X

SOME UNIQUE GEOLOGICAL FEATURES AT THE BLUEBELL MINE, RIONDEL, BRITISH COLUMBIA

By

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SOME UNIQUE GEOLOGICAL FEATURES AT THE BLUEBELL MINE, RIONDEL, BRITISH COLUMBIA

By Frank G. Shannon①

LOCATION AND HISTORY OF PRODUCTION

The Bluebell mine is on the east shore of Kootenay Lake, 50 miles north of the Canada-United States border, and 100 miles west of the British Columbia-Alberta border (Fyles, Fig. IV-1, this guidebook). The nearest city is Nelson, 30 miles to the west. Kootenay Lake is about 75 miles long and about 2 miles wide. Bluebell mine is almost directly across the lake from Ainsworth, an early, now almost dormant, silver-lead-zinc mining camp. Both the Ainsworth and Bluebell areas were involved in the earliest mining recorded in British Columbia in 1882, but were well known prior to 1882 to the early fur traders, partly because of the outcrops on the shorelines of the lake. Production was intermittent from 1895 to 1927 under various owners. From 1952 to the present time the mine has been under the management of Cominco, Ltd.

Production has been:

	Ore	*Pb* *%/ton*	*Zn* *%/ton*
By the pre-Cominco owners	550,000 tons	6.5	8.2
By Cominco	4,250,000 tons	5.2	6.2

Other products are: silver, about 1 oz. per ton, copper about 0.10 percent per ton, and cadmium 0.025 percent per ton.

Descriptions of the Bluebell mine have been published previously (Irvine, 1957), and the main features of the deposit described in this paper are taken from that publication. Detailed descriptions are based on observations made by the writer in recent years. Westervelt (1960) added considerably to our knowledge of the mineralization and described the occurrence of knebelite. Ohmoto and Rye (1970) have increased our knowledge with their studies, which are continuing, on fluid inclusions in crystals and also on the isotopes of hydrogen, oxygen, and carbon.

The Bluebell mine has four areas of geological interest that are unique. The information about them has been developed over a long period of time and, because they are abnormal, they may be of use to geologists elsewhere. These areas of geological interest are:

(1) Mineralization and mode of occurrence
(2) Structural control of mineral distribution
(3) Oxidation at depth under a sulphide cap
(4) Thermal springs with heavy emission of CO_2 gas.

REGIONAL GEOLOGY AND MINE STRATIGRAPHIC SECTION

The ore outcrops are conspicuous on a peninsula about 1 mile long by half a mile wide on the east shore of Kootenay Lake. Metasedimentary rocks of sillimanite grade of regional metamorphism dip 35° westward under the lake (Fig. X-1*a*). The Bluebell Limestone, which contains the ore bodies, has recently been correlated with the Badshot Limestone, which is thought to be Early Cambrian (see Fyles, Table IV-1, this guidebook).

STRATIGRAPHIC SECTIONS NEAR THE MINE

Starting at the lakeshore and proceeding eastward from hanging wall through footwall, the stratigraphic section consists of:

400 FEET OF HAMILL QUARTZITES

This top member adjacent to the lake is the hanging wall for the mine. White quartzite bands are interlayered with brown platy mica schist and some quartz feldspar pegmatite bands, lenses, and deformed blobs indicating shearing movement. Quartz augen and garnet porphyroblasts partly replaced by chlorite are common. Tourmaline occurs rarely. There is one lens of limestone (locally called upper limestone) 80 feet above the Bluebell Limestone in the Hamill Quartzites. The maximum thickness is 18 feet, maximum strike length 3,500 feet, and maximum dip length below outcrop at surface is 800 feet. This limestone may be correlated with limestone in the Mohican Formation in the Lardeau district (Fyles, 1964, p. 22).

100 TO 150 FEET OF BLUEBELL LIMESTONE

Mostly white, alternating fine- and coarse-grained crystalline limestone with some grey bands, some phlogopite partings, and disseminated biotite and graphite in the lower part. Some of the coarse-grained grey beds are dolomitic. No fossils have been noted. This limestone is tentatively correlated with the Badshot Limestone (Crosby, 1968; Fyles, this guidebook).

700 FEET OF LOWER INDEX FORMATION—EARLY PALEOZOIC

Graphitic grey and black schistose argillite or argillaceous quartzite forms the footwall for the mine. The beds are partly calcareous, contain fine pyrite, and are somewhat feldspathic. The formation shows a great deal of shearing on planes parallel or subparallel to the bedding. They locally contain lenses of impure limestone.

500 FEET OF INDEX FORMATION

Hornblende schist with some interlayered quartz mica schist and limy schist succeed the lower Index Formation.

1,600+ FEET OF INDEX FORMATION

Quartz-calc-silicate schist, feldspathic and calcareous in some places, with amphibolite and coarse-grained white pegmatite sills, in places containing lenses of impure limestone, form a thick sequence east of the mine.

