W.A. No. ....

NAME Sullivan Mine

SUBJECT EXTERNAL PUBLICATIONS

PROPERTY FILE

001830

82FNE052-04

M28-1506

MINERAL INDUSTRIES IN WESTERN CANADA

THE TENTH COMMONWEALTH MINING AND METALLURGICAL CONGRESS – SEPTEMBER 2-28, 1974

82FNE052(96) PROPERTY FILE

SPONSORED BY: THE CANADIAN INSTITUTE OF MINING AND METALLURGY

COMINCO LTD.

SULLIVAN MINE - KIMBERLEY, B. C.

(Latitude 49° 42' N, Longitude 116° 00' W, Elevation 3,900 Feet)

LOCATION

The Sullivan mine and concentrator are located within the City limits of Kimberley, B.C. in the Purcell range of southeastern B.C. The mine is located on Mark Creek, approximately two miles north of the City centre and the concentrator two miles south of the City centre. The holdings include 680 Crown-granted claims and fractions and 582 recorded claims.

CLIMATE

The air temperature ranges from a January minimum of minus 20 degrees Fahrenheit to a June maximum of 89 degrees Fahrenheit, measured in 1973. Freezing conditions commence in October and persist for the ensuing six and a half months. Snowfalls account for 12.24 of the 21.20 inches of annual precipitation, with the fallen snow cover reaching a maximum thickness of 41.5 inches during late March at the Sullivan snow station. This is located 5,100 feet above sea level on the surface above the Sullivan Hill.

HISTORY

Two original claims, the "Hamlet" and "Shylock", of what was later to develop into the Sullivan Mine, were located by four prospectors, Pat Sullivan, Ed Smith, John Cleaver and Walter Burchett, in August 1892, following a 37 day trek overland on foot from Kootenay Lake to St. Mary's Prairie. One of the partners, Sullivan, was killed in the Coeur d'Alene district of Idaho in the winter of 1892, but the remaining three continued work on their claims at intervals, when finances permitted, until 1896.

In that year the partners were bought out by the Sullivan Group Mining Company, formed by a group of Spokane men who were also interested in the Le Roi Mine at Rossland. The Sullivan Group Company also built a smelter at Marysville, which was completed in 1903 but, beset by financial and metallurgical problems, was shut down in 1907.

The mine was purchased in 1909 by the Federal Mining and Smelting Company which formed a subsidiary, the Fort Steele Mining and Smelting Company. The Consolidated Mining and Smelting Company (Cominco) took a lease and option on the property in December 1909. The following year the Company commenced the purchase, which was completed in 1913.

Development work for the next few years was directed at finding sufficient lead ore which would be low enough in zinc for smelting in the Company's plant at Trail, B.C.

This method of selective mining was extremely profitable and by 1914 the Sullivan had become the largest producer of lead in the British Empire, production in that year being 35,500 tons of ore containing 12,000 tons of lead and 500,000 ounces of silver. At the same time, development and diamond drilling programs had proved up a considerable tonnage of what was then considered as low grade lead ore because of its high zinc content.

Although at this stage, the froth flotation process had been developed, the problem with the complex Sullivan ore was one of selective flotation.

In 1917, Mr. R. W. Diamond took charge of what had become an intensive investigation of the various methods for separating this complex ore into three sulphide products - lead, zinc and iron. As a result of this investigation and at a time when zinc prices were falling rapidly, a differential flotation process was successfully achieved in 1919. The following year, large scale testing - in Trail - proved the process to be economical.

This technological discovery in the mineral processing field also lead to a radical change in mining methods at the Sullivan Mine.

Selective mining was no longer necessary and a more systematic method of mining the hitherto low grade ores could be commenced.

The information and experience obtained from this test work was immediately used to design a concentrator which was to be built in Kimberley.

In the spring of 1922, construction of the Sullivan mill commenced on the Chapman Camp site three miles from the mine portal. It commenced operation in August 1923 at a daily rate of 3,000 tons. The size of the concentrator was increased in steps until by 1949, when the sink-float plant was introduced, the capacity was 11,000 tons per day.

In the interval between August 1923 and December 31, 1973, the concentrator has treated about 109,736,000 tons of Sullivan ore. The total production from the approximate date of its acquisition by the present owners to December 31, 1973 is about 110,735,850 tons of ore.

GEOLOGY

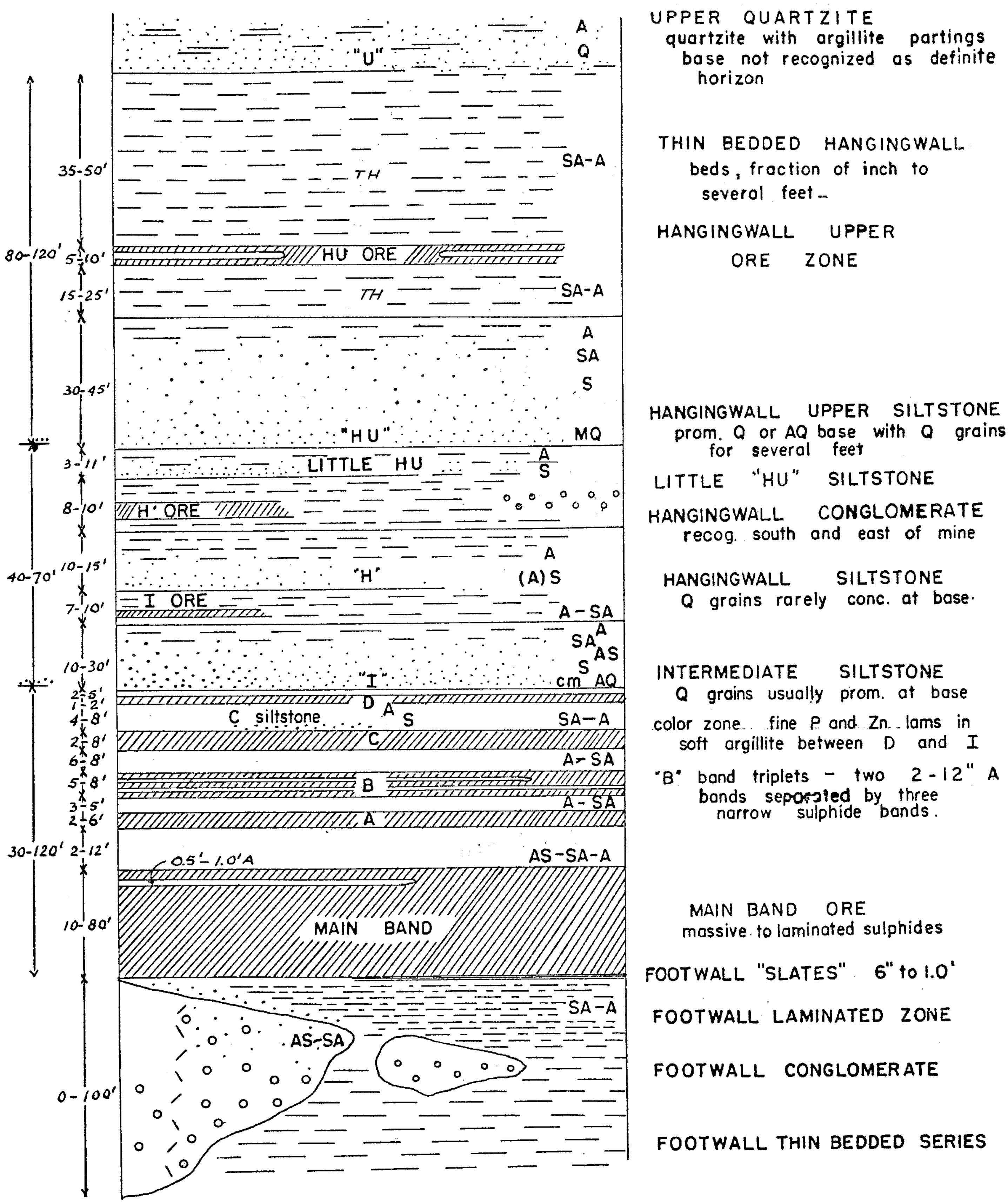
The orebody is 7,000 feet long, from several feet to 300 feet thick, and roughly resembles an inverted saucer. The strike is north-south and the dip averages about 30 degrees to the east, gentle in the upper part of the mine, steepening in the central portion and flattening along the eastern edge.

The orebody occupies one limb of a north-plunging anticline, the crest of the anticline coinciding approximately with the western margin of the orebody. It occurs in the lower Proterozoic Aldridge formation, which in the Kimberley area is composed of at least 15,000 feet of alternating argillites, siltites, and dirty quartzites. The Aldridge is the lower member of the 35,000 foot thick Purcell group of sediments. It contains a high proportion of turbidite-type beds and is thought to represent the early basin filling of the Purcell geosyncline.

COMINCO LTD.

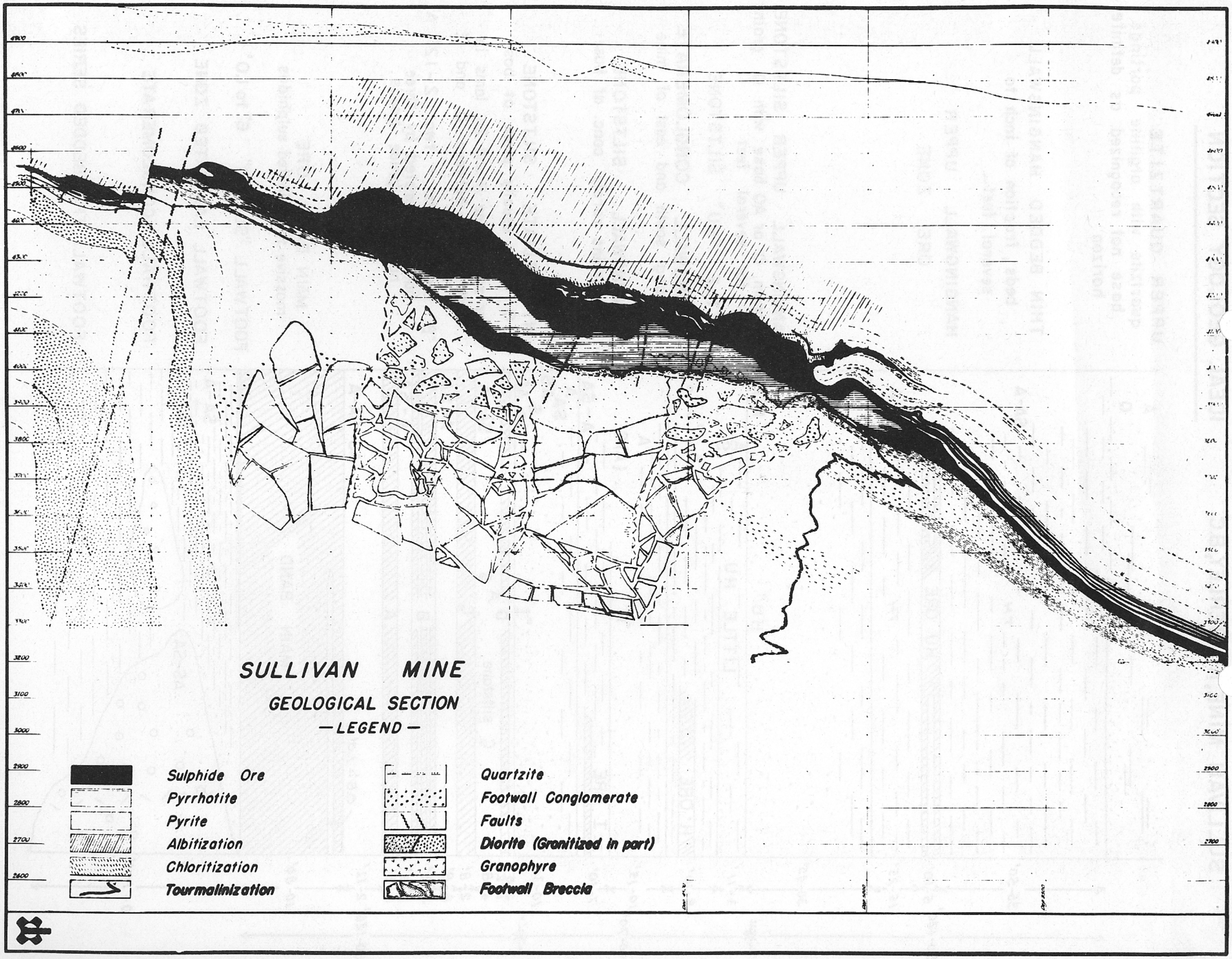
SULLIVAN MINE, KIMBERLEY, B.C.

IDEAL GEOLOGY SECTION



Q - Quartzite S - Siltstone A - argillite AQ - argillaceous quartzite
AS - argillaceous siltstone SA - silty argillite
c.m.f.g. = coarse, medium, fine grained

Quartzite · Siltstone · Ore · Thin bedded
Laminated · Conglomerate


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

In the lower section of the mine, stratigraphy in the ore zone is very regular, with bands of sulphides interbedded with bands of barren rock, and sedimentary structures are preserved in great detail. In the upper portion of the mine, this delicate layering is only present in very small areas, large areas of massive ore occur, and there are large zones of essentially pure iron sulphide with little or no lead or zinc. The upper zone also varies broadly from place to place, with confused streaking or banding in some locations and no internal structure in others. The principle sulphides are pyrrhotite, sphalerite, galena, and pyrite. Chalcopyrite and arsenopyrite are minor constituents.

Magnetite is farily common in some parts of the orebody and cassiterite is present in small amounts. In the oxide zone, cerrusite and pyromorphite are common.

Concepts of the ore gensis of the Sullivan orebody have evolved with time, with major difficulties in interpretation arising due to regional metamorphism and to the striking difference in the mode of mineralization from one part of the orebody to another. Any syngenetic theory based on the finely preserved sedimentary features in the lower orebody must explain the massive concentrations of metal in the upper orebody. On the other hand, conventional hydrothermal replacement theory fails to explain the apparently sedimentary nature of deposits in the lower mine. Neither theory alone fully accounts for the complex structure of the orebody and it is possible that a more complete explanation of the genesis of Sullivan ore will be forthcoming when regional metamorphism in the Kimberley area is better understood.

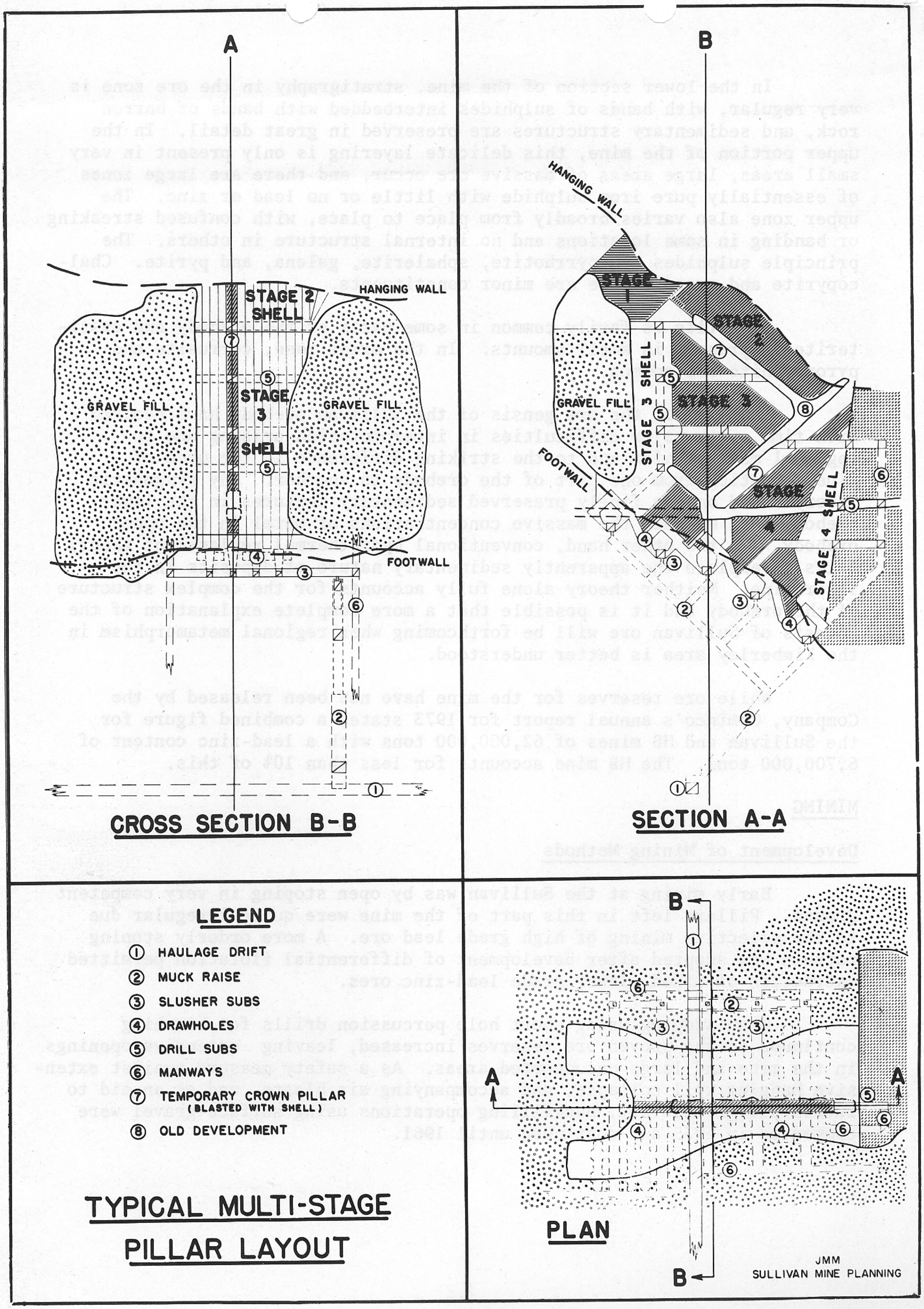
While ore reserves for the mine have not been released by the Company, Cominco's annual report for 1973 states a combined figure for the Sullivan and HB mines of 62,000,000 tons with a lead-zinc content of 6,700,000 tons. The HB mine accounts for less than 10% of this.

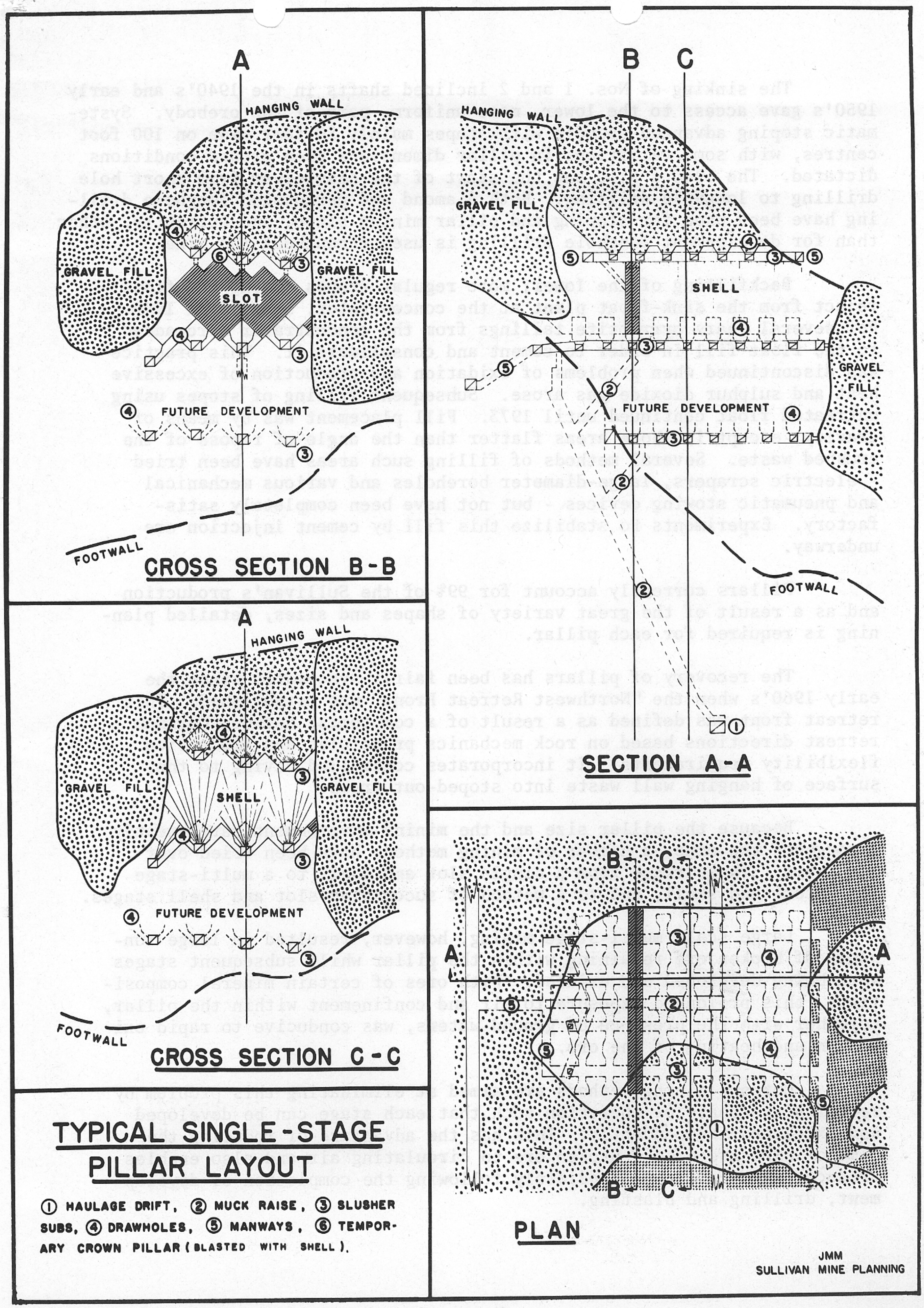
MINING

Development of Mining Methods

Early mining at the Sullivan was by open stoping in very competent ground. Pillars left in this part of the mine were quite irregular due to the selective mining of high grade lead ore. A more orderly stoping pattern was adopted after development of differential flotation permitted extraction of mixed, lower grade lead-zinc ores.

Open stoping using short hole percussion drills for benching continued as the proven ore reserves increased, leaving extensive openings in the mine and large unsupported areas. As a safety measure against extensive hanging wall collapse, and accompanying air blasts, and as an aid to future pillar recovery, backfilling operations using surface gravel were commenced in 1935 and continued until 1961.


A
B
HANGING WALL
STAGE 2 SHELL
GRAVEL FILL
STAGE 3 SHELL
GRAVEL FILL
FOOTWALL
CROSS SECTION B-B
STAGE 1
STAGE 2
STAGE 3
STAGE 3 SHELL
FOOTWALL
STAGE 4
STAGE 4 SHELL
SECTION A-A
LEGEND
① HAULAGE DRIFT
② MUCK RAISE
③ SLUSHER SUBS
④ DRAWHOLES
⑤ DRILL SUBS
⑥ MANWAYS
⑦ TEMPORARY CROWN PILLAR (BLASTED WITH SHELL)
⑧ OLD DEVELOPMENT
TYPICAL MULTI-STAGE PILLAR LAYOUT
PLAN
JMM
SULLIVAN MINE PLANNING



TYPICAL SINGLE-STAGE PILLAR LAYOUT

① HAULAGE DRIFT, ② MUCK RAISE, ③ SLUSHER SUBS, ④ DRAWHOLES, ⑤ MANWAYS, ⑥ TEMPORARY CROWN PILLAR (BLASTED WITH SHELL).

The sinking of Nos. 1 and 2 inclined shafts in the 1940's and early 1950's gave access to the lower, more uniform, part of the orebody. Systematic stoping advanced downdip with stopes mainly 50 feet wide on 100 foot centres, with some variations in pillar dimensions when ground conditions dictated. The 1940's also saw the start of the changeover from short hole drilling to longhole drilling. Both diamond and percussion longhole drilling have been used for stoping and pillar mining since, and currently, other than for development longhole drilling is used throughout the mine.

Backfilling of the lower, more regular stopes, using the float reject from the sink-float plant at the concentrator, started in 1949. For several years pyrrhotite tailings from the concentrator were added to the float fill in order to cement and consolidate it. This practice was discontinued when problems of oxidation and production of excessive heat and sulphur dioxide gas arose. Subsequent filling of stopes using untreated float continued until 1973. Fill placement was by means of gravity, except in those areas flatter than the angle of repose of the crushed waste. Several methods of filling such areas have been tried - electric scrapers, large-diameter boreholes and various mechanical and pneumatic stowing devices - but not have been completely satisfactory. Experiments to stabilize this fill by cement injection are underway.

Pillars currently account for 99% of the Sullivan's production and as a result of the great variety of shapes and sizes, detailed planning is required for each pillar.

The recovery of pillars has been fairly systematic since the early 1960's when the "Northwest Retreat Front" was established. This retreat front was defined as a result of a compromise between optimum retreat directions based on rock mechanics principles and production flexibility requirements. It incorporates controlled caving to the surface of hanging wall waste into stoped-out areas.

Because the pillar size and the mining environment vary greatly throughout the mine, a number of mining methods have been tried over the years. These range from a single slot and shell to a multi-stage slot, core and shell, and to a method of successive slot and shell stages.

Large scale multi-stage mining, however, resulted in large tonnages of broken ore remaining within the pillar while subsequent stages were being developed and drilled. With ores of certain mineral compositions, this prolonged exposure to air and confinement within the pillar, together with the presence of ground waters, was conducive to rapid oxidation and heating of the ore.

Current mining methods are aimed at eliminating this problem by reducing the scale of operation such that each stage can be developed and extracted independently. This has the advantage of reducing the time of exposure of the broken ore to circulating air and also enables production to commence immediately following the completion of development, drilling and blasting.

Although each pillar must be planned in detail, there are several design parameters which control the final layout. As a rule, every attempt is made to keep blastholes between 40 and 75 feet long. Slusher drifts are placed at about 40 foot intervals with drawholes every 20 feet.

Blasthole size depends upon ground type and ground conditions but in general, 1-5/8 inch diameter diamond drill holes are used in soft sulphide ore and 2 inch diameter percussion holes in harder ground. Recently, diamond drilling up to 2-7/8 inch diameter blastholes has been successfully tried in fractured ground and has led to studies of hydraulic drills to further the practice.

The introduction of Atlas Copco ring drills for percussion longhole drilling is planned to improve productivities and the working environment.

Blastholes are drilled on a 7 foot burden and a 7 foot toe spacing and are blasted using 75% gelatin, Cominco ANFO, or more recently, packaged slurry explosives. Loading techniques have been greatly improved by use of pneumatic loaders for both NCN explosives and packaged slurries.

Broken ore is scrapped from drawholes beneath each broken pillar using electric scrapers, to muck raises and hence to loading chutes in the drift below.

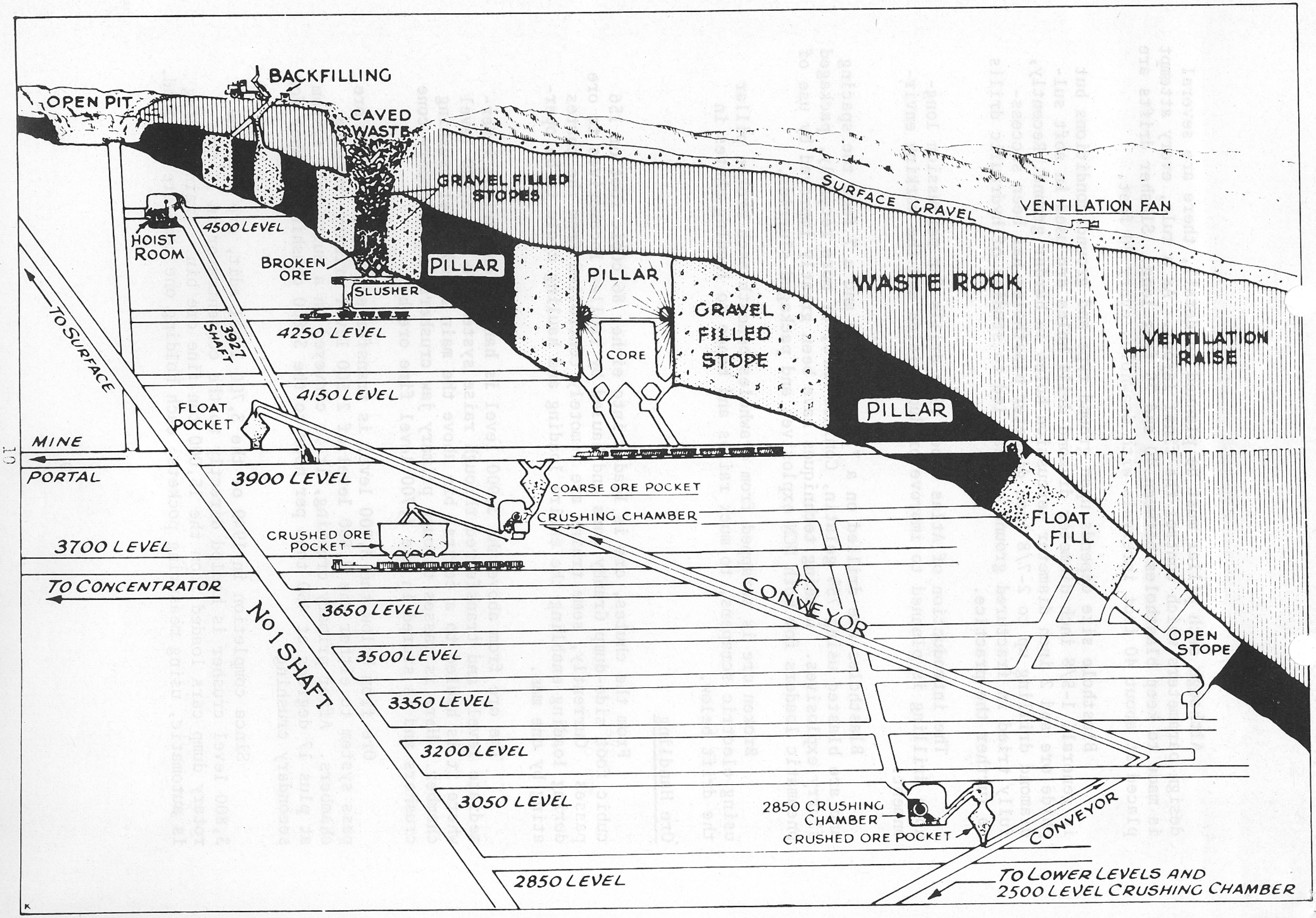
Ore Handling

From the chutes, ore is loaded into either 86 cubic foot or 156 cubic foot side-dump Granby cars and hauled by trolley locomotives to ore passes. Currently, some trains are remotely controlled from the chutes during loading enabling the entire loading and hauling cycle to be operating by one man.

The ore from above the 3,900 level is handled on various intermediate levels and transferred through raise systems to the 3,900 level where it is hauled to a central bin above the main 3,800 level crushing chamber. Here is passes through primary jaw crushers and secondary cone crushers and is stored in the 3,700 level fine ore bin.

Ore from below the 3,900 level is transferred through a main ore pass system to either the 2,850 level of 2,500 level primary crushing chambers. After primary crushing, it is conveyed on a multi-belt system at plus 17 degrees at 450 tons per hour to the 3,800 crushing chamber for secondary crushing.

Since completion in 1949 of the 3,700 level adit, ore from the 3,800 level crusher is hauled directly to the concentrator in 15 ton rotary dump cars loaded from the 15,000 ton fine ore bin. Train loading is automatic, using measuring pockets, each holding one complete car load.


