SILVER CUP MINE, LARDEAU
REGIONAL FRAME-WORK AND STRUCTURAL ORE CONTROL

by

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Ph.D., University of Hamburg, 1952

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GEOLOGY AND GEOGRAPHY

We accept this thesis as conforming to the
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degree of MASTER OF SCIENCE

Members of the Department
department of Geology and Geography

THE UNIVERSITY OF BRITISH COLUMBIA
April, 1957
ABSTRACT

The Silver Cup mine is about 10 miles east of Trout Lake in the Central Lardeau. From 1895 to 1915 it produced about 1.5 million oz. of silver and some lead, zinc, and gold. The problem of the paper is to study its geological setting and structural ore controls.

Eastwood has shown that the mine is close to the axial plane of a major isoclinal anticline that is overturned to the southwest and plunging to the northwest. He has correlated the greenstones in the core of the anticline with the top of the Bunker Hill Group and has named the overlying black slates and phyllites Triune Formation. These two stratigraphic units were divided into three and four members respectively. The repetition of certain horizons and the trend of contacts indicates that the major anticline here has two apices separated by a tightly compressed syncline.

Ninety five per cent of the production of the mine came from a zone that has a maximum length of 300 feet, a maximum width of 200 feet and has been stoped down to 1200 feet below its outcrop. Geological mapping shows that the ore is contained in openings of a structure that is a combination of a drag fold and a compressional bulge which is dipping with the host horizon to the northeast and raking.
steeply to the northwest. Host is the basal member of the Triune formation, a siliceous graphitic slate.

Three other ore zones in the vicinity of the main zone have a similar lenticular shape and steep rake and are contained in the same member, but they are not all in the same structural position with respect to the two apices of the major anticline. These observations suggest that the mechanical properties of the host rock rather than a continuous structure such as a fault or a shear zone are responsible for the localization of ore. It is shown how the texture of the host rock, the thickness of the host member and the texture of the overlying rocks facilitate the formation of lens-like openings if differential stresses are applied.

Due to the steep rake of the structures, these stresses cannot be related to relative movement of outer layers towards the apices of the anticline. Their origin is not known but two hypotheses based on field evidence are offered.
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Date April, 30, 1957.
ACKNOWLEDGMENTS

The author is indebted to all members of the field party that worked for the British Columbia Department of Mines in the Lardeau in the summer of 1956. Dr. G.E.P. Eastwood has given much advice and support, in the field as well as later on; Mr. J.J. Twiss has done the plane table work very accurately, and Mr. Douglas Irving and Mr. Ian Faulks have given able and willing assistance.

At the University of British Columbia my work has been supervised by Dr. W.H. White to whom I am ingratiated for numerous helpful suggestions and criticisms. The writer has received valuable advice in the petrographic work by Dr. K.C. McTaggart and also wishes to thank Dean H.C. Gunning for direction.

Mr. Wragge has given the permission to use plans of the Silver Cup mine, and the Granby Consolidated Mining and Smelting and Power Company has kindly supplied reports that were written in connection with exploration work.
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INTRODUCTION

I. Silver Cup Mine

1. Location and Access

The Silver Cup mine is located 50° 38' N, 117° 22' W at an elevation of 6800 feet in the Central Lardeau. It lies on a northwesterly sloping hillside below the Silver Cup peak and above the south fork of Lardeau Creek.

The mine can be reached in the following way: a road, passable for cars, leads from Trout Lake through Ferguson to Eight mile, (distance about 8 miles). The continuation from there to Towser camp, about two miles long, is now in poor repair but could easily be reconditioned for truck use. Two cabins can be used at present in Towser camp. The road from the camp site to No. 7 level has a steep grade and is in places covered by slides.

Trout Lake itself may be reached by road from Kaslo
via Lardeau and Gerard, by road and ferry from Revelstoke, via Arrowhead and Beaton, or directly by seaplanes.

2. Distribution of Ore Zones

Ninety five per cent of the production came from two leads that are parallel to each other and approximately parallel to the bedding which is dipping steeply to the northeast. The northeastern zone, called "Silver Cup lead", has been mined from 12 levels to about 1200 feet below its outcrop. The southwestern zone, named "Blind lead" did not crop out and ends a few hundred feet above the lowest workings. These leads apparently consisted of lenticular shoots of high grade ore connected by low grade material and sparsely mineralized quartz stringers.

About 1200 feet northwest of the main zone, another ore body called the "Sunshine" zone has been stoped to about 200 feet below the outcrop.

3. History, Development, and Production

All mineralized zones in the area were discovered early in the eighteen nineties. In the first stages the surface exposure of the Silver Cup lead was developed by a shaft. When, from a lower point of the hill side, the Silver Cup cross cut (No. 3 level) was driven, a second zone of mineralization, called the "Blind lead", was encountered. The next lower adit (No. 4 level) was placed 400 feet to the northwest.
PLATE I

Silver Cup Mine

View from the west

F = Free Coinage workings, dump.
S = Surface of main zone.
3 = No. 3-level dump.
4 = No. 4-level dump.
7 = No. 7-level dump.
R = Road
It encountered little mineralization here, only the area directly below the stopes of No. 3 level and the surface workings contained ore. The next step in the development was a winze sunk from No. 4 level in the vicinity of the Silver Cup lead.

