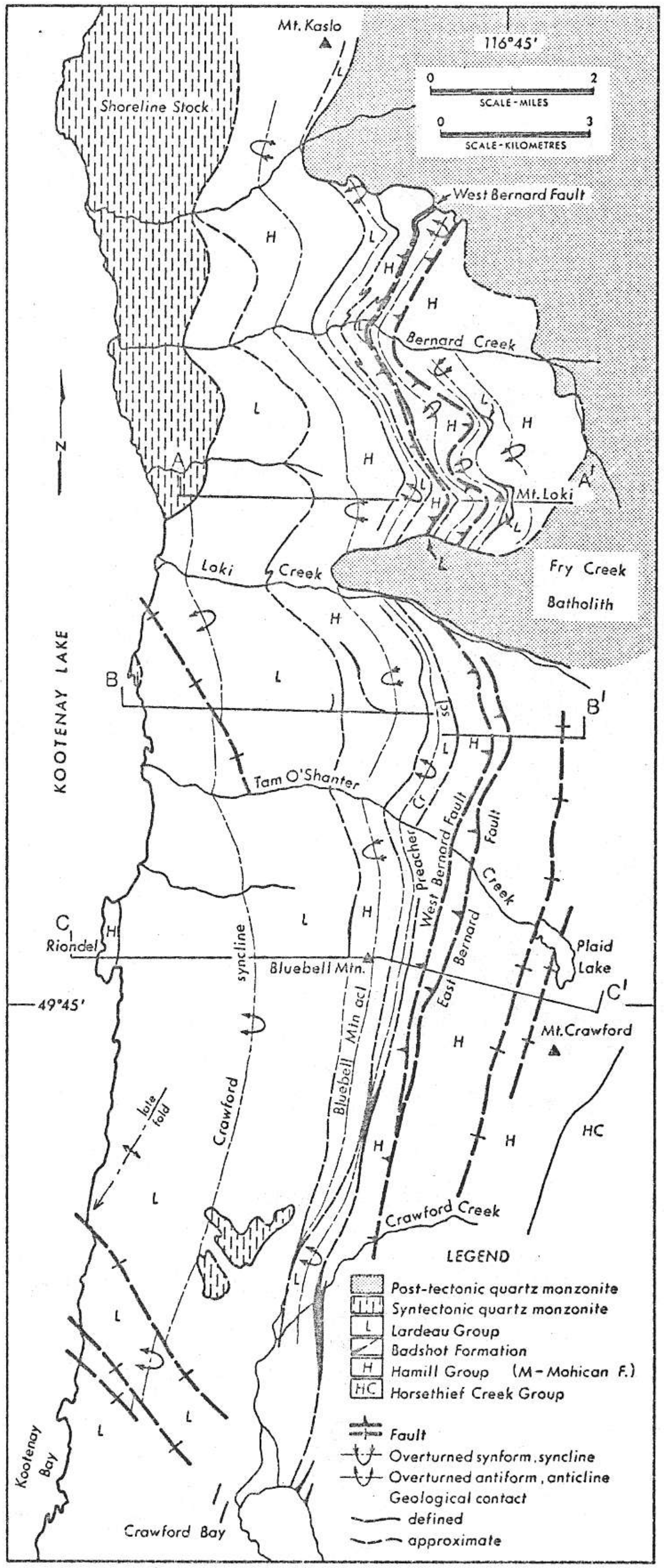


FIGURE 4-3: GEOLOGICAL MAP OF THE RIONDEL AREA

The lower Cambrian Hamill Group (equivalent to the Cranbrook Formation in the Purcell anticlinorium) unconformably overlies the Horsethief Creek Group. In the Riondel area (Höy, 1974) it comprises more than 1600 m of medium to coarse grained (unit H1, Fig. 4-6) feldspathic to pure quartzite, overlain by 1500 m of white to dark grey quartzite interlayered with dark, cross-bedded siltstone, phyllite, and schist (unit H2). The uppermost 200 to 300 m of the Hamill Group includes a prominent pure white quartzite layer (unit H3) overlain by dark grey biotite-quartz schist and quartzite (H4).

The Mohican Formation is a gradational unit between the Hamill Group and the Badshot marble. It is comprised of predominantly medium-grained, brown-weathering muscovite schist, grey dolomite marble and, less commonly, micaceous white quartzite layers. The Badshot marble is the most distinctive marker unit in the Riondel area. It consists of calcite or dolomite marble with accessory tremolite, phlogopite, graphite and quartz.

The overlying Lardeau Group is subdivided into 4 distinct units (Fig. 4-6). A fine to medium-grained muscovite schist or biotite gneiss (unit L1) immediately overlies the Badshot marble. It, in turn, is overlain by dark grey to black hornblende gneiss and amphibolite (unit L2), quartzite, biotite schist and rusty-weathering siliceous marble (unit L3), and rusty-weathering pelitic gneiss (unit L4). The total exposed thickness of Lardeau Group metasediments in the Riondel area is approximately 1200 m, although this is a minimum figure due to intense deformation.

STRUCTURE

The structure of the Riondel area is dominated by a large recumbent antiformal fold which has been named the Riondel nappe (Höy, in press). The following description is taken from a B.C. Department of Mines preliminary map (Höy, 1974):

> "The most conspicuous structures in the area are a set of very tight to isoclinal 'Phase 2' folds with west dipping axial surfaces (Fig. 4-2). These folds plunge at shallow angles to the north (and locally to the south), and their axial planes dip westward becoming more upright to the east. A pronounced foliation and lineation are parallel to their axial planes and fold axes respectively. West of the West Bernard fault (Fig. 4-3) they have developed in an inverted panel of rocks; older rocks form the cores of synforms and younger rocks the cores of antiforms. East of the West Bernard fault, the folds have developed in an upright panel of rocks.
>
> The oldest recognizable structure (Phase 1) is represented by the overturned stratigraphic succession that represents the underlimb of a large recumbent anticline, the 'Riondel nappe' (Fig. 4-4). Its axial zone and upper limb have been removed by erosion. The overturned limb extends under Kootenay Lake in the west and is bounded on the east by the West Bernard fault. Its western closure is deduced from regional considerations; in the Duncan Lake area parts of

