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THE GEOLOGY AND ORE DEPOSITS OF THE BOULDER CREEK MINING DISTRICT, CUSTER COUNTY, IDAHO

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CONTENTS

ILLUSTRATIONS

THE GEOLOGY AND ORE DEPOSITS OF THE BOULDER CREEK MINING DISTRICT, CUSTER COUNTY, IDAHO

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ABSTRACT

This report describes the occurrence of silver-lead deposits in the Boulder Creek Mining District in southwestern Custer County, Idaho. These deposits, which are unique in that the chief ore mineral is the rare mineral jamesonite, a complex lead, iron, antimony sulfide, occur partly as fissure fillings and partly as replacements along shear zones in metamorphosed Paleozoic rocks (Milligen formation).

At the Livingston mine, which has been the largest producer, the ore occurs along the Livingston vein, chiefly as a replacement of a rhyolite porphyry dike. This dike, known as the Scotch dike, has been cut by the Livingston fault (or vein), which directed the upward flow of mineralizing solutions from a deep magmatic source. The solutions were, for the most part, restrained from diffusing into the argillite wall rock by its impervious nature; but, where they entered the permeable and easily fracturable dike rock they spread out forming the larger ore bodies. Most of the larger ore bodies occur at the contact of the Livingston fault and the western or footwall portion of the dike; however, some occur at the eastern or displaced dike and fault contact. As such, these contacts provide the structural control for the ore deposits. Future exploration work should aim at such vein and dike intersections, for they are the likely sites for ore deposition.

The ores are mesothermal or moderately deep seated in character and should persist to depths greater than those yet reached in mining.

INTRODUCTION

PURPOSE

The presence of ore deposits in the Boulder Creek district, particularly in the area near the Livingston mine, has been known since the early 1880's; however, the ruggedness of the terrain, plus the distance to an available market has tended to discourage mineral exploration. During the 1920's the district experienced a "boom" in mining, but in 1930 operations in the area ceased, and except for occasional work by lessees, there has, until recently, been little activity.

In 1946, interest in the region was renewed, and attempts were made to re-open some of the old properties. Unfortunately, during the interlude between 1930 and 1946 much of the compiled geologic information on the district had been lost or forgotten. Since the dearth of geologic data hampered exploration attempts, the Idaho Bureau of Mines and Geology undertook to map and re-study the district in the hope that information gained would enhance the possibilities for renewed mineral production. This study was carried on during the summer of 1948.

The field studies were concentrated in the area surrounding the Livingston mine and also in that area near the headwaters of Livingston Creek and southeast towards Boulder Creek. (Fig. 1) A combined topographic and geologic map of the area was prepared on a scale of 1" = 200 feet. (Fig. 2) All mine workings were mapped and studied in detail.

ACKNOWLEDGMENTS

While in the field the writer was ably and efficiently assisted by Mr. George Glarborg, a student at the University of Idaho, School of Mines. Mr. Tommy MacKay, manager of the Livingston mine, and his wife, were very hospitable and helpful in assisting the field party. Appreciation is also extended to C. R. Kurtak, chemist, and L. S. Prater, metallurgist, both of the Idaho Bureau of Mines and Geology, for their assistance in the preparation of the report.

GEOGRAPHY

LOCATION

The district described lies in the southwestern part of Custer County, Idaho. It embraces that area near the headwaters of, and drained by, Jim, Livingston, and Boulder Creeks. The area is about 60 miles northwest of Mackay, Idaho, the nearest railroad shipping point.

The district is accessible by a secondary road which follows the East Fork of the Salmon River from its mouth, upstream to its junction with Boulder Creek, thence up that stream.

During the past summer, a rough, bulldozed road was constructed into the northeastern part of the area. This road extends up Livingston Creek, from its junction with Slate Creek, and ends at the Fisher Brother's property near Crater Lake. The road is very steep and travel is restricted to vehicles with 4-wheel drives.

TOPOGRAPHY

The Boulder Creek district is in the extremely mountainous and rugged country of south-central Idaho. It lies on the northeast side, and near the crests of the