While this work was in progress, the Sunshine bodies had been developed from two levels. The lower level was extended southward and, at 1700 feet from the portal, reached the Silver Cup lead. Although this drift followed shear zones for most of its way, no high grade ore was found. From then on these workings, known as the No. 7 level, became the main haulage and base for development. At first, two levels were opened up above the No. 7 level, then four levels below. Below No. 10 level, no workings on the Blind lead are to be seen on mine maps, and the drifts on the Silver Cup lead are short. The costs of pumping water and hoisting ore from the lower levels became exceedingly high and at the same time extensive exploration on No. 8 level did not find a continuation of the Sunshine ore bodies. Therefore, by 1914, all development was stopped and the levels below No. 7 surrendered to the water. Thereafter only minor quantities of ore were taken out of the upper levels by leasers.

The history of the mine has been influenced significantly by the methods of milling. In the first period, only high grade ore was taken out and shipped to Tacoma, the low
grade material being stored in the stopes or dumps. In order to treat this material a mill was built in 1905 at Five-Mile and connected with the Silver Cup mine by a tram line. This mill also served the Netti L mine. Several thousand tons of ore were milled, but due to exceedingly high tailing losses the plant had to be shut down after one year of operation. After this failure, the customary method of high grading was continued. The ore shipped by 1914 had an approximate grade of: gold $6.00 per ton, silver 150 oz. per ton, lead 30% and some copper and zinc. The grade of the material left on the dumps was estimated as: gold $3.50 - $8.00; lead 3.5 - 4%, copper 1.0 - 1.5%, silver 30 - 50 oz., zinc 5 - 20%. In 1936-37, a small flotation mill was set up at Towser camp and a tram line to the dump of No. 7 level was constructed. In that year 290 tons of concentrates were shipped to Trail. Apparently the mill was also operated in 1941.

At present there are still considerable quantities of low grade ore left on the dumps of No. 3 and No. 4 levels and of the old Silver Cup shaft that will be useful should the property ever be put into production again. The total production of the mine amounts to 9600 tons of shipping ores and several thousand tons of mill feed.

A new programme of exploration in this mine was started in 1952-53 by the Granby Mining and Smelting Company.
Number 7 and No. 9 levels were drained, rehabilitated, mapped, and sampled. Ten diamond drill holes, 200 to 250 feet long were completed to test for parallel structures. This work, however, had no further consequences.

II. Other Ore Zones

In the vicinity of Silver Cup mine are three other ore zones that will be treated briefly. All were discovered at the same time as the Silver Cup mine and all produced the same type of ore.

1. Triune Mine

The Triune mine is on the northwestern face of Triune Mountain, about 4000 feet southeast of the main zone of the Silver Cup mine.

The mine has four adits that are stacked on dip above each other and are between 350 and 650 feet long. The upper three levels are connected by a raise.

The mineralized zone was probably about 200 feet long, 500 feet deep, and 4 to 5 feet wide and situated between the upper three levels. It did not extend down to the lowest level.

In the years 1901 to 1905, 534 tons of high grade ore were shipped which were assaying Ag 240-400 oz., Pb 35 - 50%, and Au .9 oz. The property stayed idle then and was
worked again from 1916 to 1919. In this period similar high grades were produced; the quantities are unknown.

2. Towser Tunnel

"Towser tunnel" is situated about 1800 feet northwest of the Sunshine zone. The workings are about 500 feet long and consist of drifts, crosscuts and a raise to the surface. The ore body was about 175 feet long, between 4 and 5 feet wide and terminated at a depth of about 50 feet from the surface. The total production is not known.

3. Free Coinage Workings

The Free Coinage workings are situated about 300 feet southeast of the main zone and comprise more than 1000 feet of drifts, crosscuts, and raises and several open cuts. There are no orebodies, only a large number of small and sparsely mineralized quartz veins.

III. Previous Geological Work and Sources of Information

The only comprehensive description of the geology of the Lardeau has been given by J.F.Walker, M.F. Bancroft, and H.C.Gunning in the G.S.C. memoir 161 (1929).

Since 1953 G.E.P. Eastwood of the British Columbia Department of Mines has been studying a section in the central Lardeau trying to work out structure and stratigraphy in more detail. His work also covered the area of Silver Cup and
Triune mines. A preliminary map is to be published in 1957.

Information about development and production of the mine is contained in the annual reports of the British Columbia Minister of Mines. In 1903 R.W. Brock made a brief description for the Geological Survey of Canada. Gunning's work at the Silver Cup mine and in its vicinity includes a study of the mineralogy of the ore, the gangue, and the regional alteration, some underground mapping, and descriptions of structures. Confidential reports in connection with exploration work were written by D.M. Cannon in 1941, by W.S. Hamilton in 1951, and by J. Sullivan in 1953. Sullivan also did the geological mapping of No. 7 and No. 9 levels.

IV. Problem of the Thesis

Problem of the thesis in general is to determine the geological setting of the mine within the regional framework that has been established by Eastwood and to find the structural ore control. A particular question arises from the distribution of ore bodies and from the history of the mine: several ore zones occur on strike, and the concept of continuous veins has guided exploration. However, the ore bodies are horizontally very short and extensive only in depth. Long exploration drifts like the No. 4, No. 7, and No. 8 tunnels of the Silver Cup mine and the Free Coinage workings have shown no lateral extension of the high grade zones. The question is, whether more or less continuous veins exist; and
if not, why the ore bodies are approximately on strike. The
mineralogy of the ore will be treated only very briefly.
This subject has been studied by Gunning from a regional point
of view.