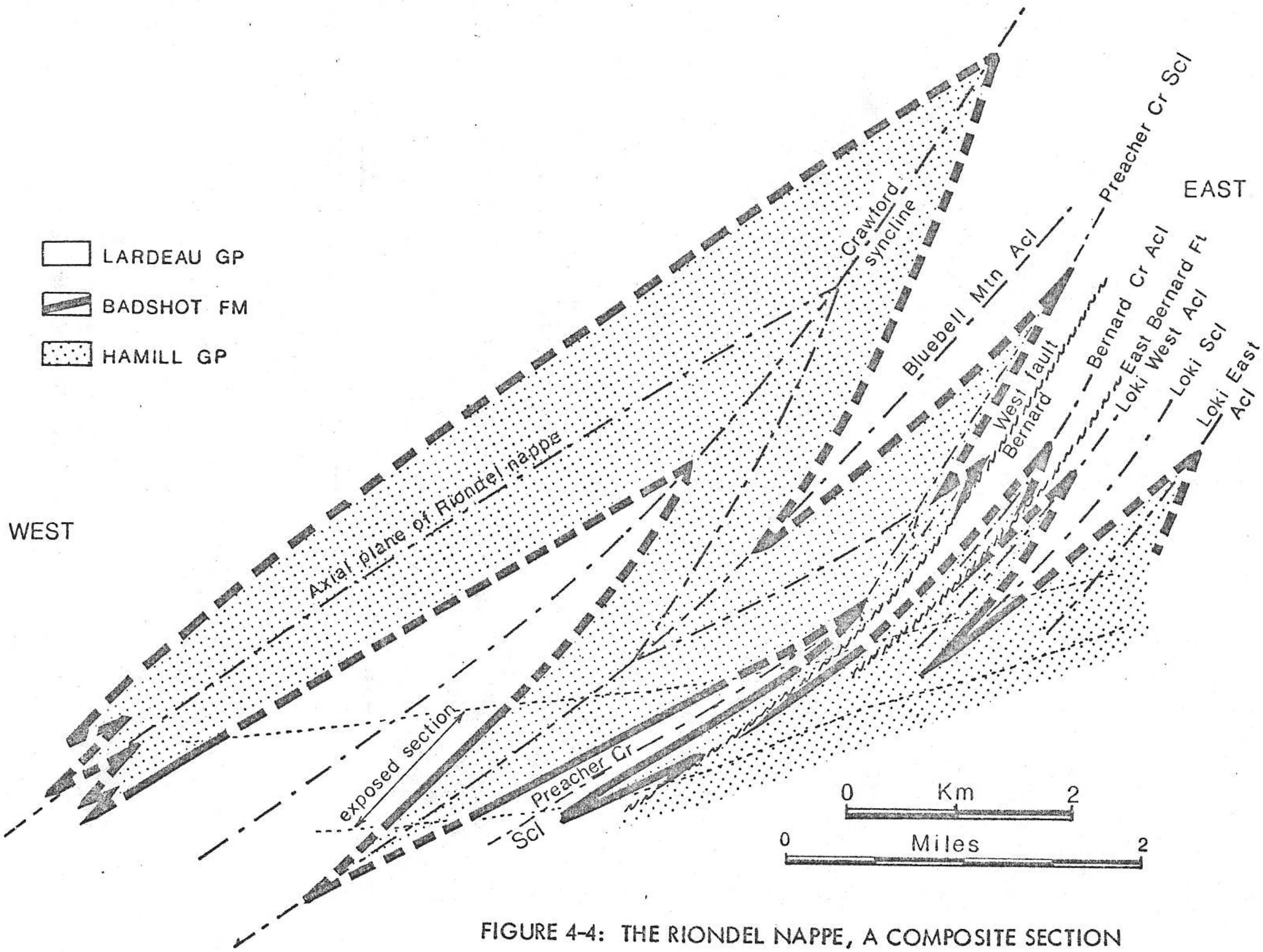


FIGURE 4-4: THE RIONDEL NAPPE, A COMPOSITE SECTION

both the lower and upper limbs of comparable style folds are exposed and indicate western closures (Fyles, 1964).

The limbs of Phase 2 folds have been deformed by small-scale folds that plunge to the southwest. The 'Sherraden Creek' antiform-synform pair (south of Riondel) is the largest of these and the only Phase 3 fold shown on the map (Fig. 4-3).

Two west dipping reverse faults, the West Bernard and East Bernard faults, transect the entire area from north to south. The West Bernard fault, as mentioned above, separates an inverted panel of rocks in the west from a right-side-up panel in the east. The East Bernard fault separates two Phase 2 anticlines, replacing the intervening syncline. Both are parallel to the axial planes of Phase 2 folds. Two strike faults cut the lower Hamill rocks east of the reverse faults. These are steep, and although locally parallel with the layering, cut up-section to the north. They shear the axial plane foliation associated with the Phase 2 structures and appear to be normal faults as stratigraphy is not repeated across them. Steeply dipping, southeast-trending faults with small right lateral displacements are conspicuous just north of Crawford Peninsula. These faults cut all other structures."

ROAD LOG: CRESTON TO RIONDEL (Hwy 3a)

The second leg of the field trip (Day 2) continues generally up-section through the Upper Proterozoic succession on the west side of the Purcell anticlinorium into highly deformed and metamorphosed lower Cambrian metasediments in the central Kootenay Arc.

Mileage

0.0 Town of Wynndel, 7 miles north of Creston.

3.9 Contact of Bayonne Batholith with the Dutch Creek Formation.

The route continues for approximately 14 miles through the Bayonne Batholith. The Batholith is a discordant post-tectonic pluton that truncates several large folds in the Creston and Kitchener Formations. Its composition varies from a granite to a granodiorite, with the main bulk of the intrusion being an equigranular to locally porphyritic granodiorite. It has been dated (K-Ar) at 100 m.y.

9.1 STOP 4 - 1 - Boulder Creek: exposure of the Bayonne Batholith.

20.5 STOP 4 - 2 - Columbia Point: exposure of Toby Formation, just north of the Bayonne Batholith contact.

Pebbles and boulders are deformed, generally quartzitic in nature, although dolomite and argillite clasts are also common, suspended in an originally argillaceous matrix. Aalto (1971) describes the Toby Formation as a tillite, deposited during widespread glaciation in early Hadrynian time. Lis et. al. (1976) and Atkinson (1976) believe the Toby Formation, and similar coarse conglomerates in the overlying Horsethief Creek, were deposited as mudflows or as fluvial gravels in structural depressions north of prominent fault scarps.

21.5 STOP 4 - 3 - Exposure of Horsethief Creek Formation: grey sericite phyllite, grit and minor quartzite near the base of the Horsethief Creek.

26.5 Exposure of quartzite and minor calcareous quartzite, Horsethief Creek Formation.

27.3 Exposure of grey limestone; this thick and prominent limestone unit near the central part of the Horsethief Creek Group is probably correlative with "the middle marble member" of the Horsethief Creek in the northern Selkirks, well to the north of the Trans Canada Highway (Brown et. al., 1976). The grits, quartzite and pelite that we have just passed through are the equivalent of the "lower pelite member", and overlying schist and quartzite, the "upper pelite member". The total thickness of Horsethief Creek sediments in the northern Selkirks is in excess of 4,000 m compared with greater than 8,500 m in the Kootenay Lake area.

27.7 Lockhart Beach campsite.

28.9 La France Creek.

31.4 Exposure of conglomeratic mudstone in the upper part of the Horsethief Creek Group.

37.2 A small discordant granite pluton conceals the contact of the Horsethief Creek and the overlying Hamill Group.

40.2 STOP 4 - 4 - (Fig. 4-5). View of hills due north of Crawford Bay. The Badshot marble closes in a tight synformal structure on these slopes, with older Hamill quartzites in its core. Tight antiformal structures immediately to the west and east have younger Lardeau rocks in their cores, indicating that the sequence of metasedimentary rocks in the Riondel area is inverted. This inverted panel is the underlimb of a large westward closing nappe structure that roots to the east and closes west of the most western exposures in the Riondel area.

The next four stops outline the detailed stratigraphy of the metasedimentary rocks in the vicinity of the Bluebell deposit. The youngest rocks in the map area, Index Formation gneisses, are examined first (STOPS 4 - 5, 6, 7), then the Bluebell deposit and host Badshot limestone is visited, and finally, underlying quartzite and schist of the Hamill Group.