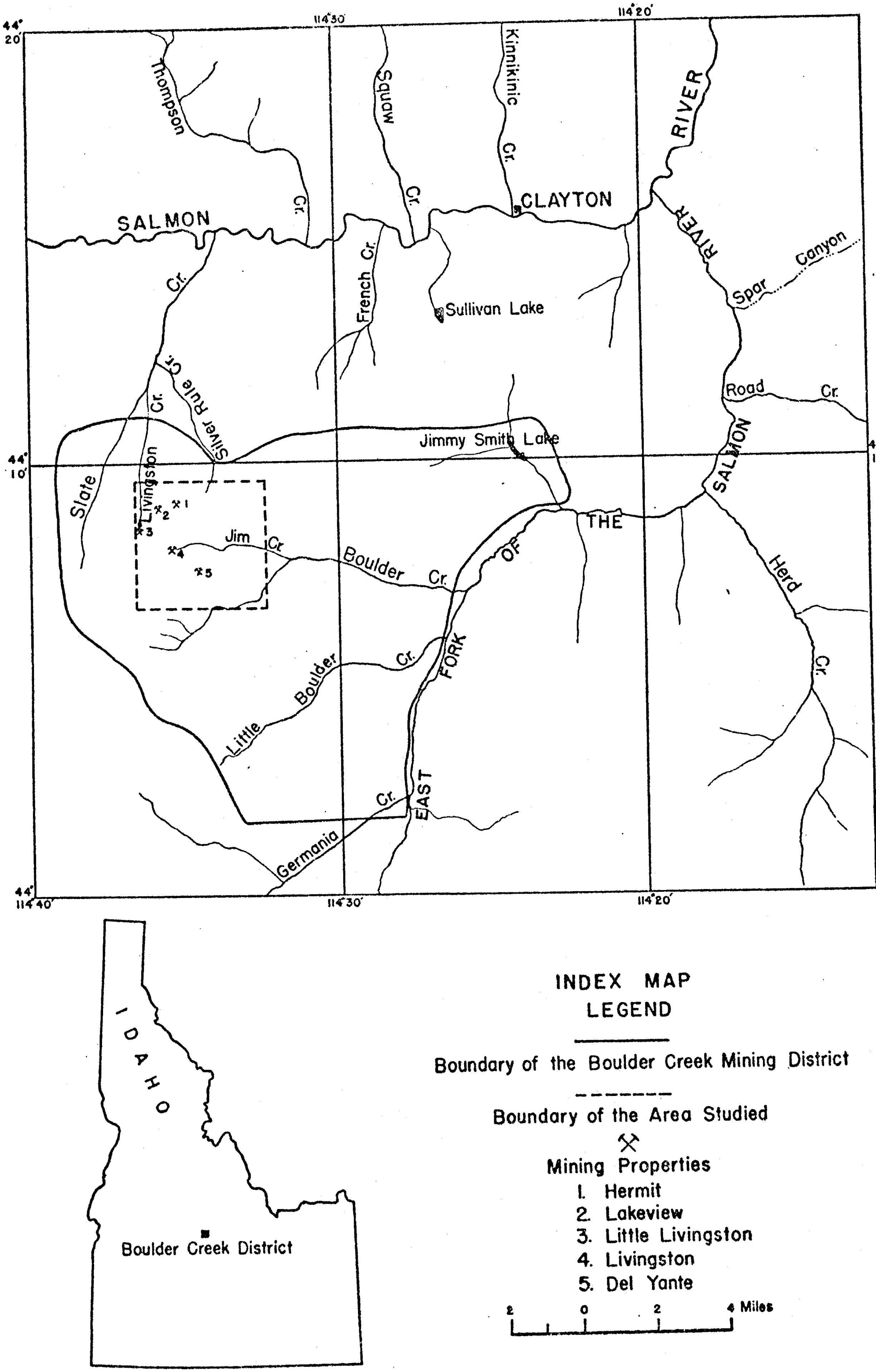
44°
20'
114°30'
114°20'
Thompson
Cr.
Squaw
Cr.
Kinnikinic
Cr.
CLAYTON
RIVER
SALMON
French Cr.
Sullivan Lake
RIVER
Spar
Canyon
Cr.
Silver Rule Cr.
Cr.
Road
Cr.
Jimmy Smith Lake
SALMON
44°
10'
Slate
Livingston
1
2
3
4
5
Jim
Cr.
Boulder
Cr.
THE
OF
Herd
Cr.
FORK
Little
Boulder
Cr.
Cr.
EAST
Germania
44°
114°40'
114°30'
114°20'
IDAHO
Boulder Creek District
INDEX MAP
LEGEND
Boundary of the Boulder Creek Mining District
Boundary of the Area Studied
Mining Properties
1. Hermit
2. Lakeview
3. Little Livingston
4. Livingston
5. Del Yante
2
0
2
4 Miles

Figure 1.

White Cloud Mountains, whose altitudes range as high as 11,820 feet. The mountains have been deeply incised by steep-walled canyons, headed by precipituous-walled cirques, the product of alpine glaciation, and are for the most part virtually inaccessible to motor transportation.

The most noticeable topographic feature locally is known as Railroad Ridge, so called because of its uniformity in elevation, width, and length. The ridge is capped by water and ice-worn boulders and gravels that were derived largely from granitic rocks to the west. It represents an ancient, glacier-fed river channel that drained the mountainous area to the west. The ridge forms the northwest canyon wall of Jim Creek.

GEOLOGY

FOREWORD

To unravel the many geologic problems, and to describe in detail, the lithology, stratigraphy, and structural features of the entire Boulder Creek district, would require time and efforts beyond the scope of this report. For this reason the following discussion is limited to those areas, and to those geologic features, which bear directly upon the problems of mineralization.

A hurried reconnaissance of the district reveals that the southwestern part is underlain by granitic rocks, a portion of the Idaho batholith; the central part by folded, northwest-trending Paleozoic sediments of which the Milligen formation is the chief component; and the northern and eastern parts by extrusive volcanic rocks, members of the Challis volcanics.

SEDIMENTARY ROCKS

Milligen Formation

Distribution: The Milligen formation is well exposed near the Livingston mine. There it outcrops boldly as escarpments and precipitous slopes. Locally, the beds are contorted and have divergent strikes and dips; but in general the formation trends northwest and beds dip steeply northeast. At the Livingston mine the Milligen outcrops as a broad belt, over a mile in width; however, when traced northwest to the upper limits of Slate and Livingston Creeks, the width increases to several miles. South of the mine, the trend of the belt is almost due north, the width decreases and the formation is restricted to the eastern face of the high ridge leading from the mine toward Boulder Creek.

Character: Most of the Milligen formation is a black, carbonaceous argillite containing some intercalated limestone and quartzite. Where exposed near the Hermit and Livingston mines, the argillite is black, dense, and thinly bedded. The dark coloration is caused by carbonaceous material that undoubtedly originated as organic matter deposited with the muds and silts which originally made up the formation. In thin section, the carbonaceous material appears as thin wisps and wavy streaks, which gives the rock its laminated appearance. The lamination as well as the bedding are highly contorted, indicating that the formation has been subjected to vigorous deformation.