V. Current Field Work by the Author

The author spent eight weeks of the season 1956 on
the problem supported by a crew of one to three helpers. In
this time the maps accompanying the paper were prepared. The
geological map of the surface of the main zone is based on
plane table work. The geological map of the Silver Cup mine
was produced mainly by plane table work but supplemented by
tape and compass traverses and combined with old mine plans.
The sheet is an outcrop map but such outcrops that are in-
significant for the location of contacts because of their
situation or because they are too highly altered were neglected.
The geology of the area not covered by the plane table survey
was plotted on a base map at the scale of 1000 feet to the
inch. Later on this base map was enlarged, and the major
results of the plane table survey were transferred to it.
Only the levels No. 3, No. 4, No. 7 and No. 8 of the Silver
Cup mine, the Towser tunnel and the Free Coinage workings were
accessible or could be opened up. Because Gunning had mapped
the Free Coinage workings and Sullivan the No. 7 level; and
because the Towser tunnel was flooded with two to three feet
of water and the No. 8 level has no mineralization or inter-
esting features we only mapped the levels No. 3 and No. 4.
I. Stratigraphy

1. General Statement

Eastwood recognized three major stratigraphic units in the area. The oldest are green phyllites that he correlated with the top of the Bunker Hill group. They are overlain by the graphitic slates and phyllites of the Triune formation. The youngest formation is the Ajax Quartzite. The age of these rocks is not exactly known. Hundreds of feet lower in the section is the Badshot Formation that has been correlated with an older Cambrian limestone member of the Laib formation. Considerably higher up is the Christie Point Group (coinciding in part with the previous Milford Group) that contains Mississippian fossils. Therefore the rocks in this area probably belong somewhere in the older Palaeozoic. The two older units were divided by the author into three and four members respectively. Because some rock types appear in several members, at first the lithology will be described in general and then, briefly, the individual formations and members.
<table>
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<tr>
<th>FORMATION</th>
<th>LITHOLOGY</th>
<th>AGE</th>
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<td><strong>Staubert Formation</strong></td>
<td>Till, talus, alluvium. Some calc-tuffs or travertine nonconformity</td>
<td>Quaternary</td>
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<td></td>
<td>small granitic intrusives relations unknown</td>
<td>Cretaceous?</td>
<td>Kuskanax ?</td>
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<tr>
<td></td>
<td>scattered small stocks of diorite and gabbro intrusive contact</td>
<td>?</td>
<td>Badshot, band 2a</td>
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<td></td>
<td>limestone, almost entirely recrystallized contact covered</td>
<td>?</td>
<td>Lardeau series</td>
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<td><strong>Beaton Formation</strong></td>
<td>Quartzite, phyllite, argillite, limestone contact probably conformable</td>
<td>?</td>
<td>Lardeau series</td>
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<tr>
<td></td>
<td>silty slates and phyllites, pebble-conglomerate, argillaceous limestone</td>
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<tr>
<td></td>
<td>contact covered</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Christie Point Group</strong></td>
<td>shale, chert, slate, limestone, sandstone, contains several fossiliferous zones, one of Mississippian Age</td>
<td>Carboniferous</td>
<td>Patches of Milford Group for lower part, Lardeau series Upper part.</td>
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<tr>
<td>Formation</td>
<td>Description</td>
<td>Contact Type</td>
<td>Group</td>
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<td>Ferguson Group</td>
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<td>Jowett Formation</td>
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<td>Ajax Quartzite</td>
<td>quartz grit</td>
<td>?</td>
<td>Lardeau series</td>
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<td>Triune Formation</td>
<td>black slates and phyllites; locally green phyllites and dolomite</td>
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<td>Lardeau series</td>
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<td>Bunker Hill Group</td>
<td>green gritty phyllite and schist, dark grey argillite and phyllite, fragmental greenstones (volcanic), limestones</td>
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<td>Perrylode Formation</td>
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<td>Lardeau series</td>
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</table>

disconformity (angular unconformity not proven)

phyllite, quartzite, garnet, pebble conglomerate

conformable contact

Grits and black phyllites

gradational contact

greenstone, green phyllite, grit, black phyllite

conformable contact

quartz grit

conformable contact

black slates and phyllites; locally green phyllites and dolomite

concordant contact

green gritty phyllite and schist, dark grey argillite and phyllite, fragmental greenstones (volcanic), limestones

concordant contact probably disconformity

black phyllite, quartzite, limestone

contact covered
<table>
<thead>
<tr>
<th>Formation</th>
<th>Description</th>
<th>Series</th>
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<tr>
<td>Badshot Formation</td>
<td>limestone, much recrystallized</td>
<td>Badshot Formation</td>
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<td>angular unconformity</td>
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<td>Mohican Formation</td>
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<td>Hamill series</td>
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<tr>
<td></td>
<td>probably angular unconformity</td>
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<td>recrystallized limestone</td>
<td>Hamill series</td>
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<td>conformable contact</td>
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<td>Marsh-Adams Formation</td>
<td>impure quartzite, green schist</td>
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<td>contact probably conformable</td>
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</tr>
<tr>
<td>Mt. Gainer Quartzite</td>
<td>quartzite</td>
<td>Hamill series</td>
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</tbody>
</table>
3. Lithology

All rocks in the area show the characteristics of low-grade regional metamorphism and fit into the greenschist facies. They also have been subjected to carbonate, silica and chromium-mica alteration. (See Part II, 1-2).

A. Green Phyllite

Macroscopic Characteristics:

The rock is a green phyllite with a poor schistosity. In some places fine, lighter colored spots show up that are probably lithic fragments.

Microscopic Characteristics:

A few thin sections show that the rock is made up dominantly of lenticular fragments of volcanic rocks which are in the order of a millimeter in size. In the other sections the original rock fragments are only weakly suggested. The mineral assemblage consists dominantly of chlorite, (mostly penninite), actinolite, members of the epidote group, ferristilpnomelane, leucoxene and plagioclase; wherever it was possible to determine the composition of the plagioclase, it was found to be albite. The schistosity of the rock is due to the arrangement of the chlorite. The microscopic characteristics of the rock and its close association with the lapilli tuff suggest an original tuff.
Alteration:

The green phyllite in many places is carbonatized. The carbonate usually is present in uniformly distributed grains that are about 200 microns in size and often elongate parallel to the schistosity. The carbonate weathers rusty brown and at incipient stages gives a sprinkled appearance to the surface. With higher degrees of alteration the whole mass becomes red.