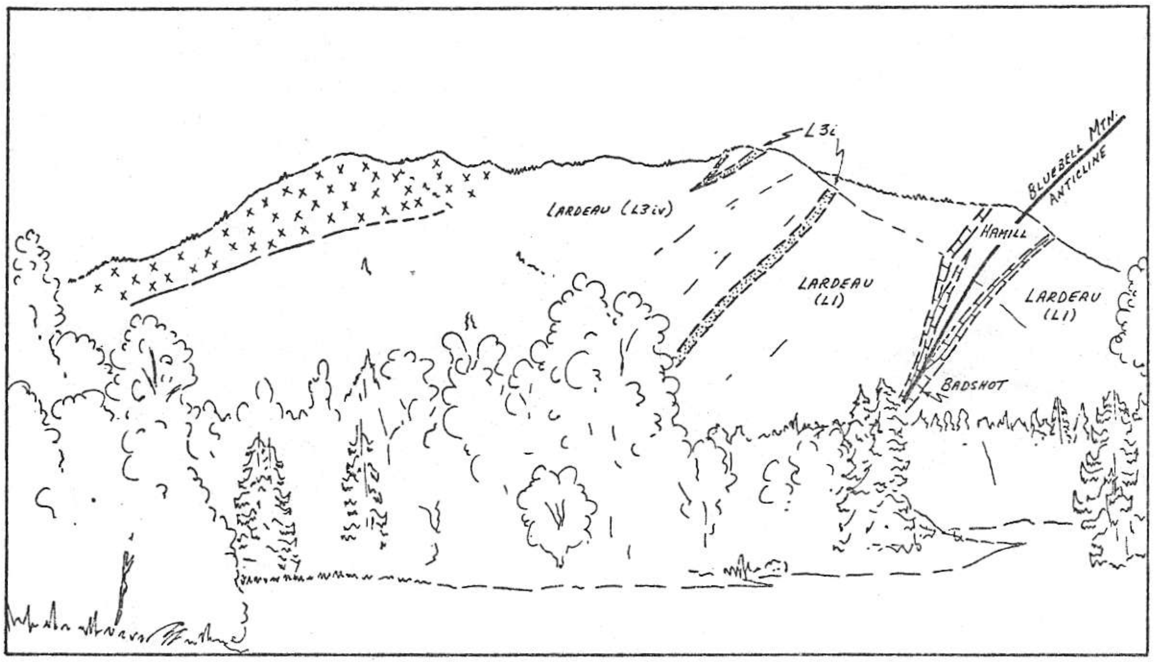


Fig. 4-5: Sketch showing closure of Badshot marble in core of synformal Bluebell Mountain anticline on slopes north of Crawford Bay.

42.6 STOP 4 - 5 - Unit L4, the youngest member of the Lardeau Group exposed in the Riondel area, occurs within the core of an antiformal syncline, the Crawford syncline. It is a rusty-weathering paragneiss that commonly contains large boudins of amphibolite. Sillimanite and kyanite, largely altered to a white mica, are common in more pelitic layers.

43.5 Riondel road turn-off.

44.0 STOP 4 - 6 - Unit L3. The succession within this unit includes a basal quartzite interlayered with biotite schist, overlain by thinly laminated dark amphibolite, then thin rusty-weathering siliceous marble that grades upward into grey-green calc-silicate gneiss, the dominant part of the unit. The well-layered nature of the calc-silicate gneiss is evident in this exposure. A study of metamorphic reactions among calc-silicate minerals in this unit indicates that the regional metamorphic grade increases towards the west (Höy, 1976).

47.9 STOP 4 - 7 - Unit L2. Dark grey to black hornblende gneiss and amphibolite comprise unit L2. Calc-silicate gneiss layers, quartzite layers and a number of thin calcite marble layers are also common within the unit.

49.1 Town of Riondel.

The next stop visits the Bluebell Mine (described in detail in the following paper). Exposed on Riondel peninsula are quartzites and interlayered pelitic schists and gneisses of the Hamill Group, structural footwall rocks to the Badshot marble and Bluebell mineralization.

	unit	approximate thickness	description
Lardeau	L4	?	biotite-quartz-feldspar gneiss
	L3	400-450	calc-silicate gneiss, impure rusty-weateering marble, and a quartzite at the base
	L2	600-800	biotite-hornblende gneiss, amphibolite; minor marble and calc-silicate gneiss
	L1	100-150	micaceous schist
	Badshot	15-30	calcite or dolomite marble
	Mohican	10-40	rusty-weathering marble, schist and quartzite
Hamill	H4	230	dark quartzite, dark quartz-rich schist
	H3	60-200	massive, white quartzite
	H2	2000	muscovite-biotite schist, quartzite, siltstone, and minor amphibolite
	H1	1600	massive, white quartzite, gritty quartzite

Figure 4-6: Detailed succession of metasedimentary rocks in the Riondel area.

REFERENCES

Aalto, K.R. (1971): Glacial marine sedimentation and stratigraphy of the Toby conglomerate (Upper Proterozoic), southeastern British Columbia, northwestern Idaho and northeastern Washington. Can. J. Earth Sc., V. 8, No. 7, pp. 753-787.

Atkinson, S.J. (1976): Summary of mapping project, Toby Creek area, northeast section, Lardeau District, British Columbia. B.C. Dep. Mines Pet. Resources, Geol. Fieldwork (1976), pp. 119-123.

Brown, R.L., Perkins, M.J. and Tippett, C.R. (1976): Structure and stratigraphy of the Big Bend area, British Columbia. Geol. Surv. Can., Report of Activities.

Fyles, J.T. (1964): Geology of the Duncan Lake area, Lardeau District, British Columbia. B.C. Dep. Mines Pet. Resour., Bull. 49.

Höy, T. (1974): Geology of the Riondel area. B.C. Dep. Mines Pet. Resour., Prel. Map 16.

————(1976): Calc-silicate isograds in the Riondel area, southeastern British Columbia. Can. J. Earth Sc., V. 13, No. 8, pp. 1093-1104.

————(in press): Stratigraphy and structure of the Kootenay Arc in the Riondel area, southeastern British Columbia. Can. J. Earth Sc.

Lis, M.G. and Price, R.A. (1976): Large-scale block faulting during deposition of the Windemere supergroup (Hadrynian) in southeastern British Columbia. Geol. Surv. Can., Paper 76-1A, pp. 135-136.

Rice, H.M.A. (1941): Nelson map-area, east half, British Columbia. Geol. Surv. Can., Mem. 228.

PART 5

DAY 2: AN OUTLINE OF THE GEOLOGY OF THE BLUEBELL MINE, RIONDEL, B.C.

(P.W. Ransom)

HISTORY:

The earliest lead-zinc mining in British Columbia was from the Bluebell-Ainsworth camp in 1882. The Bluebell deposit was known to fur traders and trappers before then and stories about them using Bluebell ore to make lead shot for their guns have been quite convincingly told by some of the old timers from the area.

Production was intermittent from 1895 to 1927 under various owners. From 1952 to 1971 the mine was operated by Cominco Ltd. In late 1971 production ceased and shortly after, in 1972, the mine was flooded. The production has been:

	Short Tons	Pb%	Zn%	Ag Oz/Ton
Pre Cominco Owners	540,000	6.5	8.2	2.8
Cominco Ltd.	4,777,000	5.1	6.1	1.6
TOTAL	5,317,000	5.2	6.3	1.7
Known Unrecoverable Mineralization	385,000	4.9	5.6	1.4
TOTAL SIZE OF DEPOSIT	5,702,000	5.2	6.3	1.7

In addition some copper and cadmium in the ore was recovered. The copper content was 0.1% and the cadmium content, 0.03%.