OPEN PIT
BACKFILLING
CAVED WASTE
GRAVEL FILLED STOPES
SURFACE GRAVEL
VENTILATION FAN
4500 LEVEL
HOIST ROOM
BROKEN ORE
PILLAR
PILLAR
WASTE ROCK
SLUSHER
GRAVEL FILLED STOPE
TO SURFACE
3927 SHAFT
4250 LEVEL
CORE
VENTILATION RAISE
4150 LEVEL
FLOAT POCKET
PILLAR
MINE PORTAL
3900 LEVEL
COARSE ORE POCKET
CRUSHING CHAMBER
FLOAT FILL
CRUSHED ORE POCKET
3700 LEVEL
TO CONCENTRATOR
CONVEYOR
3650 LEVEL
No 1 SHAFT
OPEN STOPE
3500 LEVEL
3350 LEVEL
3200 LEVEL
3050 LEVEL
2850 CRUSHING CHAMBER
CRUSHED ORE POCKET
CONVEYOR
2850 LEVEL
TO LOWER LEVELS AND 2500 LEVEL CRUSHING CHAMBER

Development waste from above the 3,900 level is hauled out of the mine via the main portal on that level and waste from below the 3,900 level is hoisted to surface via No. 1 Shaft.

Services

The mine is serviced by the main tunnel on the 3,900 level. The tunnel extends from a portal near the mine offices 6,000 feet to the fringe of the orebody and another 6,000 feet to the farthest working place.

The levels below the 3,900 level are serviced either by No. 1 Shaft, located at the south end of the orebody or by No. 2 Shaft located near the centre of the orebody.

As well as providing the supply function for men and materials, the No. 1 Shaft is also equipped to hoist waste from below 3,900 to the surface. It extends from the surface at elevation 4,380 feet to the 2,400 elevation, a slope distance of approximately 3,200 feet. Hoisting is done by a Bertram-Nordberg 850 HP double-drum 12 foot diameter hoist, with a rope speed of 1,620 feet per minute. Total hoisting capacity of the shaft is 190 tons of waste rock per hour from the 2,850 level to the surface bin.

No. 2 Shaft is inclined at 40 degrees, handles men and materials only. It extends from 3,900 level to 3,350 level. Hoisting is done by a Vulcan 500 HP double-drum hoist with a maximum rope speed of 850 feet per minute. The levels above the 3,900 level are serviced by the 27 Raise in the south and 30 Raise in the north. These are internal inclined shafts equipped to handle men and materials. The two upper levels, 4,650 and 4,500, have surface portable above the small inactive open pit at the outcrop of the orebody.

Electric power is delivered to the Sullivan Mine at 66,000 volts, at three surface sub-stations having a combined rating of 12,900 kilovolt amperes. Peak load requirements is 9,940 kilowatts, derived from a total connected load of 20,000 HP. All stationary motors underground are supplied with 550 volt, 3 phase, 60 cycle power, except for a 500 HP hoist motor and two 300 kilowatt motor-generator trolley sets connected at 2,300 volts.

The mine is served by a combined exhaust and forced draft primary system circulating 980,000 cfm of ventilating air from surface. The dust control from the crushing plants, conveyor transfers and ore dumps form part of the return air. Fans on primary ventilation comprise six units on exhaust and five units on intake duty. There are also 125 fan units of various capacities on hand to operate the secondary ventilation circuits. The general ratio of air weight handled by the fans amounts to 5.0 tons of air per ton of ore produced.

Four of the intake fans have natural gas fired heating units which provide 840,000 cfm of heated air in cold weather and can provide 54 million BTU per hour at maximum output.

Compressed air for the mine is supplied by seven electrically driven compressors totalling 4,700 HP with a combined capacity of 24,000 cubic feet per minute, compressing to 105 pounds per square inch.

Minor repair work is done underground in shops located at various central points throughout the mine.

Safety

The Sullivan Mine has made great progress in accident prevention. In the last four years the frequency rate (accidents/million man hours worked) dropped from 62.1 to 50.8 and the severity rate (days lost/million man hours worked) from 2,005 to 1,700.

GENERAL STATISTICS

Production

	Tons of Ore	
Production 1973	2,214,415	
Since commencement to December 31, 1973	110,735,850	
Rate per working day, 1973	9,504	
Rate per calender day, 1973	6,067	
Production: tons/manshift in mine	20.4	
in plant	52.7	
overall	14.7	
Concentrate production	320,000	tons per year
Contained metals	100,000	tons per year Zn
	93,000	tons per year Pb
	3,000,000	ounces per year Ag

Development

	Feet
1973	31,990
1910 to 1973	1,479,120

Raising Cycle:

Hours to drill 8 feet round	3 to 4 hours
Tons broken/foot of hole	0.10 ton/foot
Tons broken/pound of powder	0.36 ton/pound

Raise Boring:

Raise borer is a 41R Robbins	
Pilot hole size	9-7/8 inch diameter
Ream hole sizes	4 ft. and 5 ft. diameter
Pilot hole penetration rate	
in argillite	10 feet/hour
in chert	6 feet/hour
Ream hole penetration rate	
in argillite	6 feet/hour
in chert	2.3 feet/hour

Backfill Yardage

	Gravel Fill	Float Fill	Devel. Waste	Cave	Cu.Yd. Total
1973	-	1,555	-	518,385	519,940
1934 to 1973	7,762,788	4,644,556	709,435	12,377,106	25,493,885

Drilling

Blasthole Drilling	Footage	Tons/Foot Drilled	Footage Shift	Explosives Lbs/Tons
1973	396,766	2.6	66.8	0.38

The U-13-30 pillar blast in August 1973 with 81 tons of explosives was the largest blast (re tons of explosives) to take place underground at the Sullivan Mine to date.

Core Hole Drilling 1973 - 3,932 feet underground
3,612 feet surface

Distribution of Personnel

As of December 31, 1973, the total mine crew strength was distributed as follows:

1 - Mine Superintendent
1 - Assistant to Mine Superintendent

A. Operation

1 - Operating Superintendent

Below 3,900:

1 - Assistant Operating Superintendent
1 - Foreman
7 - Shift Bosses
3 - Belt Bosses
1 - Timber Boss

310 Hourly Paid Employees

Above 3,900:

1 - Assistant Operating Superintendent
3 - Foremen
1 - Transportation Foreman
20 - Shift Bosses

208 Hourly Paid Employees

Total Hourly Paid Employees Underground = 518

B. Maintenance

1 - Maintenance Superintendent
1 - General Foreman
5 - Foremen
6 - Maintenance Bosses
1 - Clerk

74 Hourly Paid Employees

C. Mine Engineering

1 - Senior Mine Engineer
9 - Engineers
6 - Supervisors
28 - Technicians and Draftsmen
3 - Clerical Workers

2 Hourly Paid Employees

D. Technical Development

1 - Supervisor
4 - Engineers
6 - Technicians

E. Geology (including Exploration)

2 - Senior Geologists
6 - Geologists
14 - Technicians
1 - Clerk

F. Safety

1 - Senior Safety Officer
1 - First Aid Man on Staff
4 - First Aid Men underground on General Roll

G. Contract

1 - Contract Engineer
1 - Planning Engineer
2 - Contract Survey Technicians
1 - Clerk

In Summary, as of December 31, 1973, there were:

152 men on Staff
444 on Operation
74 on Maintenance

Total Mine: 670 Employees

REFERENCES

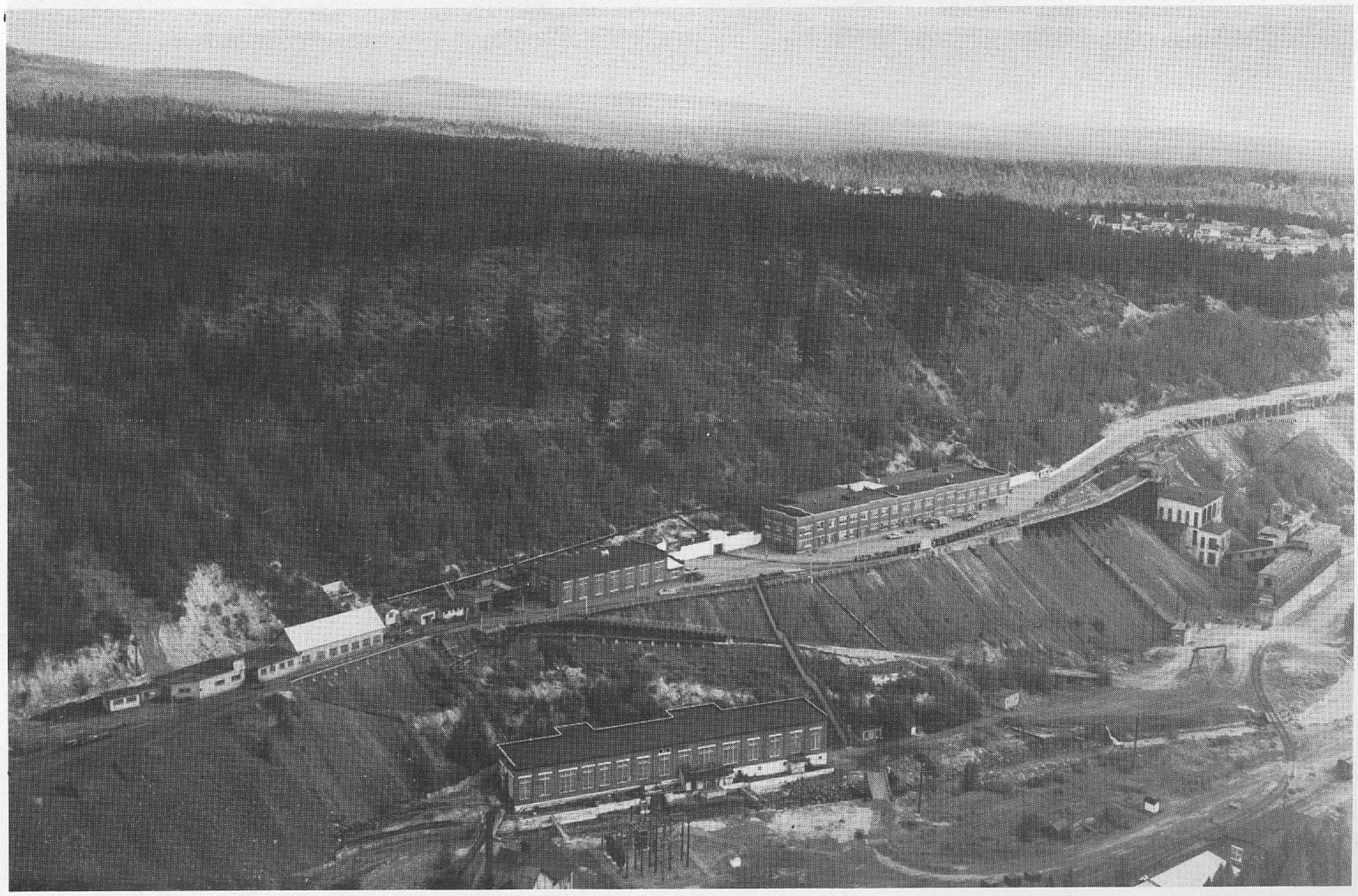
1. Mining at the Sullivan.
   Sullivan Mine Staff.
   AIME World Mining Symposium on Mining and Metallurgy, of Lead and Zinc - Volume 1, Page 259 - 15p, 1970.

2. On the Origin of the Sullivan Orebody, Kimberley, B.C.
   A.C. Freeze Tectonic History and Mineral Deposits of the W. Cordillera - Volume 8, Page 263 - 31p, 1966.

3. Rock Mechanics Applied to the Extraction of Pillars at the Sullivan Mine,
   M.J. Royea and K.G. Davies. CIMM Bulletin, Volume 61, Page 678, Page 1,185 - 10p, October, 1968.

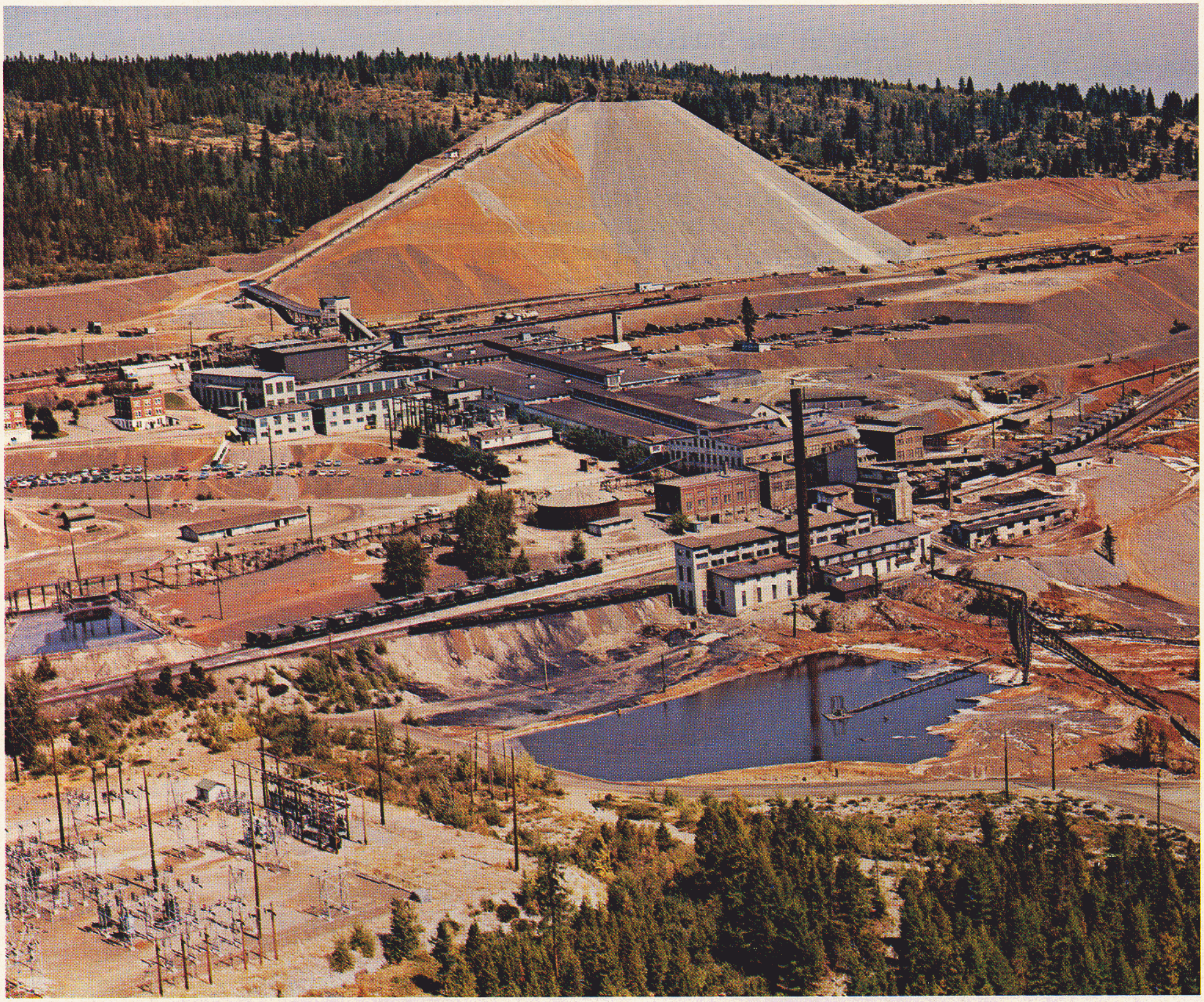
4. Feature Story,
   E/MJ September, 1973.

5. Development of Flotation at Sullivan,
   R.W. Diamond, CIMM, Volume 60, No. 665, September, 1967.



Surface plant, Sullivan Mine, Kimberley, B.C.

Photo courtesy of Cominco Ltd.



Cominco's Sullivan Concentrator, Kimberley, B.C.

George Hunter photo

COMINCO LTD.

SULLIVAN CONCENTRATOR - KIMBERLEY, B.C.

HISTORY

The significant development of a differential flotation technology for Sullivan lead, zinc, iron ore was begun by Cominco personnel at Trail, B.C. in 1917 and was culminated in 1920. Construction of a concentrating plant based on this principle was started in 1922 and completed in 1923. Start-up was August 23, 1923 at a rated capacity of 2,500 tons per day. Over the years a series of plant expansions have increased the throughput ability to the current rate of between 10,000 and 12,000 tons per day.

PROCESSING OF SULLIVAN ORE

The major processing units for Sullivan ore include: (a) an underground crushing plant; (b) a four mile electric haulage way, mine to mill; (c) a sink-float plant that rejects approximately 30 percent of the total mill feed tonnage as a discardable waste rock product; (d) a dezincer flotation circuit that floats the zinc from the lead recleaner concentrate and (3) a gravity plant that recovers tin from the zinc rougher tailing.

Working a five-day week, 24 hours per day, the concentrator treats 2,100,000 tons of ore per year that produce: (a) 160,000 tons of a 64.0 grade lead concentrate; (b) 195,000 tons of a 49.0 grade zinc concentrate; (c) 600,000 tons of a 52.0 grade iron concentrate and (d) 460,000 pounds of a 60.0 grade tin concentrate. The silver content is 20 ounces per ton in the lead concentrate and 2.5 ounces per ton in the zinc concentrate.

The lead and zinc concentrates are shipped to the Cominco smelter at Trail, B.C. The tin concentrate is shipped to custom smelters. The iron concentrate is laundered, as a 40.0 percent slurry, one mile, to the fertilizer plant for the production of sulphuric acid and subsequent ammonium phosphate fertilizer.

The staff at the concentrator is headed by Concentrator Superintendent, E. N. Doyle, Production Superintendent, C.C. Sideco and Development and Technical Superintendent, A.H. Winckers.

UNDERGROUND 3,800 CRUSHING CHAMBER

There are two main working areas in the Sullivan Mine: (a) above the 3,900 foot level; and (b) below the 3,900 foot level. The mine-run ore from above the 3,900 foot level is crushed in the 3,800 crushing chamber, whereas the ore from below the 3,900 foot level is coarse crushed at either the 2,500 or 2,850 mine jaw crushing stations, then transported via the 3,802 conveyor system to the 3,800 crushing chamber for fine crushing (Symons cones)

The ore from above 3,900 foot level is crushed in one of two jaw crushers, with discharge openings of 5.5 to 6.0 inches. The jaw crusher discharge combines with coarse crushed ore from below the 3,900 foot level as feed to two 5 foot by 10 foot Dillon screens, with a screening surface of 3.0 inch burnt hole plate. The screen undersize is finished product and the screen oversize is feed to two 7.0 foot standard Symons cone crushers with a discharge opening of 1.25 inches. The symons discharge plus the Dillon screen undersize is weighed by a weightometer as it is conveyed to storage in a 10,000 ton ore pocket.

THE 3,700 HAULAGEWAY

The crushed ore is transported four miles to the concentrator by 40 ton electric locomotives that haul 40 car trains. Eight loading chutes are used to load the ore from the 10,000 ton ore pocket into the 40 car train, which has a capacity of about 600 tons or 15 tons per car. An average of 20 trips per day are required to maintain the concentrator tonnage rate. The four mile rail haul to the concentrator is two miles underground and two miles on the surface. At the concentrator a Differential Car rotary dump that empties five cars at a time without uncoupling is used to discharge the ore into a 3,200 ton storage bin.

During the period 1949 to 1968 float material used for backfill at the mine was loaded at the concentrator and transported by the ore train on the return trip. Currently very little float material is used at the mine.

SINK-FLOAT PLANT

The sink-float plant was installed in 1949 as part of an extensive program to update both mining and milling operations at Kimberley. The sink-float plant consists of two Huntington Heberlein units, each with a capacity of 275 to 300 tons per hour. Normally both units are in operation at a tonnage rate of 550 tons per hour.

The feed to the sink-float plant is minus 2.0 inch ore from the underground crushing plant and there are three products: (a) fines - a minus 3/16 inch product that is screened from the total plant feed; (b) float - the nonsulphide plus 3/16 inch material and (c) sink - the sulphide plus 3/16 inch material.

The ore is sampled for tonnage, assay determinations and moisture content as it is conveyed from receiving bin to plant. Prior to the separation process, the ore is washed and screened on 3/16 inch punched plate to screen out the fines (some clay) which could contaminate the galena medium.

The washed plus 3/16 inch ore is feed to two 11 x 11 foot separator units that contain a galena medium at 2.95 specific gravity. The float material is floated from the top and the sink material is recovered by bucket elevator from the bottom. The density of the galena medium that is circulated through the separator units is controlled automatically by two gamma gauges.

The tonnage split of the sink-float products is approximately, fines 20 percent, float 30 percent and sink 50 percent.

The float material is stockpiled by means of a system of inclined conveyor belts and an automatic stacker. The current tonnage in the stock pile is estimated at seven million tons. Float material is used for mine backfill or sold to the Canadian Pacific Railway as track ballast.

GALENA MEDIUM CIRCUIT

The coarse lead concentrate from the primary grinding circuit is pumped directly to a 30 foot thickener; the thickened underflow is pumped to an 8 foot by 12 foot Oliver drum filter, with the cake discharging into the heavy medium tank, to maintain a relatively high density of 3.30 to 3.40. The heavy medium is used for make-up to control the plant process medium at a constant density of 2.95 regulated by gamma gauges. The plant process medium is screened then flows by gravity to either the separators, heavy medium tank, filter bath or the clean-up flotation machine; normally 90.0 percent goes to the separators. A 12 cell M.S. flotation machine is used to float the coarse galena from the water used at both the float and sink washing screens. The floation concentrate is pumped to the thickener. The flotation tailing, thickener overflow and filter filtrate are pumped to the primary grinding circuit.

GRINDING CIRCUIT

The sink material is feed to the primary grinding circuit which consists of one 11.5 x 12.0 foot Hardinge rod mill in open circuit with six 4 x 10 foot Hardinge ball mills. A portion of the ball mill discharge is feed to a coarse lead flotation circuit and the concentrate from this circuit is make-up material for the sink-float plant galena heavy medium.

The product of the primary grinding circuit plus the Flotation Returns are feed to the secondary grinding circuit that consists of eight Hardinge ball mills, four 4 x 10 foot and four 4 x 8 foot, which are in closed circuit with fourteen 20 inch Kreb cyclones. The cyclone overflow, normally 87 to 89 percent minus 200 mesh, is feed to the lead flotation circuit.

The sink-float plant fines are treated in a separate classifier-cyclone-thickener circuit.

Three 4 x 8 foot Hardinge ball mills are used in zinc regrind service, the zinc rougher concentrate is reground ahead of the first zinc cleaning stage.

The flotation returns are a composite product of lead middling plus all mill spills.

FLOTATION

The differential flotation of Sullivan ore is comprised of three circuits: (a) lead roughing followed by two cleaning stages and a dezincer circuit; (b) zinc roughing followed by three stages of cleaning and (c) iron roughing with one stage of cleaning.

The grinding product is thickened to 50 to 55 percent solids as feed to the lead rougher circuit, the concentrate is cleaned twice and the tailing recycled; the second cleaner concentrate is feed to the dezincer flotation circuit. For dezincing, the recleaner lead concentrate is conditioned at 100 to 110 degrees Fahrenheit, copper sulphate is added to activate the zinc and lime to depress the iron. The conditioned pulp is pumped to a 12 cell No. 30 Denver machine with nine cells as roughers and three cells as cleaners. The lead is depressed and recovered as the rougher tailing and the zinc cleaner concentrate is combined with the third stage zinc cleaner concentrate as a final zinc product.

The lead rougher tailing is feed to the zinc flotation circuit, the rougher concentrate is reground in three Hardinge 4 x 8 foot ball mills then cleaned three times; in each instance the cleaner tailing is recycled.

The zinc rougher tailing is conditioned with sulphuric acid to pH 6.5 for iron flotation, the iron concentrate is cleaned to 52 to 55 percent iron then laundered in slurry form, to the fertilizer plant for roasting, to produce SO_2 for acid production for fertilizer manufacture.

Note: In the lead flotation flowsheet a regrind circuit is shown. This was operative until quite recently, when the lead regrind mills were put in zinc regrind service.

FILTRATION

The lead flotation concentrate is pumped to a 50.0 foot Dorr thickener; the thickened underflow 73.0 to 78.0 percent solids flows by gravity to a 20.0 foot stock tank, then is pumped to two 8 foot x 12 foot Oliver drum filters. The filter cake (moisture 8.0 percent) is conveyed directly into 80.0 ton cars ready for shipping. Similarly the zinc concentrate is thickened to 63.0 to 68.0 percent solids and filtered on six 6 x 6 American disc filters, the filter cake (moisture 12.0 percent) is conveyed to a gas fired Struthers-Wells 8 x 65 foot dryer. The dryer discharge, which averages 4.5 percent moisture, discharges directly in 80 ton shipping cars.

TIN PLANT

The tin mineral in Sullivan ore is cassiterite and is recovered in a gravity circuit. The tailing of the iron rougher flotation circuit is feed to the tin plant gravity circuit, with an average grade of 0.06 to 0.10 percent tin. The tin is concentrated and recovered on rougher and cleaner tilting blankets with two 4-cell flotation machines to remove any tramp iron. The blanket cleaner concentrate feeds Diester tables that upgrade the cassiterite to 60 percent tin.

The concentrate is dried and then screened to remove any tramp iron and stored until a 50 ton shipment is ready for custom smelting.

TAILING POND

Two products are laundered to the tailing pond: (a) the iron that is not used in the fertilizer plant and (b) the tailing of the tilting blankets in the tin plant gravity circuit, each are stored in a separate area. Wooden trestles support the 12 x 12 inch wooden launders that transport the tailing to the distributing area. The total area of the tailing pond is 766 acres and the total tonnage of stored solid is in excess of 60,000,000 tons.

Sullivan Concentrator - Major Equipment

Jaw Crushers	1 Dominion 36 inch x 48 inch
	1 Buchanan 36 inch x 42 inch
Screens	2 Dillon 5 feet x 10 feet
Locomotives	3 Canadian General Electric 250 volt
Sink-Float Units	2 Huntington Heberlein
Rod Mill	1 Hardinge 11.5 feet x 12 feet
Primary Ball Mills	6 Hardinge 4 feet x 10 feet - 2.0 inch balls
Secondary Grinding	14 Krebs 20 inch cyclones
	4 Hardinge ball mills 4 feet x 8 feet
	4 Hardinge ball mills 4 feet x 10 feet
Grinding Power	Requirement is approximately 9,000 HP
Steel Consumption	Crusher steel 0.019 pounds per ton
	Grinding media 0.89 pounds per ton
	Grinding liners0.04 pounds per ton

Note: Eleven of the seventeen ball mills are rubber lined.

Flotation Machines

Coarse Lead	4 - 4 Cell No. 24 Denver	800 cubic feet
Lead Rougher	5 - 12 Cell No. 30 Denver	6,000 cubic feet
Lead Rougher	2 - 14 Cell No. 48 Agitair	1,120 cubic feet
Lead Cleaner	2 - 10 Cell No. 30 Denver	2,000 cubic feet
Lead Recleaner	1 - 10 Cell No. 30 Denver	2,000 cubic feet
Dezincer	1 - 12 Cell No. 30 Denver	1,200 cubic feet
Zinc Rougher	5 - 12 Cell No. 30 Denver	6,000 cubic feet
Zinc 1st Cleaner	2 - 10 Cell No. 30 Denver	200 cubic feet
Zinc 2nd Cleaner	1 - 11 Cell No. 30 Denver	1,100 cubic feet
Zinc 3rd Cleaner	1 - 10 Cell No. 30 Denver	1,000 cubic feet
Iron Rougher	2 - 12 Cell No. 30 Denver	2,800 cubic feet
Iron Cleaner	2 - 16 Cell No. 40 Agitair	1,280 cubic feet
Iron Scavenger	1 - 4 Cell No. 24 Denver	200 cubic feet
Iron Scavenger	1 - 4 Cell No. 40 Agitair	160 cubic feet

Note: All No. 30 Denver machines are equipped with D.R. mechanism.

Thickeners

1 - 115 foot Dorr to thicken lead rougher feed
1 - 60 foot Dorr in sink-float "Fines" service
1 - 50 foot Dorr in water clarification service
1 - 50 foot Dorr to thicken lead filter feed
1 - 50 foot Dorr to thicken zinc filter feed

Filters

2 - Oliver drum 8 feet x 12 feet, cotton fabric, media life three months.

6 - American 6 foot x 6 foot disc-cotton, filter bag usage 300 per month.

Dryer

1 - Struthers-Wells 8 foot x 65 foot gas fired.

Reagent Usage - Pounds per ton

Xanthate	0.181 lead zinc flotation
Lime	3.145
Frother	0.015
Copper Sulphate	1.359
Cyanide	0.071
Sulphuric Acid	1.873
Phosocresol	0.073
Xanthate	0.109 iron flotation

REFERENCES

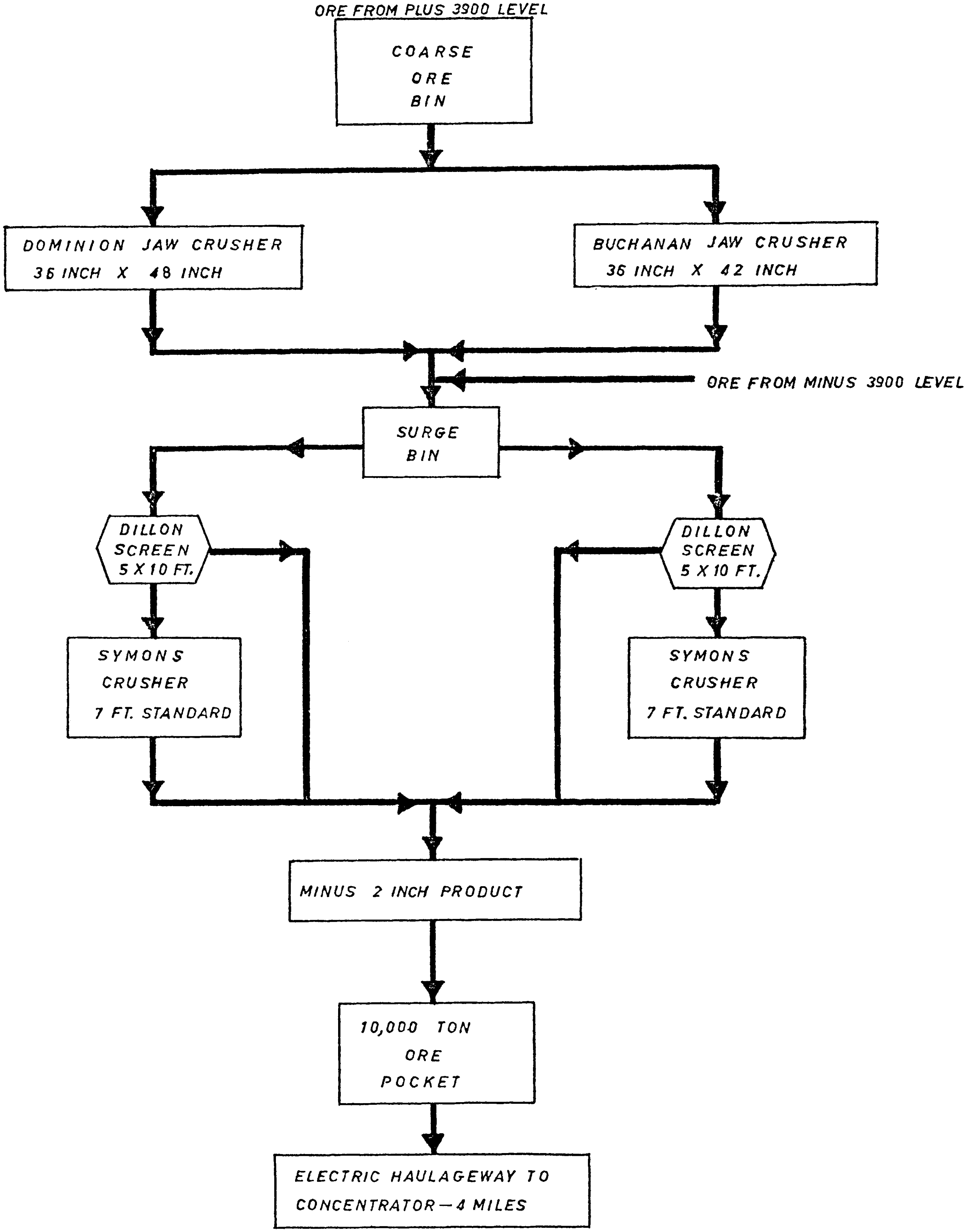
1. The Sink-Float Process in Lead Zinc Concentration by E. N. Doyle.