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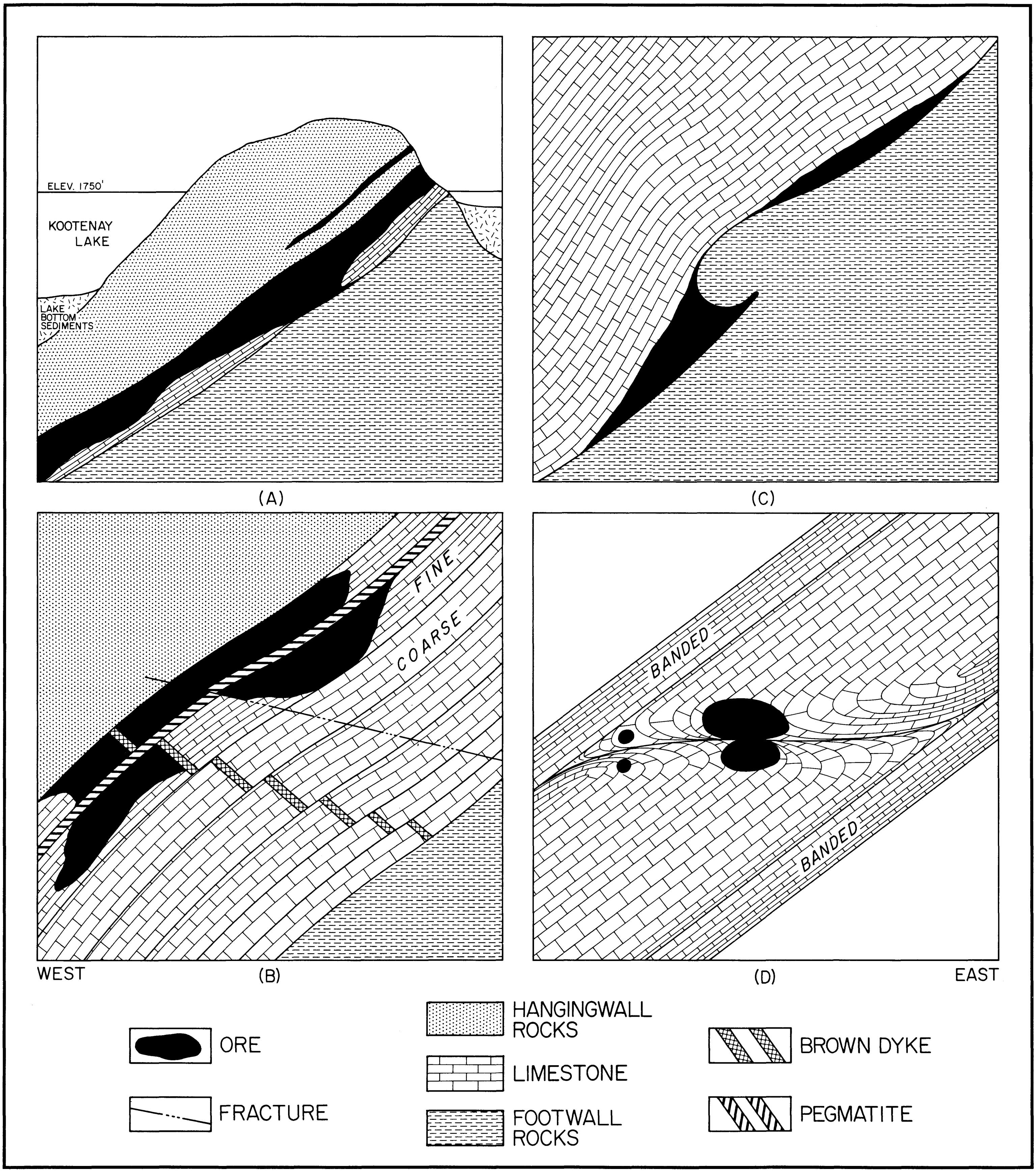


FIGURE X-1.—Diagrammatic cross-sections showing:
A. A typical structural section in the Kootenay Chief Zone.
B. Displacement of a brown dyke and the occurrence of ore.
C. and *D.* Typical locations of ore bodies.

The above formations, to the casual observer, would seem to be right side up. Projections of the structure from 30 miles to the north near Duncan Lake, however, indicate them to be on the overturned limb of an isoclinal fold. All the rocks strike about N. 5° E. and dip about 35° W.

GENERAL MINE GEOLOGY

MINE AREA INTRUSIVES

"BROWN DYKES"

These earliest intrusives are pre-regional folding. They are fine grained with a brownish-pink groundmass containing some mica and pyroxene, which, upon alteration to chlorite, becomes green. There are very few of these dykes, but they have been noted in widely scattered parts of the mine. They all strike roughly north-south and dip 30° to 60° to the east. This type of dyke has been found only in the limestone.

PEGMATITE SILLS

These were emplaced before or during regional deformation, but later than the brown dykes noted above. They are fine- to coarse-grained, white, quartz-feldspar rocks, which include granodiorite, aplite, and granite pegmatite. Strong foliations are developed in some places, with the same metamorphic minerals as in the surrounding rocks (Crosby, 1968). The dykes are found in all rocks near the Bluebell mine, and vary in thickness from several inches to several hundreds of feet. It is thought they are pre-Cretaceous in age.

"GREENSTONE DYKES"

Numerous dark green-grey dykes, up to 5 feet thick and near andesite in composition, are present in all rocks near the mine. They contain phenocrysts of plagioclase (labradorite to andesine), olivine, pyroxene, hornblende, and abundant biotite, which are often replaced by calcite, epidote, chlorite, and magnetite. The dykes commonly have a bleached margin about 2 inches wide where they are in contact with limestone. They are the youngest intrusives, have not been folded or affected by regional metamorphism, and are pre-ore. The average strike is nearly east-west, and the dip is steep either to the north or to the south. Probably these dykes, which are commonly grouped with lamprophyres occurring widely in the Kootenay Arc, are Cenozoic in age.

MINERALIZATION AND ITS MODE OF OCCURRENCE

Ore, because it cuts the lamprophyre dykes, appears to be Cenozoic. The primary ore minerals, galena and black ferriferous sphalerite (marmatite) occur as coarsely crystalline aggregates, and are found both along cross fractures and as bedded replacements. Silver in small amounts is associated with galena, but no silver minerals have been identified. Pyrrhotite is the most abundant and probably the earliest sulphide mineral. Occasionally it is found in large separate masses in the larger ore bodies, or, more often, intimately associated with the galena and sphalerite. Pyrite is almost exclusively a secondary mineral, but minor primary pyrite occurs. Small amounts of arsenopyrite, chalcopyrite, siderite, and rhodochrosite are present. Considerable crystalline pyrrhotite, marmatite, arsenopyrite, minor chalcopyrite, and galena occur with quartz and calcite crystals in vuggy openings.