GEOLOGICAL SETTING AND STRUCTURE

The rocks of the Riondel peninsula consist of an overturned Lower Cambrian sequence that dips 30° west (Fig. 5-1). The oldest rocks are quartzite and quartz-mica schist of the Hamill Group. They now lie on the younger Mohican Formation, a 30 m thick unit of quartz-mica schist and locally developed marble. This marble, ranging up to 4 m in thickness, is known as the Upper Limestone and it occurs at the division between the Hamill Group and Mohican Formation. A small amount of ore was recovered from the Upper Limestone. Mohican Formation schists form the hangingwall of the Badshot Formation, a 30 to 50 m thick marble that hosts the Bluebell orebody and locally is referred to as the Bluebell Limestone. The Bluebell Limestone consists of calcite and tremolite and contains minor amounts of phlogopite, biotite, chlorite and graphite. On the footwall side of the Bluebell Limestone are schists and gneisses of the Index Formation, the youngest metasedimentary rocks on the peninsula. In the immediate mine area

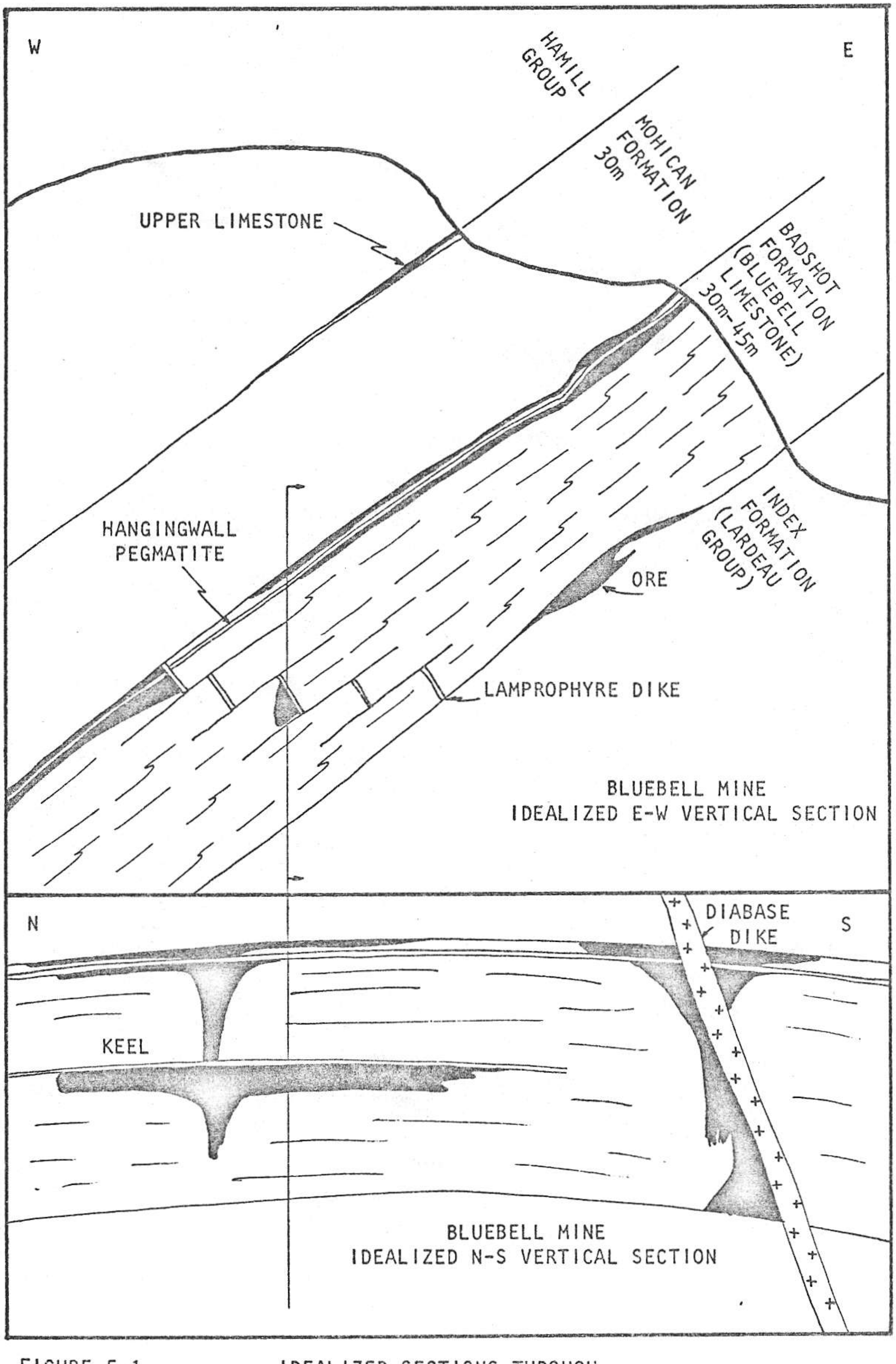


FIGURE 5-1 IDEALIZED SECTIONS THROUGH PART OF THE BLUEBELL MINE

the schists are typically graphitic and pyritic quartz-mica schists and calc-silicate schists. Impure marble and amphibolite also occur locally within the Index Formation.

Felsite pegmatite sills and lenses up to 10 m thick occur within both the Bluebell Limestone and Index Formation. The most notable pegmatite is one which forms a continuous sheet 1 to 3 m thick from 1 to 10 m below the hangingwall of the Bluebell Limestone.

The structural setting of the Bluebell deposit has been the subject of studies by many geologists. Cominco geologists first recognized small-scale folds ("S" shaped when the viewer faces north) within the Bluebell Limestone and adjacent schists. These small-scale folds seem to indicate that the Bluebell Limestone was on the lower limb of an overturned west-dipping anticline (Fig. 5-2a). This anticline could be doubly plunging with both noses covered by the lake. Alternatively the noses may be exposed in outcrops on the west side of Kootenay Lake. This type of structure could occur in the structural level below the Riondel nappe, discussed next.