B. Green Phyllite with "Augen" Structure

Macroscopic Characteristics:

Like the tuff this rock is a green phyllite, but characteristic for it are lighter colored "augen" that are uniformly distributed through the whole mass.

These lenticular fragments vary in size and are in the average, perhaps a cm. long. Some of them show vesicular texture.

Microscopic Characteristics:

Microscopic examination shows that the rock is a lapilli tuff. The "augen" appear to be fragments of various volcanic rocks such as amygdaloidal flows and feldspar and pyroxene-porphyries. The matrix consists dominantly of chlorite, fine needles of actinolite and minerals of the epidote group, and of some leucoxene.
Alteration:

Like the other greenstones, this rock is often carbonatized, and higher degrees of alteration destroy its diagnostic characteristics; but at moderate degrees the augen structure can still be recognized as lighter colored spots within a network of dark brown lines.

C. Graphitic Slate (approaching phyllite)

Macroscopic Characteristics:

The rock is black and has shiny cleavage planes; in cross-section it appears rather siliceous. Usually the cleavage is not pronounced, but when strongly weathered, the slate is quite fissile and resembles very closely the black phyllite. The absence of higher degrees of alteration then is the only diagnostic feature.

Microscopic Characteristics:

The dominant component of the rock is quartz. The grains are generally between 5 and 50 microns in size and most commonly between 10 and 20 microns. They are fairly angular and vary from elongate to equidimensional in shape. Up to 10% of the section may consist of carbonaceous matter that occurs in fine parallel layers which often show folds. A minor constituent is muscovite. This mineral is not concentrated in layers but occurs as individual flakes oriented in various directions between adjacent quartz grains.
Alteration:

The rock is affected by silicification and carbonatization, but it is not subject to a complete alteration that obliterates its diagnostic properties. Iron carbonates may be present as brownish weathering nodules that usually are uniformly distributed. White quartz has been introduced in larger or finer veins that are parallel to schistosity or occupy cross fractures. Such cross veins often show peculiar curved shapes due to differential movements within the member.

D. Black Phyllite

Macroscopic Characteristics:

In the member T2 the rock is very dark, fragile, and fissile. In the member B1 the color varies to a bluish grey and the texture becomes more massive.

Microscopic Characteristics:

The dominant component of this rock is carbonaceous matter that usually amounts to more than 50% of the section. It is arranged in parallel layers and may be associated with muscovite or chlorite. Quartz and perhaps feldspar may comprise a third or less of the rock. The grain size is between a few and 50 microns. The grains are usually lenticular and elongate parallel to the schistosity.
Alteration:

This rock type is to a much higher degree subject to alteration than the graphitic slate. At incipient stages nodules of carbonates appear. With higher degrees the rock gradually loses its schistosity and is transformed into a massive aggregate consisting dominantly of carbonates that may be veined by quartz and chromium mica and on first sight can hardly be distinguished from highly altered greenstones. On closer examination, however, it is mostly possible to detect the original cleavage as silvery planes with dark brown spots within the rusty weathering mass.

E. Quartzite

The quartzite is grey and has a poor cleavage. It is made up mainly of poorly sorted and rather angular grains of quartz and some feldspar that range in size between .2 and 2 mm. Small amounts of micaceous material, dominantly muscovite, are arranged in fine, parallel layers. Grains of carbonate and opaque iron minerals are scattered through the mass.

4. Description of the Formations and Members

A. Bunker Hill Group, Uppermost Formation

Member BI.

This member is exposed only in the core of the south-
western anticline where it wedges out to the northwest. The maximum thickness here is about one hundred feet. The member is made up of thinly interbedded black and green phyllites; the green phyllites appear to be lithic tuffs. Due to the lack of exposure and the high degree of alteration it was not possible to trace individual beds, but it seems that the two types interfinger irregularly. The thickness of individual beds varies from several feet to fractions of an inch.

Member B2.

This member consists of green phyllite that probably is a lithic tuff. It is about 50 feet thick.

Member B3.

Member B3 is a green phyllite with augen structure and a lapilli tuff. It is about 50 feet thick.

B. Triune Formation

Member T1

The member T1 is made up of graphitic slate. On the southwest limb of the major anticline its thickness varies from a few to 150 feet, on the northeast limb it ranges from 30 to 300 feet. These variations may in part be due to sedimentary reasons, partly they may be plastic deformations.

Member T2

This member is made up dominantly of black phyllite but it also contains lenses of lapilli tuff and tuff and of green phyllites that were not studied in thin sections. The
thickness of T2 varies: on the southwest limb it ranges between 200 and 400 feet, on the southeast limb it is about 250 feet.

Member T3

The lithology of this member is the same as of Member T1: it consists of graphitic slate. The apparent thickness of the southwest limb is about 1000 feet, of the northeast limb about 550 feet; but there may be repetitions due to folding or faulting.

Member T4

Member T4 is present only on the southwest limb where it is about 200 feet thick. It consists of interbedded graphitic slate and quartzite. The missing of this member may be due to sedimentary reasons or it may have been caused by squeezing, which is quite characteristic for the northeast limb of the major anticline.