At the head of the cirque immediately west of the Livingston mine buildings, alternating beds of light and dark quartzite, from 6 inches to 2 feet thick are prominently displayed. The coloration in the darker quartzitic beds reflects the presence of carbonaceous material. However, some of the dark beds are intercalated argillites. The quartzitic rocks are fine-grained, almost flint-like in appearance. Some of the beds are quite shaly and locally, where in contact with granitic rocks, have been strongly affected by contact metamorphism. Where also calcareous, these shaly quartzites have been metamorphosed to aggregates of such minerals as diopside, tremolite, and anothophyllite. These minerals give the rock a light, somewhat mottled appearance, and the rock thus affected may easily be mistaken for a fine-grained igneous rock. Some excellent exposures of the rock occur in the west 2263 drift and in the cliff face adjacent to the Livingston mine portals.

A thick lense of impure limestone underlies the Livingston mine buildings. This lense may be traced to the northwest and southeast, thinning in both directions. The limestone is blue-black, fine-grained, and thinly bedded. It commonly weathers to a blue-gray, and in some places to a rusty brown.

Age: Ross,[1/] who has studied the Milligen formation in the Boulder Creek area, regards its age as Mississippian. This age assignment is based on fossil evidence plus stratigraphic correlation with similar rocks of that age. The Milligan is similar lithologically to the younger overlying Wood River formation, 2,3/ but the two are separated by a basal conglomerate. As the conglomerate does not appear in the Boulder Creek district, the rock is regarded as Milligen.

IGNEOUS ROCKS

Quartz Monzonite

Distribution and correlation: Granitic rock of general quartz monzonite composition is widespread in the western and southwestern parts of the Boulder Creek district, underlying much of the Boulder Creek basin and extending well up, and in places, beyond the summits of the surrounding mountains. Good exposures occur on the mountain top immediately west of the Livingston mine. This rock is regarded as an outlying part of the Idaho batholith; the main body of which lies a few miles to the west.

Character: Although there are some compositional variations, the prevailing rock type is quartz monzonite. It is medium grained, light gray, and has a granitoid texture. The rock is composed of dull white feldspars (orthoclase and oligoclase), quartz, and biotite. Accessory minerals include apatite, sphene, muscovite, and magnetite. Some of the rock in places contains phenocrysts of flesh colored orthoclase measuring up to one centimeter in length.

Age: The quartz monzonite intrudes the Milligen formation (shown in excellent exposures on the mountain top west of the Livingston mine) and is overlain by the Challis volcanics (Oligocene?) to the southeast. The rock therefore was emplaced after Mississippian time and before Oligocene time. As it appears to form a part of the Idaho batholith, it was probably intruded in late Jurassic or Cretaceous time as fixed by others, 4.5/ who have studied the age of the batholith.

Dikes

Porphyritic dikes are plentiful in the granitic rock of the Boulder Creek basin, less so in the adjacent Paleozoic rocks. These dikes are composed chiefly of rhyolite porphyry.

One of the rhyolite porphyry dikes (the Scotch dike) is particularly important because of its influence on the location of ore at the Livingston mine. This dike has been cut by the Livingston fault with displacements as much as 160 feet, less so in places because of strike and dip variations. (Fig. 4, Section B-B'). The displaced segment is prominently displayed in the cliff face near the mine portals where it is from 20 to 40 feet thick. It may be traced southwest beyond the ridge crest and northwest to the basin of a small cirque where it is concealed beneath moranic debris. (Fig. 2).

Exposures of rhyolite porphyry are numerous in the western extensions of the Livingston mine. Some of these exposures may be mapped as dikes, but in places the rock is so sheared and contorted that projections can not be made from one mine-level to another.

The dike-rock has been variously described in times past. Former miners called it "turkey-egg granite"; other writers, 1, 6, 7/ have referred to it as aplite, alaskite, quartz porphyry, and quartzite. It is hereby proposed that the dike be termed rhyolite porphyry, because this classification is the only one which accurately satisfies its petrographic and compositional characterisitics.

The hand specimen shows a dark aphanitic groundmass in which are plainly discernable dark phenocrysts ranging from 1 to 2 millimeters in diameter. The phenocrysts are chiefly quartz; however, some are orthoclase. They are the most prominent features in the dike rock, and in some underground working places they provide the only means by which the rock may be distinguished from fine-grained quartzite. At the outcrop the rock weathers to a whitish color, but may be streaked and mottled pinkish-red, because of oxidation of contained sulphides.

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*All references cited are listed at the end of the paper.

All exposures of the rhyolite porphyry are petrographically similar, except where in contact with the Livingston vein; there, the rock is highly silicified. In thin section, the groundmass of the rock is seen to be composed of sugary-textured quartz, orthoclase, albite, and sericite. The dike segment on the hanging wall side of the Livingston vein commonly displays a multitude of tiny lens--like slips that are filled with optically oriented sericite. The orientation has resulted from the intense stresses that acted upon the dike during fault movement. Ore minerals occur throughout all segments of the dike, both as fissure fillings and as replacements. The ore minerals are commonly displayed in joint planes and in fracture openings at the outcrop.

No definite age is assigned the dikes because of insufficient collaborative evidence. That they are younger than the quartz monzonite is proven by the manner in which they cut that body. Ross, 1/, places the dikes as end members of the magmatic activity which emplaced the batholith. On the other hand Anderson, 10/, in studying similar dikes in adjacent areas, holds that such intrusions are the results of a later magmatic cycle of Tertiary age. As evidence, he points to the chilling at relatively shallow depths. Thus the quartz monzonite must have been thoroughly chilled and deeply eroded before dike invasion.

Extrusive Rocks

Challis Volcanics

The eastern, or foothill parts, of the district are covered by a thick series of interbedded andesites, latities, basalts, and tuffs. These volcanic extrusives have been mapped by Ross, 1/, but since they do not contain ore deposits locally, they were not studied in detail.