The gangue consists of limestone with considerable pegmatite, coarsely crystalline quartz, and carbonates. Wall rock alteration is negligible. Knebelite, an iron manganese silicate (olivine group) is found in abundance in cross fractures and in bedding deposits closely associated with them, and is considered to be the earliest replacement mineral (Westervelt, 1960). Some light-brown to yellow sphalerite is found in some places where marmatite is intimately associated with knebelite; also fine-grained magnetite is present where galena is associated with knebelite. Minnesotaite (Irvine, 1957) and dickite (Ohmoto and Rye, 1970) are found in limited quantities as alterations of knebelite.

Quartz lines vuggy openings, mostly close to the mineralizing fractures, and is almost never found in the knebelite-rich areas. Quartz crystals of the latest period of deposition usually contain numerous carbonate and sulphide inclusions and also CO_2 gas and liquid inclusions along the growth zones (Ohmoto and Rye, 1970).

DESCRIPTION OF ORE BODIES

Irvine (1957, p. 98, 100) described the ore bodies as follows:

> There are three known centres of mineralization in the mine, spaced at approximately 1,500-foot intervals along the strike of the Bluebell limestone.

These are called the Comfort, Bluebell, and Kootenay Chief zones (see Figs. X-2 and X-3).

> In these mineralized centres the lead-zinc ore bodies, which occur as massive sulphide replacements, are localized along steep cross fractures, which extend across the limestone from hanging wall to footwall. The cross fractures themselves are only a portion of an inch in width, the ore shoots being formed by sulphide replacements along beds adjoining the fractures. Replacement of this sort proceeds in irregular fashion for 5 to 10 feet from the fractures, then cuts out abruptly. The shoots thus form tabular bodies, transverse to the bedding and having irregular outlines due to variations in the extent to which the replacement has proceeded along various beds cut by the cross fractures. In places the control of the mineralization will shift from one cross fracture to an adjoining one, or there may be several adjoining cross fractures, each with sulphide mineralization. Where mineralized fractures are closely bunched in this way the ore may coalesce into larger bodies, 30 to 40 feet, or in exceptional cases as much as 100 feet, in width, ...

and may extend from hanging wall to footwall.

> Where beds particularly favourable to sulphide deposition occur, the ore may spread out from the mineralized fractures for as much as 100 feet along the bedding planes. The most consistently favourable beds for replacement of this type are the dense, closely banded limestone beds in the upper part of the Bluebell Limestone, and the ore occurs either just under the hanging wall quartzite or just under the pegmatite sills which lie a few feet stratigraphically below the base of the quartzite.