5. Environments of Deposition

The presence of carbonaceous matter in the Bunker Hill group as well as in the Triune formation indicates deposition in a basin with restricted circulation and oxygen supply. The dominant feature during most of the time represented in this section is the sedimentation of silt which suggests a slope (= clinoform) environment. In the early period this process was briefly overshadowed by a volcanic explosion
PLATE II

Triune Mountain

View from the northwest

A = Ajax Quartzite with infolds of Triune and Jowett Formations.

T4, T3 = members of the Triune Formation

3 = No. 3-level dump

4 = No. 4-level dump

To the left the axis of the central syncline is plotted
in the source area resulting in the deposition of pyroclastics. The restricted lenticular shape of the last pyroclastic facies may be explained by submarine erosion. At the end of the period deposition shifted towards coarser sediments that finally dominated in the Ajax Quartzite. This shift may indicate a change towards a shelf environment.

II. Major Structure

Eastwood has shown that a major fold which has been traced for several miles, extends into the area of Silver Cup and Triune mines. It is an isoclinal anticline that is overturned to the southwest and plunges to the northwest. Our mapping indicates that this anticline in the vicinity of Silver Cup mine has two apices separated by a tightly compressed syncline.

This concept is based on the repetition of certain horizons and the trend of contacts. No information was obtained from drag folds. Although such structures are common farther out on the limbs, here, in the core of the anticline, no drag fold was found that could be related with confidence to the relative movement of outer layers towards the apex of the major anticline. Furthermore, no conclusions about fold structure could be drawn from bedding-cleavage relations because the cleavage dips steeper than the bedding on all limbs and generally strikes $10^\circ$ west of the axial planes. No explanation can be given at present for this anomalous relation;
PLATE III

Silver Cup Anticline on Five-Mile hillside
View from Silver Cup mine

The anticline is outlined by the Ajax Quartzite which, especially on the southwest limb, is intricately folded.
it is not yet known if there was a second period of regional stress.

The outcrop map shows that none of the members could be traced continuously, but the distribution of T1 and B3 may be used as the key to the structure. Rocks of this type are exposed not only at the southwest and northeast limbs of the major anticline, but also in its centre. In the centre B3 borders T1 to the northeast and to the southwest and both wedge out to the southeast. The repetition could be explained by cyclic deposition and the wedging by the combined effect of the rising topography and an anticlinal structure. If this were true, B3 should widen with depth and T1 appear in its centre on the steep southeastern slope of the ridge between Alpha and Silver Cup peaks, that provides an almost vertical section. However, B3 thins out and T1 does not appear at all. This indicates a northwesterly plunging syncline. This explanation is supported by two other features: (1) In the core of the major structure, near Towser tunnel, black phyllite crops out. The appearance of this rock type can be explained by a synclinal keel of the member T2. Supposing an anticlinal structure, we would have to postulate a facies change or a complicated fold for which there is no other evidence. (2) Southwest of the centre the members B1 and B2 seem to pinch out to the northwest which indicates a northwesterly plunging anticline complementary to the central syncline.
Considering the trends of the contacts, the topography, and the approximate thickness of the members, the plunge of these folds was calculated to be about $35^\circ$. This is relatively steep; plunges obtained on drag folds of the Ajax Quartzite are normally between $20^\circ$ and $30^\circ$. Apparently the plunge increases in the core of the anticline near the Triune basin. The occurrence of mineralization and later intrusives in this area might have a relation to such a structural anomaly. But, at present this is a mere hypothesis that is based on little evidence. It may well be that the trend of contacts has been influenced largely by facies changes or structural squeezing and does not allow to reconstruct the anticline in such a manner. Nevertheless, a composite cross-section has been prepared from sections at various levels (Figure 1). A plunge of $33^\circ$ and parallel trend of the limbs were used in this illustration.

No major fault was observed in the area.
FIG. 1

SECTION THROUGH CORE OF SILVER CUP ANTICLINE
N 40E / 57 SE
PART II. ECONOMIC GEOLOGY

I. Mineralization and Alteration

1. Mineralization

The mineralogy of the mine has been described by Gunning from a regional point of view. A few polished sections were studied by the author but no additions could be made. The ore minerals in their paragenetic sequence are:

(oldest) pyrite, carrying small amounts of submicroscopic gold.

sphalerite, with minute blebs of exsolved chalcopyrite

freibergite

galena.

In the early stages of mining ruby silver was also reported.

Of the gangue minerals quartz was found to be later than sphalerite and earlier than galena. Carbonate fills fine fractures in all other minerals and appears to be the latest mineral.

The assemblage seems to be typical for a mesothermal lead-zinc-silver deposit. The exsolution temperature of chalcopyrite from sphalerite, however, was determined by Buerger as $350^\circ-400^\circ C$, (Edwards, p. 98), which suggests a temperature slightly higher than that proposed by Lindgren for the mesothermal group.
2. Rock Alteration

As pointed out by Gunning, rock alteration is a common feature in the Lardeau and perhaps related to the mineralization. The dominant mineral group introduced are Ca Mg Fe carbonates; less abundant are quartz and chromium bearing mica of the fuchsite-mariposite series.

Field evidence and microscopic examinations show that in the Silver Cup area the chromium mica is always associated with quartz and that both are later than the carbonates.

The alteration is wide spread. Due to the lack of exposure the structural controls could not be clearly recognized, but a lithological control is apparent; the green and black phyllites are much more susceptible to alteration than the siliceous black slate. Because the graphitic slate is the most favourable rock type for ore deposits in this area alteration cannot be used as a guide for exploration here.