Ross, 1/, who has pioneered the study of this formation, has given their age as Oligocene (?).

ALLUVIUM

Glacial Deposits

Glacial deposits are well exposed on the small bench south of the Livingston mine near the Del Yante property. They also occur in the cirque immediately behind and in the area surrounding the Livingston mine buildings. The most prominent deposits form a capping on Railroad Ridge. Other extensive deposits overlie the Challis volcanics on the ridge south of Jim Creek.

These deposits are composed of poorly sorted alluvium ranging from coarse sands to boulders 15 feet in diameter. Most of the material has been derived from the granitic areas lying to the west.

The glacial deposits are the products of alpine glaciation which was widespread in the central Idaho region during Pleistocene time.

STRUCTURE

The contortion of the Milligen formation indicates that structural deformation in this area has been intense. This deformation is strikingly evident in the eastern canyon wall near the headwaters of Livingston Creek. Here, the denuded and precipitous wall presents a perfect cross section of an asymmetrical syncline. A fault of large but unknown magnitude cuts the northern limb of the syncline, which, together with its accompanying dragfolds, may be viewed from several miles distant.

Although most of the deformation is older than the quartz monzonite, no attempt is made to assign either an age or a cause for this deformation. Such postulations would require collaborative evidence beyond the scope of this report. Criteria concerning the general age of the deformation are present along the granitic contact on the mountain top west of the Livingston mine. In this area a large block of argillite, striking NW and dipping steeply to the NE is enclosed by quartz monzonite. The larger, parent body of argillite located nearby has the same strike and dip as the enclosed block. This indicates that the argillite was folded before encroachment by the granitic magma.

Some structural disturbances have occured since the granitic intrusion. A good example is the Livingston fault which displaces not only the older argillite, but also the younger dikes.

ORE DEPOSITS

The ore deposits in the district occur along shear zones, partly as fillings of open fissures and partly as replacements of the host rock. These shear zones are made up of enumerable small, closely spaced slips (shears) that represent discontinuous movement for a period of time. The hanging wall of some of the pillars in the Christmas stope on the Livingston vein reveals this character admirably. Here, thin-banded laminated zones of sheared argillite, some as much as 3 feet thick, attest to the repeated movement to which these rocks have been subjected.

An important, if not the most important aspect of the shearing has been the compatibility of the rocks that were subjected to shearing stress. Some rocks, such as the pliant argillites, have been deformed by flowage, and locally by shearing, whereas the more competent rocks, i.e., the dikes and some quartzites have readily failed by fracturing. Thus, fracture openings in the competent rocks have provided the main avenues of approach for the mineralizing solutions. In places these solutions diffused into and replaced the bordering, unfractured host rocks, forming ore deposits. Here and there the solutions were able to permeate along the shear planes in the argillite, producing a banded or book-like structure in which thin layers and small masses of ore are separated by bands and irregular layers or argillite. This structure is the product of progressive shearing in which each separate shear plane has formed a receptacle for mineral deposition. It was apprently easier for the recurrent shearing to form a new opening than to reopen an old one that had been healed with ore.

The ore bodies are not continuous but are confined to shoots of definite rake.

These shoots may be separated by barren ground or ground so little mineralized as to be scarcely distinguishable from the country rock. The ore shoots are structurally controlled and where the control is such as to inhibit mineral deposition, ore was not formed.

The ores were deposited under mesothermal or moderately deep-seated conditions and should continue to depths not yet reached by mining.

The age at which ore deposition occurred is undetermined. In as much as the ores replace the rhyolite porphyry dike-rock, they are obviously younger. If the dikes were emplaced in early Tertiary times, as implied by Anderson, 10/, then it is probable that the ore was deposited during the early Tertiary epoch of mineralization that was so prevalent throughout the west.

PROPERTIES

THE LIVINGSTON MINE

Location

The Livingston mine, owned by the Livingston Mines, Inc., is located at the head of Jim Creek, at an altitude of 9,300 feet, about 62 miles northwest of Mackay. The mill is on Boulder Creek, about 2,000 feet lower and 4 miles, by road, from the mine. The mine and mill are connected by an aerial tramway. The property comprises 7 patented and 25 unpatented mining claims. It is equipped for small scale mining operations.

History

The exact discovery date of the Livingston mine is not known, but is thought to be in the late 1880's or early 1890's. Rich lead-silver ore was found in the outcrop and some of this was shipped, by mule-back, to the old smelter at Clayton, Idaho. Some ore was shipped as far as Denver, Colorado. The Livingston Mines, Incorporated was organized in 1922, and at that time this corporation inaugurated a broad development program which included the construction of a road 9 miles long from the mouth of Boulder Creek to the mill site and thence up Jim Creek to the mine; the installation of a 300-ton flotation mill; the erection of a 3-mile aerial tramway from the mine to the mill; and the building of a hydro-electric power plant of 650 h.p. capacity, together with transmission lines to the mine and mill.

By 1923 most of the construction work was completed and in addition a considerable amount of underground development had been done in the mine. Some high-grade ore was shipped to the smelter, but records of these shipments were not available to the writer. At that time it was said 8/ the Livingston was the most rapidly expanding mine in the State of Idaho.