2. Cominco AIME World Symposium on Mining and Metallurgy of Lead and Zinc, Engineering and Mining Journal, September, 1973.

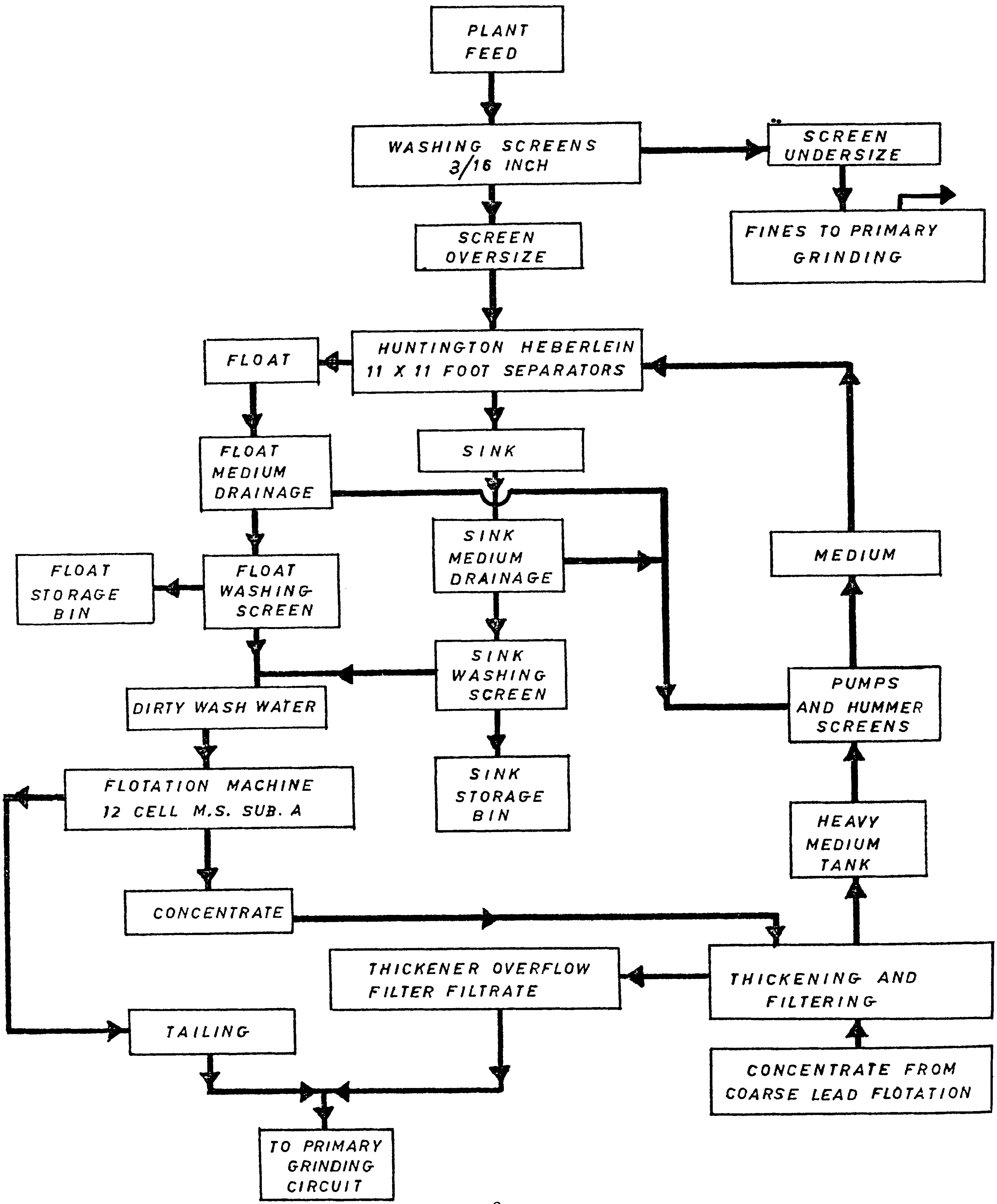
3. Dezincing of Lead Concentrate at the Sullivan Concentrator, by H. J. Chalmers.

   1st of Volume 56 No. 3 July 1961, Quarterly of Colorado School of Mines.

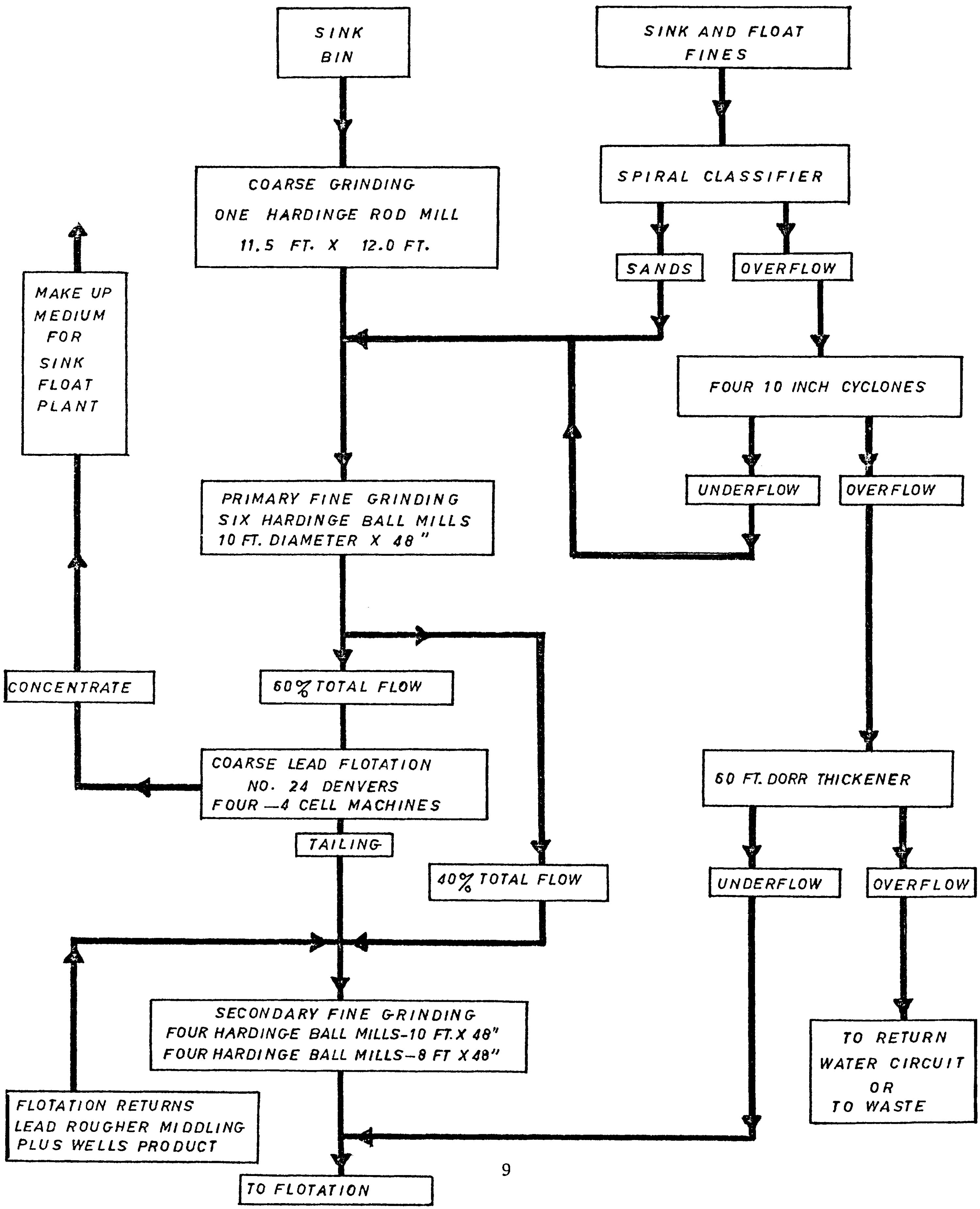
SULLIVAN CONCENTRATOR
UNDERGROUND CRUSHING PLANT



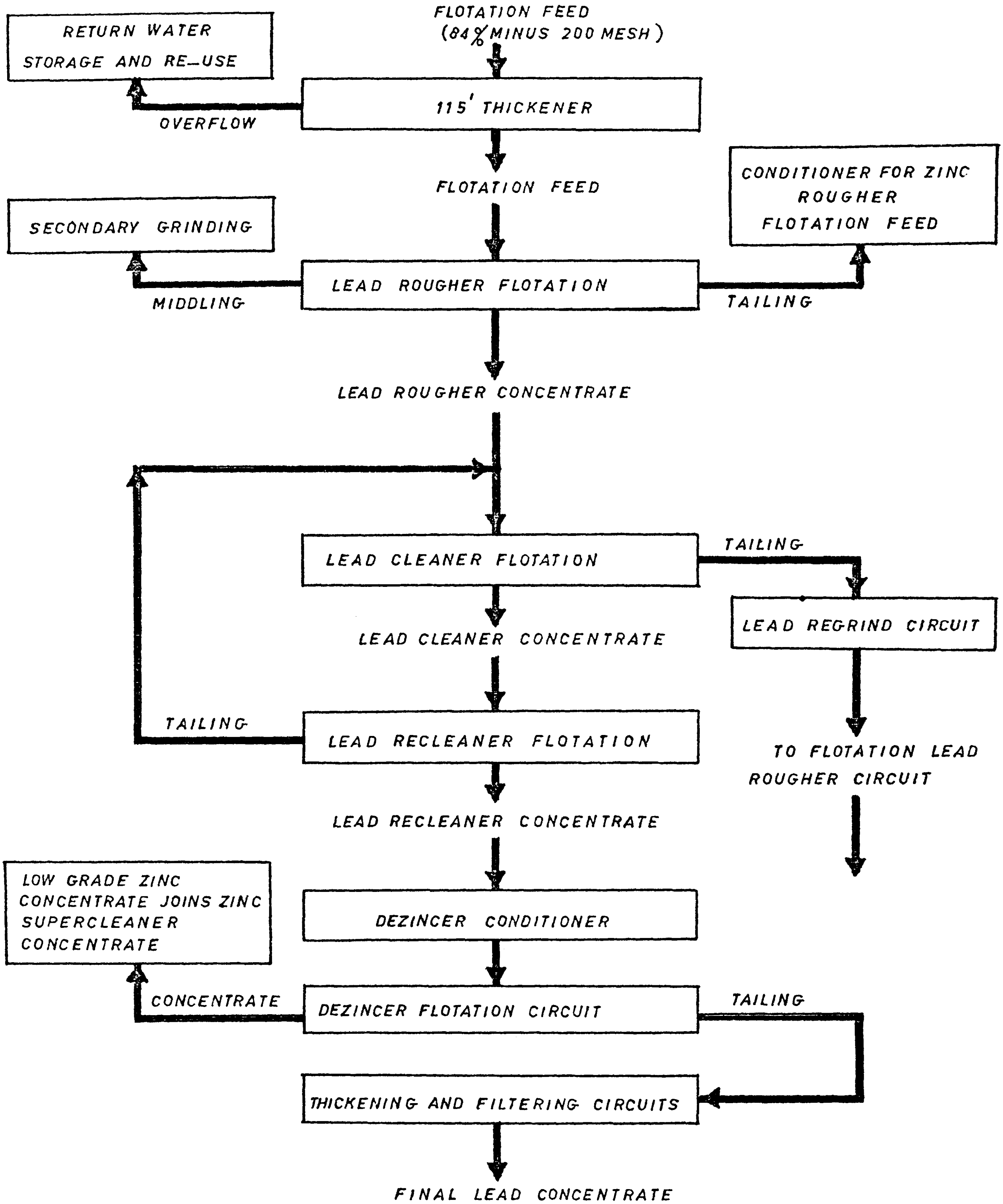
SULLIVAN CONCENCENTRATOR
SINK AND FLOAT PLANT



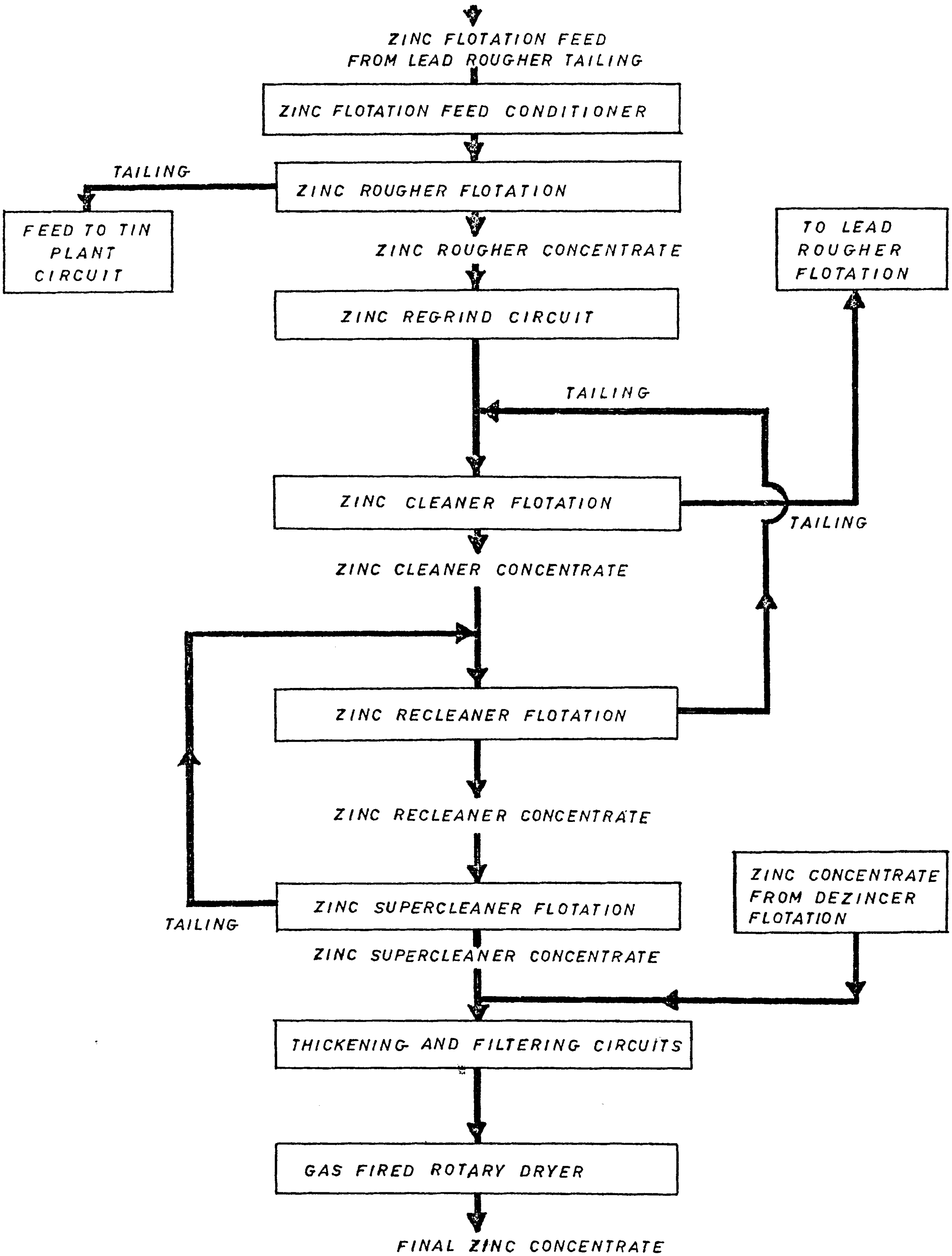
SULLIVAN ONCENTRATOR GRINDING CIRCUIT



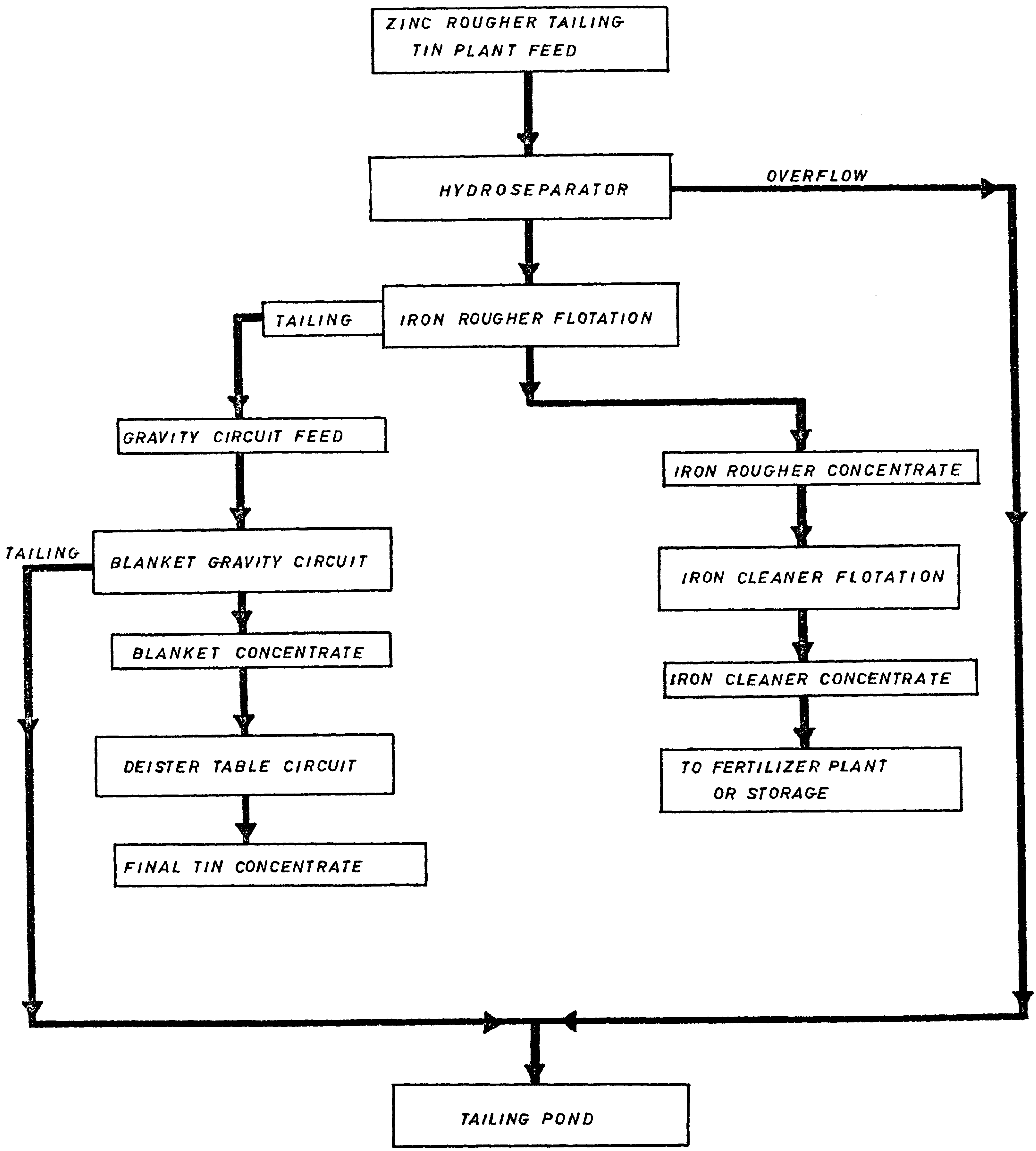
SULLIVAN CONCENTRATOR
LEAD FLOTATION CIRCUIT



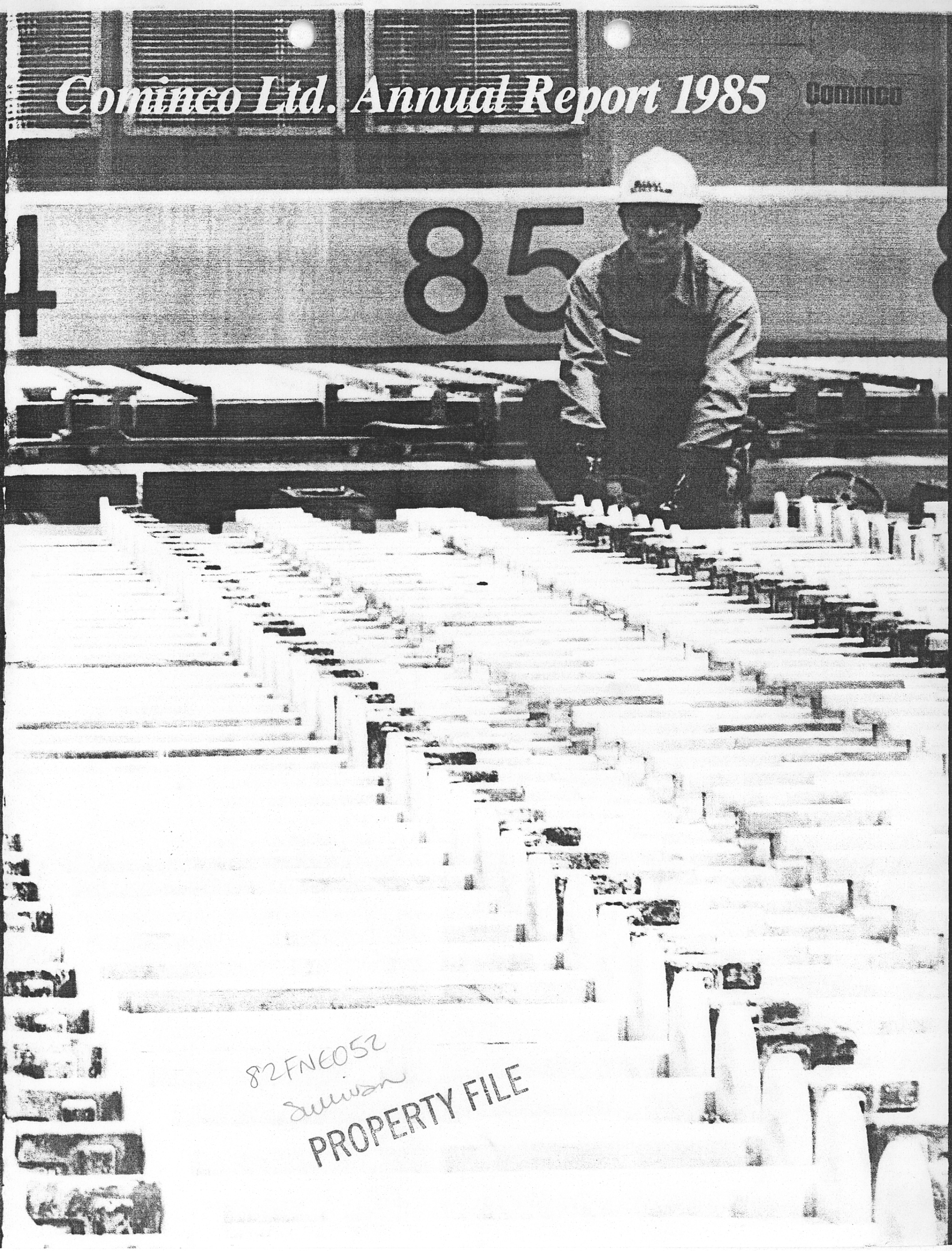
SULLIVAN CONCENTRATOR
ZINC FLOTATION CIRCUIT



SULLIVAN C NCENTRATOR
TIN PLANT CIRCUIT



Cominco Ltd. Annual Report 1985



82FNE052
Sullivan

ten weeks' consumption. The supply of copper concentrates was tight for most of the year. Prices in U.S. dollars were depressed through the year due to lower demand and the high level of inventories. The monthly price of refined copper on the London Metal Exchange peaked in May at 69.4 cents U.S./lb. The average for the year was 64.9 cents U.S./lb., 2.3 cents U.S./lb. higher than the 1984 average.

Gold and Silver

Prices for both of these metals were at lower levels during 1985 due to reduced activity by investors. Gold prices averaged U.S.$317 an ounce for the year compared with U.S.$360 an ounce in 1984. The average price of silver in 1985 was also lower at U.S.$6.14 an ounce, down from U.S.$8.14 an ounce in 1984.

Action Taken

The Metals Division is responding to the current oversupply in the zinc and lead industry by reducing production. The Division continues to cut costs and improve productivity and it is re-evaluating the position of its higher-cost operations. For the longer term, the Division is concentrating its efforts on the development of low-cost operations in order to be competitive in world markets.

Production curtailments at Trail were announced in June and October 1985. The effect was to reduce zinc production by 10 per cent between July 1 and December 31. Production cuts will continue in 1986.

At the Sullivan Mine, zinc concentrate production was reduced in the second half of 1985 in keeping with the zinc metal production curtailments at Trail. Zinc concentrate production will also be reduced in 1986.

The Polaris Mine began in October 1985 to reduce production of zinc concentrate by 25,000 tons *(22,700)* and lead concentrate by 4,000 tons *(3,600)* before the onset of the 1986 shipping season in August.

Pine Point Mines and the Black Angel Mine, which are nearing the end of their economic lives based on current depressed prices for their products, have adopted plans to extract ore as economically as possible.

Pine Point Mines, which is now a high-cost producer of zinc and lead concentrates, will maximize production rates from the best ore sources available to reduce unit costs of production.

The Black Angel Mine in Greenland, another high-cost producer of zinc and lead concentrates, is also maximizing production rates. A decision on the continuation of the operation beyond June will be made in April 1986.

The Red Dog zinc-lead-silver mine in Alaska will, when brought into production, provide the Trail Operations with an assured, long-term and low-cost supply of concentrates. The feasibility study for developing the mine has been completed. Assuming satisfactory conclusion of negotiations with the State of Alaska for development of the road and port facilities to service the mine, construction on the road and port could start in 1986. These negotiations are expected to be concluded in the first quarter of 1986, and will provide for payment of fees by Cominco for use of the facilities when operations commence.

Aberfoyle Limited began construction of an adit to investigate ore resources at its zinc-lead-silver property at Hellyer, Tasmania in 1985. Development costs of this operation could be reduced significantly if Aberfoyle's nearby tin mill at Cleveland could be converted to process zinc and lead ore. Tin mining at Cleveland is expected to cease in 1986 due to the depletion of ore reserves.

Exminesa made a decision in June to proceed with the building of a zinc-lead underground mine and concentrator at Troya, Spain. Annual mill capacity will be 330,000 tons *(300,000)* of ore a year, and the total cost of the project is $35 million. Production is expected to begin in 1987.

The Metals Division has been planning the modernization of the lead smelter at Trail to reduce costs. The total cost of this project is estimated to be $270 million, and when completed will be capable of producing 176,000 tons *(160,000)* of lead a year. In November 1985 Cominco reached an understanding with the Federal Government of Canada for $69 million in equity financing. Negotiations to obtain support from the Province of British Columbia, which is an integral part of the overall financing, were proceeding satisfactorily at year-end. The proposed new smelter will raise the refined lead operation to the high level of technology found in the modernized zinc operation, meet foreseeable environmental standards, ensure low-cost, competitive production, and provide long-term employment opportunities.

Cominco and Lornex Mining Corporation Limited announced in

Mining and Integrated Metals

Revenues and Operating Profit (Loss)

	Revenues		Operating Profit (Loss)	
	1985	1984[1]	**1985**	1984[1]
		(millions)		
Trail Metallurgical Operations	**$417**	$441	**$(15)**	$(22)
Sullivan Mine	**72**	97	**(8)**	19
Pine Point Mines	**110**	120	**7**	19
Polaris Mine	**71**	100	**5**	28
Black Angel Mine	**44**	56	**(4)**	14
Magmont Mine	**25**	31	**2**	9
Con Mine	**36**	44	**(4)**	5
Buckhorn Mine	**6**	1	**(3)**	(4)
Valley Mine	**67**	59	**6**	1
Cominco UK	**2**	2	**(1)**	—
Metals Division Overhead[2]			**(5)**	—
	$850	$951	**$(20)**	$ 69
First Quarter			**$ 2**	$11
Second Quarter			**6**	23
Third Quarter			**(8)**	33
Fourth Quarter			**(20)**	2
			$(20)	$69

[1] Certain of the 1984 figures have been restated to conform with the 1985 presentation.
[2] Includes administration, research and environmental costs previously included in corporate expenses.

January 1986 that they had reached an agreement which will combine the Valley copper operation in British Columbia with a nearby mine and mill operated by Lornex. Integration of the units will result in lower costs, make the project profitable even at today's low prices, and should enable the venture to operate at any low point in future metal cycles. The companies will have equal management of the venture, and Cominco will receive 55 per cent of the profits. The capital requirements, estimated at between $70 and $100 million, are expected to be raised by the new venture, and will not be a direct financing requirement of Cominco.

The Metals Division is bringing these new developments along as quickly as possible, and in the long term is working to optimize the considerable potential in our metals business.

Trail Metallurgical Operations

The integrated smelter and refining complex at Trail, B.C. produces a wide range of metals, principally refined zinc, lead, silver and gold. Annual production capacity is 300,000 tons *(272,000)* of refined zinc and 150,000 tons *(136,000)* of refined lead; over half of Cominco's Canadian-mined zinc and lead concentrates are refined at Trail. To supply the smelter and refinery, additional quantities of custom concentrates are purchased. Electrical power from Cominco's two hydro-electric generating plants serves the operations in Trail and Kimberley and any surplus is offered for sale to West Kootenay Power and Light Company, Limited and to other utilities.

The amount of refined zinc produced at Trail reached a record total in 1985. However, a cutback in the production rate at mid-year, in response to world oversupply, kept output below plant capacity. Refined lead production was slightly higher than in 1984. Because of closures of mines not related to Cominco, lead concentrates high in silver and gold content were scarce, resulting in lower silver and gold production at Trail from these sources during 1985.

A comprehensive reorganization of the management structure and a rationalization of the work force brought the number of employees at the Trail Metallurgical Operations to 2,562, down 19 per cent from the previous year.

Production of Refined Metals

		1985	1984
Zinc	tons	**289,700**	285,600
	(tonnes)	***(262,800)***	*(259,100)*
Lead	tons	**132,300**	129,700
	(tonnes)	***(120,000)***	*(117,700)*
Silver	oz	**9,758,900**	10,609,200
	(kg)	***(304,000)***	*(330,000)*
Gold	oz	**30,800**	37,400
	(kg)	***(960)***	*(1,160)*
No. of employees at year-end		**2,562**	3,164

Sullivan Mine

The Sullivan Mine at Kimberley, B.C. continued to be the principal supplier of zinc and lead concentrates to Trail. In operation since 1909, this mine is Cominco's oldest producer.

The amount of ore milled and production of zinc and lead concentrates was below that of the record set in the previous year because of the decision taken at mid-year to reduce metal production at Trail. Total revenue declined, the main factors being lower metal prices for zinc, lead and silver, and the lower production.