3. Age of Mineralization

The age of the mineralization is not known with certainty. However, a lower limit is given by the probable age of the host rocks - lower Paleozoic, and it is likely that, as Gunning has pointed out, the mineral deposits in the Lardeau are related to neighbouring batholithic intrusions which are probably mostly Mesozoic in age.
III. Structural Ore Control

1. Structural Control of the Main Ore Zone

   A. Information from the Surface:

   Detailed mapping on the surface revealed certain structural anomalies that probably are related to the localization of the ore shoots.

   The most obvious feature is a pronounced curvature in the contact between B3 and T1, a feature quite unusual in this region where contacts are generally straight. This curvature resembles a dragfold indicating relative movement of the T1 horizon to the northwest. A small dragfold southeast of the main deflection is in the same sense and rakes steeply (about 60°) to the northwest. However, the trends of schistosity do not everywhere conform to the dragfold pattern. As shown on Figure 2, at a zone southwest of the contact the strata no longer follow a parallel course, but start curving in the opposite direction. In the centre of this zone of divergence are the old shaft and the first stopes of the Silver Cup lead. The structural position of the Blind Lead is less clear. The stopes of the lead are contained in the major "bulge" but the contact T1 - T3 is poorly exposed; only a few structural trends were available, and it is also not quite clear where, to what extent the zone here was mineralized.
FIG. 2 STRUCTURAL TRENDS AT SURFACE

- STOPE
- CONTACT
- STRIKE OF SCHISTOSITY
B. Information from Mine Maps

The distribution of stoped areas indicates that nowhere is the orezone more than 300 feet long whereas the rake length is more than 1200 feet. The zone is relatively short at the surface, lengthens to its maximum depth between No. 3 and No. 7 levels, then shortens at greater depth. The total width of the zone does not exceed 150 feet and is usually less than 100 feet. It dips about $66^\circ$ to the northeast and rakes about $86^\circ$ to the northwest.

C. Information from Geological Mapping Underground

The observations underground may be summed up in three points.

(i) The ore stays in the same member TI and at about the same distance from the member B3 as at the surface. It was not possible, however, to outline the "bulge" underground. This structure was noticed at the surface by a deflection of the contact and the trends of schistosity. The contact, however, is exposed underground at a few places only, and the structural trends were not apparent because the drifts usually follow shear zones that are highly crumpled and show very irregular attitudes.

(ii) Little ore has been left in the levels examined. Wherever observed, the vein material is present in stringers or veins parallel to the schistosity of the country rock. Individual stringers of vein material range in width between
FIG. 3 OUTLINES OF OREZONES

A: SECTION N57E / VERT. (SILVER CUP AND BLIND LEADS.)

B: SECTION S33E / 66 NE THROUGH SILVER CUP LEAD.
a fraction of an inch and a foot, mineralized zones as a whole are up to several feet wide. The wall rock is highly crumpled. The crumpling seems to be in all directions and dragfolds do not have uniform attitudes or sense of movement. The contortion usually dies out within ten or twenty feet from the vein normal to strike but persists on strike from one stope to the next. The two leads are not continuously mineralized but made up of a series of lenticular ore shoots.

(iii) A new feature underground not apparent on the surface (perhaps due to lack of exposure) is the existence of extensive crumpled zones outside the high grade zone that are only sparsely mineralized. A few perfect dragfolds were obtained in No. 4 and No. 7 levels indicating relative movement of the footwall to the northwest but there is also dragfolding in other directions. The general pattern shows so little uniformity that no conclusions can be drawn concerning the relative movement in these zones.

D. Interpretation

Examination of the surface showed three significant features:

1. The contact T1-B3 resembles the section through a dragfold with steep rake.

2. The trends of schistosity are not uniformly parallel to this contact but, at a certain distance, are deflected in the opposite direction. The trends of the attitudes are lenticular in the overall picture.
PLATE IV

Mineralized zone in No. 4 level, No. 11 drift

Mineralization (white bands) is stringer-like; the hostrock is crumpled
3. The Silver Cup lead is located in the centre of divergent attitudes. The structural control of the Blind lead is not clear but it is contained in the major zone of deformation.

From the distribution of stope areas on mine plans we concluded that the high grade ore zone is lenticular, dips with the host horizon to the northeast, and rakes steeply to the northwest.

Correlating these observations we arrive at the concept that the strata form a structural bulge that is lenticular in vertical and horizontal section. This structure contained zones of open space and low pressure that caused the deposition of ore. Some internal shearing may have taken place; but the crumpling of the wall rock is perhaps mostly due to the adjustment of strata remaining in the centre of such openings to the general shortening of the structure.

Dragfolds at the contact B3 - T1 indicate relative movement of the T1 to the northwest. This movement is thought to be responsible for the formation of the major bulge. It probably involved much larger parts of the horizon, as indicated by the shear zones in No. 4 and No. 7 levels. But the shearing alone did not provide sufficient open space for ore localization.

2. Structural Control of Minor Ore Bodies

Due to the lack of exposure or access, the infor-
mation about the other ore bodies in the vicinity of the main zone is much poorer. However, a few features common to most of them were noticed and these features are significant for the interpretation of the structural ore control in the area as a whole.

A. Sunshine Zone

This mineralized zone is located at the contact between T1 and B3 and present in both members; but control and grade in the two rock types are different. In the greenstone the mineralization occurs in small fissures and faults that are commonly striking to the northeast and dipping to the southeast. Such veinlets are exposed in an open cut above the No. 7 level portal and about 250 feet from the portal within the level. This type apparently was not economic because it has generally not been mined, and the exploration drifts and raises of No. 8 level obviously avoided the greenstone. Host rock of the ore was the member T1. Judging from remnants exposed in No. 7 level it occurred in lenses between bulging planes of schistosity. It is reported that in the upper level two lenses were present that were 10 and 25 feet long and persisted down to No. 7 level. The width of the stopes is about six feet, the ore zone possibly was narrower. The depth probably did not exceed 200 feet. These dimensions again indicate a high grade zone that is short, narrow, but relatively deep and resembles in that respect the Silver Cup and Blind leads and the Triune body. Several small
dragfolds in No. 7 level indicate relative movement of T1 to the northwest and one dragfold suggests upward movement of the hanging wall. Due to the lack of exposure at the surface, however, an interpretation of the major structure could not be made.