The period, 1929 to 1930, witnessed the maximum amount of activity. The mine and mill were then in full production, employing as many as 130 men. The bulk of the ore was found in one long ore shoot that was continuous on the lower levels but

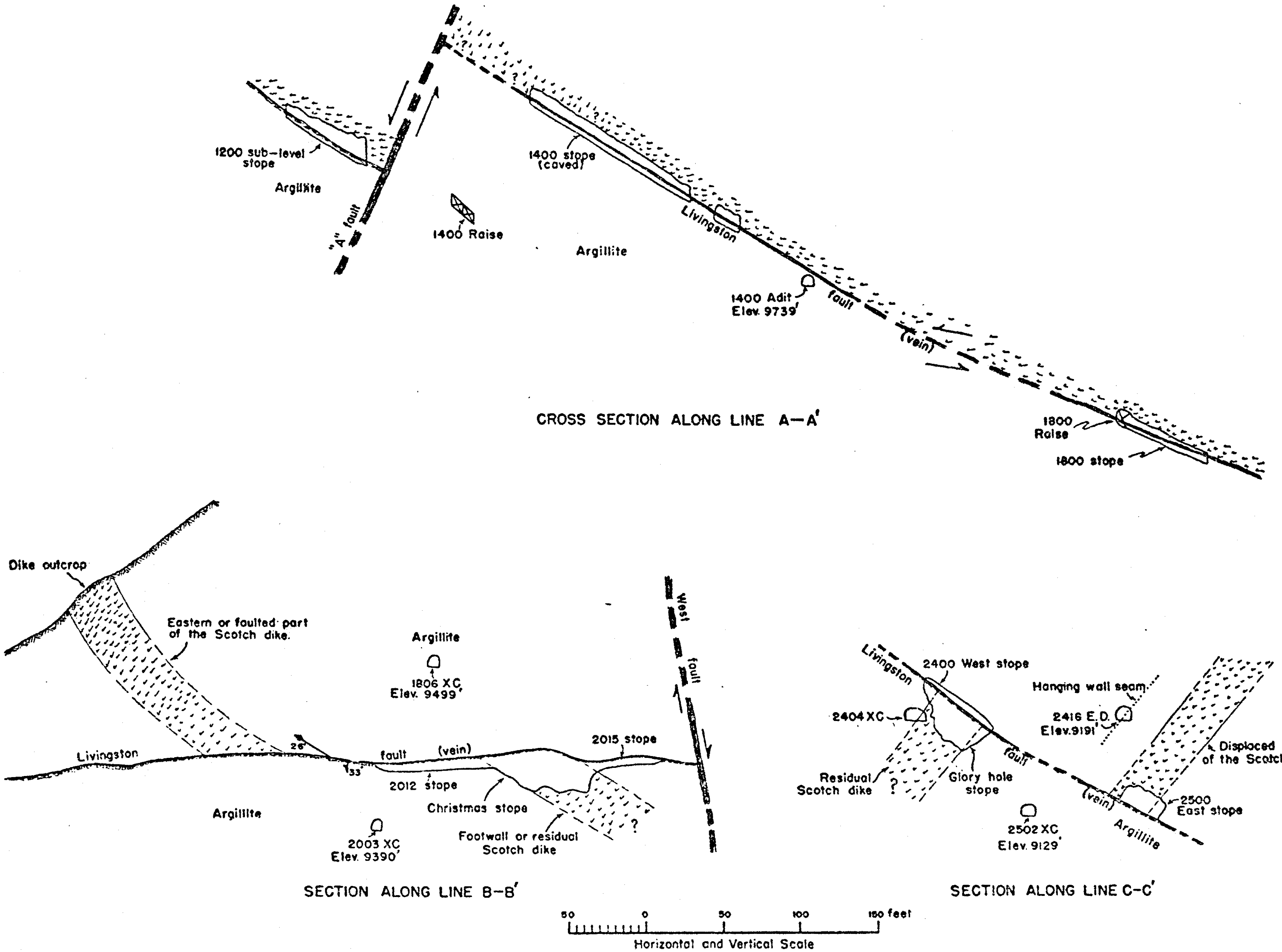


Fig. 4 Geologic Cross Sections of the Livingston Mine

broken and displaced in the upper parts of the mine. Levels were driven on this ore shoot being identified with respect to a plane at the apex of the vein on the ridge of the mine. These levels included the 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2500, giving a total mineable distance, measured down dip. of approximately 1,900 feet. (Fig. 3). In addition to the mining operations, exploratory workings were extended on both sides of the ore shoot, in an attempt to find and develop more ore bodies. These attempts proved fruitless.

In 1930 operations at the mine came to a sudden halt. The company failed to file its annual report and shortly thereafter the mine went into receivership. Several explanations have been advanced to account for the corporation's sudden dissolution. For the most part the explanations are suppositions advanced by people who claim to have been familiar with the mine's problems. Some people hold that the low price of lead was responsible; others accredit the closing to exhaustion of ore reserves. Mismanagement has also been blamed as the reason for the failure of the mine.

From 1930 to 1946, the mine changed ownership several times. During this time the mining and milling equipment was removed. However, from time to time sporadic attempts were made by lessees to reopen the mine, but most operations consisted of removing the pillars in old stopes and gouging into a few favorable faces.

In 1946 new owners obtained the property and attempted to resume operations. The aerial tramway was repaired and put into operation. Mining equipment was installed and operations were resumed between the 2400 and 2500-levels. The ore produced was shipped to the U.S. Smelting, Refining and Mining Co.'s smelter at Midvale, Utah. During the fall months of 1948 a 100-ton flotation mill was obtained and the owners are currently attempting to complete its installation.