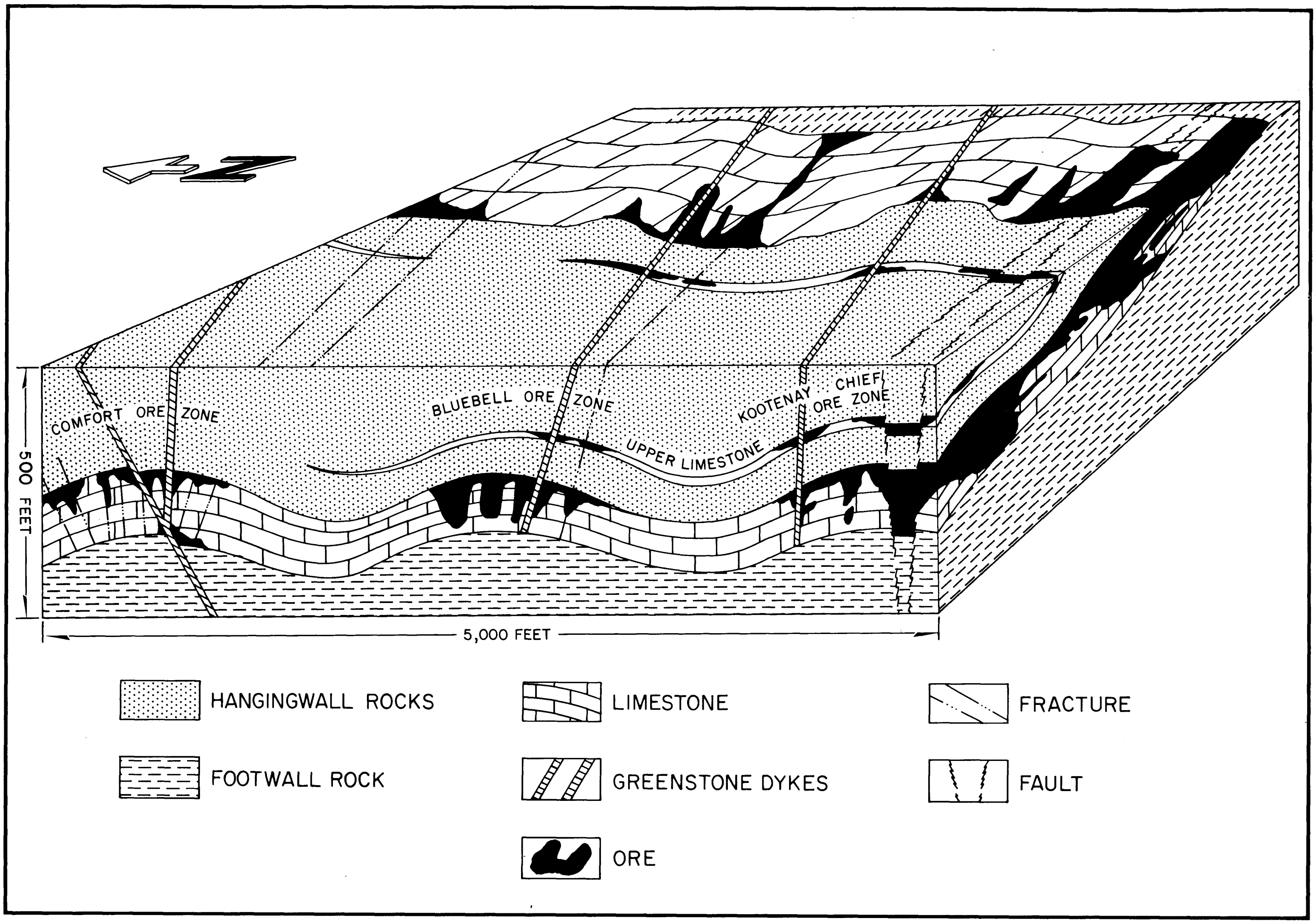


FIGURE X-2.—Block diagram of the Bluebell mine area showing mode of occurrence of the ore.

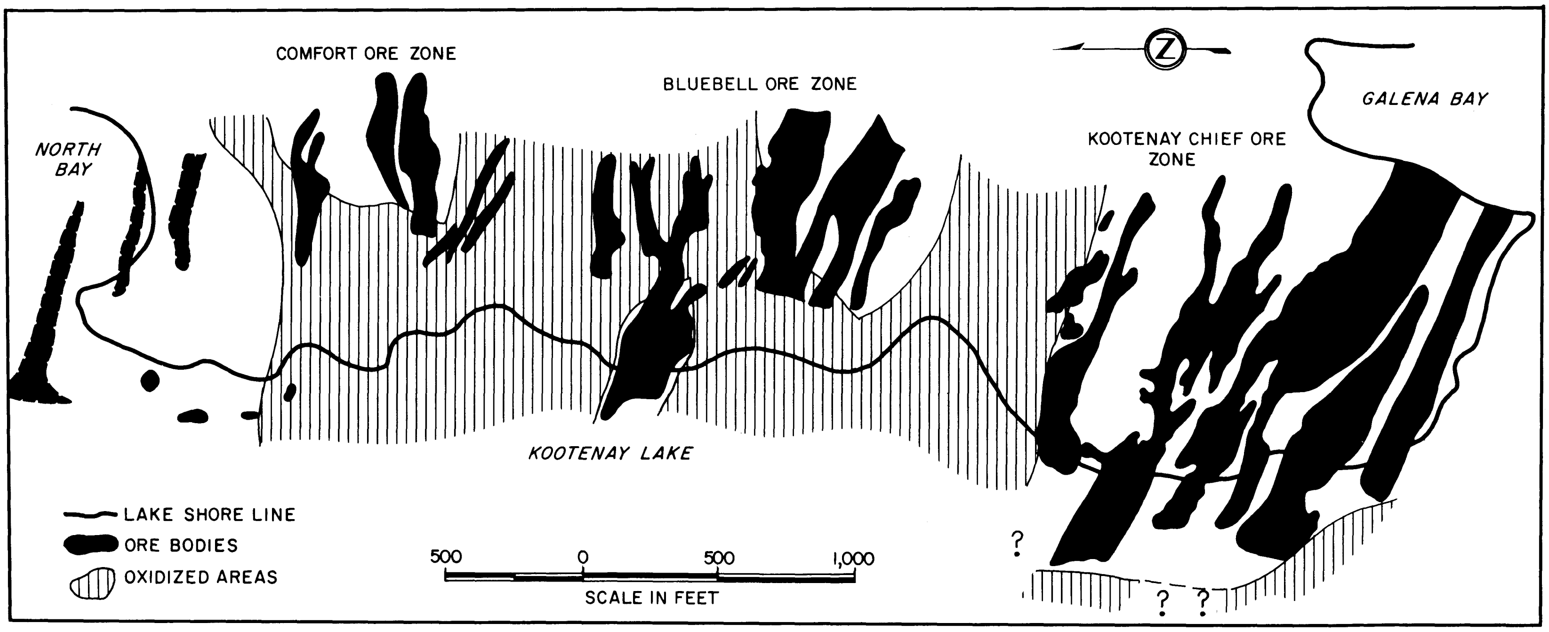
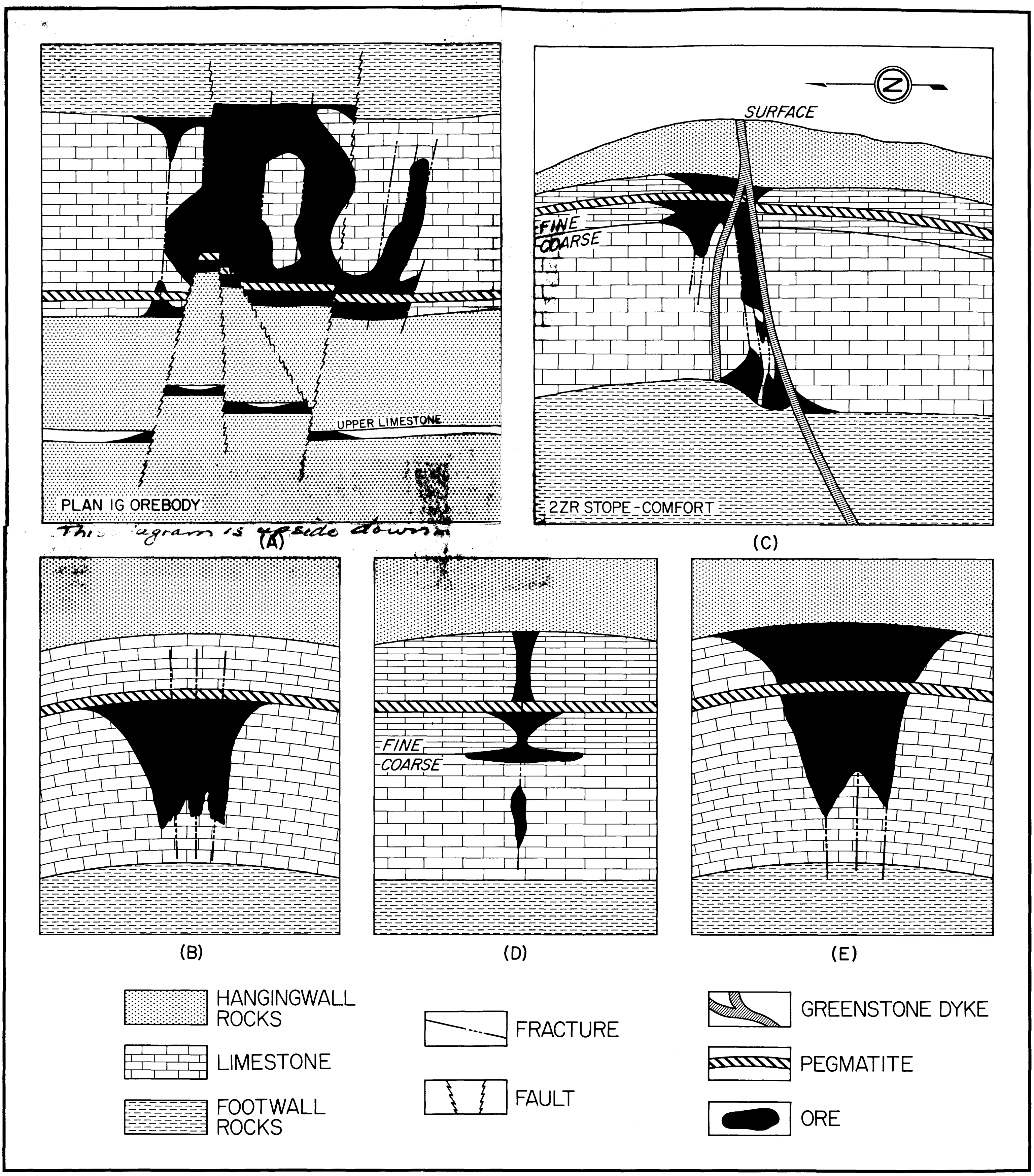