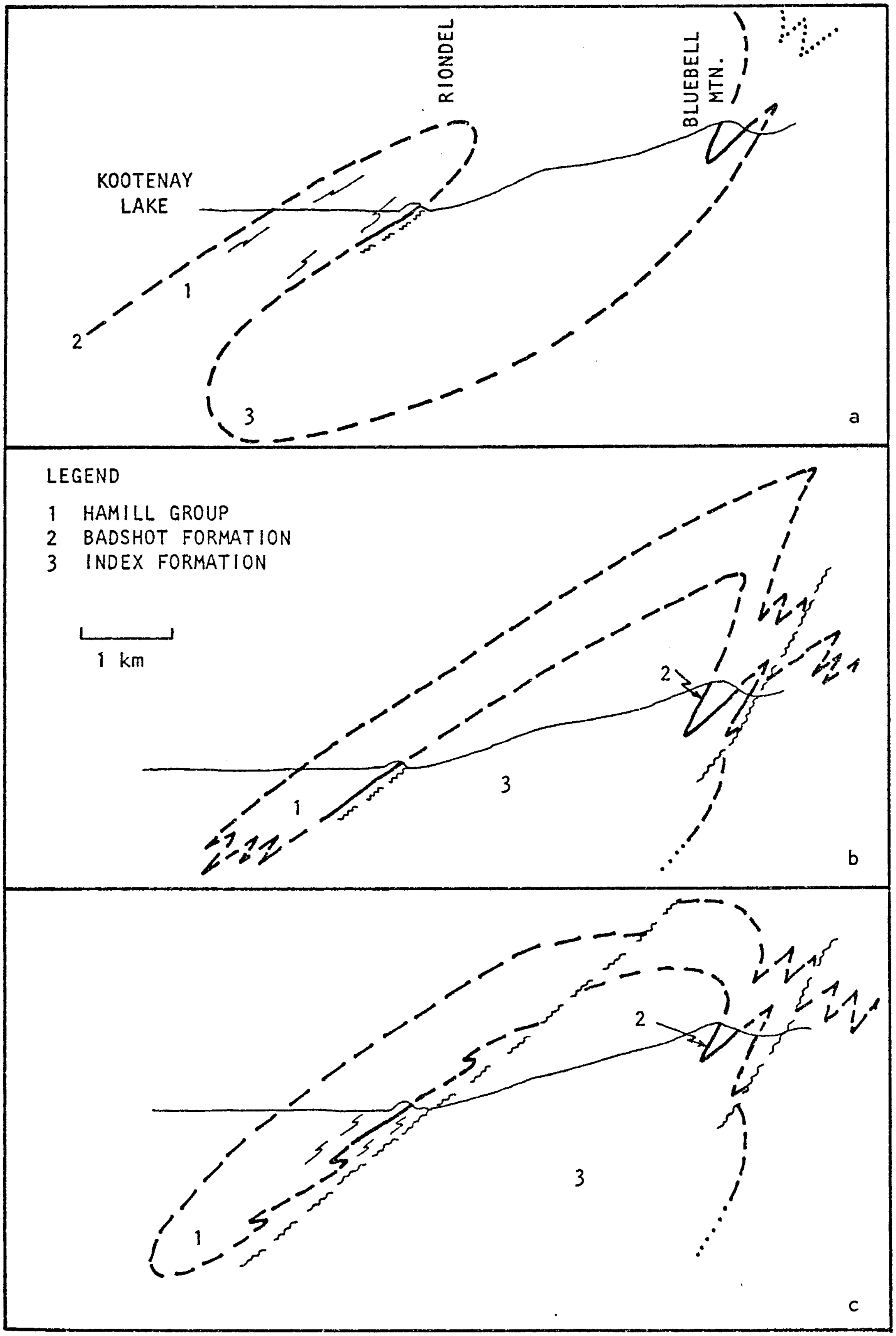
An alternative interpretation, originally proposed by J.T. Fyles, of the B.C. Department of Mines, places the Bluebell Limestone on the underside of a nappe. Recent mapping (Höy, 1974) has verified this type of structure east of Riondel (Fig. 5-2b). The "S" folds of Bluebell, however, are the wrong sense for both first and second phase folds in the nappe. It is suggested that the Riondel nappe, during the latter stages of its development, moved westwards and down, possibly sliding under its own weight. The resulting drag would likely have developed a "fir-tree" pattern of drag folds on the underside of the nappe, satisfactorily, explaining the "S" type folds at the mine (Fig. 5-2c). Alternatively, "S" folds may be related to a pervasive but relatively minor third phase of deformation in the Riondel area. The "Z" type folds one might expect to develop during F_1 and F_2 stages of folding were not observed underground. This may be because either they did not form or, more likely, they became so attenuated that they could not be easily recognized. Refolded folds have been observed in the footwall schists along the Riondel shoreline.

Lamprophyre dykes at the mine have also been deformed by forces similar to those that developed the "S" folds. The dykes strike north-south and dip 55^{o} east. They have been offset 2 to 10 m by bedding-parallel normal faults spaced 5 to 10 m apart (Fig. 5-1).

ORE OCCURRENCES AND GENESIS

Ore shoots at Bluebell are clustered in three zones, the Comfort (north), Bluebell (centre) and Kootenay Chief (south), separated by barren intervals about 500 m in length. The ore shoots are parallel to steep tensional cross-fractures which have the following average attitudes in the three zones:

Zone	Strike	Dip
Comfort (north)	N72 W	83 N
Bluebell (centre)	N75.5 W	82 S
Kootenay Chief (south)	N62.5 W	84.5 N



INTERPRETATIONS OF THE STRUCTURAL SETTING OF THE BLUEBELL MINE,

FIGURE 5-2 RIONDEL, B.C.

These fractures seldom penetrate the hangingwall. A zone of brecciated limestone about 15 m wide marks the boundary between the limestone segments of different cross-fracture orientation.

The ore was predominantly massive coarse pyrrhotite, sphalerite and galena; however, disseminated sulfides, narrow bands of medium to coarse sulfides in quartz and marble and sulfide-filled fractures were also mined. Ore shoots ranged in size from irregular pods of a few thousand tons to continuous masses of up to one million tons that extended down-dip as much as 500 m. In cross-section, an average ore shoot was mushroom-shaped, the stem representing cross-cutting keels 1 to 30 m wide and the cap representing a bedding-conformable horizon up to 6 m thick that extended laterally as much as 50 m from the keel zone. The keel zones extended below the conformable ore some 10 to 20 m, narrowing and grading into a series of steep mineralized fractures that became uneconomical to mine. Some of the fracture zones and keels of the larger ore shoots extended to the footwall. A few ore shoots also developed along the footwall in a style complementary to hangingwall ore shoots. Depressions along the footwall and arches along the hangingwall were particularly favourable areas for ore accumulations. Ore shoots more than doubled in thickness and spread out laterally as 'runs' along strike on the down-dip side of displaced lamprophyre dyke segments. Very little ore occurred on the up-dip side of these segments and not until 30 m further up-dip did ore attain normal thicknesses.

A few pre-ore diabase dykes that were sub-parallel to the ore fracture systems cut the Riondel sequence. Ore tended to localize on the underside of the dykes that cut ore shoots. A 1 to 3 m thick bed of graphitic quartz-mica schist, the "Mid-Limestone Schist", occurs near the middle of the Bluebell Limestone on and below the bottom level at the north end of the mine. Drilling indicated areas of bedding-conformable sulfides situated below this schist.

Mine geologists thought that the ore shoots were replacement deposits in the limestone. Underground observations indicate that hydrothermal ore solutions entered steep east-west tensional fractures in the limestone from the footwall, ascended along these fractures into dilatant zones, and spread out below impermeable barriers such as the hangingwall schist, hangingwall pegmatite, the lamprophyre and diabase dykes, and mid-limestone schist.

Regional metamorphic studies indicate that metamorphism took place at depths between 18 and 28 km. Detailed fluid inclusion studies infer ore formation to have taken place at a depth of 7 km. If these interpretations are correct, ore formation occurred after the metamorphic culmination. I envisage hydrothermal solutions having been released at depth from interstitial traps as a result of the decrease in the confining pressure caused by the erosion of overlying rocks. On ascending, these solutions scavenged metals and combined in sufficient quantities in large enough channelways eventually to form the Bluebell orebody.

MINERALOGY AND OXIDATION

The mineralogy has been well described by several geologists. In summary the minerals associated with the Bluebell ore deposit are:

1. Ore Minerals: Galena and marmatitie (sphalerite).
2. Other Sulfides: Pyrrhotite, arsenopyrite, pyrite and chalcopyrite.
3. Gangue Minerals: Quartz, calcite, siderite, rhodochrosite, knebelite, minnesotaite, dickite, chlorite, and magnetite.
4. Oxide Zone Minerals: Pyrite, hematite, limonite, native copper.