Production

The exact metal production at the Livingston mine cannot be ascertained. During its earlier years an unknown amount of ore was shipped to several different smelters, but all records have since been lost. Throughout the period 1926 to 1930, which witnessed the mine's maximum production, the bulk of the ore was processed in the mill and the lead and silver concentrate was shipped to the United States Smelting, Refining and Mining Company's smelter at Midvale, Utah. They record the following:

TABLE I

Production of the Livingston Mine from 1926 to 1930*

Year	Dry tons of crude ore	Dry tons of conc.	Gross value of crude	Gross value of conc.	Combin. conc. & crude grs. values
1926	80.18	273.75	$2,160.16	$9,309.75	$11,469.91
1927	109.14	3,023.19	3,933.06	153,946.34	157,879.40
1928		3,625.21		146,702.66	146,702.66
1929		4,499.32		285,722.20	285,722.20
1930		928.54		48,978.06	48,978.06
Total	189.32	12,350.01	$6,093.22	$644,659.01	$650,752.23

* Courtesy of Mr. Blaine Watts, Ore Buyer for the U.S.Smelting, Refining, and Mining Company. (Refer to Table I.)

Following dissolution of Livingston Mines, Inc. in 1930, there was some production by lessees and holding concerns, but the amount of ore produced is not known as the records have since been lost.

Much of the ore mined during the period of active exploitation never arrived at the smelter. The early day milling practice was a haphazard affair, with far too much metal going into the tailing pond. Haley 6/estimates that of the crude ore processed, 8.3 tons were required to produce 1 ton on concentrate. Little effort was made to recover the zinc; some was shipped to the lead smelter as a middling product, but the mill did not produce a zinc concentrate. According to Haley, the mill tailings, from 1925 to 1926, assayed approximately as follows:

Pb	Zn	Ag	Au
4.8%	6.9%	2.07 oz.	Trace

With time the milling practice improved, but at the best, the tailings averaged:

Pb	Zn	Ag	Au
1.8%	5.9%	1.08 oz.	Trace

Because of the poor milling practice, Haley has estimated that 86.3 per cent of of the zinc, and 5,742,105 lbs. of lead went into the tailing pond. Much of the tailing pond is still intact, but the tailings are now so badly oxidized that any future processing will involve some rather difficult metallurgical problems.

Faulting

There have been three and possibly four separate periods of faulting in and near the Livingston mine; all of which have in some way had an effect on the occurrence and distribution of ore. These are grouped into pre-mineral and post-mineral faults.

Pre-Mineral Faults

West Fault: The West fault, the most important of the pre-mineral faults, lies immediately west of the mine portals. (Fig. 2). The zone of broken rock along the fault averages about 4 feet wide. It has a slightly curving northwest trend and generally a steep southwest dip. In places, however, the dip is vertical and even changes to steeply northeast. The fault is of the normal variety with the hanging wall relatively downthrown with respect to the footwall, although actually the movement has been obliquely downward.

The West fault has been intersected at several points by drifts and crosscuts on the 1800 and 2200-levels, in the western part of the mine. Where intersected it has been called the "main fault", and is invariably a zone of heavy shearing that requires tight timbering to hold the ground in place. The fault is also well exposed in the 2015 stope. Here, the ore terminates abruptly against the fault plane.

As rhyolite porphyry penetrates the fault zone with sharp, frozen contacts, extending across the fault lineations, (Fig. 5, No. B), the fault is obviously pre-dike.

East Fault: The East fault is intersected by the 2204 crosscut near the base of the 2250 transfer raise. The fault is 4 to 5 feet wide, strikes N. 22° W. and dips about 35° SW. It bears evidence of heavy shearing and contains abundant slickensides. Like the West fault, it is a normal fault in which the hanging wall has moved downward, raking to the northwest.

The 2204 crosscut should intersect the eastern end of the Livingston vein, but fails to do so. Instead, the vein stops at the East fault and does not continue beyond. Evidence in the fault plane indicates that it was present before the Livingstone vein came into existance.

The gentle dip of the fault carries it to the surface below the portals of the upper tunnels, thus it is not cut by any of the upper workings. It may be traced up the mountain side, below the 1400 and 1600 portals, until it is lost below the surface mantle. To the northwest it disappears beneath talus slopes.

Dike Faults: Many faults containing rhyolite porphyry dikes (Dike faults) radiate out from the body of quartz monzonite, decreasing in number and magnitude away from the contact. Opening of the faults apparently took place after the East and West faults had come into existance, perhaps as a consequence of renewed structural adjustments.

Livingston Fault: The Livingston fault, or Livingston vein, is well exposed in cross section of the steep mountain slope adjacent to the mine portals. It passes through the 1400-level portal, and may be traced down the mountain side, passing below the lower mine portals. The fault has a westerly strike and an average 33° N. dip. It has a comparatively short strike length, as it is terminated at one end by the West fault and on the other by the East fault. The Livingston is a reverse fault along which the hanging wall has been displaced up the dip, raking to the southeast. It has displaced the Scotch dike, the relative displacement being east and southeast (Fig. 4, Section B-B'). The segment of the dike that outcrops on the mountain side is in the hanging wall of the Livingston fault.

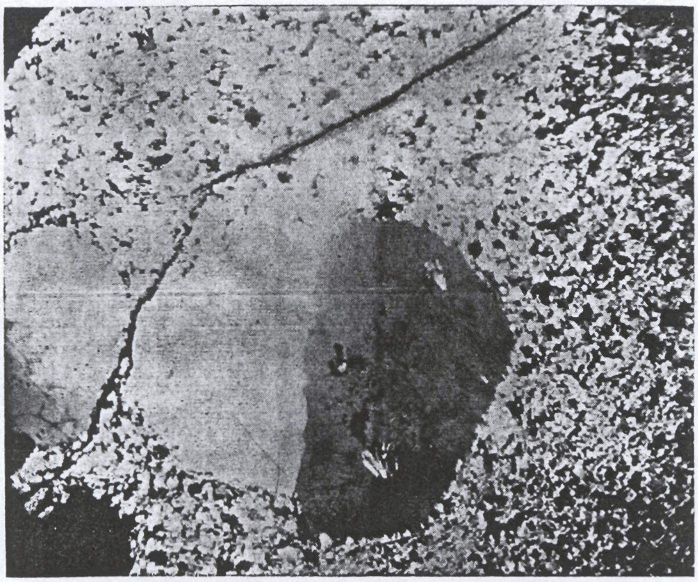
The mineralizing solutions had access to the Livingston fault at the time of movement and were channeled upward along the more permeable parts of the fault zone. The faulting was not accomplished in one state, but was discontinuous and consisted of successive slips, which permitted recurrent surges of the mineralizing solutions.