B. Triune Mine

The mine was not inspected underground. From the surface exposures and from old reports the following information was obtained.

1. The dimensions of the stoned zone are roughly 500 feet in depth, 200 feet in length, and 5 feet in width, which indicates a relatively short and flat body that is elongate along dip. The similarity of proportions to the main zone suggests perhaps another manto shaped body.

2. The ore zone is contained dominantly in the horizon T1; the mineralization in the greenstone seems to be insignificant. It dips with the host member steeply to the northeast.

3. The member T1 here is bordered by a large greenstone mass to the northeast and a smaller body to the southwest that thins out upward and to the southeast. The upper limit of the ore zone seems to lie approximately where the greenstone ends.

4. At the surface some shearing is visible in the horizon T1. At one place small dragfolds, plunging 30° to the northeast indicate upward movement of the hanging wall. Emmens states
that the host rock of the ore is "much broken and twisted by local disturbance".

From this information it appears that the ore is localized in a shearzone within the member Tl and that the shearing is possibly related to the greenstone body at the southwest. (See section 4C)

C. Free Coinage Workings

The workings are mainly in the members Tl and T2; a crosscut extends through B3 and into B2. No ore bodies are present, only a large number of small quartz veins which are sparsely mineralized. Gunning's underground mapping shows a large shear zone which reflects the warping of the Tl horizon at the surface. This shear zone is the major control. Structurally the quartz veins are of three types:

1. Relatively narrow veins parallel to schistosity.
2. Irregular, short but often relatively wide lenses related to intense crumpling.
3. Tension fractures related to major warps. These fractures are dipping steeply to the northwest.

D. Towser Tunnel

The Towser ore body is about 175 feet long, 4 to 5 feet wide. It terminates about 50 feet below the present surface but may have extended considerably above it. Host rock is the member Tl. Drusy cavities are present and the ore
PLATE V

Triune Mine

View from the north-west

T1, T2, T3 = members of the Triune Formation (black slates and phyllites).

T2A = greenstone, probably tuff, member of the Triune Formation

B = Bunker Hill Group, uppermost formation, greenstone member

W = workings of Triune mine, (No. 4 and No. 2 levels).
seems to have formed by open space filling. But due to limited access and exposure the controlling structure was not recognized.

3. Summary and Conclusions

Two features are common to the four producing zones:

1. They are all in the basal member of the Triune formation.
2. Triune, main and Sunshine zone are deep but narrow and short and seem to be lenticular. The same may be true for the Towser body, but erosion has obscured the picture here.

On the other hand, the zones are not all in the same structural position with respect to the two anticlines: the main zone and the Sunshine zone are on the southwest limb of the southwestern anticline, the Towser body is on the southwest limb of the northeastern anticline, and on Triune mountain the two apices are no longer recognizable; the mine here is on the southwest limb of the major anticline. There seems to be a certain preference of the showings for the southwest side that may have been caused by structural reasons, but perhaps is only accidental because this area is better exposed.

The deposits are isolated and certainly not parts of continuous veins. They may, in their origin, be related to extensive shear zones. But the shear zones themselves, where exposed in the No. 4 and No. 7 levels, of the Silver Cup mine and in the Free Coinage workings, do not contain ore.
The only certain conclusion we can draw is that TI seems to be the favourable member. This implies a stratigraphic ore control. Stratigraphic ore controls are of different types: they may be sedimentary, chemical (with replacement deposits) or mechanical (with open space fillings). These deposits are certainly neither sedimentary nor of the replacement type; (replacement deposits would have preferred the greenstone). It seems, therefore, that the mechanical properties of the host horizon under certain stress conditions were favourable for the formation of lenticular openings which localized ore deposits. Next we will investigate what these properties were like and how such openings may have been formed.

4. Causes of Ore Controlling Structures

A. Texture of the Host Rock

Microscopically the member TI consists of silt sized quartz grains with fine layers of graphitic material in between. Two important mechanical properties result from this texture:

1. low cohesion between the layers of graphitic material and the quartz,
2. fair competence within the quartz layers.

The graphitic layers are potential shear planes. If the rock is subjected to differential pressures it will most
likely react to the components parallel to the schistosity by slippage on these planes. Due to the competence of the quartz layers these movements may be transmitted relatively far but will die out because of crumpling. In this process of movement and crumpling, layers that are separated by high concentrations of carbonaceous material may break apart and bend in different directions, leaving lens like openings in the centre. The length and the width of these openings will be determined by the strength of the rock and by the confining pressure. The third dimension, however, is not dependent on these factors; it is limited only by the extent of the front at which the differential forces are acting. Thus may be produced openings that are short and narrow but relatively deep.

The other rock types in the area do not possess this combination of mechanical properties and therefore do not produce the same type of structure. The black phyllite has a much more pronounced schistosity but a low competence. This rock frequently shows intense crumpling, but the deformations extend only over short distances and consist of short folds.

The greenstone, on the other hand, possesses a fair competence but a poor schistosity. It does not show crumpling at all and seems to react to force by plastic deformation.
Mineralized openings in the greenstone consist of joints or faults. These structures are essential controls in the Sunshine Lardeau mine at Camborne, but they have no importance in the Silver Cup area.