		1985	1984
Ore milled	tons	**2,397,000**	2,725,000
	(tonnes)	***(2,175,000)***	*(2,472,300)*
Zinc			
Average ore grade		**4.1%**	4.0%
Concentrate	tons	**170,600**	187,000
	(tonnes)	***(154,800)***	(169,600)
Average concentrate grade		**49.1%**	49.8%
Lead			
Average ore grade		**5.1%**	5.1%
Concentrate	tons	**167,600**	194,300
	(tonnes)	***(152,000)***	(176,300)
Average concentrate grade		**62.1%**	61.6%
Silver			
Average ore grade	oz/ton	**1.5**	1.7
	(g/tonne)	***(51)***	*(58)*
No. of employees at year-end		**986**	1,125

Pine Point Mines

Cominco owns 51 per cent of the shares of Pine Point Mines Limited, which has zinc-lead mines and a concentrator at Pine Point, N.W.T., on the south shore of Great Slave Lake. All of the zinc concentrate produced is treated at Cominco's metallurgical plants at Trail, while most of the lead concentrate is sold to an associated company, Mitsubishi Cominco Smelting Company Limited.

Over the past several years the cost of production of zinc and lead concentrates at Pine Point has reached relatively high levels, and the operation is now — on a world scale — a high-cost producer. This is due mainly to increased strip ratios and mine dewatering costs. The deterioration in the zinc market since May 1985 resulted in losses in the last four months of the year.

Accordingly, in order to reduce unit costs of production, it was decided to revise production plans for 1986 and 1987 to maximize production rates from the best ore sources available, reduce the strip ratio, and run the mill at full capacity. Inevitably, this course of action will result in a shortened mine life. Because of this, a provision of $42.6 million (Cominco's share – $21.9 million) was made to reduce fixed assets, deferred pit preparation costs and other assets to their net realizable values. The provision also covers estimated costs to be incurred on closure of operations. The major factors that will affect the continuation of production are the following: improvement in the price for zinc and lead; Pine Point obtaining adequate financing; and reasonable assurance of operations providing a positive cash flow.

Negotiations were in progress in March 1986 with Pine Point's bankers for the increased credit facilities required to finance the build-up of inventory which will result from the revised plan.

In 1985, 2.0 million tons *(1.8)* of ore were found on the property, including 0.5 million tons *(0.4)* in one new high-grade deposit with a low strip ratio. Planned exploration expenditures of $1.5 million for 1986 were suspended in March due to financial constraints.

		1985	1984
Ore milled	tons	**2,356,000**	2,512,000
	(tonnes)	***(2,137,000)***	*(2,279,000)*
Zinc			
Average ore grade		**8.2%**	7.6%
Concentrate	tons	**300,500**	302,900
	(tonnes)	***(272,600)***	*(274,700)*
Average concentrate grade		**59.2%**	58.7%
Lead			
Average ore grade		**3.0%**	2.3%
Concentrate	tons	**82,900**	67,600
	(tonnes)	***(75,200)***	*(61,400)*
Average concentrate grade		**74.7%**	75.2%
No. of employees at year-end		**492**	588

Polaris Mine

The Polaris zinc-lead mine, located on Little Cornwallis Island, N.W.T., is the world's most northerly base metal mine. Concentrate production is shipped in a 12-week season at the end of the Arctic summer when the sea is open for navigation. The mine went into commercial rates of production in 1982. Most of the concentrates are sold to European smelters. A small amount of zinc concentrate is treated at a custom smelter in Europe and the metal is then sold by Cominco.

Innovative, low-cost improvements in operating practices resulted in an increase in milling capacity to an annual rate of 1,035,000 tons *(939,000)* of ore in 1985. This was achieved in a concentrator originally designed to process 827,000 tons *(750,000)* of ore a year.

Zinc and lead concentrate production were both above last year's levels, by 10 per cent and 7 per cent respectively. Metal recoveries were also excellent, with zinc recovery at 96.1 per cent and lead recovery at 91.1 per cent, each up 0.5 percentage points over 1984.

Initial development of the South Keel ore zone was completed and this area of the mine supplied 90 per cent of the ore milled in 1985.

Exploration work was limited to establishing the remaining east boundary of the Keel ore zone and some fill-in holes. Ore mined was replaced by new ore found. The limits of the main ore body are now well defined.

The operation continued its policy of employing as many northerners as possible. There were 28 northerners employed in a total work force of 264 at December 31, of whom 16 were Inuit or Native Indians.

		1985	1984
Ore milled	tons	**1,035,000**	903,000
	(tonnes)	***(939,000)***	*(819,100)*
Zinc			
Average ore grade		**13.1%**	13.7%
Concentrate	tons	**210,200**	191,900
	(tonnes)	***(190,700)***	*(174,100)*
Average concentrate grade		**61.8%**	61.7%
Lead			
Average ore grade		**3.5%**	3.8%
Concentrate	tons	**43,400**	40,700
	(tonnes)	***(39,300)***	*(36,900)*
Average concentrate grade		**76.2%**	76.9%
No. of employees at year-end		**264**	272

Operations were suspended for one month starting in mid-December 1984 following a period of low prices and returns from concentrate sales, and resumed early in January 1985.

Black Angel Mine

Cominco holds a 62.5 per cent interest in Vestgron Mines Limited, which, through its wholly owned subsidiary Greenex A/S, owns and operates the Black Angel zinc-lead-silver mine and concentrator at Maarmorilik on the west coast of Greenland. Zinc and lead concentrates are transported from the mine to European smelters during the June-November shipping season. Shipments from Maarmorilik totalled 125,600 tons *(114,000)* of zinc concentrate and 26,700 tons *(24,200)* of lead concentrate.

Revenues from sales of zinc concentrate were severely affected by low zinc prices, especially in the second half of the year, the period when prices are settled for most of Greenex's production. Lead concentrate revenues continued at low levels throughout the year.

In November, prompted by the extremely depressed prices for zinc and lead and the resulting effect on revenue, Greenex re-evaluated its business position. Late in the year Greenex reached an agreement with its bankers and the Governments of Greenland and Denmark which would permit operations to continue at least until June 1, 1986. The agreements require Greenex to decide by April 11, 1986 whether to continue operating the mine or to close it permanently. If operations are to be discontinued, the banks will maintain lines of credit necessary to provide for shipment of concentrates, closing of the mine and liquidation of assets during the balance of 1986. In the event that Greenex decides to continue operating, new financing must be arranged to pay off Greenex's existing debt and for the operating costs and supplies required for the 1986-1987 production year.

Greenex also reached agreement with the Greenlandic Government that its obligations relating to rehabilitation of the mine site on termination of operations will not exceed 80 million Danish kroner ($12.6 million at the year-end exchange rate).

Because of the mine's uncertain future, Cominco wrote off its $14.1 million investment in Vestgron Mines.

		1985	1984
Ore milled	tons	**802,900**	744,000
	(tonnes)	***(728,400)***	*(675,000)*
Zinc			
Average ore grade		**9.6%**	11.0%
Concentrate	tons	**131,300**	135,000
	(tonnes)	***(119,100)***	*(122,500)*
Average concentrate grade		**59.0%**	58.2%
Lead			
Average ore grade		**2.7%**	3.0%
Concentrate	tons	**28,500**	28,400
	(tonnes)	***25,900***	*(25,800)*
Average concentrate grade		**68.9%**	68.9%
Silver			
Average ore grade	oz/ton	**0.6**	0.7
	(g/tonne)	***(19)***	*(24)*
No. of employees at year-end		**326**	357

Magmont Mine

The Magmont Mine, located near Bixby, Missouri is a producer of lead, zinc and copper concentrates. It is operated by Cominco American Incorporated in a joint venture with Dresser Industries Incorporated.

Ore production at Magmont in 1985 reached an all-time high of 1,147,000 tons *(1,041,000)*, with productivity improving to a record 26.9 tons/manshift. These achievements were due to improvements in mining efficiency and increased mill throughput by minimizing downtime for maintenance.

The lead flotation circuit in the concentrator was modernized with the replacement of the original cells by large-volume flotation cells.

Over 40 per cent of Magmont's total ore production was extracted from Magmont West.

		1985	1984
Ore treated[1]	tons	**1,147,000**	1,115,000
	(tonnes)	***(1,041,000)***	*(1,011,000)*
Lead			
Average ore grade		**7.51%**	7.1%
Concentrate	tons	**55,300**	49,800
	(tonnes)	***(50,200)***	*(45,100)*
Average concentrate grade		**73.3%**	77.0%
Zinc			
Average ore grade		**1.9%**	2.1%
Concentrate	tons	**15,500**	16,600
	(tonnes)	***(14,100)***	*(15,000)*
Average concentrate grade		**58.3%**	60.0%
Copper			
Average ore grade		**0.3%**	0.2%
Contained in concentrate			
	tons	**600**	500
	(tonnes)	***(500)***	*(400)*
No. of employees at year-end		**180**	182

[1] Ore treated is reported at 100 per cent; the concentrate tonnage reported is Cominco's 50 per cent share of production.

Con Mine

The Con Mine in Yellowknife has been operating since 1938 and is the oldest producing gold mine in the Northwest Territories. Ore is milled and bullion produced at the mine. The gold output is refined by the Canadian Mint and is sold in Canada.

Net sales revenue decreased due to lower gold production and prices. The lower gold production resulted from time lost in the installation of new hoist ropes necessitated by the deepening of the Robertson shaft. The deepening of this main shaft by 810 feet *(247 m)* to 6,235 feet *(1,900 m)* was completed during the year and nine miles *(15 km)* of new hoist ropes were installed. The extended part of the shaft will enter full service in mid-1986, after ore and waste-pass systems are developed on four new working levels. The total cost of the project is $9.6 million.

Exploration at Con resulted in ore additions of 134,100 tons *(121,700)* to reserves. However, after some reclassification of ore, overall reserves decreased by 220,000 tons *(200,000)*, which represent the amount of ore mined in 1985.

		1985	1984
Ore milled	tons	**217,900**	243,700
	(tonnes)	***(197,700)***	*(221,000)*
Gold			
Average ore grade			
	oz/ton	**0.39**	0.39
	(g/tonne)	***(13)***	*(13)*
Production (including gold from the arsenic plant)	ounces	**78,000**	89,100
	(kg)	***(2,427)***	*(2,772)*
Arsenic trioxide			
Production	thousand lb	**2,500**	2,800
	(thousand kg)	***(1,100)***	*(1,266)*
No. of employees at year-end		**343**	341

Buckhorn Mine

Located in Eureka County, Nevada, the Buckhorn heap-leach gold recovery operation is operated by Cominco American Incorporated, which owns a 76 per cent interest. The mine reopened in March 1985, after a four-month shutdown for ore handling and crushing modifications. The modifications resulted in a 30 per cent increase in crushing capacity.

Sufficient new ore was found to offset ore mined and to maintain the reserves. A major drilling program beyond the limits of known deposits was started in 1985.

		1985	1984
Ore milled[1]	tons	**600,000**	194,000
	(tonnes)	***(544,000)***	*(176,000)*
Gold			
Average ore grade			
	oz/ton	**0.057**	0.0416
	(g/tonne)	***(2)***	*(1)*
Silver			
Average ore grade			
	oz/ton	**0.702**	0.472
	(g/tonne)	***(24)***	*(16)*
Production			
Gold	ounces	**12,800**	3,100
	(kg)	***(398)***	*(96)*
Silver	ounces	**76,800**	7,400
	(kg)	***(2,389)***	*(231)*
No. of employees at year-end		**66**	36

[1] Ore milled is reported at 100 per cent; production ounces are Cominco's 76 per cent share of production.

Valley Mine

The Valley Mine in the Highland Valley of British Columbia sold 85 per cent of its copper concentrate directly to smelters in Japan, with the remainder going to metal traders. An arrangement to combine the Valley Mine operation with that of nearby Lornex Mining Corporation Limited was announced in January 1986.

Profitability of the mine improved in 1985 because of higher copper prices, and by an increase in the milling rate to an average of 28,900 tons *(26,200)* of ore per day, 10 per cent more than in 1984.

The production increase was achieved with the addition of two large float cells in the flotation section but with no increase in grinding or hauling capacity. Productivity, in terms of tons milled per manshift, rose 9 per cent.

In May 1985 the normal strip ratio of 0.9:1 was resumed to allow orderly pit development.

		1985	1984
Ore milled	tons	**10,247,000**	9,300,000
	(tonnes)	***(9,296,000)***	*(8,437,000)*
Copper			
Average ore grade		**0.49%**	0.51%
Contained in concentrate			
	tons	**43,600**	41,700
	(tonnes)	***(39,500)***	*(37,900)*
Average concentrate grade		**43.8%**	43.0%
No. of employees at year-end		**451**	416

Aberfoyle

Aberfoyle had revenues of $51 million in 1985, compared with $50 million in 1984. Cominco's share of 1985 earnings was $1.5 million. In 1984 Aberfoyle operated at near breakeven and consequently Cominco recorded no earnings. The improvement was the result of higher sales volumes and profit margins at the Que River mine, lower exploration costs, and benefits in the exchange rate between the Australian and Canadian dollars.

Trading in tin on the London Metal Exchange was suspended in October after the International Tin Council's tin price support system failed. Trading had not resumed at year-end. Because Aberfoyle's tin production was sold on forward contracts, the effect of the crisis on Aberfoyle's results in 1985 was limited.

At the Hellyer zinc-lead-silver sulphide discovery three kilometres north of Que River, where 18 million tons *(16)* of ore were previously identified, work on a 4,000-foot *(1,200-m)* adit to investigate ore underground reached the mid-point at year-end. The nearby Cleveland tin mill is being converted to a trial milling facility for Hellyer ore, and will be ready for testing in mid-1986.

Ore Reserves

Cominco's ore reserves are recalculated annually by the Company's engineering and geological staff based upon evaluation of operating results, drilling, other engineering data, and long-term metal price forecasts.

Operating Mines (Measured and Indicated)

	1985				1984			
	Ore Tons × 1000	**%Pb**	**%Zn**	**Ag oz/ton**	Ore Tons × 1000	%Pb	%Zn	Ag oz/ton
Sullivan	**36,000**	**4.3**	**6.3**	**1.0**	44,000	4.4	6.3	1.0
Pine Point	**16,000**	**2.7**	**6.7**	**—**	24,000	2.7	6.0	—
Polaris	**21,000**	**3.8**	**14.3**	**—**	22,000	3.8	14.3	—
Black Angel	**1,600**	**3.0**	**9.7**	**0.8**	2,000	3.3	10.1	0.8
Magmont	**6,900**	**6.5**	**1.1**	**0.4**	7,900	6.5	1.2	0.4
Que River	**1,800**	**6.8**	**11.7**	**6.0**	2,100	7.0	12.1	6.0
Rubiales	**8,600**	**1.2**	**7.0**	**0.4**	11,000	1.1	6.8	0.4
Con	**1,500**	**0.40 oz Au/ton**			1,700	0.42 oz/Au/ton		
Buckhorn	**3,200**	**0.04 oz Au/ton**			3,100	0.04 oz Au/ton		
Valley	**608,000**	**0.47% Cu**			616,000	0.47% Cu		
Ardlethan	**700**	**0.47% Sn**			400	0.49% Sn		
Cleveland	**100**	**0.75% Sn**			300	0.77% Sn		
Warm Springs	**7,500**	**30.0% P_2O_5**			7,600	30.0% P_2O_5		
Vade	**148,000**	**25.3% K_2O equiv.**			150,000	25.3% K_2O equiv.		
Owens Lake	**33,000**	**sodium carbonate equiv.**			33,000	sodium carbonate equiv.		
Hondeklip	**300**	**0.3 carats diamond/ton**			400	0.4 carats diamond/ton		
Fording	**234,000**	**clean met. coal equiv.**			239,000	clean met. coal equiv.		
Operating Mines (Inferred)								
Polaris	**4,700**	**2.1**	**10.7**	**—**	4,000	2.5	12.1	—
Que River	**1,400**	**3.9**	**7.5**	**2.0**	1,400	3.9	7.5	2.0
Valley	**156,000**	**0.48% Cu**			156,000	0.48% Cu		
Potential Mines (Measured, Indicated and Inferred)								
Red Dog	**85,000**	**5.0**	**17.1**	**2.4**	85,000	5.0	17.1	2.4
Hellyer	**18,000**	**6.4**	**11.8**	**4.3**	18,000	6.4	11.8	4.3
Troya	**4,600**	**1.1**	**11.1**	**—**	4,400	1.1	11.5	—
Pinchi	**1,200**	**6.4 lb. Hg/ton**			1,200	6.4 lb Hg/ton		
Douglas	**12,000**	**31.0% P_2O_5 equiv.**			12,000	31.0% P_2O_5 equiv.		
Fording	**2,100,000**	**thermal coal**			2,100,000	thermal coal		

Mineral reserves of Cominco and associated companies are classified as measured, indicated and inferred. The term "measured" is limited to those reserves at a mine which can be accurately determined as a result of surface or underground exposure and/or drill hole intersections. Reserves are classified as "indicated" where there is sufficient information about the deposit or a portion of it to form the basis of a mine production forecast. Reserves computed on the basis of limited drilling and geological data, and through application of geological projections, which are insufficient to support a mine production forecast, are classified as "inferred."

Ore reserves as at December 31, 1985 at mines of Cominco and at mines of associated companies, which were then in production or being prepared for production, were estimated as shown in the table. In several cases significant reductions in reserves will be noted from the previous year. This reflects the effect of increasing mining costs and forecasts of lower metal prices.

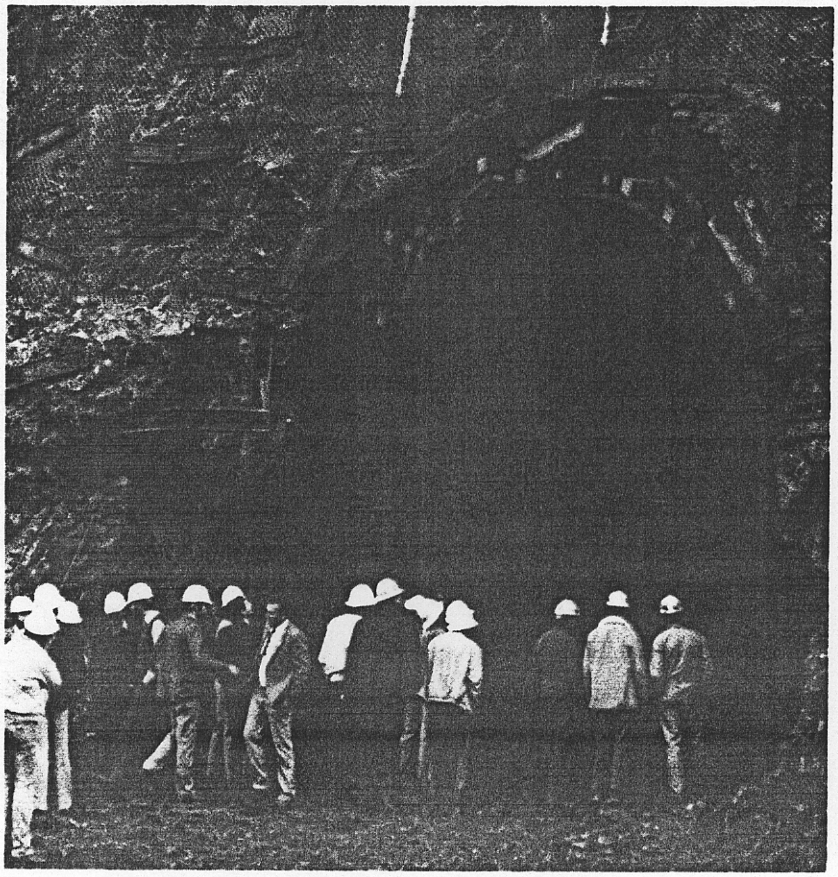
Exploration

Cominco Exploration's goal is to locate mineral resources either at Cominco's existing operations or in new deposits. The location and development of new reserves requires continuous effort, adapting to the increasing complexity of the search for new deposits, and sufficient lead time to develop new operations. Accordingly, Cominco maintains a significant level of exploration, but one adjusted to current economic conditions in the mineral industry. For 1986 this will result in a 35 per cent reduction in expenditure compared with 1985.

Exploration costs in 1985 totalled $41.4 million, approximately the same as in 1984. Of this amount, general exploration totalled $17 million and exploration at producing mines $7.6 million. These amounts were charged against 1985 earnings. The balance of $16.8 million was spent on identified mining properties and was capitalized as investments in mining properties which will be amortized against future earnings.

Projects in Canada accounted for 33 per cent of the total expenditure, and flow-through share funding of $11 million was used for most of the Canadian exploration. Expenditures in the United States accounted for 30 per cent of the budget, and the balance of 37 per cent was spent on projects in other regions including Australia, Western Europe and Latin America.

The official opening of the exploration/development adit at the Hellyer zinc-lead-silver discovery in Tasmania, Australia, took place in May 1985. Work on the 4,000-foot (1,200-m) *tunnel had reached the mid-point by the end of the year.*



Exploration programs were carried out at all the operating mining properties with major efforts at Black Angel ($2.4 million) and at Pine Point ($4.3 million), where ore reserve positions are most critical.

The search for new deposits continues to emphasize zinc and gold, and these accounted for 42 per cent and 43 per cent respectively of total exploration expenditures. In addition, specific projects had silver, copper, diamonds, platinum, niobium or industrial minerals as their objective. Diamond drilling or equivalent work was carried out on over 50 properties and results on more than 20 of these were sufficiently encouraging to warrant follow-up work in 1986.

In Canada, the search for gold was widespread, and several projects in the Slave area, N.W.T. and in northeastern Ontario warrant further work in 1986. One of the most promising Canadian projects in 1985 was the Aley niobium prospect east of Williston Lake, in north central B.C. where trenching and diamond drilling have identified several zones of attractive niobium mineralization. More drilling will be required to determine the size and grade of these deposits.

In Australia, Aberfoyle, an associated company, has begun an adit at the Hellyer property in Tasmania to permit underground exploration of this high-grade zinc-lead-silver deposit located in 1984. In Western Australia, drilling on the Bardoc project near Kalgoorlie has developed three small zones of gold mineralization which can be mined by open pits. The deposits aggregate 1.7 million tons grading .12 oz gold/ton *(1.5 million tonnes grading 4 g gold/tonne)* and construction of a production plant to treat the deposits was recently approved by Aberfoyle.

In the United States, engineering plant design and arrangements for transportation facilities are underway at Red Dog with limited exploration to maintain our interests in other attractive claim groups in the area. Other zinc exploration was carried out in Idaho and Montana. Two previously discovered zinc-lead-copper-silver deposits in the Ambler district, Alaska were purchased during the year, and will be the subject of further exploration at an appropriate time. Gold exploration is concentrated on promising prospects in Nevada.

Draper Dobie
25 ADELAIDE STREET WEST, TORONTO
625 DORCHESTER BLVD., WEST, MONTRÉAL
1055 WEST HASTINGS STREET, VANCOUVER

Toronto 867-3770 | Toronto from Montréal 875-5857 | Montréal 871-1026 | Vancouver 687-2461

PROPERTY FILE

February 20, 1973

COMINCO LTD. ($28)

SUMMARY AND RECOMMENDATION

The shares of Cominco Ltd. are strongly recommended at prices below $30 for substantial capital appreciation both this year and in 1974.

Since our major report on Cominco was published in October, 1972, a number of events have taken place which have considerably brightened the outlook for this company:

(1) Production at Fording Coal has greatly improved and a substantial price increase for its coal is expected to be announced in the very near future. This operation is no longer expected to prevent Cominco's earnings from increasing substantially both this year and in 1974.

(2) Controls on fertilizer prices in the United States were removed in January. Cominco's earnings from this section should, as a result, be improved considerably.

(3) Lead prices on the London Metal Exchange have strengthened as a result of the recent currency realignment and are expected to remain buoyant.

(4) In spite of other world currencies strengthening against the U.S. dollar, the Canadian dollar has weakened from the $1.02 in effect when our report was published in October. This is significant as each 1% decline in the value of the Canadian dollar affects Cominco's earnings by 5%.

Our earnings and cash flow estimates for Cominco are as follows, together with the lead and zinc prices and exchange rates we have used to obtain them and the effect of changes in these variables.

	Actual 1971	Actual* 1972	--- Estimated --- 1973	1974
Earnings per Share	$0.74	1.17	1.50	1.80
Cash Flow per Share (before extraordinary items)	$2.47	2.80	3.39	4.06
Effect of following variables on EPS and CFPS:				
1¢/lb Change in Lead Price			$0.13	0.13
1¢/lb Change in Zinc Price			$0.21	0.24
1% Change in $Cdn/U.S. Exchange Rate			$0.08	0.09
Average Lead Price ¢/lb	12.6	14.4	15.1	15.6
Average Zinc Price ¢/lb	15.8	18.4	20.0	20.5
$Cdn/U.S. Exchange Rate	99.0	101.0	100.0	100.0

At the current price of $28, the multiples on estimated 1972, 1973 and 1974 earnings and cash flow are are as follows:

	1972	1973	1974
Price Multiples on Estimated Earnings	23.9	18.7	15.6
Price Multiples on Estimated Cash Flow	10.0	8.3	6.9

In the past five years the high and low multiples on earnings and cash flow before extraordinary items have been as follows:

* Cominco's basis of consolidation was changed in 1972 to include all subsidiaries.

The figures shown for 1971 are on the old basis of consolidation and for 1972 they are what we estimate earnings and cash flow would have been on the old basis. After the 1972 financial statements are available, we will be able to estimate earnings for 1973 and 1974 to reflect the new basis for consolidation. We expect that they will be slightly higher than our estimates as shown above. (In 1971 earnings and cash flow on the new basis were 6¢ and 22¢ per share higher than on the old basis).

FORDING COAL

Because of the uncertainty which Fording Coal has constituted up to this point, we have not so far recommended the purchase of Cominco stock. We are now, however, in a position to estimate the performance of the coal mine as (i) Cominco has indicated what production has been and what its expectations are regarding future production; (ii) we are now better able to estimate Fording's operating costs; (iii) a significant increase in Fording's coal price is expected shortly.

Production

In 1972 Fording Coal produced 1,000,000 long tons of coal for export to the Japanese steel mills and, by December, monthly production had risen to 170,000 tons or 82% of the monthly target for the first contract year ending March 31, 1973. Cominco has indicated that production at the full monthly target rate of 250,000 tons per month is expected during the second quarter of 1973.

In our earnings estimates, as set out below, we have assumed, as a precaution, that production will be 90% of the contractual quantity in 1973. We have assumed 100% in 1974.

Operating Costs

Operating costs in 1972 at the coal mine of Kaiser Resources - a comparable operation - appear to have been between $11.50 and $12.00 per long ton of clean coal produced.

A comparison of the number of men employed at Kaiser and at Fording and the fact that Fording's stripping ratio is lower than Kaiser's would indicate that Fording's operating costs will be lower.

We have assumed that Fording's operating costs are $12.50 per long ton in the first quarter of 1973 and $11.50 over the remainder of the year. For 1974 we have assumed costs at $11.00 per ton as the increased production we are anticipating should result in a reduction in unit costs.

Prices

Fording Coal's management is in Japan at the time of this writing to advise the purchasers of the coal regarding the progress made to date and the outlook for the operation. We understand that Fording Coal is also requesting a price increase.

The price paid for Fording's coal is currently U.S.$14.89 per long ton. This compares with the U.S.$18.73 being received by Kaiser Resources and the U.S.$18.72 being paid to McIntyre Porcupine. The latter two companies are also seeking increases in their coal prices and it is important to note that, since the Japanese yen was revalued on February 13, these companies could be granted increases in excess of $2.00 per ton without their Japanese customers paying any more in terms of their own currency.

(3) Fording Coal will be included in Cominco's consolidated accounts on an equity basis commencing with the current year.

(4) A variation in operating costs or in the coal price of $1.00 per ton affects Cominco's interest in Fording Coal's profits or losses by 5 cents per share.

FERTILIZERS

Controls on fertilizer prices in the United States were removed in January. Phosphate prices increased almost immediately by $6 per ton and are expected to continue to strengthen over the balance of the year. Cominco sells about 80% of its fertilizer production in the United States and more than one half of its total fertilizer production is in the form of phosphates.

Cominco's earnings from the fertilizer section should be slightly higher in 1973 then were anticipated in our October report and significantly higher in 1974 when the full impact of the price increases is felt.

LEAD AND ZINC PRICES

Lead prices, particularly on the London Metal Exchange, are now expected to be somewhat higher than the estimates we have been using for projecting Cominco's earnings.

This development is a direct result of the currency realignment of February 13. Producers outside of the United Kingdom and Italy who market lead on the basis of London Metal Exchange prices will be receiving less for their product in terms of their own currencies. These producers have an indirect influence on the lead price and may be expected to support the LME at a higher level than before the revaluation of their currencies.

We are expecting the recent monetary realignment to force another increase in the European Producer Price for zinc and bring it to the 20¢ per pound level which we were already using for our Cominco earnings estimates.

The lead and zinc prices we are now using for our estimates are as follows:

LEAD PRICES

		Actual	--- Estimated ---	
		1972	1973	1974
London Metal Exchange	¢/lb	13.5	14.5	15.0
United States Producer Price	¢/lb	15.0	15.5	16.0
Canadian Producer Price	¢/lb	15.4	15.5	16.0
Estimated Cominco Average	¢/lb	14.4	15.1	15.6

COMINCO LTD.

APPENDIX

SHARE PRICES, MULTIPLES AND OTHER STATISTICS

Current Price: $28 Dividend: $0.90 Yield: 3.2%

Price Range 1970:	$19-1/8 - $35-1/2
1971:	$17-7/8 - $25-3/8
1972:	$22-5/8 - $30-3/4
1973 to date:	$24-7/8 - $29-3/8

	1972	1973	1974
Estimate of Earnings per Share	$1.17	1.50	1.80
P/E Ratio on Estimated EPS	23.9	18.7	15.6
Estimate of Cash Flow per Share	$2.80	3.39	4.06
P/CF Ratio on Estimated CFPS	10.0	8.3	6.9

Financial Position (June 30, 1972)

Long Term Debt	$ 93,900,000
Working Capital	$109,360,000

Marketability

	000's
Shares Outstanding	16,970
Less: Canadian Pacific Investments (53.9%)	9,151
Floating Supply	7,819
Trading Volume (1972)	1,398

FIVE YEAR SUMMARY

Year	Price Range High	Price Range Low	Earnings* Per Share	Price/Earnings Ratio High	Price/Earnings Ratio Low	CF Per Share*	Price/CFPS Ratio High	Price/CFPS Ratio Low	Divid-Ends Paid	Yield High	Yield Low
1972	30-3/4	22-5/8	1.17	26.3	19.3	2.80	11.0	8.1	0.80	2.6	3.5
1971	25-3/8	17-7/8	0.74	34.3	24.2	2.26	11.2	7.9	0.70	2.8	3.9
1970	35-5/8	19-1/8	1.45	24.6	13.2	3.22	11.1	5.9	1.40	3.9	7.3
1969	41-1/4	28-1/8	1.54	26.8	18.3	3.25	12.7	8.7	1.40	3.4	5.0
1968	39-7/8	22	1.90	21.0	10.5	3.50	11.4	6.3	1.40	3.5	6.4
			Mean	26.6	17.1		11.5	7.4			

* Before extraordinary items. The 1972 figures are our estimates using the pre-1972 basis of consolidation.

DRAPER DOBIE
INSTITUTIONAL RESEARCH

PROPERTY FILE

COMINCO LTD. ($29½) - AN UPDATE

MAY 7, 1973

BUY

25 ADELAIDE STREET WEST, TORONTO
625 DORCHESTER BLVD., WEST, MONTRÉAL
1055 WEST HASTINGS STREET, VANCOUVER

Toronto 867-3770
Toronto from Montréal 875-5857
Montréal 871-1026
Vancouver 687-2461

May 7, 1973

COMINCO LTD. ($29½)

AN UPDATE

CONTENTS

APPENDICES

COMINCO LTD. ($29½)

SUMMARY AND RECOMMENDATION

In our update of February 20, 1973 we strongly recommended the purchase of Cominco Ltd. for capital appreciation in 1973 and 1974. The price of the stock subsequently rose from $28 to $32½ but has since declined to the present level of $29½.