The sequence of mineralizing events has been described as follows. The earliest and highest temperature mineral formed was knebelite, a manganese olivine closely resembling fayalite. The ore that formed in association with knebelite had some unique characteristics such as:

1. Some of the pyrrhotite occurred as 0.5 to 1 cm laths and needles in a runic type pattern.
2. Amber to golden sphalerite was often noted, sometimes rimming black marmatite.
3. Magnetite occasionally occurred in close spatial relationship to galena.

Runs of massive sulfides similar to typical massive ore from knebelite-free ore shoots also occurred in the knebelite zones. The massive ore (of either zone) contained varying amounts of pyrrhotite, galena and marmatite within or interfingering with marble. Vugs, often containing spectacular crystals and crystal clusters of quartz, calcite, pyrrhotite, pyrite, arsenopyrite, marmatite and galena, were developed in the massive ore during the final mineralizing phase.

Subsequent to the formation and uplift of the ore deposit to the present erosional level, oxidation of some of the ore took place. The irregular distribution of the oxidized areas suggests that descending oxidizing ground water followed irregular channelways and oxidized only the parts of the ore shoots that they came in contact with. To explain this, ground water must have flowed through the Bluebell Limestone to levels as much as 300 m below the present surface level of Kootenay Lake (533 m above the sea level). It has been suggested that this occurred when a river flowed south through this area at a sufficiently low elevation to allow the flow of oxidizing ground water through the Bluebell Limestone. The river, it is believed, was eventually blocked by the Columbia basalt flows in the Spokane area.

A paragenetic sequence defining the stages of oxidation observed in the Bluebell ore is summarized below:

1. Fresh pyrrhotite cut by hairline veinlets of pyrite.

2. Disintegrating pyrrhotite cut by 1 mm to 5 mm wide veinlets of pyrite.

3. Sponge pyrite only, no pyrrhotite left; hematite forms.

4. Sponge pyrite completely converted to sponge hematite with some limonite.

5. Development of masses of limonitic mud. Blocks of high grade galena and sphalerite appeared relatively unaffected. The limonitic mud often contained fine galena and sphalerite grains.

THERMAL WATER

Flows of CO_2-charged thermal waters from fissures in the Bluebell Limestone was an active geological process that frequently caused problems underground. These waters contained a greater quantity of dissolved solids and chlorine than the lake water indicating, possibly, that the thermal waters had a juvenile component.

A number of cave phenomena were observed to form over short periods of time (weeks to years). 'Soda straws', stalactites, and 'bacon strips' were commonly observed suspended from the backs of mine openings. 'Birds nests' with loose eggs formed under steady drips and 'flowstone' deposits and 'frozen waterfalls' formed in constantly flowing thermal water. Where trains ran through slow-moving thermal waters the swash caused growing concretions to roll around resulting in well-rounded uniform sized particles (typically pea to marble-sized).

CONCLUSIONS

Geologically related problems such as the flows of thermal and lake water, the CO_2 gas, the soft and rotten ground along many of the thermal water courses, the masses of oxide mud in many ore shoots and the position below Kootenay Lake all had a profound effect on mining. The operators and miners deserve considerable credit for their ingenuity, perseverence, and hard work in handling these problems.

SELECTED BIBLIOGRAPHY

Crosby, P. (1968): Tectonic, plutonic, and metamorphic history of the Central Kootenay Arc, B.C. Geol. Soc. Am. Spec. Paper 99, 94p.

Fyles, J.T. (1964): Geology of the Duncan Lake Area, B.C. Dep. Mines Pet. Resour., Bull. 49, 87p.

——————(1967): Geology of the Ainsworth-Kaslo Area. B.C. Dep. Mines Pet. Resour., Bull. 53, 125p.

Höy, T. (1974): Geology of the Riondel area, B.C. Dep. Mines Pet. Resour., Prelim. Map 16.

————(1976): Calc-silicate isograds in the Riondel area, southeastern British Columbia. Can. J. Earth Sc., V. 13, pp. 1093-1104.

Irvine, W.T. (1957): The Bluebell mine; in Structural Geology of Canadian Ore Deposits, V. 2, Can. Inst. Min. Meta.

Ohmoto, H. and Rye, R.O. (1970): The Bluebell mine, B.C., I, Mineralogy, paragenesis, fluid inclusions, and the isotopes of hydrogen, oxygen and carbon. Ec. Geol. V. 65, no. 4., pp. 417-437.

Shannon, F.G. (1970): Some unique geological features at the Bluebell mine, Riondel, B.C.; in Lead-zinc deposits in the Kootenay Arc, Soc. Ec. Geol., N.W. Field Conference Guidebook, Bull. 61.

Westervelt, R.D. (1960): An investigation of the sulfide mineralization at the Kootenay Chief orebody, Bluebell Mine, B.C. Unpubl. MSc thesis, Queen's Univ., Kingston, Ont.

Winzer, S.R. (1973): Metamorphism and chemical equilibrium in some rocks from the central Kootenay Arc. Unpubl. PhD thesis, Univ. of Alberta, Edmonton, Alberta.

Cominco maps and reports by:
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PART 6

DAY 3: H.B. MINE, SALMO, B.C.

(G. F. Warning and staff)

INTRODUCTION

The H.B. Mine and concentrator is situated about seven miles southeast of the village of Salmo, B.C. on the north side of the Sheep Creek valley.

The property was originally staked by Horton and Benson (hence H.B.) in about 1907 and was purchased by Cominco Ltd. in 1927. Intermittent work was carried out until 1946. Later, an extensive diamond drilling program was undertaken followed by underground exploration.

With sufficient ore outline, construction of a 1000-ton/day concentrator was started in April of 1952 and completed in the spring of 1953. Due to unfavourable metal prices operation did not commence until May, 1955 and was suspended in 1966. The mine resumed production in early 1973.

GEOLOGY OF THE H.B. MINE

The H.B. Mine is located within the Kootenay Arc which in the Salmo area consists of an assemblage of metasediments ranging from quartzite and argillite of the Hamill Group, limestone of the Reeves Formation and argillite of the overlying Lower Laib Formation. The H.B. orebodies are localized within the dolomitized lower part of the Reeves Limestone (which has been correlated with the Badshot Formation to the north, Fyles et. al., 1959).

In the mine vicinity, the Lower Laib is folded isoclinally with axial planes striking north-south and inclined steeply east. The folds plunge 20 degrees to the south. The main orebodies are confined to a syncline approximately 3500 feet in length and 200 to 400 feet wide. The Garnet ore zone 500 feet to the west is in a smaller syncline. There are essentially two types of orebodies, a steeply dipping variety of ore stringers and a flat lying type. Both types conform to the 20 degree plunge of the fold.

The fine-grained dolomite host rocks for the ore are either described as "crackled" or as "grey, massive". Crackle dolomite is a white dolomite containing dark carbonaceous material in lineations, patches and streaks. It represents a banded rock which has undergone tremendous stresses. The grey, massive dolomite is untextured and hosts only a small percentange of the total H.B. reserves. The mineralogy of the ore is simple consisting of sphalerite, pyrite, and galena with pyrrhotite occurring locally. The larger steep zones have a Zn:Pb ratio of about 6:1 whereas the flat zones have a Zn:Pb ratio of 2.4:1.

The boundaries of the H.B. orebodies are determined by the structure, lithology, and topography. To the south, the ore zones pinch-out apparently caused by an upward re-folding of the synclinal package. To the east and west the syncline and the dolomite host rock control the extent of mineralization. To the north, the ore zones plunge up to surface and are almost completely oxidized within 300 feet of surface.