Post-Mineral Faults

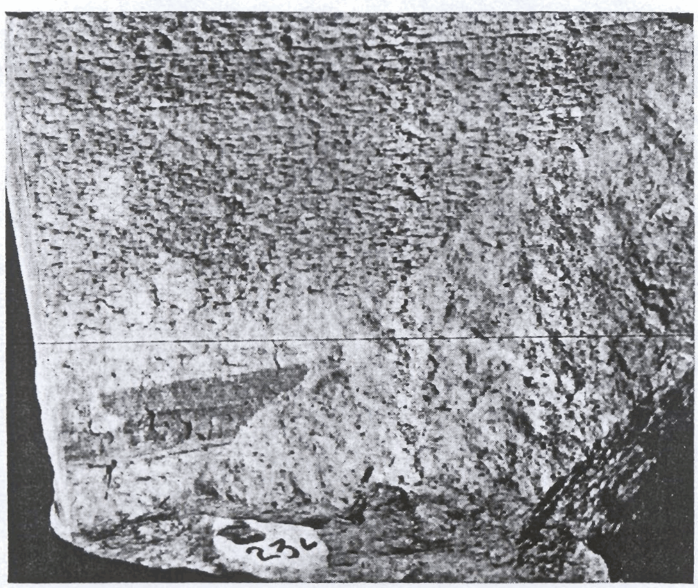
"A" Fault: The "A" fault belongs to the fourth period of faulting, which occurred after the Livingston fault had been mineralized. This fault, which is intersected by the 1200 and 1400-levels, strikes northwest and dips steeply to the southwest. It is a normal fault and intersects both the Scotch dike and the Livingston vein, displacing them downward on its hanging wall side. (Fig. 4, Section A-A').

Summary of Fault Action

The older, pre-mineral East and West faults came into being during an early structural disturbance. Later faulting produced fractures which were filled with igneous material. Still later adjustments in which thrusting forces were involved, acting from



A. Photomicrograph of a thin section of Scotch dike from the 1400-level of the Livingston mine showing an orthoclase phenocryst set in an aphanitic groundmass. The fracture cutting the top part of the picture contains optically oriented sericite. Crossed nicols. X 40.



B. Photograph of specimen taken from the West fault showing a fragment of rhyolite porphyry (right) cutting sharply across fault lineations. The sharp, frozen contact denotes that the fault was in place before intrusion of the stringer.

Fig. 5

the northwest, gave rise to the Livingston fault. This gently dipping fault, lying between the East and West faults, served as a glide-plane on which the hanging wall block was thrust over the footwall, raking to the southeast. The same force also probably brought about renewed movement of those bounding parts of the East and West faults lying above the Livingston fault. Ore structures indicate that movement along the Livingston fault continued during mineralization. Post-mineral faulting is evidenced by the "A" fault which has displaced the Scotch dike and the Livingston vein.

Description of the Ore Bodies

Practically the entire production of the mine has come from one long continuous ore shoot in the Livingston vein. This shoot attains its maximum size between the 1800 and 2200-levels, where it is known as the Christmas stope. There are other mineralized veins in the mine, some in fractures, other than the Livingston fault. These include the Little Falls, the Scotch, the Blumenthal, the oxidized stopes on the 1200 and 1200 sub-levels, and some small unimportant offshoots.

Livingston Vein

The Livingston vein, which occupies the Livingston fault, strikes eastwest and dips 28° to 44° N. The mean dip is about 33 degrees. The ore shoots within the plane of the vein do not follow the dip, but rake 26 degrees to the northwest. This gently dipping fracture is a reverse fault in which the hanging wall has been displaced up the dip, raking to the southeast. The vein is 2 to 6 inches thick where exposed on the steep mountain side. There, because its strike carries it directly into the mountain, it is exposed in perfect cross section. As the vein is traced to the west it is found to cut and displace the Scotch dike. The east or displaced segment of the Scotch dike lies against and forms a part of the hanging wall of the Livingston fault. (Fig. 4, Section B-B'). Farther to the west, the stationary part of the Scotch dike is encountered abutting the footwall side of the Livingston fracture. It is this area, the contact of the Livingston fault and the stationary or under part of the Scotch dike, that is the site of the major, elongated ore shoots.

An excellent sample of the contact between the vein and the under segment of the dike may be seen on the 2000-level. Here, the tunnel, which is well out into the hanging wall of the Livingston vein, cuts the displaced segment of the Scotch dike 90 feet from the portal. The dike, where cut by the tunnel, strikes N. 33° W. and dips 68° SW. Farther in, the tunnel turns south, and crosscuts the Livingston vein, which, at the point of intersection, is 18 inches thick. At this point the vein has argillite on both walls. After intersecting the vein, the tunnel drifts to the west, and in approximately 40 feet, the vein starts to thicken; bulging on the footwall side. This is the 2000-level entry to the Christmas stope; which, on this level, is 210 ft. in strike length, and in the middle is as much as 30 feet thick. Throughout its entire length on this level, the hanging wall of the stope is argillite. The wall has a compact, smooth, fairly even surface, and is unsupported, except for 2 or 3 small pillars. When the pillars are studied in detail it becomes readily apparent that the hanging wall surface was the principal plane of shearing. Below the hanging wall is a zone of shearing from 1 to 3 feet thick. This zone is composed of sheared argillite with bands of sulphides, and presents good evidence that shearing was progressive along innumerable small slips.