In our judgment, the main reason for the weakness which has developed is widespread apprehension over the effect of the proposed royalty system on mining revenue in British Columbia. We consider this apprehension to be unjustified in view of the following:

- only about 25% of Cominco's revenue is from B.C. mining operations.
- a royalty of 2½% on Cominco's mining revenue in 1974 is estimated to reduce the Company's earnings in that year by only 7¢ per share. (The $15,000,000 which the B.C. Government is planning to raise in 1974 will be equivalent to about 2½% of the gross value of total mine production).

The years 1973 and 1974 are expected to be years of strong earnings and cash flow gains for Cominco. Beyond 1974 expansion possibilities currently being investigated could add considerably to the Company's earnings prospects. These include (1) a copper smelter in British Columbia (2) a zinc smelter in Europe (3) a lead-zinc mine in Spain and (4) a lead-zinc mine in the Arctic.

We therefore recommend that investors take advantage of the current weakness to accumulate shares for a capital appreciation of up to 50% over the next one to two years.

It should also be observed that dividend payments in 1973 could be 50% higher than in 1972. We estimate that dividends of $1.20 per share **can** be expected this year and $1.40 per share in 1974 - compared with $0.80 per share in 1972.

OUTLOOK FOR EARNINGS, CASH FLOW AND STOCK PRICE

Since our February 20 update was published, lead and zinc prices have increased and we now consider that the average prices for these metals which we were using for our estimates of Cominco's earnings in 1973 and 1974 should be increased. (We have discussed the outlook for prices in our May 1, 1973 update on the lead and zinc industries).

Our 1973 and 1974 earnings and cash flow estimates for Cominco are as follows, toegether with the metal prices we have used. We have also shown the effect of changes in these prices.

	----Actual---		--Projected--	
	1971	1972	1973	1974
Earnings per Share	0.81	1.24	1.86	2.10
Cash Flow per Share (before Extraordinary items)	2.74	3.54	4.43	4.89
Effect of following variables on EPS and CFPS:				
1¢/lb Change in Lead Price			0.13	0.13
1¢/lb Change in Zinc Price			0.21	0.24
Average Lead Price ¢/lb	12.6	14.4	16.0	16.0
Average Zinc Price ¢/lb	15.8	18.4	21.0	22.0

At the current price of $29½, the multiples on estimated 1973 and 1974 earnings and cash flow are as follows:

	1973	1974
Price Multiple on Estimated Earnings	15.9	14.0
Price Multiple on Estimated Cash Flow	6.7	6.0

In 1971 and 1972 the high and low multiples on earnings and cash flow before extraordinary items were as given below.

(Before 1971 comparable multiples are not available, as earnings on the basis of consolidation now used have not been published for prior years.)

	Price/Earnings Ratio		Price/Cash Flow Ratio	
	High	Low	High	Low
1972	24.8	18.2	8.7	6.4
1971	31.3	22.1	9.3	6.5

It is clear that the 15.9X multiple on estimated 1973 earnings at which Cominco is currently trading is lower than the lowest earnings multiple registered in 1971 or 1972. It may be expected that multiples on earnings will decline as earnings increase.

With respect to cash flow multiples, however, we have noticed a much greater consistency from year to year for Cominco and for a number of other Canadian mining companies.

Cominco's multiples on cash flow as reported on the old basis of consolidation were remarkably consistent from year to year, as the figures in the appendix of our February update indicate.

It is therefore probable that Cominco's cash flow multiple range will continue the same as in 1971 and 1972, i.e. between about 6X and 9X each year. Applying these figures to our cash flow estimates gives a price range of $26 to $39 in 1973 and a range of $29 to $44 in 1974.

Downside risk at $29½ would therefore appear to be limited to 12% while the potential for appreciation would appear to be as much as 50% over the next one to two years.

FORDING COAL

Fording Coal Limited, owned 40% by Cominco, reported a loss for the first quarter of 1973 of $4,000,000. In our February update we estimated a loss of $4,130,000. The closeness of the two figures indicates to us that our estimates of operating costs are realistic.

Fording Coal has been given an interim price increase effective April 1, 1973 of $2.50 per ton, bringing the price to $17.73 F.O.B. Roberts Bank. A further increase is to be negotiated this fall and will be applied retroactively to April 1, 1973.

The Japanese have given assurances that Fording's coal price will be competitive with other Western Canadian coking coal prices.

The prices of the coal shipped to Japan by McIntyre and Kaiser have recently been increased to $21.95 and $19.85 per ton respectively. For our projections of Fording's earnings we have assumed that the price increase to be granted later in the year will be $2.50 per ton, giving a price of $20.23 per ton retroactive to April 1.

(Our February update assumed one increase of $4.00 effective April 1, 1973.)

On the basis of the price assumptions as given above and the operating cost assumptions as detailed previously, we estimate that Fording will have a loss of $5,100,000 in 1973 (12¢ per Cominco share) and a profit of $400,000 (1¢ per share) in 1974. These figures assume production at 90% of the contractual quantity this year and at 100% in 1974.

ESTIMATE OF CONSOLIDATED EARNINGS

Cominco's consolidated earnings in 1972 with our estimates for 1973 and 1974 are as follows:

COMINCO LTD.
ESTIMATE OF CONSOLIDATED EARNINGS
1972 - 1974

			----Projected------			
	1972		1973		1974	
Cdn. $000,000's						
OPERATING PROFITS:						
Lead and Zinc (E)	34.7	(43%)	54.8	(49%)	62.7	(49%)
Other Metals (E)	22.5	(28%)	25.7	(23%)	27.2	(21%)
Fertilizers and Potash (E)	8.7	(11%)	16.4	(14%)	22.4	(18%)
Other Revenue	14.0	(18%)	14.8	(13%)	15.0	(12%)
Total	79.7	(100%)	111.7	(100%)	127.3	(100%)
Less: Interest Expense	8.2		8.0		11.0	
	71.7		103.7		116.3	
Add: Income from Investments	2.6		2.7		2.7	
	74.3		106.4		119.0	
Less: Depreciation, etc.	35.0		39.5		43.4	
	39.3		66.9		75.6	
Less: Mining and Income Taxes	15.0	(38%)	28.1	(42%)	31.7	(42%)
	24.3		38.8		43.9	
Less: Minority Interests	3.4		5.2		8.5	
	20.9		33.6		35.4	
Add: Equity in profit (Loss) of Fording Coal	-		(2.0)		0.2	
Net Earnings*	20.9		31.6		35.6	
- Per Share	$ 1.24		1.86		2.10	
Cash Flow*	60.1		75.1		83.0	
- Per Share	$ 3.54		4.43		4.89	

* Before extraordinary items

NOTE: "Other Revenue" is primarily from the sale of hydro-electric power.

EXPANSION POSSIBILITIES

Copper Smelter

For some time now, Cominco has been working on the engineering design of a 70,000 ton per year copper smelter at Kimberley, B.C. As some of the facilities required in a copper smelter complex already exist at Kimberley, the cost of construction would amount to only about $20,000,000. This sum is considerably below the cost of erecting a smelter where such facilities do not exist.

Cominco has stated that it is awaiting only the resolution of problems with the provincial and federal governments before making a final decision.

A copper smelter would not be a highly profitable operation. However, it would be of decided significance to Cominco by providing the means for the Company to become an integrated copper producer at some later date. Cominco intends that 70%-owned Valley Copper will be brought into production when the Free World supply demand position for copper justifies new production decisions. To reduce Valley's production to the finished metal stage within the province would be a considerable advantage to Cominco both in terms of increasing the value of Valley's production and in terms of lowering the royalties on the metal content mined.

For the time being, however, it should be assumed that, if the smelter is constructed, it will operate initially with purchased concentrates.

Zinc Smelter

Cominco recently announced that it is looking at the viability of a smelter in Europe. A complete feasibility study is now being conducted.

A zinc smelter per se is unlikely to operate at a high margin of profit. However, if used primarily to treat Cominco's own zinc mine production - and this is the Company's intention - a smelter would add considerably to the returns on that production. The Black Angel mine in Greenland (owned 61.5% by Cominco) will, commencing in 1974, produce annually 80,000 to 100,000 tons of zinc in concentrate. This would be available to Cominco's smelter when the current contracts expire.

Rubiales Zinc-Lead Mine

Cominco has a 63% interest in a zinc-lead property at Rubiales in Northern Spain. Figures on ore reserves and grade have not been published but Cominco has indicated that the property will develop into a medium sized operation.

Arvik Mines

Cominco has a 75% interest in the Polaris property of Arvik Mines Ltd., on Little Cornwallis Island. Development work has indicated potential reserves of 20 million tons of 20% zinc-lead ore.

While it appears that year-round mining will be possible, the remote location of the operation would imply both production and transportation difficulties encountered at no other mine in the world. Cominco is currently investigating means to overcome these difficulties.

The possibility of Polaris becoming an important zinc-lead mine in the late 1970's should not be ruled out.

DIVIDENDS

Cominco's earnings, dividends and payout ratio over the past six years with our projections for 1973 and 1974 are as follows:

Year	Earnings Per Share*	Dividends Per Share	Payout Ratio %
Projected			
1974	2.10	1.40	66.7
1973	1.86	1.20	64.5
Actual			
1972	1.18	0.80	67.8
1971	1.00	0.70	70.0
1970	1.45	1.40	96.6
1969	1.81	1.40	77.3
1968	2.05	1.40	68.3
1967	2.32	1.50	64.7
Mean 1967-1972	1.64	1.20	73.2

* Including Extraordinary items

It will be observed that, on the basis of historical payout ratios, dividend payments of $1.20 per share might be expected this year and $1.40 per share in 1974. Our estimates of cash flow in these two years confirm that dividends of this order can be supported.

COMINCO LTD.

APPENDIX I

SHARE PRICES, MARKETABILITY AND FINANCIAL POSITION

Current Price:	$29 1/2	Dividend $ 0.90	Yield 3.0%
Price Range:	1970	$19 1/8 -$35 1/2	
	1971	$17 1/8 -$25 3/8	
	1972	$22 5/8 -$30 3/4	
	1973 to date	$24 7/8 -$32 1/2	

Financial Position (Dec. 31, 1972)

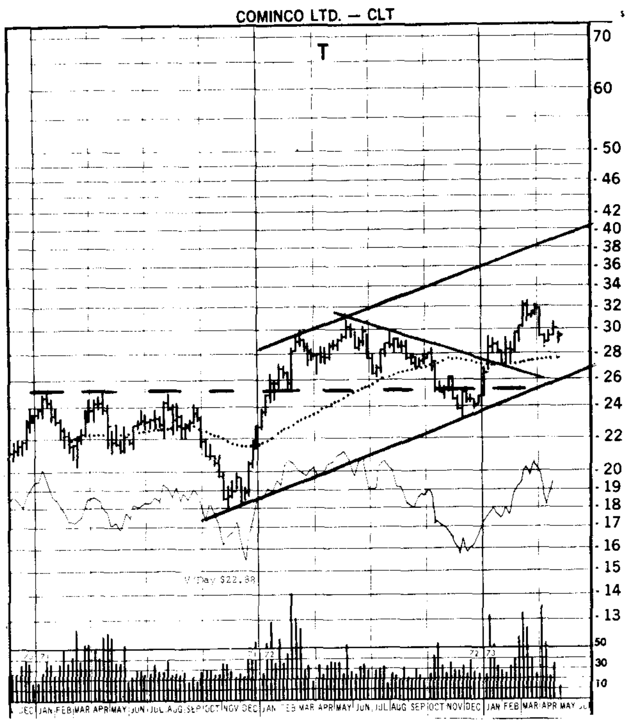
Long Term Debt	$ 118,239,000
Working Capital	$ 106,874,000

Marketability	000's
Shares Outstanding	16,970
Less: Canadian Pacific Investments (53.9%)	9,151
Floating Supply	7,819
Trading Volume (1972)	1,379

COMINCO LTD.

APPENDIX II

PRICE CHART AND TECHNICAL COMMENT



The substantial support visible in the $28-$30 range appears to have contained the April correction; and with a test of the mid-April low apparently succesful, the next move of consequence by Cominco should carry upwards towards the $36-$40 resistance area.

Technically speaking, Cominco merits current purchase consideration for a 1973 objective of $36 to $40.

Chart Courtesy of Independent Survey Company Ltd., P.O. Box 6000, Vancouver, B.C.

ON the ORIGIN of the SULLIVAN OREBODY

KIMBERLEY, B.C.

by

A. C. Freeze

Senior Geologist Consolidated Mining & Smelting Company of Canada, Ltd. Kimberley, B.C.

INTRODUCTION

The Sullivan orebody is one of the great base-metal sulphide deposits of the world and in some respects it is one of the finest examples of a group of sulphide-rich deposits that are increasingly referred to as being of the conformable or strata-bound type. This tendency for many geologists to emphasize the characteristic of conformability of the sulphide bodies with the sedimentary and volcanic units that enclose or are interlayered with them appears to derive from a conviction that the genesis of these deposits is in some way significantly different from other sulphide rich deposits in which parallelism with the enclosing lithic units is slight or essentially absent.

For a time, many massive sulphide deposits were thought by most geologists to have been emplaced largely through the medium of metal-bearing thermal waters derived from a deep-seated magma source that was undergoing differentiation. As the metal-bearing fluids rose, they deposited their metallic burdens wherever suitable structures and physico-chemical conditions were encountered. Not all geologists, however, have been satisfied with the hydrothermal theory as an explanation for the origin of these massive sulphide deposits, principally because none of the chemical mechanisms postulated for collecting and transporting the metals in the thermal waters appeared to be adequate for the task at hand. It is only natural then that some geologists would become attracted to the sulphide-rich group of conformable metalliferous deposits and that they would become intrigued with the possibility that the observed conformability between the sulphide units and the lithic units might arise from a direct and interrelated set of phenomena. That is, the deposition of the sulphide was contemporaneous with the deposition of the associated lithic material. Vigorous and aggressive support for this concept of origin for these deposits appears to have developed at about the same time in South Africa and Australia during the late forties and early fifties arising from research into the Origin of the Rhodesian copper belt deposits and the great silver-lead-zinc lodes at Broken Hill, Australia. Shortly after this, more impetus was given to this movement by the work of Kraume (1955) at Rammelsburg and by Ehrenberg, Pilger and Schröder (1954) at Meggen, Germany. The latter geologists have presented strongly stated cases for a marine hydrothermal syngenetic origin for these deposits.

Canadian geologists are notably exploration-minded and therefore have followed and participated very actively in discussions of these problems. Their concern over these matters increased greatly following the discoveries of the Manitouwadge orebodies in Ontario; the numerous base-metal deposits in the Bathurst area of New Brunswick; and the important ore discoveries of this type in the Mattagami Lake area of Quebec. As the intensity of argument increased, it is not surprising that geologists who are antagonistic to the views of the hydrothermalists would question the official position of the Sullivan geological staff that the Sullivan orebody was formed principally by some process involving selective replacement of favourable argillaceous beds by metalliferous hydrothermal solutions derived from a body of differentiating magma at depth.

The Sullivan geological staff through the visits and writings of geologists dealing with other strata-bound base-metal deposits have been keenly aware of this challenge to their position on the origin of the Sullivan orebody almost from its inception and accordingly have been active in trying to discover new evidence that would help to clarify the points at issue. In addition, we have cooperated with govern-

82FNE052 (9E)

ment and university geological groups on several investigations that were beyond the ability of the department to undertake on its own. The results of some of these studies have been published and it is hoped that reports on the others will appear soon because they are all valuable scientific contributions toward a better understanding of Sullivan geology. Perhaps it should be mentioned here that the Sullivan geological staff is and has been a large one for over two decades and it would not be correct to construe from the above statements that all of its members are or were of one mind on the question of the origin of the deposit.

SCOPE AND ACKNOWLEDGEMENTS

When the original request for this paper was made, it was suggested that emphasis should be largely on evidence from the field and underground rather than on evidence derived from laboratory studies. In the main, the writer has followed this suggestion.

In preparing this paper the writer has drawn freely from all the published and private reports dealing with the geology of the Sullivan that were available to him and of necessity will be passing on ideas and observations that have come from such a wide variety of sources that it would be impossible for him to acknowledge them all. However, he does wish to acknowledge a very great indebtedness in this regard to the present and former members of the Sullivan geological staff.

It is impossible within the limits of the space available to review thoroughly the details of the regional and local geology, which have an important bearing on the problem. Good up-to-date accounts of the essential aspects of Sullivan geology have been available for some years and many of the critical points relating to the origin of the deposit have been dealt with in them. The writer therefore, presumes that most readers are personally well acquainted with the published accounts and so proposes to give, with the aid of illustrations, some highlights on the regional and local geology that he considers to be significant in regard to the question of origin. But he hastens to point out that he does not know of any evidence that unequivocally establishes that any one of the hypotheses suggested is the correct one. Nevertheless, if it is necessary or desirable to take a position on the question, he believes that the weight of evidence at this time favours an epigenetic hydrothermal replacement origin over those invoking a syngenetic origin.

PREVIOUS HYPOTHESES

Almost all of the early workers believed that the Sullivan orebody is an epigenetic hydrothermal replacement deposit. The private or published accounts of S.J. Schofield (1915), G. M. Schwartz (1927), H. M. A. Rice (1937), A. G. Pentland (1943), C. O. Swanson and H. C. Gunning (1945, 1948), to mention only some of the authors whose writings are readily accessible, clearly indicate this. Most, if not all stated that they believed that the ore is related to one or another phase of local igneous activity and so their disagreements, if any, were over dating rather than over processes of formation. For example, Rice (1937) believed that the deposit was formed by processes arising from the injection of the local granitic intrusions. At that time, all the granitic intrusions in the region were thought to have formed during Late Cretaceous or Early Tertiary time. Swanson and Gunning (1945) on the other hand, considered that the evidence arising from their investigations favored relating the formation of the orebody to a period of Precambrian igneous events one manifestation of which was the injection of the Moyie doleritic intrusions. Inasmuch as the ore was found to disrupt and replace some of the sills and dikes of the Moyie intrusive suite, they considered the ore to be younger but consanguineous possibly representing a late differentiate of a deep seated parental magma. It is of interest to note that many years after this suggestion was made, scientists of the Geological Survey of Canada (Leech, 1962) clearly established that the Aldridge formation is intruded and highly metamorphosed by a Late Precambrian granite that outcrops a few miles to the southwest.

More recent writers on this broad group of deposits have not been as concerned over the question of dating as they have over the question of the processes involved in forming these deposits, and the following will serve to illustrate two of the current modes of thinking on this subject:

Sullivan (1957) suggested that the metals in the Sullivan Mine are derived from 'euxenitic shales' and their concentration into the present orebody was effected during a period of local granitization. He does not appear, however, to have been prepared to relate the time of granitization to a known period of local igneous or tectonic activity as he did not specify a time for the emplacement of the ore in its present position.

Stanton (Stanton and Russel 1959, Stanton 1960) suggests that the metals in most conformable base-metal deposits have been introduced into a sedimentary basin by processes arising from and associated with a period of contemporaneous volcanism. The metals, presumably derived from the volcanic rocks and their exhalation products, became dispersed in the sea water and subsequently were precipitated, largely by biogenic agencies. The metals therefore could be deposited subaqueously during a period of accumulation, compaction and diagenesis of the associated sediments. He then suggested that the present form and textures of the minerals in these deposits may have developed at a later date by a regrouping of the minerals in response to subsequent changes in environment. Although Stanton does not include the Sullivan specifically with the conformable deposits that he believes formed in the above way, he does mention that it has many characteristics that are similar to them.

In conclusion, it would appear that the most pressing questions regarding the origin of the Sullivan orebody at this time are:

(1) What was the original source of the metals?

(2) How were they collected, transported and finally deposited?

(3) Have they been significantly remobilized and redistributed since they were first deposited in the upper limits of the crust or in their present site?

(4) How well do the inferred processes for its formation fit the observed geological facts?

Let us now examine some aspects of the regional and local geology as well as something of the orebody itself to determine whether any insight into these questions can be achieved.

REGIONAL SETTING

The Sullivan orebody is enclosed in Lower Purcell sediments of late Precambrian age and it lies on the east limb of a segment of the large north-plunging Purcell 'geanticline' (Reesor 1957, Leech 1961). The age of the strata in this large structure ranges from Late Precambrian to Devonian. Although this indicates that the structure is at least post-Devonian, there is considerable evidence to suggest that it had a long history of development that extended well back into the closing stages of the Proterozoic era. The secondary folds that have developed on this major anticline are mostly open but a few are overturned. These secondary folds are broken up by several northeasterly-trending reverse or thrust faults, a few of which extend for remarkable distances and the stratigraphic displacement across some of them is very large. Generally, the northwest block appears to have been thrust to the southeast. Not much is known about the manner in which these faults developed, but one is known to be interrupted by a large Cretaceous or Early Tertiary batholith and the initial development of some of these faults may go back to Late Precambrian time.

Closer in, the orebody lies between the north-dipping Hidden Hand and Kimberley faults (Fig. 17-1). Essentially, both of these structures appear to be normal faults and the stratigraphic displacement on the latter could be in the order of 10,000 feet. Numerous northeasterly-to northwesterly-trending normal faults and fractures that dip steeply West or vertically, occur in the mine and its general vicinity. The Sullivan fault belongs to this group and these structures are generally referred to as Sullivan type faults, etc. The stratigraphic displacement across this system of faults is not usually large, commonly in the order of a few tens of feet. The latest movements on some of them in the mine have displaced the ore. However, marked changes in the character of the ore on either side of them indicate that they probably have a pre-ore history.

STRATIGRAPHY AND SEDIMENTATION

The oldest sediments in the region belong to the Purcell system. They were laid down in the Beltian trough or geosyncline during the Proterozoic Era and, in the Purcell range, they may be as much as 45,000 feet thick. The geosyncline appears to have been a relatively simple basin of deposition that was abundantly supplied with clastic sediment from a lowlying borderland. Generally, the uplift of the borderland in the region of the mine seems to have kept pace with the subsidence of the basin of deposition because most of the sediments in the latter were deposited in shallow water.

The oldest formation, the Fort Steele, has been mapped on the west flank of the Rockies in the Cranbrook area (Rice 1937). Although it has not been identified positively in the Purcell range, there is some evidence to suggest that its metamorphic equivalent may be present near the mouth of Matthew Creek about 10 miles southwest of the mine. This formation is of interest here only because the lower two-thirds of the exposed section consists principally of orthoquartzites that have textures clearly indicative of deposition in sh w water in which strong wave and cu it action prevailed. The top third of this formation consists mainly of thin bedded silty argillite, argillite and calcareous argillite, suggesting that these beds were deposited in deeper or at least in quieter waters.

Aldridge formation conformably overlies the Fort Steele formation and is at least 15,000 feet thick. It is of special interest to us because it contains the Sullivan orebody near the transition between its lower and middle members (Reesor, 1954).

The Lower Aldridge is about 4,000 feet thick in the Purcell range. It consists principally of grey-green, rusty weathering, thinly interbedded impure fine-grained quartzite, siltstone, silty argillite and argillite.

The rusty appearance of these rocks and those of the Upper Aldridge is so distinctive that it has been used as a major criterion in mapping in this region. These rocks generally contain pyrrhotite as fine disseminations, as laminations or as small variously shaped masses. Less commonly, pyrite, iron bearing silicates and/or carbonates are present instead of pyrrhotite. This raises the question of whether these sediments are more nearly related to normal pelitic sediments or to ironstones. The few chemical analyses on these rocks that are available indicate a total iron oxide content around 5%. This seems to be too low and the writer would estimate that locally, appreciable thicknesses of these rocks would approach 10% total iron oxides. Pettijohn (1956), in discussing shales, argillites and siltstones, gives a range of 6% to 8% for the iron oxide content of normal pelitic sediments. He would consider 15% to be unusual and those with over 20% to belong to the true ironstones. It would appear then that most of the sediments of the Lower and Upper Aldridge do not depart too far from normal pelitic sediment in this regard and the rusty appearance probably is largely due to the readiness with which the iron-bearing minerals weather.

The widespread distribution of the iron-bearing minerals and their tendency to be associated with primary sedimentary features strongly supports the suggestion that probably most of this iron was deposited contemporaneously with the common detrital constituents. However, since the total amount of iron is, with minor exceptions, well below the amount found in true ironstones, there is little to support the suggestion that the depositional environment may have been conducive to the formation of extensive bodies of iron-rich sediments.

Cross-bedding and scour channels are common structures in the Lower Aldridge sediments and ripple marks are found occasionally. Graded bedding is rare in the lower part of the unit but may be more frequent near the top. This is particularly true at the mine where the ore zone series contains several thick, graded beds. Lenses of intraformational conglomerate are fairly common near the top of the lower member, particularly in the Purcell range. Some of these deposits have been traced for up to three miles before pinching out and are known to attain a thickness of approximately one thousand feet. These deposits have been observed to overlie the scoured and at times deeply channeled surface of the underlying beds and their boulders as far as we can tell have been derived exclusively from materials in the basin of deposition itself. The chaotic conglomeration of boulders of all types, sizes and degree of sphericity embedded in an unsorted paste of mud that is so characteristic of much of these deposits can best be ascribed to violent submarine slides. The Middle Aldridge in the Purcell range is about 9000 feet thick. It consists principally of successions of thin to medium thick, graded beds of fine grained impure quartzite and siltstone that are separated by thin partings of argillite. The arenaceous successions alternate with zones of thin bedded argillite and silty argillite of about the same thickness. Although graded bedding is very common in the siliceous beds, clean sorting of the various size fractions is rare. Instead, the sized clastic particles are embedded in a paste of argillaceous material that ultimately becomes the principal constituent of the upper part of each bed. Loadcast structures are not uncommon at the contacts between the sandy bottoms of overlying beds and the argillaceous tops of underlying beds.

Ripple marks, scour channels, cross-bedding and other structures indicative of deposition in shallow water, where the forces of currents and waves are active, are the exception.

Iron sulphide and/or iron-bearing silicates or carbonates are much less abundant. Therefore, the weathered rocks of the Middle Aldridge are not nearly as rusty as the rocks of the Lower and Upper members.

In general, it would appear that much of the Middle Aldridge section in the Purcell range accumulated rapidly in a relatively deep water environment. O. E. Owens (1959) has studied the Aldridge formation intensively, both in the Rockies and in the Purcell mountains while he was a member of the Sullivan geological staff. He concluded that the graded beds of the middle Aldridge were deposited from turbidity currents, a suggestion that appears to be very well in accord with the criteria set forth by authorities on this phenomenon.

The textures and structures in the dominantly black and white, color-laminated argillites of the Upper Aldridge indicate that these rocks were deposited in relatively quiet, probably deep water. However, the textures and structures found in the younger rocks of the Purcell system indicate that shallow water conditions returned and generally prevailed throughout most of the remainder of Purcell time.

From the foregoing description of the regional characteristics of the rocks in the Aldridge formation and in view of the general scarceness of graphitic or other organically derived carbonaceous material in these sediments, it is reasonable to conclude that the depositional environment that prevailed in this part of the geosynclinal basin was not one that would favor the precipitation and accumulation of base-metal sulphides in important concentrations either by chemical or biochemical agencies. Evidence will be given later on to show that this conclusion holds for the area about the mine as well.

IGNEOUS ROCKS

No volcanic flows or deposits of pyroclastic material have been identified positively in the Aldridge formation. In fact, the only flows that have been recognized in the whole of the Purcell system are a few thin basaltic ones with closely associated tuffaceous deposits. They are found in the Siyeh formation or its equivalent, about 21,000 stratigraphic feet above the Sullivan ore zone. Although volcanic flows and pyroclastic deposits have been diligently sought after in the Aldridge formation and not found, it is possible that some may have been missed or not recognized. However, the amount, if any, must be small and utterly inadequate in themselves as a source of metals for a deposit as large and as rich as the Sullivan.

The Lower Aldridge sediments, however, are extensively intruded by many sills and some dikes of the Moyie intrusives which are essentially quartz diabases. This class of rocks is generally considered to be related to volcanic processes in contrast to those that are normally considered to be related to plutonic igneous activity. It is only proper therefore that some consideration should be given to the possibility that the mechanism and timing of the intrusive activity could have been favorable for metalliferous substances to gain access to the basin of deposition at the time that the Sullivan ore zone beds were being deposited either by exhalative processes or by submarine thermal springs.

As yet, there have been no direct measurements reported for the absolute ages of the various formations in the Purcell system. On the other hand, dates using the K-Ar method, have been assigned recently to several of the Moyie type sills that intrude the Aldridge formation in this region. Hunt (1961) in reporting on his investigations employing this technique interpreted his data to mean that the intrusions studied by him were injected during two main periods, one about 1500 million years ago and the other about 1100 million years ago. He suggests that the latter period corresponds approximately with the extrusion of the Purcell volcanics which are found in the Siyeh formation or its stratigraphic equivalent. It was noted previously in this paper that the Purcell volcanics lie about 21,000 stratigraphic feet above the Lower-Middle Aldridge contact which is the approximate position of the Sullivan ore zone. Hunt (1961) reports that a sill outcropping in Irishman Creek near Yahk, B. C. belongs to the earlier period and that the sill near the 3700 portal of the Sullivan mine was intruded during the later period. From Hunt's indicated position of the sill on Irishman Creek, it would appear to have intruded beds appreciably above the inferred position of the Lower-Middle Aldridge contact. This probably means that the timing for most of the Moyie intrusions was too late to have been effective in providing metalliferous compounds to the basin at the time the beds of the Sullivan ore zone were being deposited. This reduces considerably the possibility that these intrusives in themselves could have been effective suppliers of metal through a mechanism such as suggested by Kraume (1955) or Stanton (1960). Also, the reader who is familiar with the papers already published on the Sullivan will recall that dikes of similar composition and closely associated with one of these dated sills have been extensively replaced by sulphides where they cross the Sullivan ore body. This is considered to be very compelling evidence that the ore is younger than the intrusions.

Granodioritic stocks and batholiths outcrop in the region, the nearest exposures being about 10 miles southeast of the mine. Recent potassium-argon dating determinations on these granitic intrusions has revealed that not all of them are related to the Coast orogeny as they at one time were thought to be.

A small granitic stock, and its pegmatitic off-shoot, located on Hellroaring Creek about 12 miles southwest of the mine, has been fo ˀ to be Precambrian (800 million years) in age (Leech, 1961).

This intrusion invades Aldridge sediments and Moyie type sills, and it is quite possible that it was injected during the Post Purcell-Pre Windermere diastrophic period. This period of diastrophism has been referred to by White (1959) as the East Kootenay orogeny.

Although the outcrop area of the Hellroaring granitic pluton is small, a large area of metamorphosed Fort Steele or Aldridge sediments that locally contains sillimanite and garnet-bearing quartz-muscovite schist outcrops about 5 miles southwest of the mine. This suggests that a much larger body of granite may be present at shallow depth (Rice, 1937, Leech, 1961). The discovery of a Precambrian granite in the area is of great interest in view of the suggestion by Swanson and Gunning (1945) that the Sullivan orebody and the Moyie intrusives might be products of a differentiating mass of deep seated Precambrian magma.