MINING

The ore bodies are mined from underground by open, shrinkage and longhole methods.

Access to the mine is by two main openings. The portal of the main entrance, the 2800 haulage way, is situated about 300 feet above Sheep Creek and provides access from the main surface buildings. Most of the personnel and some supplies are carried in on this level, and all the ore and waste is trammed out.

The 3500 portal is located about 200 feet above Aspen Creek and provides access to the north ore zones and to the hoist room for the service shaft. Most material and a few personnel enter the mine through this opening. A third access of lesser importance, the 3300 portal, is located above the 2800 level portal and on the same slope.

Underground, ore is trammed on the 2800 level, using a Deutz-engined GIA locomotive pulling 12 (or 13) 6-ton cars from various chutes and dumpings at the coarse ore bin located on surface about 340 feet east of the portal. Ore from the north ore zones must first be trammed on the 3300 level by an electric "Titan" locomotive pulling six 4-ton cars, dumping into #1 ore pass, and thence being trammed on the 2800 level. All the other ore and waste movement underground is effected by 20 to 60 H.P. air or electric slushers and by gravity through a system of ore passes down to the 2800 level. Ore is loaded into the cars by air-cylinder operated chutes.

MILLING

The mill feed is a simple mixture of sphalerite, pyrite and galena, with a gangue of talc, limestone and dolomite.

The texture of the sulphides is generally fine grained. Milling practice includes re-grinding the zinc rougher concentrate to provide the required degree of liberation for the depression of pyrite and gangue material.

Concentration at the H.B. is conventional. Two-stage open circuit crushing is followed by open circuit rod milling and closed-circuit ball milling.

Talc flotation is effected before lead and zinc flotation. This is necessary to avoid contamination of the lead concentrate.

Flotation of lead and zinc consists of roughing, cleaning and recleaning. The concentrates are thickened, filtered and trucked to the smelter in Trail.

Typical Operating Data

Tonnage		1200 tons per day	
Crushing rate		200 tons per hour	
Crush +3/4"		29%	
-48 mesh		13%	
Pulp densities: R.M. disch.		72% solids	
B.M. disch.		78% solids	
Class. O/Flow		42% solids	

Screen analysis:	+20M	+100M	-200M
R.M. discharge	16.0	42.0	44.0
B.M. discharge	3.1	24.0	53.0
K.O.	-	5.8	71.0

Assays	% Pb	% Pb
Pb Conc.	55.0	11.0
Zn Conc.	2.5	55.0

Reagent Consumption (lb./ton feed)	
Z-11	0.15
M.I.C.	0.04
NaCn	0.15
CuSO4 (liquid)	0.60
CaO	0.65
Dowfroth	0.02
Hydrated CaO	0.04

SELECTED BIBLIOGRAPHY

Fyles, J.T. and Hewlett, C.G. (1959): Stratigraphy and structure of the Salmo lead-zinc area. B.C. Dep. Mines Pet. Resour., Bull. 41, 162 p.

Irvine, W.T. (1951): The H.B. mine in Structural geology of Canadian ore deposits, V. 2, Can. Inst. Min. Met., pp. 124-132.