FIGURE X-3.—Plan of the Bluebell mine area showing the main ore zones and areas of oxidation.



This diagram is upside down

FIGURE X-4.—Diagrammatic plan (*A*) and longitudinal sections (*B*, *C*, *D*, and *E*) showing controls of mineraltization. North arrow of *C* applies also to *A*, *B*, *D*, and *E*.

In the upper limestone there are ore bodies of limited extent. Mineralization is similar to that in the Bluebell Limestone, although there are fewer known structural controls. They extend over parts of the Bluebell and Kootenay Chief zones only (Fig. X-4*a*).

TEMPERATURES OF DEPOSITION

Paragenetic studies coupled with temperature measurements of fluid inclusions in ore and gangue minerals by Ohmoto and Rye (1970) have indicated that the massive ores were deposited at temperatures between 450° C and 500° C and that the later minerals in vugs, which comprise 10 percent of the hydrothermal mineralization, were deposited at temperatures between 320° C and 450° C. The confining pressure of the ore-forming fluids and the depth of ore deposition are estimated to be in the range of 300 to 800 atmospheres and 6 km respectively.

PARAGENESIS

Gross features of the ore zones suggest three major periods of hydrothermal mineralization:

(1) Formation of knebelite.
(2) Deposition of massive sulphides, quartz, and carbonates.
(3) Development of crystals in vugs.

Periods (2) and (3) are probably different parts of the same period of mineralization (Ohmoto and Rye, 1970).

STRUCTURAL CONTROLS OF MINERAL DISTRIBUTION

Over the long history of the mine, mostly in connection with the smaller ore bodies, a great amount of detail has been noted about the effect of structure on mineralization in limestone. In larger structural situations, only a small part may be visible, making the basic situation much more difficult to recognize. It is hoped that the following descriptions will be of help to geologists working on the early stages of exploration and mining in limestone replacement ore bodies. Several different structural control situations are described, and any combination may exist.

THE MAIN ORE CONTROL

The main ore controls are outlined by Irvine (1957, p. 101, 102) as follows:

> The beds in the vicinity of the mine form a gentle secondary synclinal cross fold, with a wave length of about three miles. The mine is situated within this folded structure which plunges down the dip of the beds. . . .
>
> Within the mine, conspicuous features in the Bluebell limestone are numerous steeply dipping cross-fractures, spaced at intervals of a few feet, and occurring continuously along the strike of the formation. Individual fractures have somewhat irregular surfaces, which indicates that they are tension fractures, resulting from warping of the limestone beds. These fractures may be unmineralized, or may be healed by sulphide, quartz, or carbonate. Smooth surfaced and flatter dipping cross-joints are also numerous, and are considered to be shear joints, resulting from the same force which caused the secondary folding. Statistical studies of the attitudes of the tension joints by the use of point diagrams show that the attitudes of the joints differ significantly in the three ore zones.
>
> | | *Strike* | *Dip* |
> |---|---|---|
> | Comfort .... | N. 72° W. | 83° N. |
> | Bluebell .... | N. 75° 30′ W. | 82° S. |
> | Kootenay Chief ..... | N. 62° 30′ W. | 84° 30′ N. |
>
> Separate point diagrams made for each 200 feet of strike length along the limestone formation show that these values do not change gradually along the strike, but that there are sharp discontinuities at points which are taken to mark the boundaries between the segments of the limestone in which conditions caused differences in the attitude of the tension joints. At these boundaries the limestone is more intensely fractured than usual, resulting in breccia-like masses which are up to 50 feet or more in width, measured along the strike of the beds. These brecciated boundaries between the limestone segments can be traced from level to level, and show that the segments trend down the dip of the beds, following the trace of the joints on bedding planes.
>
> In each segment of the limestone formation, as defined above, the ore bodies occupy a central position along the strike, while the barren intervals between ore zones are near the edges of the segments, flanking the boundary breccia zones. This suggests that at the time the ore-forming fluids were circulating, special conditions prevailed which made the central portions of the limestone segments favourable for ore deposition.
>
> In the Kootenay Chief and Bluebell ore zones, there is considerable gravity faulting in the central portions of the various zones, with strike separation of up to 30 feet along steep faults which, from their general attitude, appear to be simply tension joints along which faulting has occurred. . . . The pattern of displacement is strongly suggestive of collapse, following compressional arching of the beds.

In a section titled "Theory of structural control of ore deposition," Irvine (1957, p. 103) further stated:

> Two essential facts concerning the Bluebell ore bodies must be taken into account in any theory of structural control. First, the ore shoots, almost without exception, have a rake which agrees exactly with the trace of tension fractures on beds, thus these fractures must have had an influence on ore deposition. Second, although tension fractures are spaced [somewhat] uniformly along the limestone formation, ore shoots occur only in those located [fairly] centrally in the limestone segments; that is, near the crests of the anticlinal arches.
>
> Since only tension fractures near the crests of the arches are mineralized, it is a logical assumption that the mineralizing solutions were active at a time when arching had produced open fractures near these crests, and tighter fractures near the edges of the arches, and that the more open fractures afforded good channels for circulation and sites for ore deposition.

Ore-bearing solutions apparently circulated through this tension fracture system. (Fig. X-2).

The following local but important ore controls have been recognized:

HANGING WALL

Most of the crosscutting tension fractures do not enter the hanging wall, or if they do, they are too tight to be significant as channelways for mineralizing solutions. In the centres of the broad anticlinal arches, where mineralized fractures come in contact with it, the hanging wall has considerable damming effect on solutions rising within the limestone. The ore bodies are usually richer and extend outward along strike much farther just under the hanging wall (Fig. X-4*e*).

FOOTWALL

A damming effect by the footwall of the limestone occurs only where mineralized cross fractures intersect the footwall at a synclinal fold, and there only in the immediate area where the mineralized cross fracture crosses the fold. Mineralization does not normally extend very far into the footwall. No ore bodies are found there, but under large ore bodies narrow mineralized fractures may be present (Fig. X-1*c*).

BROWN DYKES

These narrow (up to 2 feet thick), north-striking, east-dipping dykes are commonly offset by bedding plane faults in the limestone. Although the displacement on individual faults is small and the total amount is not known, it is estimated that, between the footwall and hanging wall of the limestone, the total displacement amounts to between 100 and 200 feet. Where a mineralized fracture intersects a brown dyke, commonly, though not always, the dyke acts as a local dam, causing enrichment on the down-dip side and a barren area on the up-dip side of the dyke. Normally the mineralization will reappear some distance up-dip, apparently because the mineralizing solutions traveled around the "dam" above or below where the dyke is broken by the dip faults (Fig. X-1*b*).

PEGMATITE SILLS

One nearly continuous sill 2 to 5 feet thick and normally about 12 feet below the hanging wall extends throughout the mine in the limestone. Commonly, mineralized tension fractures through the pegmatite are only ⅛ to ½ inch wide, with green chloritic alteration up to 2 inches from the fracture. Otherwise the pegmatite is not mineralized. In the limestone, sulphides have spread along strike below the sill. Where the pegmatite has been broken by intense folding or where the fracturing is strong, this damming effect is missing (Fig. X-4*e*). Beneath strong, unbroken pegmatite, the ore sometimes stops, leaving barren limestone between pegmatite and hanging wall (Fig. X-4*b*).

FAULTS

Some faults are parallel to the mineralizing fractures; others are at an acute angle to them. Where these faults are in contact with mineralizing fractures, the mineralization may follow up the dip of the fault along the limestone, also through the hanging wall. Several good ore bodies in the upper limestone have resulted from this type of control (Fig. X-4*a*). Other structures may also effect mineralization along the faults. Ore tends to be richer in galena along the mineralizing fractures and richer in marmatite and pyrrhotite near the edges of mineralization.

"GREENSTONE DYKES"

These dykes are pre-ore and subparallel to the mineralizing fractures (Fig. X-2). Some follow faults. Mineralization occurs along the dykes as it does along the faults described above. Not all dykes carry mineralization, and those associated with intense fracturing or faulting have better ore bodies along them (Fig. X-4*c*).

CONTACTS BETWEEN COARSE- AND FINE-GRAINED LIMESTONE

The upper part of the Bluebell Limestone is mostly a fine-grained, fine-banded limestone, whereas the lower part tends to be coarser grained and vaguely or broadly banded. Where a mineralized fracture crosses the contact between these two types, the mineralization may spread out along the bedding (Fig. X-4*d*). This contact zone appears to have had a relatively high permeability, which probably was increased by movement between the beds and is now obscured by recrystallization.