Several small lamprophyre dikes, some breccia-bearing, have been found in faults in and near the mine. Actually they may be fairly common throughout the region but they are rarely seen because they decompose very readily and so become concealed. These dikes tend to intrude Sullivan type faults and fractures and in the mine, one of these dikes intruded the ore zone after the main phase of pyrrhotite deposition, but before the local introduction of the galena (Swanson and Gunning, 1945). Potassium-argon age determinations on biotite crystals from this dike indicate that it is at least 800 million years old and it therefore has a Precambrian age (Leech, 1961). These relationships seem to substantiate fairly conclusively that the Sullivan orebody was formed in Precambrian time.

SOME ASPECTS OF THE LOCAL GEOLOGY

The Sullivan orebody occupies a large segment of a somewhat warped domical structure which lies on the east limb of a north-trending anticline with axis a few miles west of the mine.

In general, the degree of conformability in attitude between many of the sulphide bands and the sulphide bands and the sedimentary beds is, indeed, most remarkable. Although this feature is not as strikingly apparent in the central part of the orebody, because much of the sulphide tends to be massive, the broad outlines of the sulphide mass are conformable with the enclosing sediments. Most of the ore in the outer zone of the deposit is distinctly banded and much of it is intimately interbanded. with layers of sediment, some of which may be cleanly and sharply separated from the sulphide bands. Even in areas of strong folding, the individual layers and/or laminae of sulphides or sediment may be preserved to a remarkable degree. However, this is not always true, because it is not uncommon to find folds within which the relatively brittle sedimentary beds have been fractured and the segments dispersed throughout the apparently more plastic sulphides and argillites.

It is perhaps desirable to note at this point that in areas of strong folding, there is a distinct tendency for the beds to be overturned toward the east. This is not the attitude to be expected for dragfolds that have developed on the east limb of an anticline whose axis lies to the west. Swanson and Gunning (1945) suggested that these puzzling folds may have formed during another period of folding than the one which produced the anticline. The recently emerging evidence for an important orogeny during the Post Purcell-Pre Windermere interval lends strong support for this suggestion.

The beds that comprise the ore zone may be up to 300 feet thick and as mentioned previously, they appear to have been deposited during a transition from a long period of sedimentation in a shallow water environment to an even longer period of sedimentation in a relatively deep water environment in which submarine landslips and turbidity currents were prevalent and were instrumental in spreading the abundant supply of sediment over wide areas of the geosynclinal basin.

The composition of the ore zone beds as deduced from nearby unmineralized or weakly mineralized sections is somewhat similar to the rocks in the footwall and hangingwall zones. That is, they are greyish to greenish argillites, siltstones, quartzites, etc. On the whole, the ore zone contains appreciably more argillite than either the footwall or hangingwall sections and the proportion of thick massive graded beds separating the thinbedded argillites, etc., is greater and better developed. The characteristics of these beds are maintained over a surprisingly wide area in contrast to the variability found in the footwall and hangingwall beds. The best marker bed in the mine is up to 40 feet thick and contains almost 16 feet of clean fine-grained quartzite and siltstone at its base. Although cross-bedding and channel scour have been observed, these structures are not nearly as common as they are in the footwall strata.

The ore zone sequence and the hangingwall sequence resemble each other in that both contain graded beds. However, the former differs from the latter in that the clastic minerals are better sorted.

Not all of the beds of the ore zone have been replaced, in fact most of the ore and/or sulphide minerals are found beneath the 'I' marker bed in the lower part of the section. The ore also tends to occupy progressively higher stratigraphic position as the deposit is traced up dip. This is clearly the case toward the southwest and northwest margins of the deposit. These fortunately happen to be areas where the diagnostic characteristics of the marker beds have not been obliterated by metamorphism or metasomatic alteration and the evidence is clearly discernable. Profitable lenses of hangingwall ore are found only in the thin bedded zones beneath the 'H', 'Hu' and 'U' markers in special structural situations. Hangingwall ore that follows the bedding is generally strikingly banded (Figs. 17-2, 17-3). This is particularly true for the outer limits of these lenses. However, the inner zone of most of these lenses is generally associated with a zone of strong fracturing or folding and the textures and structures are considerably more complicated.

Swanson and Gunning (1945, p. 652) noted that minor structures in the folded ore suggest that movement and mineralization may have been partly contemporaneous. There is considerable evidence that this may have occurred on a larger scale in a slightly different manner. In folded areas, particularly in the upper part of the mine, there is a fairly marked tendency for thicker and better grade ore to occur in anticlinal or dilatent structures in contrast to adjoining synclinal or compressed structures. Bancroft (1927) noted this and referred to these structures as zones of decompression and compression respectively. A good example of this can be seen in Figure 17-4 between departure 4500 and the dike. The sulphide zone beneath the hangingwall sag is much thinner than it is in the anticlines on either side. In addition, the zone in the synclinal part is composed essentially of pyrrhotite with so little lead and zinc that this section is not ore. In the anticlinal zone, on the other hand, the sulphides are thicker, and of better grade. A somewhat similar example is shown in Figure 17-5 near departure 5,000. Essentially the same situation maintains along the whole length of these structures. Bancroft suggested that the anticlinal or dilatant zones were more permeable, thereby enabling the mineralizing solution to penetrate the structure more readily than it could in the synclinal or compressed zones. Variation in the intensity of deformation during an extended period of mineralization might account for the variations in the amount of sulphide mineral present, particularly if there was a tendency for the proportion of the various metal ions in the incoming solutions to vary with time. The latter is in accord with the general paragenetic relations of the various sulphides in the deposit. Actually, the examples shown on the figures are extreme cases, but parallels exist in the vicinity of nearly all of the folds.

In addition to the very large tonnages of bedded and massive sulphides that constitute the main ore zone, there are several rich but thinner bodies of banded sulphides that have been found in the thin bedded zones beneath the 'H' and 'Hu' marker beds and the base of the Upper or 'U' quartzite. Most of the hangingwall bodies mined so far have been found in or near zones of folding and fracturing, and considerable wallrock alteration is commonly associated with the ore and these structures. Figure 17-3 shows some relations of one of the largest and richest of these hangingwall orebodies. It lies in the thin bedded zone beneath the 'U' quartzites. The section shows that the orebody has a mushroom-like form. There is a narrow pipe of cross-cutting sulphides and associated disseminated mineralization that breaks through the hangingwall of the main ore zone and cuts across 40 feet of hangingwall beds until it reaches the thin bedded zone between the 'Hu' bed and the 'U' quartzites. It then spreads outward over a relatively large area but the thickest and richest ore was found in the highly disturbed zone near the pipe-like structure. From here it gradually fades away both up and down dip as it passes into less disturbed ground.

Although most of the sulphide in the mine is conformable with the enclosing sediments, sulphides that truncate the bedding on a minor to moderate scale are not at all uncommon. Locally, fractures extending as much as 100 feet into the hangingwall of the main orebody carried enough galena and sphalerite to permit them to be mined and weakly mineralized sediment in some cases is known to extend upward along some of the fractures well beyond the high grade lenses. Figure 17-2 reveals that the footwall beds have been extensively and irregularly replaced by sulphides. Also tongue-like processes of ore associated with strong fractures and intense alteration of the walls are shown to extend well into the tourmalinized footwall rocks, indicating that the ore is not only cross-cutting but was deposited after the rocks were tourmalinized.

The map and sections show many of the folds, faults and fracture zones that are associated with the orebody. Unfortunately, owing to the limitation of detail that can be represented, they do not reveal the extent and intensity of widespread brecciation found in the hangingwall and footwall rocks. Most of the brecciation is associated with the area of strong folding and faulting. In the hangingwall, it is most clearly displayed in the albite rocks and these appear to have been strongly brecciated during two periods, one before or during albitization in which the fractures were healed by albite and the other that is post-albitization, having fractures that are weakly sealed by chlorite. Galena, sphalerite and pyrite have been observed locally in the chlorite seams. Much of the brecciation in the footwall rocks is post-tourmalinization and locally these breccias are heavily mineralized with pyrrhotite and/or minor galena and sphalerite. However, the history of brecciation in the footwall rocks appears to be quite complex and is the subject of a special study by one of the members of the geological staff, and apart from mentioning the presence of these important structures, it is felt that further comment should await the completion of this study.

TIN ZONE FRACTURE

The 'tin-zone' fracture is one of the large cross-cutting mineralized fractures in the mine (Fig. 17-6), and it could have served as one of the main feeders to the ore zone. It is of interest here because of the suggestion made by some of those who favor a syngenetic origin for the Sullivan, that the numerous cross-cutting veins found in the mine may not represent primary mineralization but rather that they probably consist of sulphides that have been remobilized in the main ore zone and then redistributed in the fractures by some heat generating process such as a nearby intrusion or by regional metamorphism associated with deep burial or downwarping.

The tin-zone fracture strikes northerly and dips about 80° easterly. It has been explored for at least 300 feet beneath the footwall of the main ore zone, where it still contains significant amounts of tin, lead and zinc. Where the structure has been explored intensively, it was found to pass upward through the main ore zone, with diminishing intensity, becoming a relatively insignificant structure as it approaches the hangingwall. The fracture zone is widest and most highly mineralized where it passes from normal footwall sediments into tourmalinized footwall sediments, probably because the latter is a more brittle rock than its unaltered counterpart. In 'normal' footwall sediments, the vein system is narrow and tends to be confined essentially to two clearly defined walls. The space between the walls is filled with a mash of crushed and pulverized sediment that is considerably chloritized. Narrow seams of cassiterite-bearing sulphides consisting of pyrrhotite, sphalerite and galena penetrate the crush zone, and fine veinlets and mineral clusters may spread for a few feet along minor fractures into the walls. The galena and sphalerite are coarse textured and locally, have been crushed and sheared, indicating that some minor post-ore movement has occurred.

The character of the fracture zone changes strikingly upon passing from 'normal' sediments into tourmalinized sediments. The zone of fracturing is considerably wider; open cavities, some large, are common, having formed by the shifting of large blocks with smooth conchoidal surfaces. Minor fracturing and crushing that produced many sharp angular fragments may extend for 10 to 15 feet into the walls on either side of the main fracture and the development of gouge is minimal. Within the main fracture, mineralizing solutions deposited a large irregular lens of pyrrhotite that is quite rich in tin. Generally, the cassiterite is distributed through the pyrrhotite as small crystals and grains. Locally the pyrrhotite may contain very rich pockets of this mineral. Some pyrite and minor galena and sphalerite are locally associated with the pyrrhotite, and the last two minerals appear to have formed after the pyrrhotite and cassiterite.

The highly fractured tourmalinized sediments on either side of the main fracture are mineralized by a network of veinlets composed of the above mentioned sulphides with pyrrhotite predominating. Again, cassiterite is characteristically associated with pyrrhotite and where pods or lenses of this mineral are veined by galena and sphalerite, fractured grains and crystals of the enclosed cassiterite may be veined by these minerals. Arsenopyrite has been observed as crystal aggregates up to fist size, but cassiterite has not been observed to be in intimate association with this mineral. This observation is supported by assay data. Small scattered grains of scheelite occur in the tin-bearing pyrrhotite lenses and veinlets. Surprisingly, tourmaline and garnet are rare or absent as a vein mineral in this structure.

The walls of the fractures and veinlets associated with this structure are moderately chloritized in the 'normal' sediments and only slightly so where it cuts tourmalinized sediments. Some quartz and calcite are present in the vein, the latter being localized in post-sulphide fractures.

Inasmuch as the main ore zone near the 'tin-zone' fracture consists principally of pyrrhotite, the relationship between the pyrrhotite in the fracture and in the main zone is vague. This also applies to the cassiterite. It was mentioned previously that the 'tin-zone' fracture weakens and narrows rapidly toward the hangingwall of the main ore zone and the amount of cassiterite associated with the fracture falls off to almost zero.

It must be clearly evident from the foregoing, that the 'tin-zone' fracture formed largely, if not completely, as a post-tourmalinization structure. If, therefore, as some have suggested, the sulphides and the cassiterite that are in it, are the products of a remobilization and migration from a pre-existing tin-bearing sedimentary sulphide deposit, such as the main ore zone, then the sulphides and the cassiterite especially, have migrated an amazing distance from their source and strangely only downward. The writer feels that in this case deposition from ascending metalliferous solutions is a much better explanation for the origin of the minerals in this vein even though many aspects of the process are not as yet clearly understood.

A very interesting minor feature shown on Figure 17-6 will be described now because this bit of evidence also supports a post-tourmalinization timing for the development of another tin-bearing sulphide lens. In addition, it illustrates that in some places strong, localized thermal effects have been closely associated with the introduction of cassiterite and sulphides into the footwall rocks.

The rocks for a few hundred feet north of the 'tin-zone' fracture, on the 3900 level, consist of 'normal' footwall sediments. They then change abruptly, at a small watercourse, to strongly fractured tourmalinized sediments. The fractures in this tourmalinized zone are filled by narrow veinlets of pyrrhotite and the immediate borders of the veinlets are more or less chloritized. Again, the pyrrhotite in most of the veinlets contains scattered grains of cassiterite. Continuing northward, small skeletal crystals of garnet and chlorite begin to appear in the tourmaline rock and they continue to become more abundant and better formed to the north. Eventually, many of the garnets are found to have a sieve-like texture and they contain inclusions of other minerals such as chlorite and biotite. The rock now changes rapidly to a narrow zone composed of a mixture of massive garnet and ill-defined clusters of coarse garnet, actinolite and biotite as well as minor quartz, muscovite and epidote. A few relics of relatively unaltered tourmaline rock were found in the above. Locally, the garnet-amphibole-biotite rock is mineralized with pyrrhotite and some galena and sphalerite. An examination of thin sections of this rock revealed fractured garnets veined by cassiterite-bearing pyrrhotite. Finally, a small irregularly shaped lens of cassiterite-bearing pyrrhotite was found within the thin shell of garnet-amphibole rock. The galena and sphalerite present appear to have been introduced after the pyrrhotite and cassiterite. Continuing northward the sequence of rock types is repeated in reverse order.

STEMWINDER DEPOSIT

In order to emphasize the point that discordant sulphide bodies are not uncommon or insignificant features at or near the Sullivan, although they may tend to be small by comparison to the huge Sullivan orebody, the writer has chosen the Stemwinder orebody as a final example of local deposits of this kind.

The Stemwinder deposit is a large one and it lies nearly half-way between the Sullivan and the North Star mines (McEachern, 1946). It is of interest because mineralogically, it is very similar to the Sullivan. It consists principally of pyrrhotite with considerably less sphalerite and galena. Traces of tin (probably cassiterite), arsenopyrite and chalcopyrite have been observed or inferred from assay data. Texturally, the deposit is probably more consistently fine grained than the ores of the Sullivan. However, the most striking difference is the absence of banding in the sulphides of the Stemwinder.

The deposit is essentially tabular in shape (Figs. 17-7, 17-8), is several hundred feet long and has been explored for an even greater distance in depth where it is still open. In places, it is well over 100 feet thick. Although the walls of the sulphide body are not sharply defined, they strike northeasterly and dip steeply to the southwest.

The sulphide body is not an intimate mixture of the various sulphide minerals. Rather, it consists principally of a large mass of pyrrhotite that contains an abundance of unreplaced rock fragments, particularly near its northern and southern limits. Sphalerite is more abundant than galena and these minerals are localized mostly in a small tablet-shaped lens that lies with gradational contact along the footwall of the main mass of pyrrhotite. Within this small lens of ore, pyrrhotite and sphalerite are very fine grained and intimately intermixed. Galena, on the other hand, tends to be concentrated in a small core within the sphalerite-pyrrhotite mass and its texture is coarser.

The tin bearing mineral in the Stemwinder probably is cassiterite. In any event, tin appears to be more abundant in the ore lens first referred to than in the essentially barren pyrrhotite body. However, assay data on tin are not well distributed throughout the deposit and the above relation may not be truly representative. Arsenic and antimony are present as minor metals, but the minerals in which they occur have not been identified. Garnet has not been reported to be closely associated with the sulphides as it is in many places in the Sullivan. However, small crystals of amphibole, probably tremolite, were observed to be scattered through some of the massive pyrrhotite.

The sediments enclosing the deposit are extensively but irregularly tourmalinized along both walls and some sedimentary relics within the sulphide mass are tourmalinized.

A definite structural control has not been established. However, the body is located along the axial plane of a doubly-plunging syncline that trends northerly, approximately parallel to the Sullivan-type faults and fractures. In the Sullivan, it was found that some of these fractures appear to have served as channel ways or locally to have influenced the distribution of the ore minerals. The Stemwinder orebody therefore may have formed by the deposition of sulphides from solutions rising along a set of release joints that developed along the axial plane of the Stemwinder syncline following a relaxation of forces that produced the fold (Billings, 1954, p. 118). This structural picture has been established largely through surface mapping and diamond drilling. However, attitudes observed in the sediments underground, though limited and infrequent are in accord with the surface data.

The deposit is enclosed by sediments that are thought to lie well beneath the footwall of the Sullivan ore zone. The section contains numerous lenses of intraformational conglomerate that interfinger with lenses of thin bedded or laminated argillite, silty argillite, etc. Many of the rounded fragments of tourmaline rock found in the pyrrhotite along the margins of the deposit may therefore be altered pebbles unreplaced by sulphides.

The marked similarity in the mineralogy of the Stemwinder and the Sullivan ore bodies, in addition to similarities in wall rock alterations and in some structural associations, suggest that there is a close genetic relation between the two deposits. However, the Stemwinder definitely cross-cuts the enclosing beds and it is almost impossible to conceive that it could be anything but an epigenetic sulphide deposit that formed at moderately high temperatures.

WALL ROCK ALTERATIONS

Much of the rock in the vicinity of the Sullivan mine has been intensely altered, by processes that involved the transfer of large tonnages of chemical substances into and out of the rocks affected. Quantitatively, tourmalinization and albitization are the most important processes that were active in the wallrocks about the mine. Tourmalinization is most widespread and abundant in the footwall rocks, particularly beneath the central portion of the orebody. It also has been active to a lesser degree along certain strongly deformed and fractured zones and so some tourmaline rock is present locally in both the ore zone and hangingwall beds. Locally, the contacts between the normal and the tourmalinized sediments are decidedly conformable. However, the general boundaries of the tourmalinized zone are distinctly transgressive as can be seen in Figure 17-9

Albitized rock is confined largely to the sediments in the hangingwall zone but some has been found in the footwall zone, particularly near the walls of some diorite dikes or associated with chlorite in certain large fractures that cut the tourmalinized footwall rocks. The effect of bedding on the distribution of albite is locally evident but fractures and other cross-cutting structures acted as the dominant controls in its distribution even more than in the case of tourmalinization.

Chloritized rocks seem to have formed under two sets of conditions. In one, chlorite is weakly but pervasively developed on a regional scale and is probably related to regional metamorphism and/or thermal effects of the Moyie intrusions. In this case, the chlorite would not be a true form of wall rock alteration. Chlorite that is believed to have formed as a true metasomatic alteration is closely associated with the orebody and is characterized by the development of zones of massive chlorite. These are found in some large footwall and hangingwall fractures and especially near the contact between the orebody and the albitized rocks, and in the hangingwall in the area about the central iron zone. This type undoubtedly formed by the passage of magnesium-bearing thermal waters and is therefore a true alteration product. Coarse biotite and actinolite are found locally, with massive chlorite and their formation is probably related to the same process.

Swanson and Gunning (1945) described the principal characteristics and relationships amongst the various types of altered rocks and these will not be repeated here. However, there is one aspect of the formation of tourmaline rocks that has come to light after their paper was published. It will be presented now because the writer believes that it may indicate that the Kimberley sill had intruded the sediments prior to the period of tourmalinization. Figure 17-9 shows that as the sill approaches and passes beneath the orebody it becomes dike-like and, near the western margin of the deposit, it is in contact with or even partially invades the ore zone beds.

The thermal effects of this intrusion can be observed best where the sediments have not been tourmalinized. For example, as the intrusion is approached in the southern part of the mine, the normally fine grained sediments become recrystallized to a sugary textured chlorite-biotite hornfels that extends to the intrusive contact. Within the local arch-like structure of the intrusion itself, the large mass of sediment that was enveloped by the magma was converted to an even coarser grained granitoid rock called biotite granophyre.

In the zone of intense tourmalinization, on the other hand, the tourmaline in the rocks well removed from the intrusion crystallized as a felt-like mass of pale brown cryptocrystalline needles surrounding the detrital grains of quartz, feldspar, etc. This tourmaline undoubtedly formed by the reconstitution of the original argillic constituents of the matrix or their diagenetically transformed counterparts, through the action of thermal fluids carrying boron ions. As the intrusion is approached, texture of the rock again coarsens to that of a hornfels. However, brown tourmaline is now a common mineral in addition to the minerals found in the hornfels mentioned earlier. These tourmalines are medium grained rather than cryptocrystalline. Finally, sedimentary zenoliths found within the intrusion, in the zone of tourmalinization, consist of coarse partly brown, partly blue tourmaline and quartz instead of the normal minerals that make up biotite granophyre.

The textural changes described in the foregoing suggest that the variation in the size of the tourmaline crystals was controlled by the textures of the hornfelsic and granophyric rocks which had formed in response to heat generated by the intrusion. That is, tourmalinization occurred some time after the intrusion of the sill. It will also be remembered that the cassiterite and associated sulphide minerals in the 'tin-zone' fracture had formed after the wall rocks were tourmalinized. If then, these conclusions are correct, they seriously weaken the argument for the Sullivan being a partly remobilized syngenetic deposit because the heat from the Sullivan sill could not have been available to effect this postulated remobilization.

The writer realizes that the explanation he has suggested for the relationships just described is not at this time too strongly supported by the evidence at hand. For instance, it might be suggested that the variation in the textures of the tourmalines could conceivably be the result of the Kimberley sill intruding the sediments after they had been tourmalinized rather than before and the writer is not able to present any evidence that would clearly refute this suggestion. However, he feels that in this case one should expect to find more tourmaline in the granophyric sediments that are enclosed in the intrusive where the latter is associated with the large mass of tourmalinized rocks rather than being largely confined to small scattered zenoliths near the border of the intrusive.

This leaves only one other probable way of raising the level of thermal energy in the deposit, namely: by a general rise of the geothermal gradient through deep burial or downfolding of the sediments on a regional scale. This suggestion is not supported by evidence. For example, although the sulphides in the Sullivan orebody locally contain moderately high temperature minerals such as spessartite garnet, actinolite, tremolite, scapolite and cordierite (H. T. Carswell, 1961), beds that are only a few inches away often do not contain any minerals indicative of correspondingly high temperatures. In fact, the mineral assemblages in much of the sediment in question generally indicate that the temperature of these rocks has been about that normally encountered during diagenesis or for the temperature range assumed for the lower limits of the chlorite-albite metamorphic facies. This point is supported also by investigations on the temperature of formation of the pyrrhotite, sphalerite and pyrite that are associated with the cordierite, etc. Carswell (1961) found that the minimum temperature of formation for sphalerites in the Sullivan ranged from 460° - 490° C. and for pyrrhotite from 325° - 400° C. Thus the contrast in temperature of formation between the minerals in the sediments and in the adjoining mixed sediment - sulphide layers appears to be incompatible with what one should expect if the temperature of the whole sedimentary pile had been raised appreciably by regional downwarping, etc. Nevertheless, the marked tendency for high temperature mineral assemblages to be more or less associated with many conformable sulphide-rich layers favors the suggestion that thermal energy travelled through or along some beds

DISTRIBUTION OF METALS

In the preceding pages, highlights of the local and regional geology were given in order to show that some of the recent hypotheses suggested for the origin of conformable base-metal sulphide deposits do not fit too well with the situation at the Sullivan. As a concluding step, let us now examine the patterns of distribution displayed by several of the more important metallic constituents of the deposit to determine whether this phase of Sullivan geology will shed some light on the question of origin.

The abundance of assay information required to outline reserves and to maintain grade control in a large integrated base metal complex such as Cominco, provides excellent opportunities to study the variation in the distribution of the more important metals in the deposit. The geological staff has been interested in this subject and has prepared distribution and ratio maps for several of the metals as a matter of scientific interest as well as for their proven practical value. The maps clearly reveal that there are patterns to the distribution of many of the metals in the mine and that comparisons can be made and relationships drawn with respect to geological features such as structures, zones of alteration, etc. The maps also provide excellent bases for speculation into the question of the origin of the deposit and some of them are being presented now because they do appear to offer some, if not conclusive, support for an epigenetic origin. This of course, becomes more significant when coupled with other supporting geological evidence.

Pentland (1943) gave the first published statement concerning the distribution of metals in the deposit when he described the zoning of lead, zinc and tin in his paper on the occurrence of tin in the mine. In general, he noted that there is a marked, if not precisely defined, tendency for these metals to have a concentric but not similar distribution about the central iron zone.

Swanson and Gunning (1945) cautioned against a hasty acceptance of a concentric zonal concept because the subject was complicated and in their opinion required more study. They suggested that a more intensive investigation might reveal a pattern arising from the merging of two or more linear patterns.

Distribution of Iron

The so-called central iron zone, as presently outlined, has a roughly rectangular shape and it lies somewhat south of the centre of the structural dome on which the deposit lies. It is a compound unit, the western half consisting principally of massive pyrite and/or a mixture of pyrite and chlorite. The eastern half on the other hand, consists of vaguely banded pyrrhotite and/or a mixture of pyrrhotite and chlorite (Figs. 17-10 to 17-15). Iron sulphide, principally pyrrhotite extends outward from this zone, more or less in all directions beneath the commercial ore. Incidentally, the latter generally contains abundant pyrrhotite in addition to galena and sphalerite and the pyrrhotite would appear to be largely unreplaced host material with respect to much of the sphalerite and galena. Iron continues to be an important constituent right to the margins of the deposit. However, toward the southeast margin, pyrrhotite gradually gives way to fine grained crystalline pyrite and magnetite in variable amounts commonly accompanies the pyrite. Viewed from the centre of the deposit, this change generally appears in the upper bands before it does in the main band. Another important pyrite zone has been found near the northeast margin of the deposit associated with sediments that are distinctly schistose. The pyrite here is coarsely crystalline and contains considerable carbonate and somewhat less chlorite.

Considerable pyrrhotite is present in the tourmalinized rocks beneath the central part of the deposit either as laminations or blebs in the unfractured areas or as veins and stockworks of veins in fractured and brecciated zones. Numerous veins of glassy quartz and pyrrhotite also cut these rocks.

Distribution of Lead and Zinc

Figure 17-10 shows the broader variations in the lead-zinc ratio for a large part of the main orebody. In general, it can be seen that there is a marked tendency for lead to be proportionally more abundant than zinc in an irregular belt about the central part of the domical structure. Lead gradually gives way to zinc as the dominant metal toward the margins of the deposit. Superimposed on this rudely concentric pattern is a clear but secondary tendency for the trend of ratio values to be lineally oriented in a northerly direction. In most cases these lineal patterns correspond in direction and position to Sullivan type folds and fractures.

Figures 17-11 and 17-12 s..ow, in undefined units, the variation i. ,ad and zinc content respectively for the main orebody. Both reveal a similar tendency for the two metals to be concentrated about the central part of the domical structure. Again, there are secondary north-trending patterns of highs and lows that are associated with some of the Sullivan type structures.

In addition to the zonal distribution in plan, there is a distinct tendency for these metals to be zoned in a vertical sense, particularly in the central part of the mine. This relation arises because galena and sphalerite tend to form extensive layers of rich, beautifully banded ore against the hangingwall of the main ore band. This well banded ore passes downward into a rich massive mixture of pyrrhotite, galena and sphalerite that in turn passes into a thick irregular zone of pyrrhotite that carries only a trace of galena and sphalerite. Generally this barren, pyrrhotite zone extends to the sulphide footwall. However, in several places, mineable ore shoots occur along the footwall contact owing to the introduction of galena and to a lesser extent, sphalerite, into the massive pyrrhotite as laminations, streaks or narrow, vaguely defined bands. These ore shoots probably represent relatively more permeable zones caused by a differential movement between the pyrrhotite mass and the footwall sediments during folding and their development apparently coincided more or less with a period in which lead was the main metal being introduced into the ore zone.

The distribution of lead and zinc in the hangingwall ore bodies has the same general pattern as in the main zone. That is, the highly disturbed central zone of these orebodies is generally richer in lead than zinc and zinc becomes the more abundant metal toward the margins.

Distribution of Silver

Most of the silver in the mine is associated with galena, probably as a solid solution in the latter. Small grains of tetrahedrite have been observed under the microscope, but the mineral probably is rare. Small bits of a white mineral that was thought to be native silver have been noted on occasion in microscopic studies of certain mill products.

Silver is not distributed uniformly throughout the mine and furthermore the silver content of galena varies considerably. In the main orebody, the high silver zone parallels fairly closely the high lead belt and both the silver content of the ore and the ratio of silver to lead gradually diminishes toward the margins of the deposit.

The ratio of silver to lead is in general somewhat higher for the hangingwall ore than it is for the ore in the main vein. There is also a definite tendency for the hangingwall orebodies that border the central iron zone to have higher silver to lead ratios than hangingwall orebodies that are more remote. In a very general way, the silver to lead ratio varies inversely with distance from the central iron zone.

According to Guild (1917) the maximum amount of silver that is soluble in galena is 0.1 percent (0.30 ounces per unit of lead). Inasmuch as the ratio for many samples in some of the hangingwall ore shoots is appreciably higher than this, it is quite probable that some of the silver occurs as ex-solved native silver or as other argentiferous minerals whose textures are so fine that they have escaped detection.

The reason for the tendency for the hangingwall orebodies to have a higher silver to lead ratio than the main orebody is not clearly understood. The relationship suggests that they may have formed at somewhat higher temperatures. Possibly they represent material that was deposited early in the depositional period whereas the silver in the main orebody may have been diluted by a later phase of low-silver lead that did not have access to the hangingwall orebodies.

Distribution of Tin

Cassiterite is definitely the dominant tin mineral in the Sullivan Mine. Other tin minerals may be present in small amounts but they have not been isolated and identified as yet. Tin occurs in strong traces in the mineral boulangerite but the amount in this mineral is not enough to influence significantly the distribution pattern for tin in the main orebody.

Our studies on the variation of tin (Fig. 17-13) in the main orebody reveal that most of it is concentrated in an irregular belt around the central iron zone, especially on its eastern side, and falls off to bare traces at the margins. In addition, most of the tin in the belt of highs is associated with the pyrrhotite-rich zone that lies just above the footwall of the orebody and the values tend to fall off toward the hangingwall. In detail, the distribution of values can be decidedly variable, small very rich pockets being associated with certain Sullivan-type folds, faults or fractures.

central iron zone carry more tin than the footwall veins nearer the margins.

Local concentrations of tin have also been found in the hangingwall zone but these occurrences are relatively rare. They are more abundant in the central part of the mine and are generally associated with structurally disturbed zones in which the hangingwall rocks have been tourmalinized and fractured prior to the introduction of pyrrhotite, cassiterite, etc.

Although pyrrhotite is the most common mineral associate of cassiterite, the relationship is not a direct one, because there are very large tonnages of pyrrhotite that contain practically no tin. Structures and temperature zoning may have been the principal factors governing the distribution of this mineral, the stability field of the tin ions in the mineralizing fluid being considerably narrower than that for iron.

The tin content of the hangingwall ore bodies is not well documented. From the data at hand it would appear to be low even where these ore shoots lie above areas of high tin in the main orebody.

Distribution of Arsenic

Arsenopyrite is the only arsenical mineral that has been identified in the mine. Assays indicate that most of this element in the main orebody is concentrated in a belt around the central iron zone. Its distribution pattern is therefore somewhat similar to that of tin and silver (Fig. 17-14).

Although both tin and arsenic appear to have been deposited early in the ore forming period, our information indicates that they were not deposited simultaneously to any important extent.

Information on the distribution of arsenic in the hangingwall orebodies is limited to only one of them. The scanty data indicate a central high with values diminishing toward the margins.