B. Thickness of the host horizon and mechanical properties of the overlying phyllite

With respect to lithology the horizon T3 is as favourable for ore localization as the member T1. Why do we not find these lenticular structures in T3? One difference between the two members is their thickness: T1 is very narrow, usually less than 100 feet, whereas T3 ranges up to 1000 feet in thickness. But what may be the influence of thickness?

The amplitude of these drag or crumple folds, that seem to be the ore control in the Silver Cup and Triune area, depends on the competence of the overlying horizons. The black phyllite of the horizon T2 is less competent than the siliceous slate of T1 and T3. The formation of folds within the narrow T1 certainly is facilitated by the incompetence of the bordering T2. Only a marginal zone of the member T3, however, has the same advantage. Further inside of this horizon there will be a higher resistance to deformation. The problem remains, why there are no ore deposits within the marginal zone of T3. In the next section a few more pecul-
iarities of Tl will be pointed out that may provide an answer to this question.

C. Differential Forces

(a) General Statement

The rake of the ore controlling drag and crumple folds is steep, almost vertical, whereas the major anticline probably plunges not more than 30° or 40°. Therefore these structures cannot be explained by relative slippage of outer layers towards the apices of the major fold; they seem to be related to horizontal movements.

At this stage of mapping no obvious cause of such movements is visible. All we notice is a remarkably uniform trend of the folds which indicate a uniform pressure normal to the axial planes. The horizontal displacements may have been caused by forces of which we have no knowledge; at present we only can try and relate them somehow to the general regional pressure.

The two hypotheses offered are based on the following field observations:

1. Immediately southeast of the main zone the basal Triune begins to thin and acquires the shape of a wedge pointing to the southeast.
2. The thinning is accompanied by a series of deformations
that appear to be continuous: at the main zone is the "bulge"; southeast from here, in the vicinity of the Free Coinage adit, the horizon is warped; and farther southeast, near the ridge, there is evidence of intensive shearing. The dragfolds near the main zone indicate relative movement of the member T1 to the northwest. It seems that the movement, the thinning, and the deformation are related.

The thinning of the T1 may have had two possible causes: either sedimentary changes or structural deformation. It definitely does not indicate the keel of a southwesterly plunging syncline because there is no repetition of stratigraphic horizons about such a fold axis. In the first hypothesis sedimentary changes are assumed; in the second deformation; both hypotheses do not exclude each other.

(b) Hypothesis I.

If the thinning was sedimentary the following mechanism may have acted: the regional force pressing on the wedge's inclined face had a component directed to the northwest. The component is given by

\[ f \sin \alpha \cos \alpha \]

where \( f \) is the regional force and \( \alpha \) the angle between the wedge's face and the axial plane of the folds. The factor that has to be applied to the major force is 0.07. It is
thought that the basal Triune reacted to this component like a not very competent body, mainly by crumpling and partly by movement that resulted in the formation of dragfolds. The question is whether the northwesterly component of the regional force was strong enough to overcome cohesion and friction of the rocks.

(c) Hypothesis II

In the vicinity of the Silver Cup mine the thinning of the Tl is most pronounced where the overlying Tl contains greenstone facies. Southeast from here, in the Triune basin, the Tl is covered by drift. Where it appears again, on Triune mountain, it still is very narrow and bordered to the southeast by a greenstone unit that may be continuous with the mass on the northwest side of the basin. Then the greenstone thins out and the basal Triune member begins to widen; on the top of Triune mountain it has regained its original width. The greenstone, containing considerable amounts of feldspathic material and possessing a poor schistosity is a more competent rock than the black phyllite which is made up dominantly of carbonaceous matter and muscovite. This implies that the greenstone will transmit stresses to a higher degree than the phyllite which absorbs more energy in the various processes of compaction, internal shearing, and contortion. The spacial relation between the thinning of the basal Triune member and the presence of greenstone suggests that in the
process of folding the latter rocks were pressing harder on the underlying Tl and squeezed it out to the northwest on the Silver Cup side and to the southeast on the Triune side. The thinning is thought to have been accomplished by differential movements on the planes of schistosity. As a result of these shear movements the dragfolds and bulges developed that subsequently localized ore. Again it is a problem whether the differences in stress were sufficient to accomplish such deformations.

5. Practical Applications

The practical result of the paper is that the Silver-lead-zinc deposits of the Silver Cup and Triune area occur in steeply raking, narrow, short, but deep, lenticular zones within the basal member of the Triune formation. This member should be explored systematically from the surface with suitable geophysical or geochemical methods. Unfortunately, electrical methods cannot be employed because of the graphitic nature of the host rock.

Wherever ore is found, development should primarily follow down its rake with the hope that the zone is many times as deep as it is long or wide. However, erosion may have removed considerable parts of the orebodies. Extensive exploration drifts, as present on the No. 4, No. 7 and No. 8 levels of the Silver Cup mine and in the Free Coinage workings
do not seem to be promising because the deposits are not of the vein type.

Judging from its lenticular shape the main ore zone of the Silver Cup mine may extend to greater depth, but it is not likely that the stope length should increase; unless another, similar structure were encountered for which there is no evidence at present.
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FIG. 2 STRUCTURAL TRENDS AT SURFACE

- STOPE
- CONTACT
- STRIKE OF SCHISTOSITY

0 10 20 FEET
FIG. 3 OUTLINES OF OREZONES

A: SECTION N57E / VERT. (SILVER CUP AND BLIND LEADS.)
B: SECTION S33E / 66 NE THROUGH SILVER CUP LEAD.