THIN FRACTURES

Commonly, massive sulphide mineralization stops at a weak fracture of knife-edge thickness. Upon close examination, no apparent reason for the cutoff has been found, and it has been suggested that a damming effect was caused by a very thin film of mud along the fracture that subsequently was removed (Fig. X-4*a*).

RECUMBENT FOLDS IN THE LIMESTONE

There are many small recumbent folds in the limestone, some of which are confined to a fairly restricted set of beds. They are caused by plastic folding along the bedding planes. The folds may die out as the movement is dissipated along the bedding slips. Where these folds cross an ore body, mineralization follows the crest of the fold for some distance into the limestone outside the normal boundaries of the ore on both sides (Fig. X-1*d*). The area near the crests of these folds appears to have had a relatively high permeability.

ANTICLINAL FOLDS

These folds are noted both at hanging and footwall. At the hanging wall contact, there appear to be two sets of anticlinal folds, one plunging about 20° to the southwest, the other about 20° to the northwest, and at some places where they intersect they show a pronounced "dimpling" effect of the hanging wall. These "dimpled" areas contain higher grade ore where they intersect an ore body, and ore tends to follow the crests of the folds beyond the normal outlines of the ore body. An ore body along the footwall becomes much weaker or terminates altogether along the crest of such an anticlinal fold.

SUMMARY

The one common feature in all types of ore bodies is the mineralized tension fracture, singly or in groups. It is concluded that, in the Bluebell Limestone, given a deep-seated source of mineralization, any physical feature that increases the porosity or permeability of the rock will exert some control on deposition of the ore.

DEEP OXIDATION

The unique feature of oxidation at the Bluebell mine is that the outcrops and upper levels contain fresh sulphides, with only minor gossan, and oxides encountered

150 feet below surface extend to at least 1,000 feet below surface. Early operators of the mine who worked only the Bluebell, or central ore zone, encountered heavy oxidation on the north side about 150 feet below surface. This oxidation became progressively more intense southward with depth until the whole Bluebell ore zone was oxidized 300 feet below surface, leaving only small sulphide cores. On the level 375 feet below surface, occurrences of CO_2 gas along with water flows exceeded the mine's pumping capacity and forced progressive abandonment of the mine.

When Cominco acquired control of the property, diamond drill holes located good-grade, fresh sulphides in the Kootenay Chief and Comfort zones. The old mine was dewatered, and development was driven north and south at the mine 225-foot level. In both directions oxidized areas were penetrated before good sulphide ore was reached. Later development has shown extensive oxidation that in places has extended below the lowest level, which is 1,040 feet below the surface.

LOCATION

There are four areas of major oxidation in the mine (Fig. X-3). From north to south they are:

North Comfort

North of the main Comfort zone at surface and raking southwestward through the main Comfort ore zone is an area of oxidation that includes all the main Comfort ore bodies from about 250 feet to more than 825 feet below surface. Mining is active in ore sulphides in the north part of the Comfort zone, north of this oxide zone, between the 375-foot and 825-foot levels. (Level numbers indicate vertical distance to surface.)

North Bluebell

Between the Bluebell and Comfort zones at surface and raking southwestward through the Bluebell ore zone between the 225-foot and 375-foot levels is an area of oxidation that includes all ore bodies in the main Bluebell zone to below the 825-foot level. There is one sulphide ore body on the north side of the main Bluebell zone, between the 375-foot and 825-foot levels.

North Kootenay Chief

Between the Bluebell and Kootenay Chief ore zones at surface and raking almost due west is an oxidized area that extends from north of the Kootenay Chief to below the 825-foot level.

South Kootenay Chief

Another area of oxidation extends from near the 675-foot level to below the 825-foot level on the south side of the Kootenay Chief ore zone, and west of the Kootenay Chief to 300 feet below the 825-foot level.

The net result of this situation is that fresh sulphide ore bodies near surface become increasingly oxidized with depth to such an extent that in some places the ore bodies are completely oxidized and are uneconomic.

THE OXIDIZED ORE BODIES

Oxidation of the ore presumably started along the ore boundaries, or prominent fracture zones, where acid meteoric waters came in contact with sulphides. The resulting solutions attached the limestone, leaving grey mud and generating CO_2 gas. Large crystals of selenite are occasionally found in this mud. The partly oxidized ore bodies show a halo of grey mud and oxidized ore material, while in some cases the central or higher grade portions of the ore remain relatively unoxidized. These have been extracted in some places, and because of bad ground a much higher than normal dilution has been accepted. Some of this "waste" dilution had a fair grade, but contained refractory oxides.

The sequence of oxidation appears to be: First the pyrrhotite shows tiny fractures coated with a spongy appearing pyrite. The pyrite gradually encroaches on the pyrrhotite until all the pyrrhotite has been converted to lacy or spongy pyrite, which may be intimately associated with unaltered galena, marmatite, arsenopyrite, knebelite, or quartz. Limestone and calcite disappear early. Oxidation next converts the pyrite to hematite or limonite, followed by oxidation of arsenopyrite, marmatite, and knebelite in that order. At this stage the ore body has a halo of grey mud, consists of red-brown to yellow, muddy material enclosing nodules of galena and quartz. Some of these nodules have been mined where the original ore bodies contained sizable bodies of galena. The final leaching product consists of only mud, oxides, and quartz. None of the explored oxide areas contains more than 8 percent combined lead and zinc. This fact has lead to the conclusion that there has been a considerable metal loss during the leaching process.

EXPLANATION OF DEEP OXIDATION

A Hydrosonde survey of Kootenay Lake to determine the location of the bedrock bottom of the lake shows the lowest bedrock contours west of the Bluebell to be 1,400 feet below sea level, or 3,180 feet below the adit level which is at 1,780 feet above sea level. The eastern bank of the lake tends to follow roughly the prevailing dip slope at about 32°. The west side tends to be quite steep.