Small scattered crystals of arsenopyrite are frequently observed in beds near the footwall of the main orebody, particularly where these beds have been tourmalinized and then fractured and mineralized. Locally rather rich patches have been observed in fractured footwall sediments well removed from the tourmalinized zone. However, most of these occurrences were observed visually and we do not have any quantitative data on the distribution of arsenic in this environment.

Distribution of Antimony

Boulangerite is the predominant antimonial mineral in the Sullivan. Jamesonite, tetrahedrite, gudmundite (Ramdohr 1955), chalcostibite (Carswell 1961) are other antimonial minerals that have been recognized but they occur only in small or trace amounts.

Our studies on the distribution of antimony in the main orebody reveal that there is a decided tendency for this element to be concentrated in an irregular belt near but somewhat in from the margins of the deposit and to be low in the central zone (Fig. 17-15). This is a reversal of the relationship found for tin and arsenic. Again the details of the distribution pattern have been influenced decidedly by certain Sullivan-type fractures and associated folds.

Boulangerite occurs most abundantly in or near open fractures particularly where they cut the ore. It crystallized as spectacular felt-like masses of fine flexible needles on the walls or in openings associated with the fractures. The fact that most of the fragile needle-like crystals were not crushed and broken suggests that they crystallized late in the period of sulphide deposition and after the last period of movement along many of boulangerite-bearing fractures. However, smeared and crushed aggregates of galena and boulangerite on the walls of some of the fractures indicate that part of the boulangerite had crystallized before the last movement.

Summary

In summary, it is evident that the dominant pattern for the distribution of most of the metals in the Sullivan is a clear tendency for the variation in values to be roughly concentric to the central iron zone which is located near the centre of the domical structure on which the deposit is situated. Superimposed on this broad concentric pattern are numerous smaller but important northerly trending lineal patterns that in most cases are clearly associated with certain Sullivan-type faults, fractures and/or folds. In addition, it is clearly evident that tin, arsenic, probably tungsten and to a lesser extent silver, are concentrated near the central iron zone where the effects of wall rock alteration are most intensively developed. Antimony, on the other hand, tends to be concentrated away from the central iron zone, nearer the margin of the deposit, where the effects of wall rock alterations range from weak to minimal. It should be noted that the lead and zinc content maps do not show the concentric pattern nearly as clearly as do the maps for the other metals, because so much of these metals is concentrated in the anticlinal warp at the north-central part of the mine. Here, the total thickness of the ore-zone is very much greater than elsewhere. However, the lead-zinc ratio map has a very distinctly concentric pattern and it shows that the central part of the orebody is relatively richer in lead than zinc. On the other hand, as the margins are approached, the zinc content of the body gradually increases until it becomes several times that of lead.

The zonal relations of the metals just described are manifestly not features that one would expect to find in a sulphide body that was formed in a marine sedimentary basin. On the other hand, the relations of these distribution patterns with respect to the central iron zone and the areas of intense wall-rock alteration are what would be expected for an epigenetic hydrothermal deposit in which the metal-bearing fluids emanated from a central source, with the spread of these fluids into the ore zone beds being facilitated by the Sullivan-type fractures, etc.

The position of the lead-rich zone with respect to the zinc-rich zone in the orebody is not what would be expected for a simple case of temperature zoning where the metallizing solutions spread out from a central source. Under these circumstances, the higher temperature minerals should crystallize near the point of dispersal and the lower temperature minerals farther away. Applying this to the Sullivan, one would then expect the zinc-rich belt to be near the central iron zone and the lead-rich belt to be near the margins which is not the case. The history of ore deposition at the Sullivan is therefore probably more complex and may have proceeded somewhat as follows: At the onset of metallization, the ore-bearing fluids were rich in iron, contained some zinc and were poor in lead. They spread widely and deposited iron sulphide abundantly. As time passed the fluids became zinc-rich but still carried considerable iron and possibly somewhat more lead. Because of the warming action of the advancing fluids on the country rocks, the fluids following were able to move well out from the central iron zone before the metals were precipitated. Shortly after this the intensity of mineralization appears to have fallen off substantially and by the time the fluids had become lead-rich the ore zone rocks may have cooled to the point that most of the galena was deposited just beyond the central iron zone instead of near the margins of the deposit.

CONCLUSION

In view of the abundance and the remarkable perfection of the interbanding of sediments and sulphides in the Sullivan orebody, (Fig. 17-16 to 17-18), it is quite natural and understandable that some geologists would suggest in print or in formal discussions on the subject of strata-bound or conformable massive sulphide deposits that the Sullivan orebody is some form of a syngenetic sedimentary deposit rather than a hydrothermal replacement deposit as stated in the latest papers by Cominco geologists on the subject (Swanson and Gunning, 1945; Staff, 1954). Apparently one of the main difficulties with the hydrothermal theory in the eyes of many who favor a syngenetic origin is that they find it very difficult to believe that the extent and perfection of the banding at the Sullivan could be effected by a replacement process.

Because of this conflict of opinion, the writer has attempted to review the sedimentological, structural, igneous and metallogenetic evidence, both locally and regionally, that pertains to the Sullivan in order to determine how well the evidence at hand supports or is in conflict with the various theories proposed.

The study of the composition and the textures of the Aldridge beds, and the ore zone beds in particular, indicates that they must have formed in a shallow to moderately deep marine environment that was essentially uniform over considerable distances. At this time, this part of the Beltian basin appears to have been supplied with such an abundance of fine grained clastic sediment that any chemically precipitated carbonate or sulphide or organic debris must have been well diluted by the incoming muds, and furthermore, turbidity currents appear to have been very effective in homogenizing and respreading the sediment widely across the floor of the basin. Assuming, for the moment, that most of the sulphides of iron, zinc and lead in the orebody are sedimentary, their remarkable thickness and richness within such a highly restricted area would seem to call for such uniqueness in the depositional environment of even a barred basin that it is almost impossible to rationalize it with the record for the clastic sediments so closely associated with the sulphides.

Also if submarine thermal springs of volcanic affiliations had been largely responsible for the introaround these springs would be present with the sulphides. And surely the rocks through which these mineral-charged fluids had passed would bear their imprint as do the wall rocks in the vicinity of modern thermal springs.

Our study of the evidence of igneous activity in the region reveals that the only known lavas and their associated pyroclastics were extruded only after many thousands of feet of sediment had accumulated above the ore zone beds. Even the oldest of the dated Moyie intrusions intrudes beds of Aldridge sediments that are younger than the ore zone beds. The recent discovery of a late Precambrian granite pluton and its pegmatitic offshoots in the area establishes the fact that magmas capable of differentiation were active in the area about the time the orebody was formed as postulated by Swanson and Gunning (1945).

At the mine, the large masses of intensely metasomatized wallrock and the numerous cross-cutting sulphide veins and massive replacements of similar mineralogy are clear indications that mineralizing solutions had been very active after the sediments had become consolidated and altered. The remarkable zoning can also be explained better by an epigenetic hydrothermal than by a sedimentary process. Finally in view of the fact that orebodies are relatively rare because they are the result of unusual geological circumstances, the probability that an unusually large and rich sedimentary base metal sulphide deposit would be so intimately associated with epigenetic orebodies and their unique structural and environment must be very low indeed.

In conclusion, it must be apparent that the geologic evidence at hand offers very little support for a marine sedimentary origin for the Sullivan and that it abundantly if not conclusively supports an epigenetic hydrothermal origin. Even if this is accepted as the best working hypothesis, it must be realized that only the broad framework of the formative processes has been delineated and a tremendous amount of research is still needed to complete the picture satisfactorily.

REFERENCES

Billings, M. P., 1954; Structural Geology.

Carswell, H. T., 1961; Origin of the Sullivan Lead, Zinc, Silver Deposit, British Columbia, Unpublished (restricted) Ph.D. Thesis, Queen's University.

Cominco Staff, 1954; Cominco Volume, Can. Min. Jour., May pp. 144-153.

Ehrenberg, Hans et al, 1954; Das Schwefelkies - Zinchblends - Schwerspatlager von Meggen (Westfalen), Beihefte Zum Geologischen Jarbuch, Heft 12, Hanover.

Guild, F. N., 1917; A Microscopical Study of the Silver Ores and their Associated Minerals, Econ. Geol. v. 12, pp. 297-340.

Hunt, G. H., 1961; The Purcell Eruptive Rocks, M.Sc. Thesis, University of Alberta.

Kraume, Emil, 1955; Die Erzlager des Rammelsberges bei Gossler, Beihefte zum Geologischen Jarbuch, Heft 18, Hanover.

Leech, G. B. et al, 1961; Lead Isotope and Potassium-Argon Studies in East Kootenay, Buddington Volume, Geol. Soc. America.

Leech, G. B., 1962; Metamorphism and Granitic Intrusions of Precambrian Age in Southeastern British Columbia, Paper 62-13, Geol. Surv. Canada.

McEachern, R. G., 1946; Private Report.

Owens, O. E., 1959; Private Report.

Pentland, A. G., 1943; Occurrence of Tin in the Sullivan Mine, Can. Inst. Min. and Met. Trans. v. XLVI, p. 17-22.

Pettijohn, F. J., 1957; Sedimentary Rocks, Harper.

Reesor, J. E., 1954; Preliminary Map, Dewar Creek Area, B. C. Paper 53-25 Geol. Surv. Canada.

Reesor, J. E., 1957; The Proterozoic of the Cordillera of Southeastern British Columbia and Southwestern Alberta, Roy. Soc. Can. Spec. Pub. No. 2.

Rice, H. M. A., 1937; Memoir 207, Geol. Surv. Canada.

Schofield, S. J., 1915; Memoir 76, Geol. Surv. Canada.

Schwartz, G. M., 1926; Microscopic Features of the Sullivan Ores, E & M. J. September 4th.

Stanton, R. L. and Russell, R. D., 1959; Anomalous Leads and the Emplacement of Lead Sulphide Ores, Econ. Geol., v. 54, pp. 588-607.

Stanton, R. L., 1960; General Features of the Conformable "Pyrite" Ore-bodies, Part I - Field Associations; Can. Inst. Min. and Met. Bull, v. 53, pp. 24-29.

Sullivan, J., 1957; Ore and Granitization, Econ. Geol. v. 43, p. 471-498.

Swanson, C. O., and Gunning, H. C., 1945; Geology of the Sullivan Mine, Trans. v. XLVIII, Can. Inst. Min. and Met. p. 645-667.

Swanson, C. O., 1948; The Sullivan Mine, Kimberley, B. C. Internat. Geol. Cong. Gt. Britain, Part VII.

White, W. H., 1959; Cordilleran Tectonics in British Columbia, Bull. Am. Assoc. Pet. Geol., v. 43, p. 60-100.

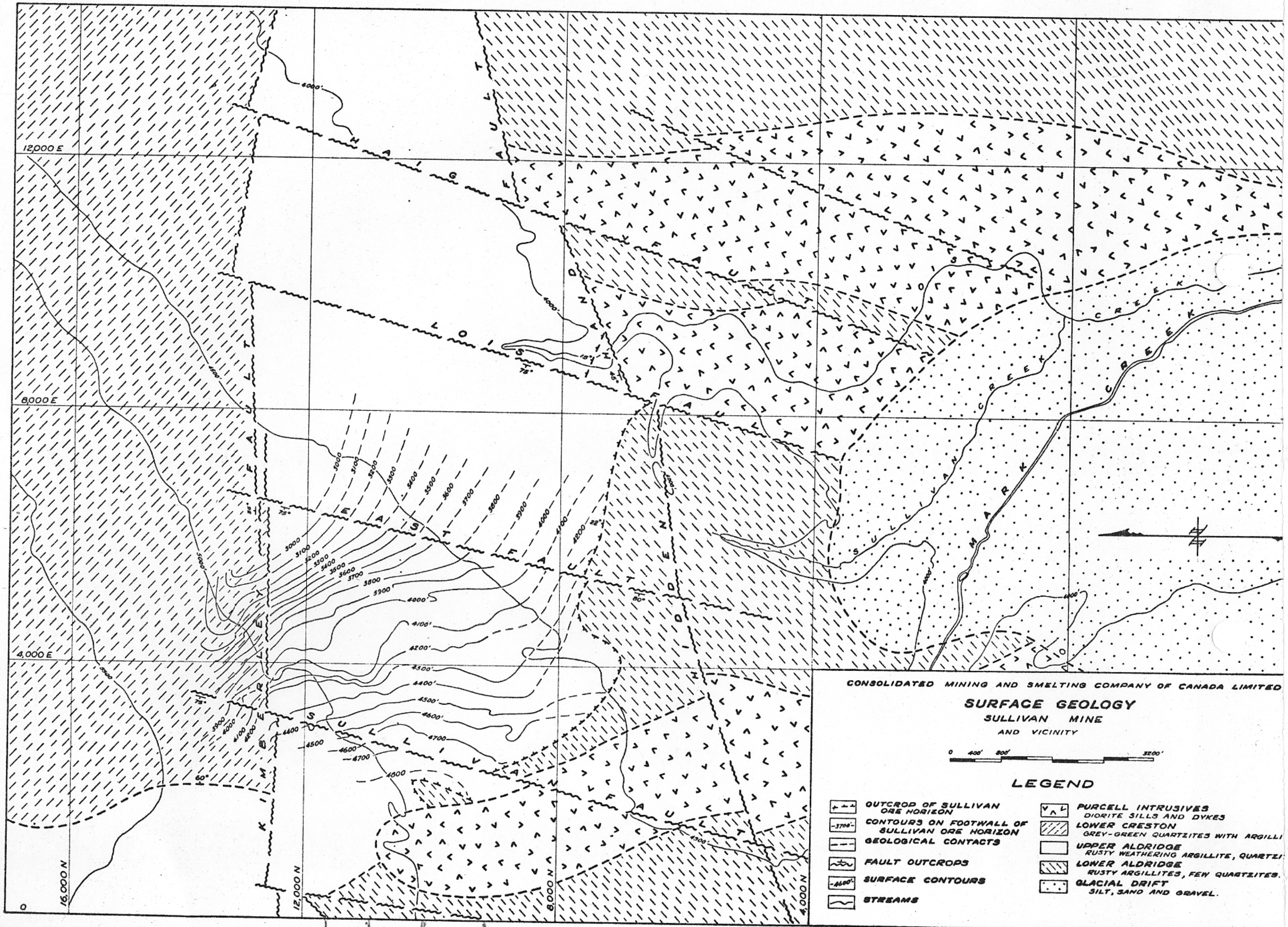

CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED
SURFACE GEOLOGY
SULLIVAN MINE
AND VICINITY
0 400' 800' 3200'
LEGEND
OUTCROP OF SULLIVAN ORE HORIZON
CONTOURS ON FOOTWALL OF SULLIVAN ORE HORIZON
GEOLOGICAL CONTACTS
FAULT OUTCROPS
SURFACE CONTOURS
STREAMS
PURCELL INTRUSIVES
DIORITE SILLS AND DYKES
LOWER CRESTON
GREY-GREEN QUARTZITES WITH ARGILLI
UPPER ALDRIDGE
RUSTY WEATHERING ARGILLITE, QUARTZI
LOWER ALDRIDGE
RUSTY ARGILLITES, FEW QUARTZITES.
GLACIAL DRIFT
SILT, SAND AND GRAVEL.
HAIG FAULT
LOIS FAULT
EAST FAULT
SULLIVAN FAULT
KIMBERLEY FAULT
HIDDEN FAULT
SULLIVAN CREEK
MARK CREEK
12,000 E
8000 E
4,000 E
16,000 N
12,000 N
8,000 N
4,000 N

Figure 17-1

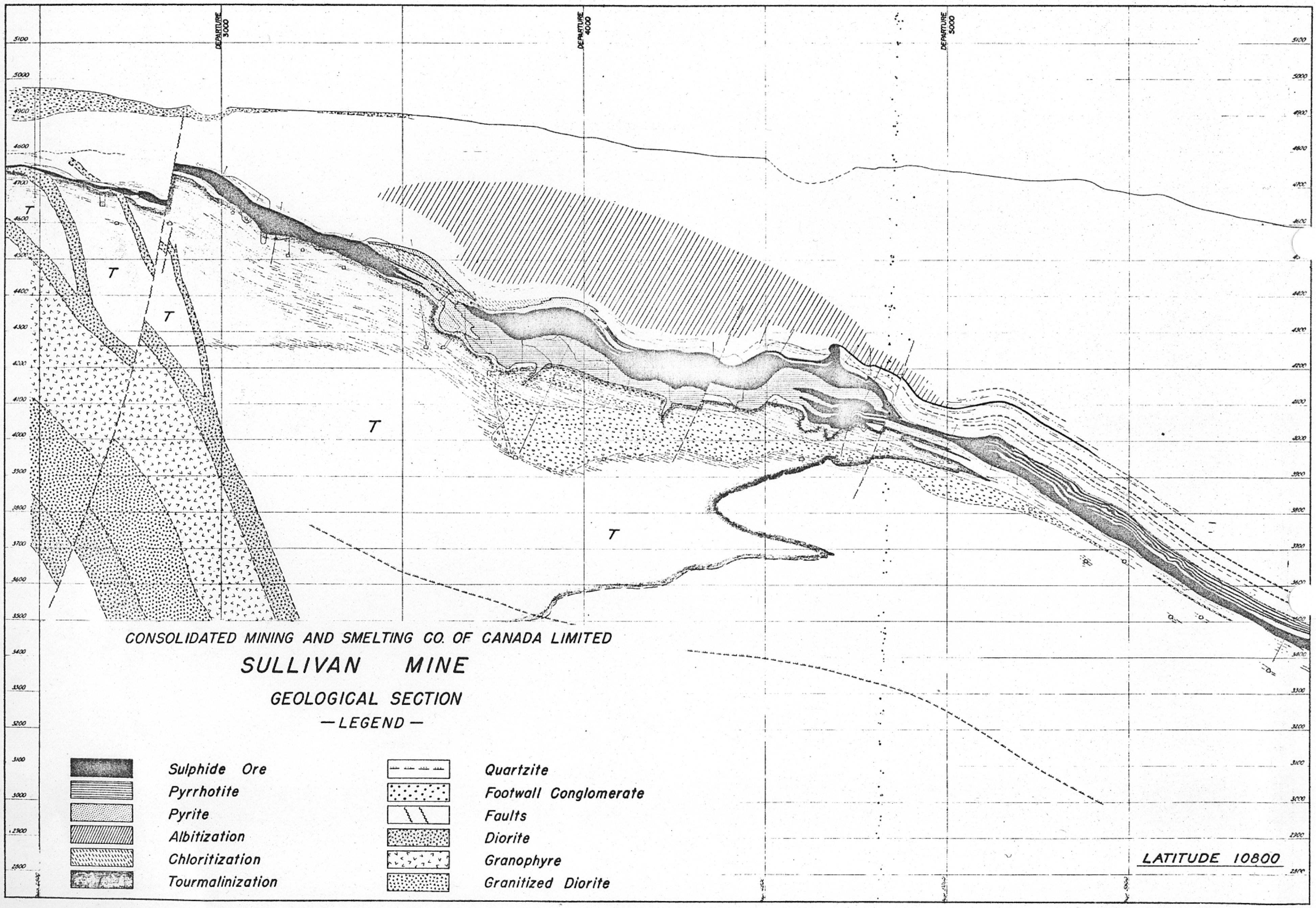

DEPARTURE 3000
DEPARTURE 4000
DEPARTURE 5000
5100
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
T
T
T
T
T
CONSOLIDATED MINING AND SMELTING CO. OF CANADA LIMITED
SULLIVAN MINE
GEOLOGICAL SECTION
— LEGEND —
Sulphide Ore
Pyrrhotite
Pyrite
Albitization
Chloritization
Tourmalinization
Quartzite
Footwall Conglomerate
Faults
Diorite
Granophyre
Granitized Diorite
LATITUDE 10800

Figure 17-2

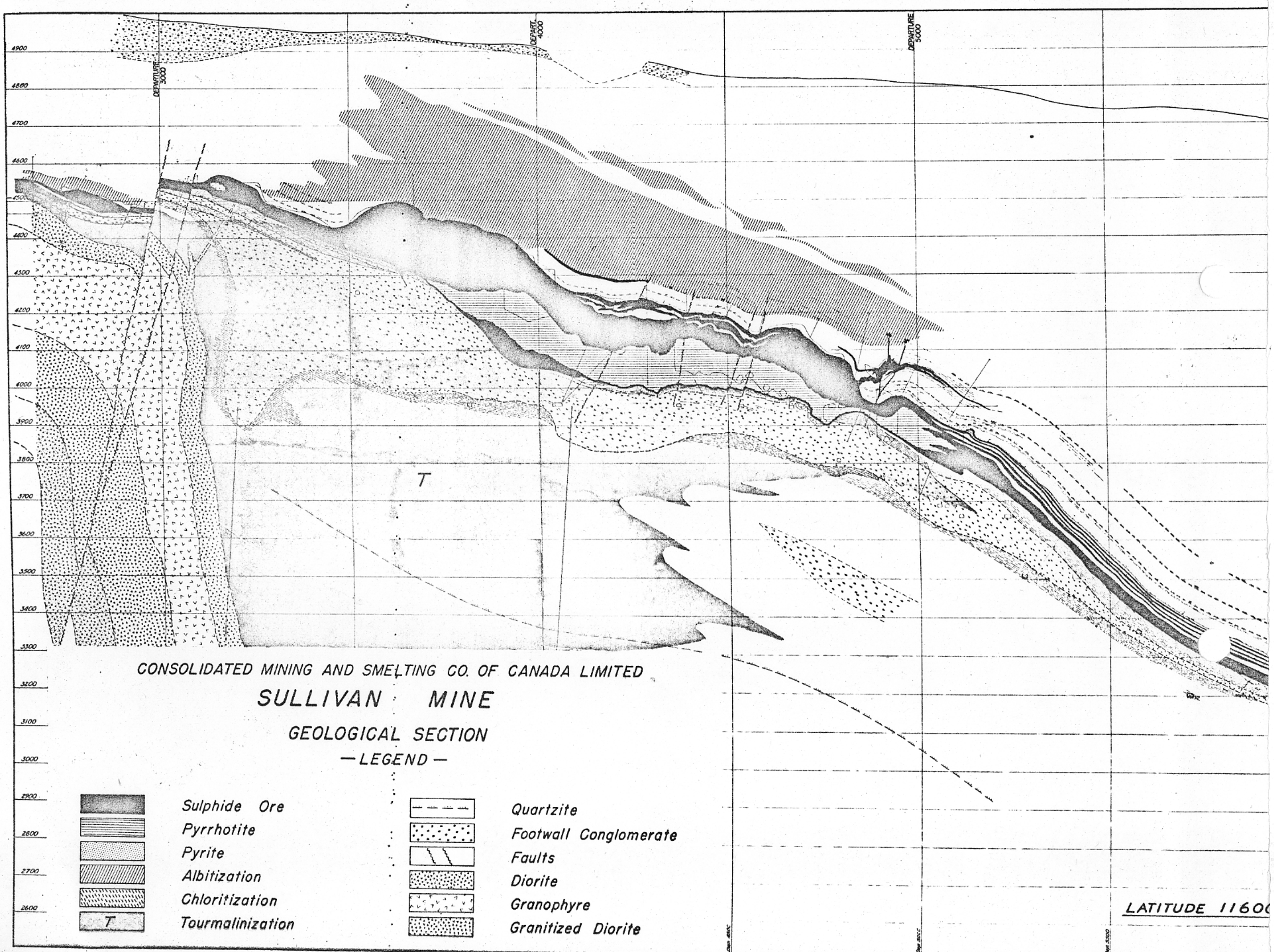
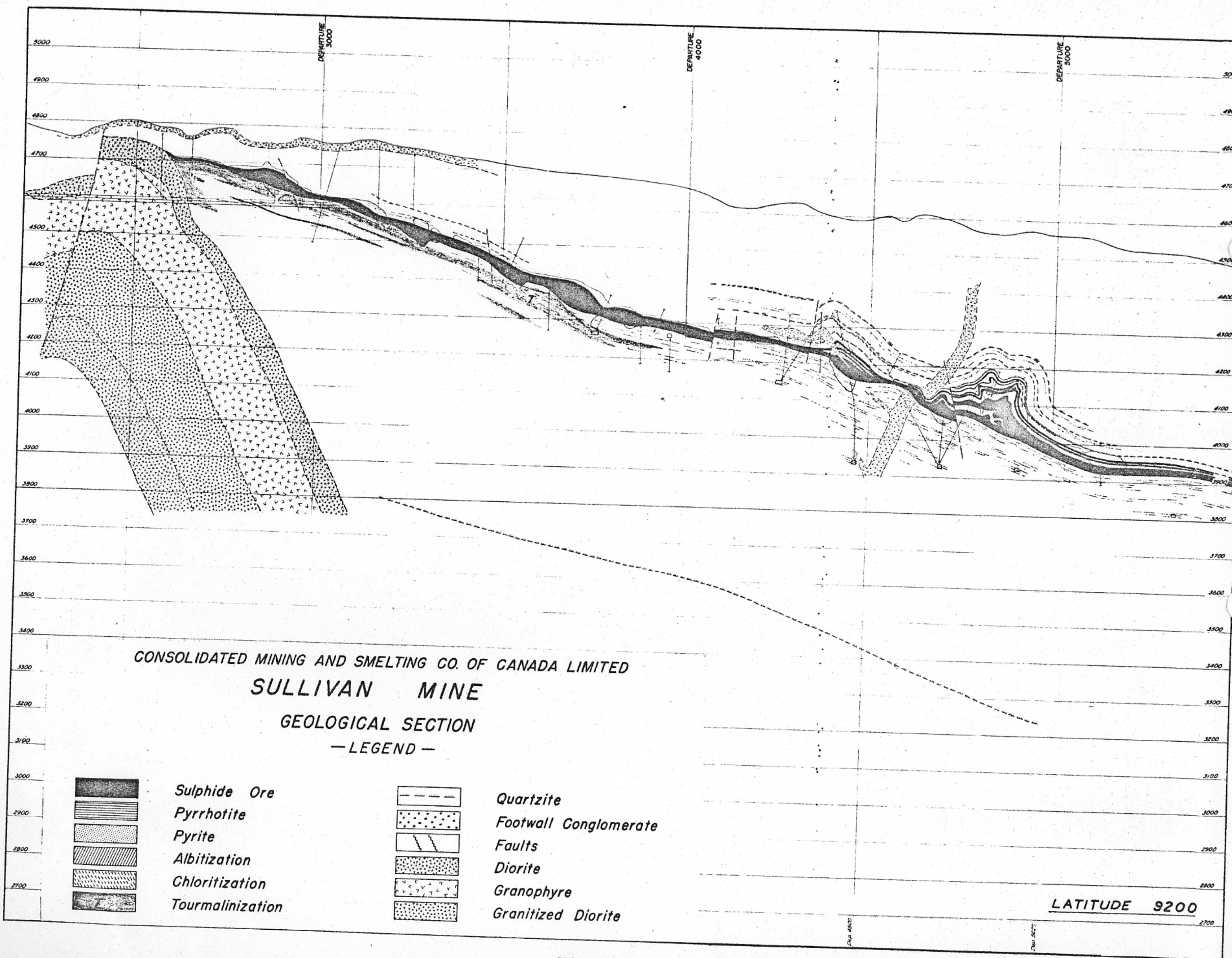

CONSOLIDATED MINING AND SMELTING CO. OF CANADA LIMITED
SULLIVAN MINE
GEOLOGICAL SECTION
—LEGEND—
Sulphide Ore
Pyrrhotite
Pyrite
Albitization
Chloritization
T
Tourmalinization
Quartzite
Footwall Conglomerate
Faults
Diorite
Granophyre
Granitized Diorite
LATITUDE 1160
DEPARTURE 3000
DEPART. 4000
DEPARTURE 5000
T
4900
4800
4700
4600
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600

Figure 17-3



DEPARTURE 3000
DEPARTURE 4000
DEPARTURE 5000
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
CONSOLIDATED MINING AND SMELTING CO. OF CANADA LIMITED
SULLIVAN MINE
GEOLOGICAL SECTION
—LEGEND—
Sulphide Ore
Pyrrhotite
Pyrite
Albitization
Chloritization
Tourmalinization
Quartzite
Footwall Conglomerate
Faults
Diorite
Granophyre
Granitized Diorite
LATITUDE 9200

Figure 17-4

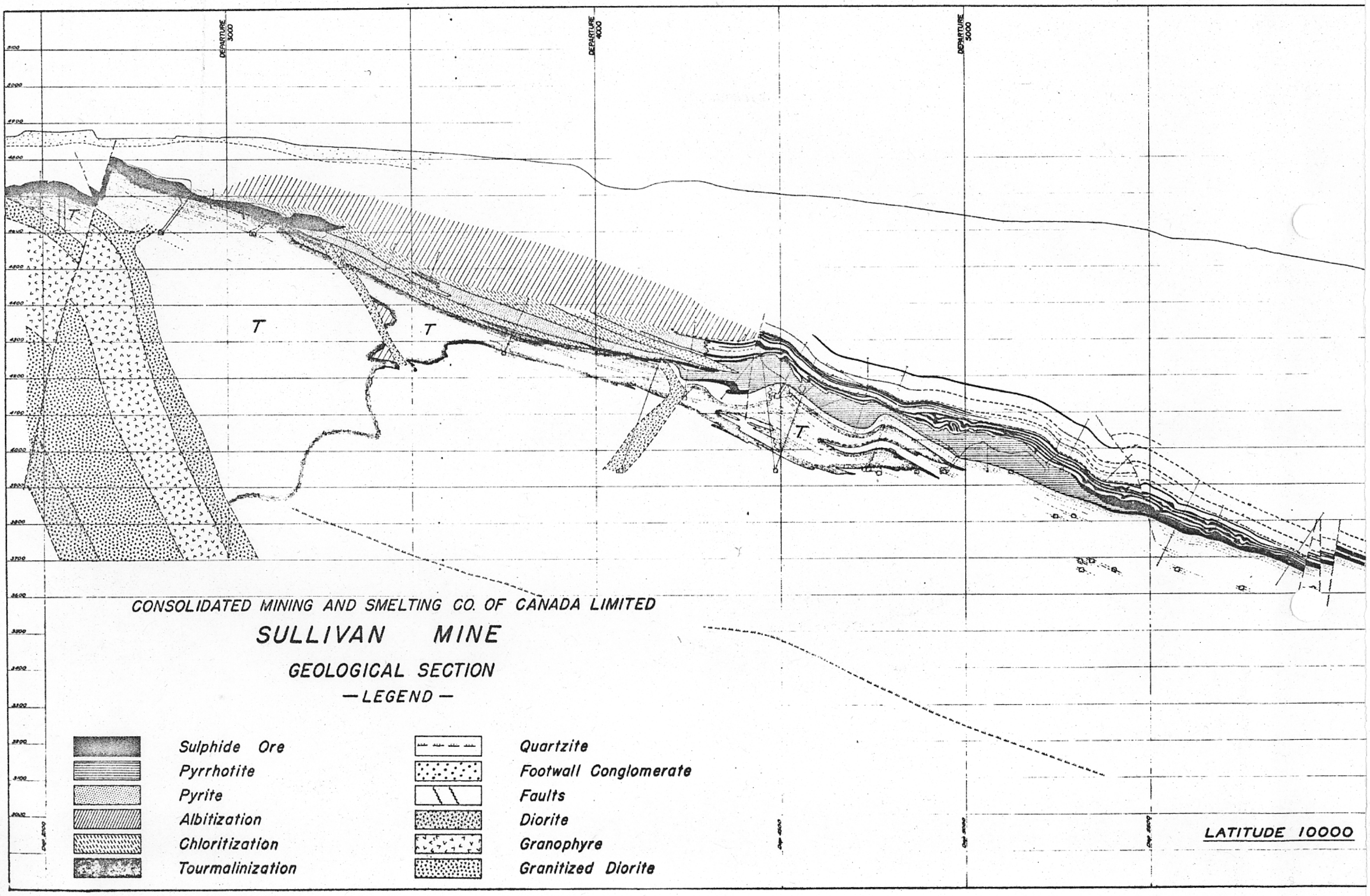

DEPARTURE 3000
DEPARTURE 4000
DEPARTURE 5000
T
T
T
T
CONSOLIDATED MINING AND SMELTING CO. OF CANADA LIMITED
SULLIVAN MINE
GEOLOGICAL SECTION
— LEGEND —
Sulphide Ore
Pyrrhotite
Pyrite
Albitization
Chloritization
Tourmalinization
Quartzite
Footwall Conglomerate
Faults
Diorite
Granophyre
Granitized Diorite
LATITUDE 10000