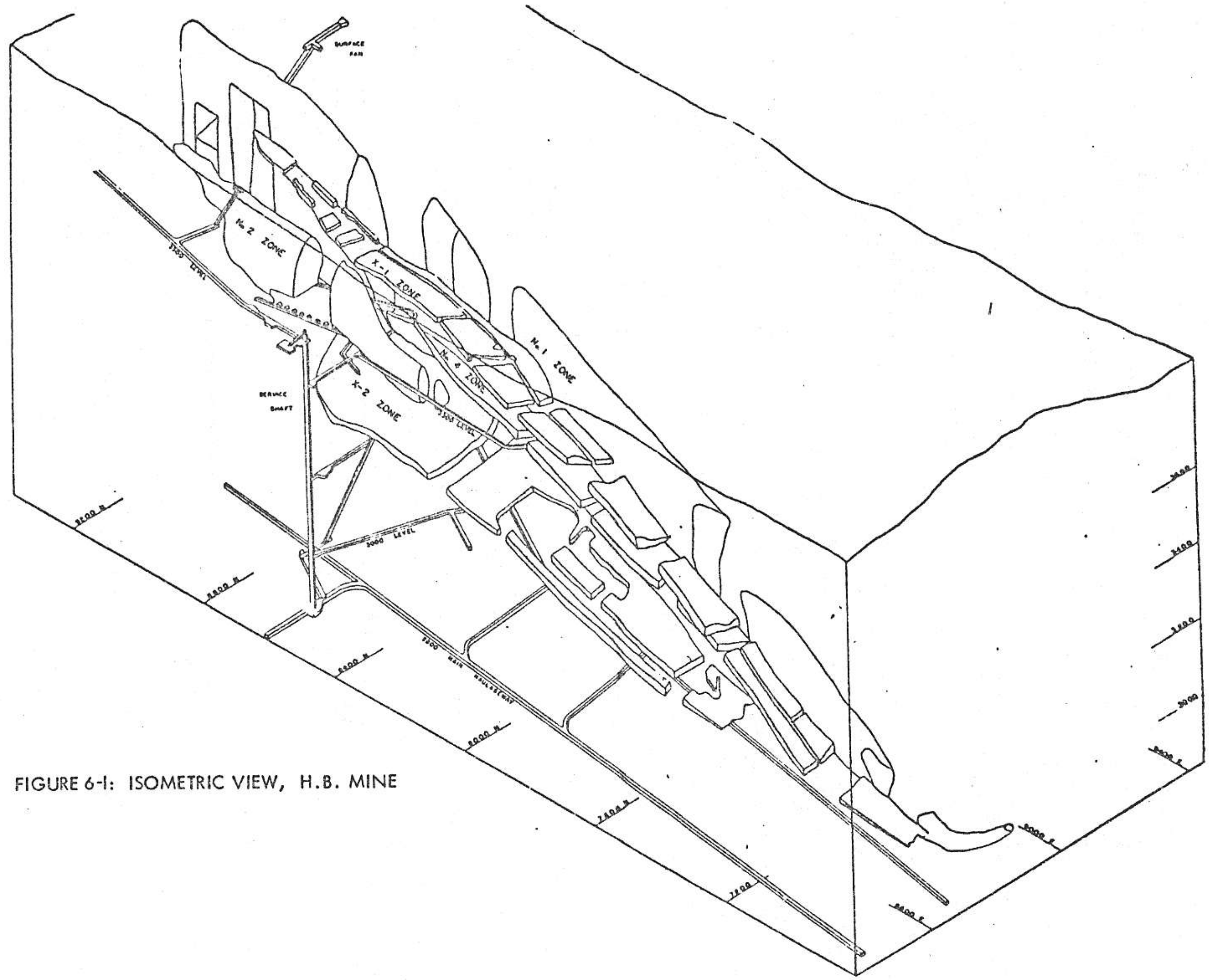

FIGURE 6-1: ISOMETRIC VIEW, H.B. MINE

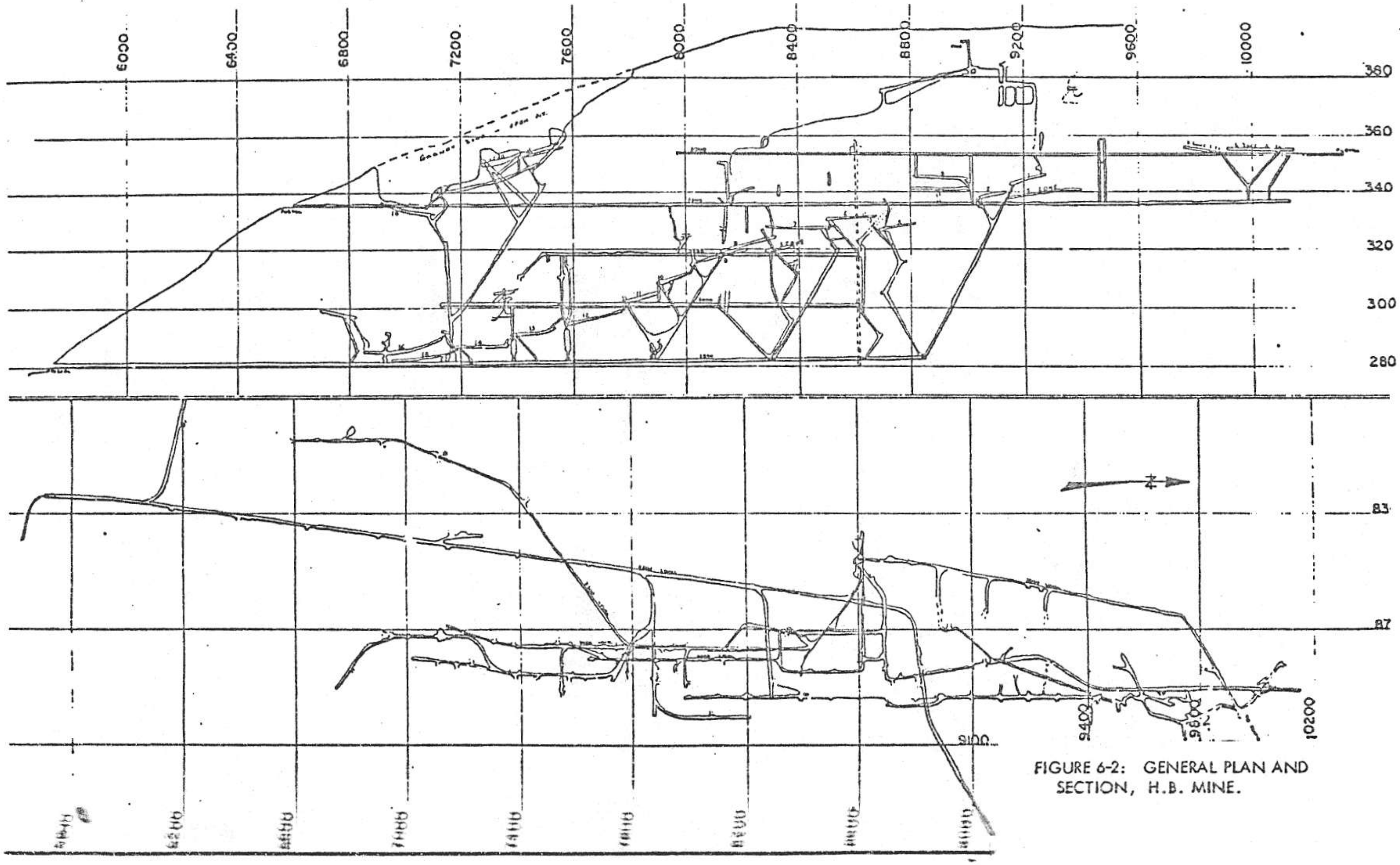

FIGURE 6-2: GENERAL PLAN AND SECTION, H.B. MINE.

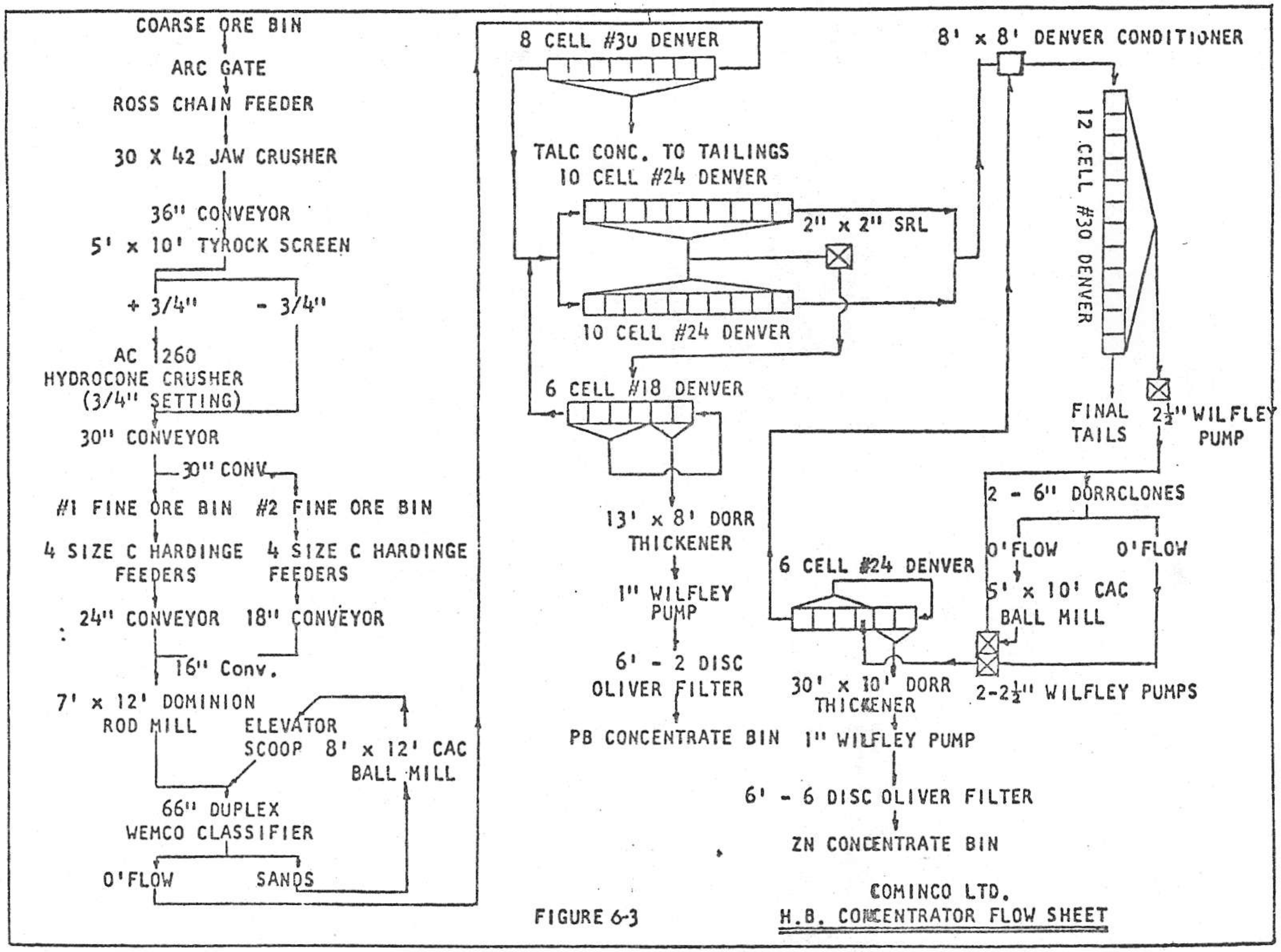

FIGURE 6-3

COMINCO LTD.
H.B. CONCENTRATOR FLOW SHEET