Investigation of the valley system shows that, most likely, the Duncan River flowed southward through the present Kootenay Lake Valley as far as Bonners Ferry, Idaho, where it met the Kootenay River, and both flowed southwestward through present Lake Pend Oreille in Idaho, and through Spokane, Washington. In Miocene time this ancestral river system was dammed near Bonners Ferry by a tongue of lava from the Columbia River Plateau (Gilbert, 1949; White, 1959). Above the dam the rivers then filled the valley, which overflowed westward through the valley of the west arm of Kootenay Lake near Nelson. This raised the water table to its present level. On the Bluebell peninsula the outcrops of sulphide ore occur on rocky cliffs along the east side of a small ridge near the shoreline. East of the ridge is a fairly extensive flat, the present townsite. The rocky ridge is cut in two places by narrow valleys leading to the lake shore. The surface outcrop of two of the major oxidized zones coincides with the low areas in the narrow valleys, and the other two oxide outcrops occur near the north and south shores of the peninsula. It is thought that before the rivers were dammed and Kootenay Lake Valley filled, Bluebell peninsula, then a bench on the mountainside, served as a catch basin for water, some of which circulated through fractures and later through cavernous openings in the limestone to the valley bottom. These structures have presumably been obliterated by the intensity and widespread action of oxidation (Fig. X-2).

THERMAL WATER

Another unusual geological feature in the Bluebell mine is thermal water. It did not occur at surface, but was discovered in the main drive in the Kootenay Chief zone on the 375-foot level. Later work indicated that the thermal water may have originally risen to a little above the 225-foot level and the upper openings became plugged with mud, an end product of solution of limestone by water. Occurrences of thermal water have become numerous and widespread at depth, suggesting that limestone dissolved in the lower levels may have precipitated as calcite and mud in the upper levels and reduced the flow. At the 825-foot mine level, thermal springs occur at intervals through the complete length of the workings, and probably contribute about half of the 5,200 gallons of water per minute pumped from the mine. Individual springs consist of very minor CO_2 or water flows, whereas others flow up to about 1,700 gallons per minute. Many of the larger springs have been grouted off. The springs are confined mainly to the limestone, although small flows through fractures have been encountered in both footwall and hanging wall rocks. The springs flow in pipelike openings and fractured areas, parallel, or nearly so, with the mineralizing tension fractures.

The thermal springs deposit almost pure $CaCO_3$ and do not have an oxidizing effect except where they come in contact with oxide zones or air, at which places limonite is deposited.

EFFECT ON MINING AND THE LIFE OF THE MINE

The thermal water emits a large amount of CO_2 gas, initially at high pressure, which poses major problems in ventilation, particularly of primary openings. Of second importance are major flows of water that must be pumped, and the precipitation of hard carbonates on all pumps, pipe lines, etc. The stopes near thermal springs usually have bad ground. These conditions cause heavy financial outlays that vitally affect exploration and mining (Hammond, 1969).

CHEMICAL NATURE AND TEMPERATURES OF THERMAL WATER

In the early stages of dealing with thermal springs in the mine, fairly complete chemical analyses were made. Later determinations were done only for temporary hardness (which compares approximately with total dissolved solids), chlorine, and pH.

Analyses of the thermal spring water show considerably higher chlorine content than nearby surface and lake waters, which are quite low in chlorine. It is assumed that the chlorine is derived from juvenile water, not from meteoric water, and that the origin of the thermal water could be estimated from its chlorine content. The temperature of the water ranges from about 44° F, which temperature suggests a high percentage of admixed lake water, to about 104° F. The hottest water contains the most chlorine. Thermal water is usually slightly acidic, but water from footwall rocks may be slightly alkaline.

Tabulated below are water analyses from the Bluebell mine and one from Ainsworth Hot Springs.

	Bluebell mine								Ainsworth Hot Springs
	Kootenay Chief Area				North Comfort Area				
	525′ Lev.	875′ Lev.	925′ Lev.	1,125′ Lev.	825′ Lev. in F.W.	825′ Lev. in 1s. near F.W.	Surface D. Drill Index Form.	Comfort 825′ Lev.	
Temp.	80°F	70°F	90°F	104°F		44°F		86°F	112°F
Analyses in parts per million									
TDS	3,300	2,500	4,700	3,340	630	320	130	3,870	800
SiO_2	110	60						175	140
Ca	430	410							
SO_4	280	190						214	55
Mg	280	160						190	7.5
Cl	80	50	106	178	18.6	10.2	23.3	70	45
B	.1	0.3							
F	2.0	1.6							
Al_2O_3	7	6							
Cu	.1	< .1						< .01	< .01
Pb	<2	<2						< .1	< .1
Zn	2	14						.02	< .01
P_2O_5	5	5							
Fe	<1	<1						2.1	0.8
Na	440	290						440	215
Mn								< .05	< .05
Sr								5	1.2
K								60	20
pH			7.2	7.4	6.5	6.5	8.5		

In comparing the Ainsworth Hot Springs analysis with the Comfort 825′ Lev. analysis (immediately to the left of the Ainsworth analysis), J. F. Harris, Cominco senior research geologist, stated:

> Notable features are the very low concentrations of heavy metals. The most striking differences between the samples are in the contents of the alkalis, alkaline earths, and the combined anions, notably Mg, Na, K, SO_4. The Bluebell water is considerably more saline than the Ainsworth sample, and the differences in compositional ratios such as Ca/Mg and SO_4/Cl, seem at first sight to argue against derivation by differing dilution from a common source.

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