Figure 17-5

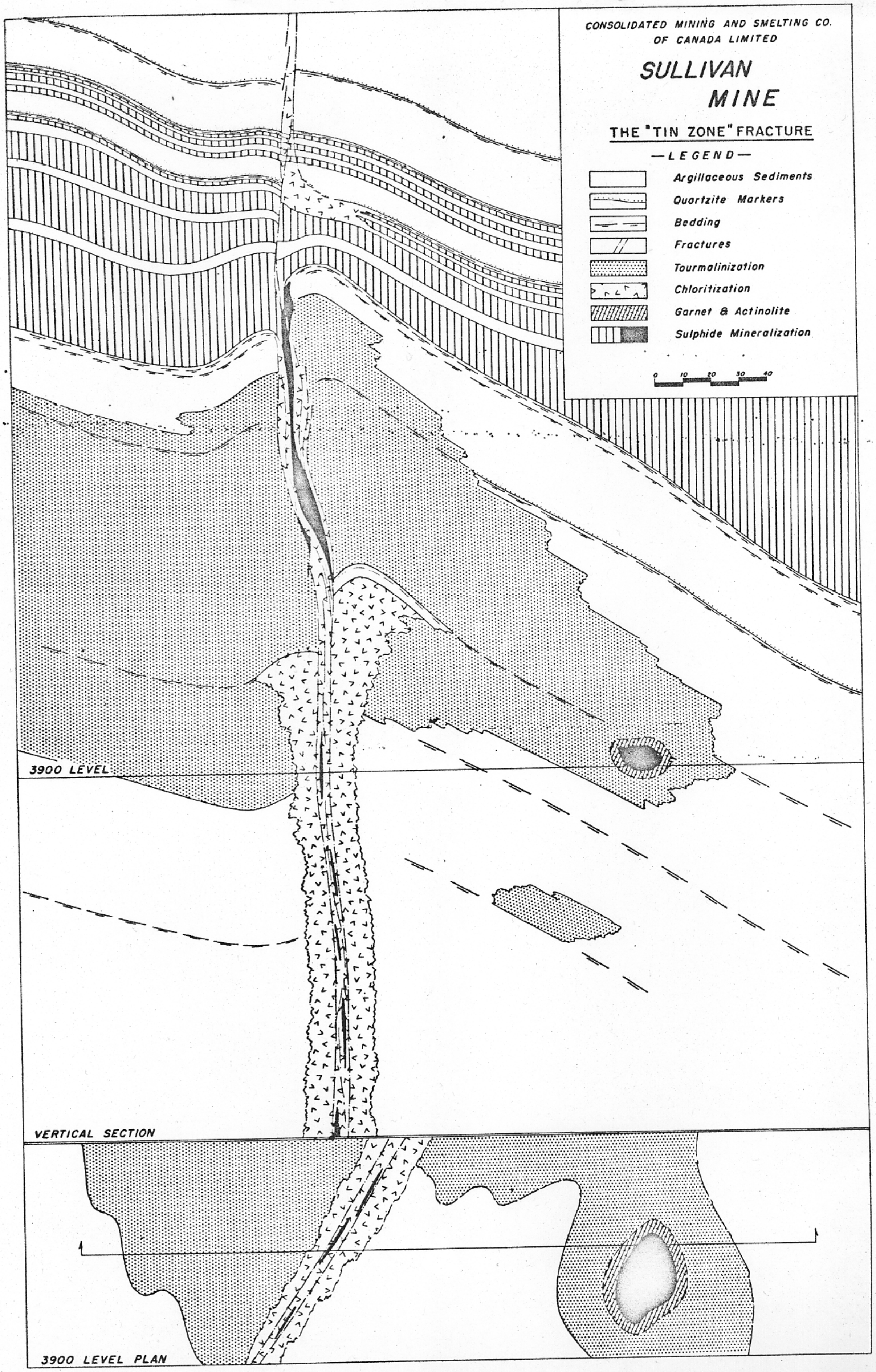

CONSOLIDATED MINING AND SMELTING CO.
OF CANADA LIMITED
SULLIVAN
MINE
THE "TIN ZONE" FRACTURE
— LEGEND —
Argillaceous Sediments
Quartzite Markers
Bedding
Fractures
Tourmalinization
Chloritization
Garnet & Actinolite
Sulphide Mineralization
0
10
20
30
40
3900 LEVEL
VERTICAL SECTION
3900 LEVEL PLAN

Figure 17-6

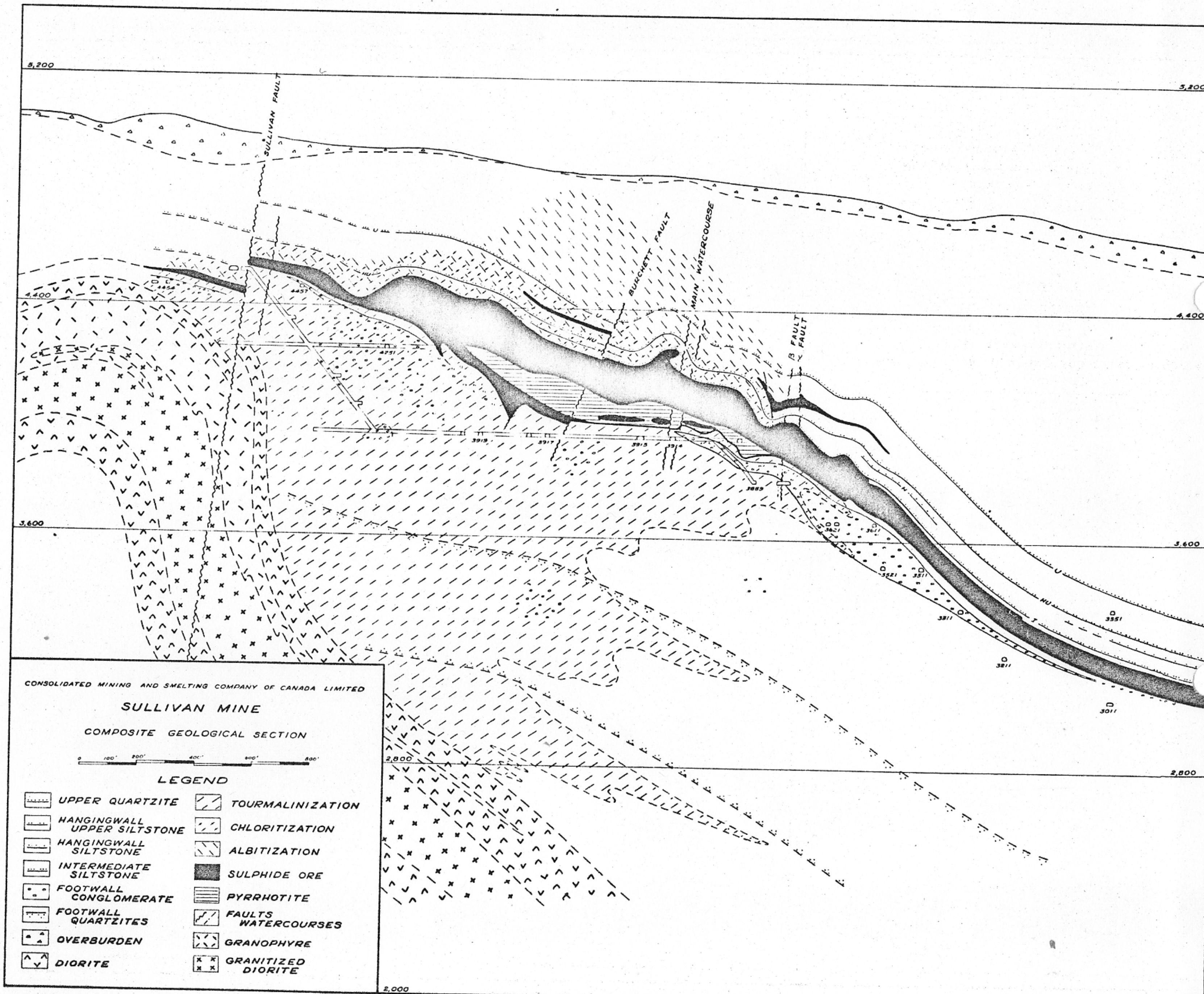

CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED
SULLIVAN MINE
COMPOSITE GEOLOGICAL SECTION
LEGEND
UPPER QUARTZITE
HANGINGWALL UPPER SILTSTONE
HANGINGWALL SILTSTONE
INTERMEDIATE SILTSTONE
FOOTWALL CONGLOMERATE
FOOTWALL QUARTZITES
OVERBURDEN
DIORITE
TOURMALINIZATION
CHLORITIZATION
ALBITIZATION
SULPHIDE ORE
PYRRHOTITE
FAULTS WATERCOURSES
GRANOPHYRE
GRANITIZED DIORITE
SULLIVAN FAULT
BURCHETT FAULT
MAIN WATERCOURSE
B FAULT
Y FAULT
5,200
4,400
3,600
2,800
2,000

Figure 17-9

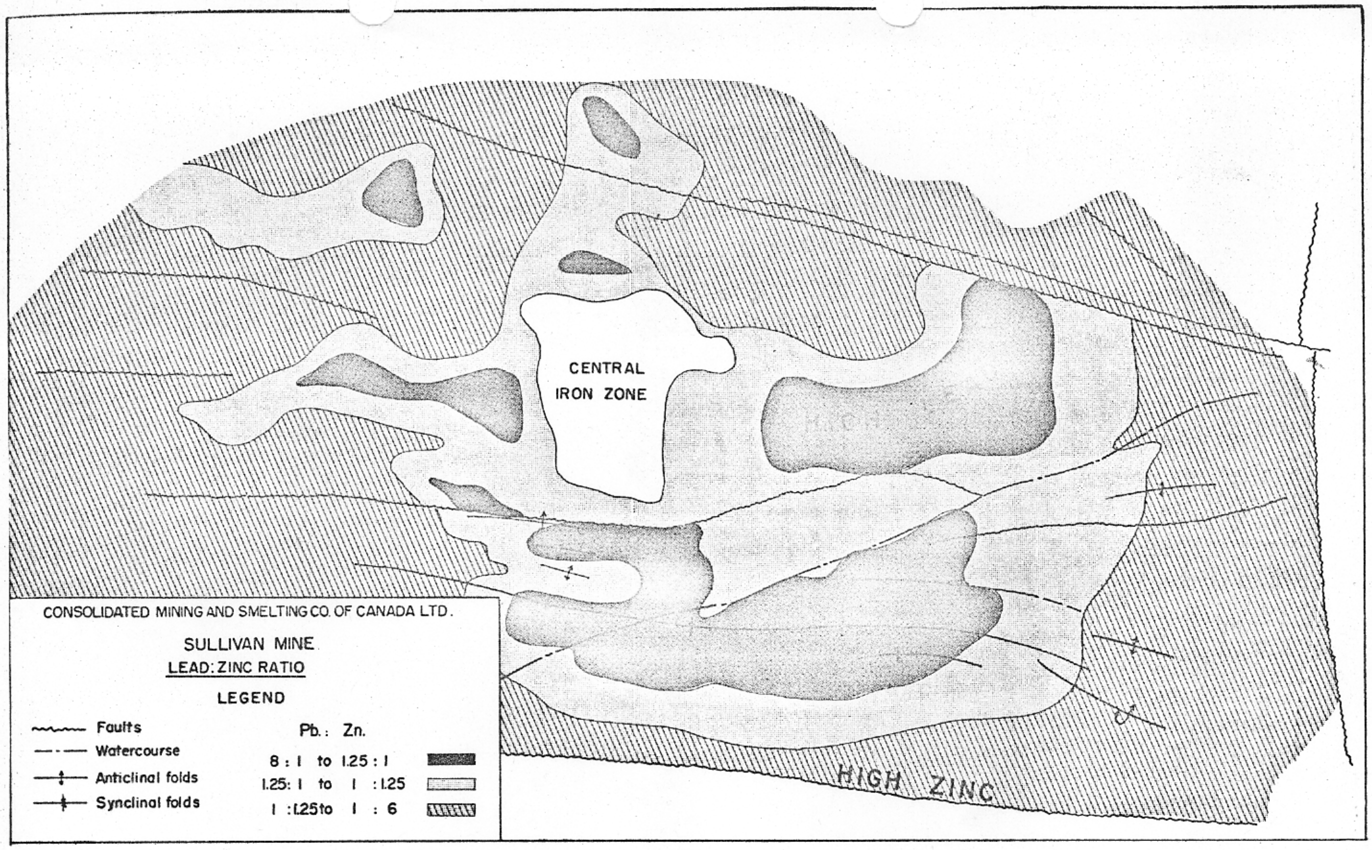


Figure 17-10

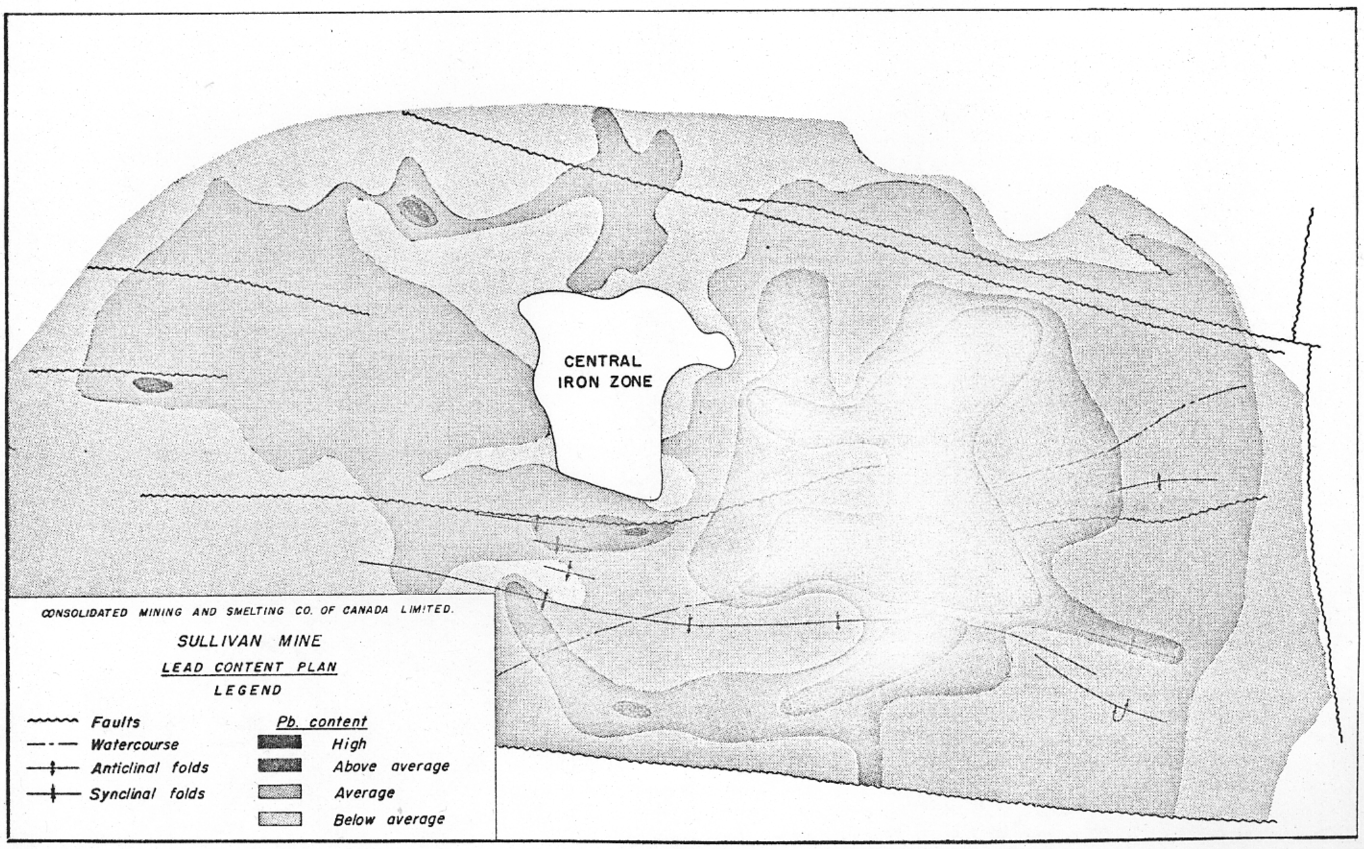


Figure 17-11

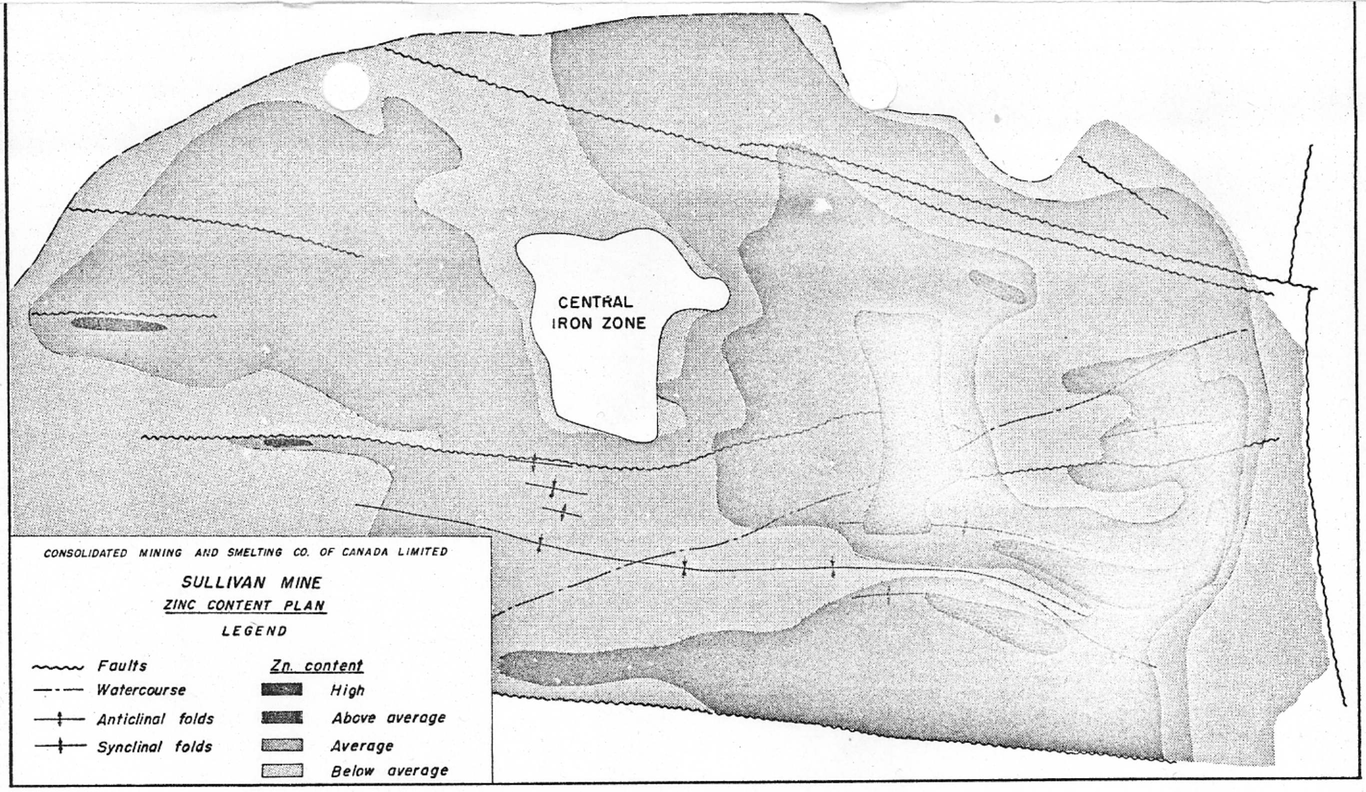


Figure 17-12

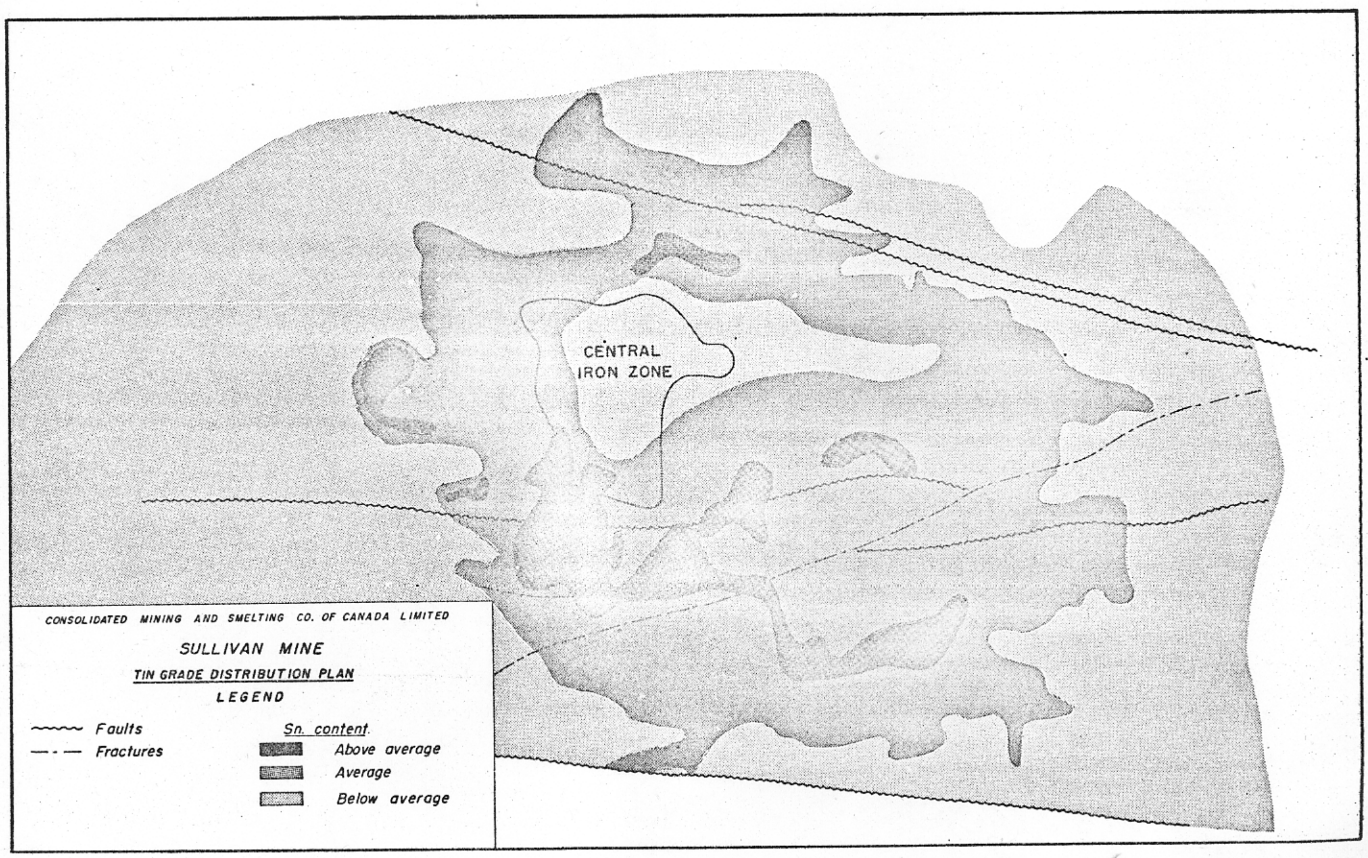


Figure 17-13

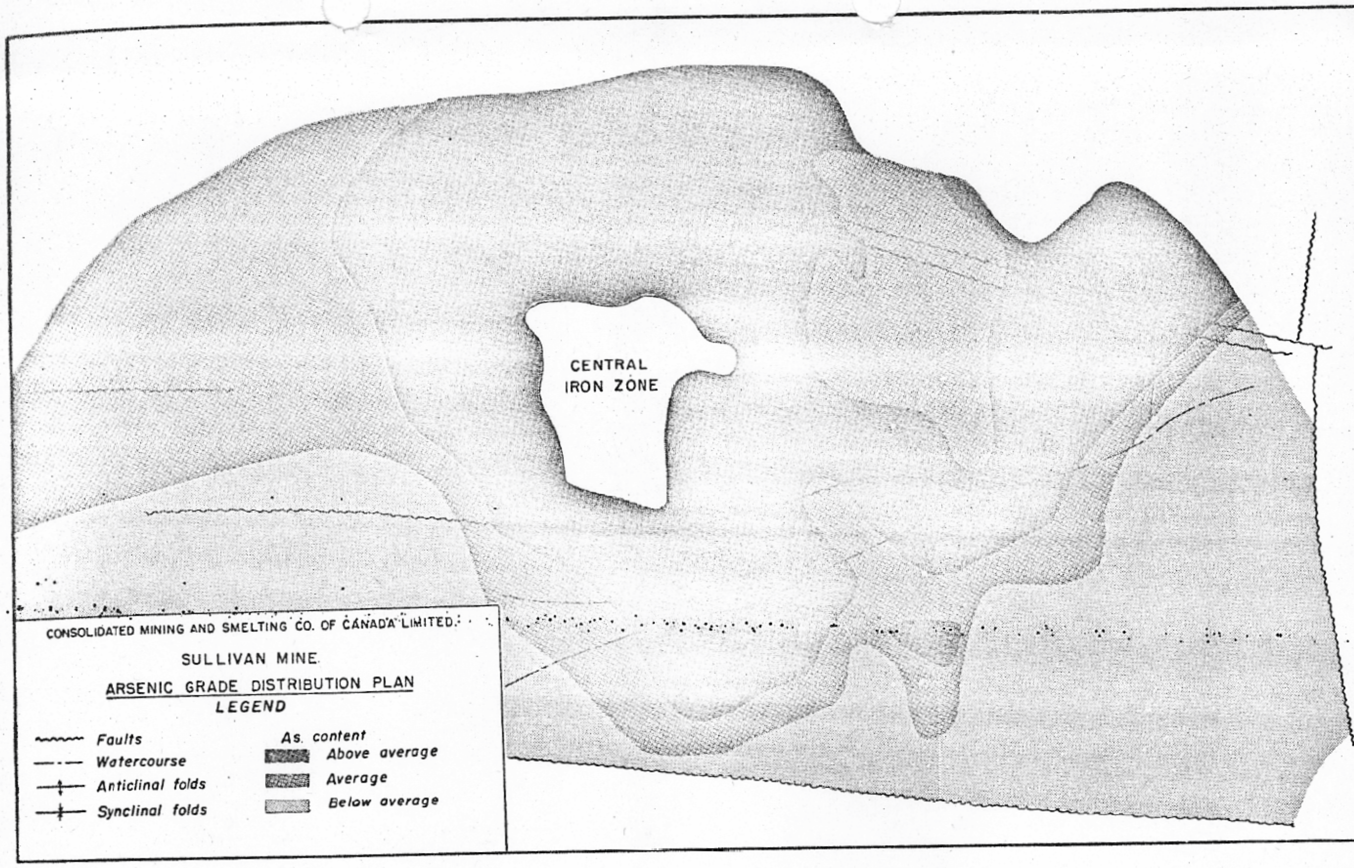


Figure 17-14

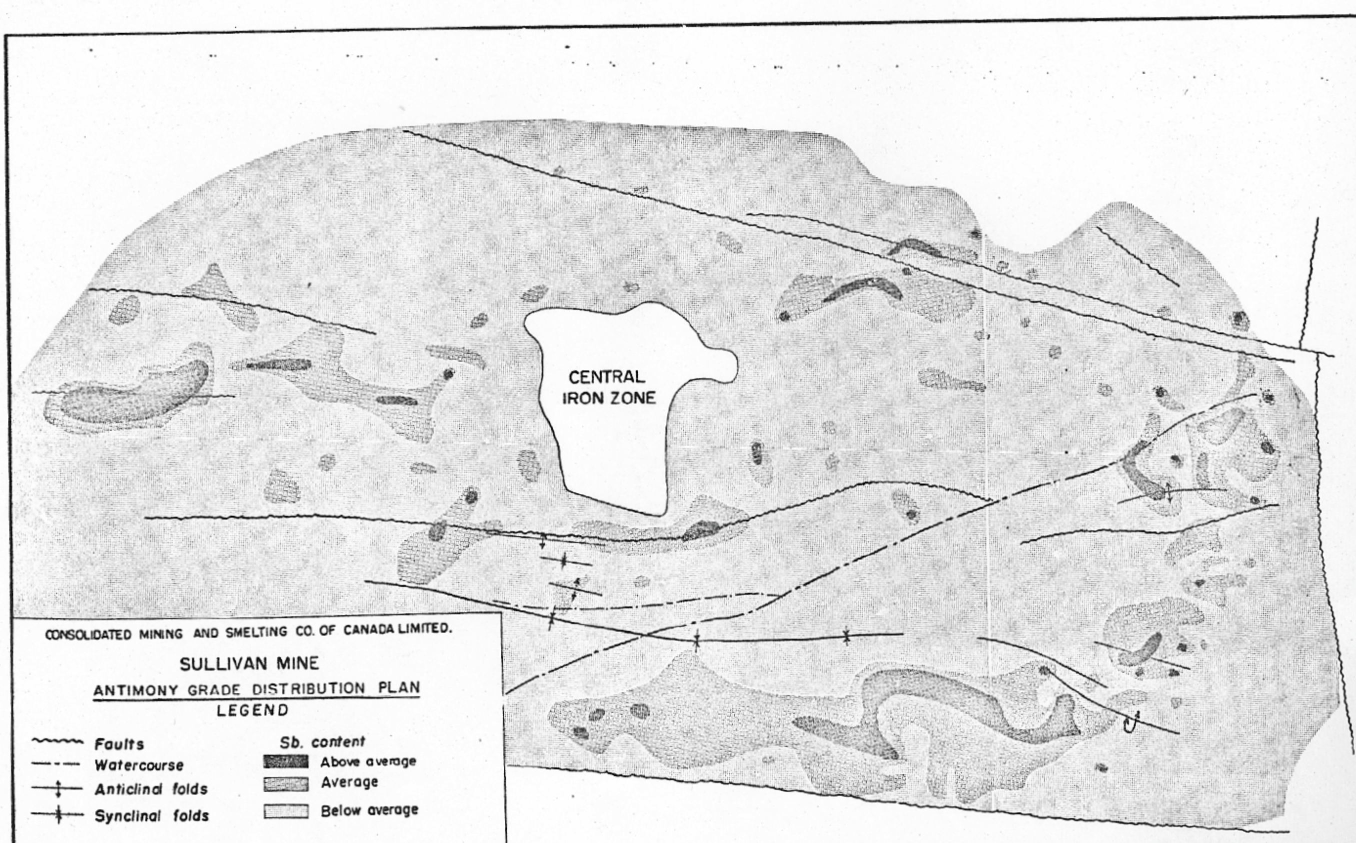


Figure 17-15