Near the point where the stope starts to widen and immediately beneath the sheared zone are good exposures of rhyolite porphyry, the footwall segment of the

Scotch dike. Here are the big bulges in the footwall that account for the increased width of the stope. In this region the mineralizing solutions, in migrating up the more pervious parts of the Livingston fracture, were impounded on the hanging wall by the tightly packed shear zone and the impermeable argillite wall rock. On the footwall side they encountered comparatively brittle, crystalline dike rock, which, subjected to the same stress as the enclosing argillite, was shattered with the formation of innumerable fracture openings. These minute openings received the mineralizing solutions that were migrating along the Livingston fault. The crystalline feldspars and quartz were more easily replaced than the carbonaceous, clay-like argillite. Thus as the solutions diffused into the dike, away from the fracture-openings, they replaced it with ore. As some parts have been more deeply and extensively fractured than others, the ore replacement extended irregularly into the dike. This irregular replacement accounts for the rough uneven footwall of the Christmas stope. The miners, in following the ore, have gone after the rich high-grade spots, leaving those parts of the vein with excess gangue and low-grade ore behind. (Fig. 4). The thickness of the Christmas stope represents the distance the ore-bearing solutions were able to penetrate from the main channelway, i.e., the Livingston fault, and replace the dike.

As the vein is followed across the Christmas stope, it re-enters the argillite and its thickness rapidly decreases. About 70 feet from the western edge of the Christmas stope, the thickness of the vein and the tenor of the ore decrease to such an extent that drifting was abandoned.

Some observers 6/ have advanced the theory that a series of northwest trending fractures intersect the footwall of the Livingston fault, and that these have admitted the mineralizing solutions, which, upon entering the Livingston fault spread out, forming ore deposits. There is no evidence to substantiate this theory. At no place in the mine are there fractures leading into the footwall which bear evidence of admitting such solutions.

The true strike and dip of the west footwall segment of the Scotch dike can not be computed from its exposure on the 2000-level. Its oblique contact with the gentle dipping Livingston vein presents a distorted picture; however, mapping on other levels show that it strikes NW. and dips steeply to the SW. In this respect it is comparable with its eastern, displaced segment.

The contact of the Livingston vein and the footwall part of the Scotch dike accounts for the NW. gently dipping rake of the Christmas stope ore body. This contact controls the location of the ore body. With the exception of the stope-like raise between the 2400 and 2200-levels in the area between the faulted dike segments, the contact of the Livingston vein and footwall dike may be traced from the 2500 to the 1800-level, thus accounting for those areas that have produced the bulk of the ore.

There are some stopes on the Livingston vein that are not on the footwall dike contact. Between the 1800 and 1600-levels, the raking ore body veers off to the east at a flatter angle and leaves the footwall dike contact. (Fig. 3.). In this area the stope decreases in size to a thickness of 4 feet and a strike length of about 3 feet. Because of the admixed gangue accumulated in maintaining the necessary width for mining operations, ore from this stope was low-grade.

A similar condition exists on the 1800-level in the western part of the mine in the 1805 H.W. stope and its downward continuation, the 2020 H.W. stope. Here, the strike of the Livingston vein changes from N. 76 degrees W. to N. 58 degrees W and the dip increases from 31 to 41 degrees. The abrupt change in vein attitude has created a ridge-like structure in the vein, and the stopes lie on this ridge. The two stopes average about 4 feet in width, and pinch out to the west and upward along the dip. They owe their positions to the changing attitude of the Livingston vein.

A small vein, from 2 to 6 inches thick is intersected by the 1806 crosscut. It appears to be hanging wall split or offshoot from the Livingston vein, but is so narrow that it has discouraged extensive exploration.

There are places where the eastern displaced segment of the Scotch dike contains ore bodies. These bodies, like those in the footwall, occur at the contact of the Livingston vein and the Scotch dike. An excellent example of this type of ore body may be seen on the 1400-level at the base of the caved 1400 stope. Here the stope is about 60 feet long and about 7 feet wide. Its most interesting feature is that the footwall is argillite, whereas the hanging wall is wholly rhyolite porphyry. The Livingston vein passes through the stope, holding closely to the footwall; and, directed the mineralizing solutions to the faulted Scotch dike.

A study of Fig. 3 suggests that the 1400 stope has been displaced to the west, inasmuch as it is not in line with the previously described Christmas stope ore body. However, Fig. 2 shows that the outcrop of the Scotch dike, near the 1400-level, swings sharply to the southeast, and that the dip flattens from 62 to 30 degrees. This change in dike attitude accounts for the seemingly westward displacement of the 1400 stope. The flatter dipping dike extends farther to the southwest before intersecting the Livingston fault.

The Livingston vein may be traced at the outcrop from the 1600 to the 1400-level, but very little mining has been done between. The vein is cut by the raise connecting the two levels, and a crosscut driven from this raise, the 1601 crosscut, leads to two raises which reputedly extend upward to good ore showings. Because of bad air these raises were not visited; but, they cannot possibly lead to the Livingston vein, since the vein passes beneath the 1601 crosscut. The raises undoubtedly extend to the mineralized part of the Scotch dike, which has been explored overhead by the 1400-level N. drift.

Another example of an ore body on the hanging wall contact of the Livingston vein and the displaced segment of the Scotch dike is the east stope connecting the 2400 and 2500-levels. This stope has a strike length of 30 to 40 feet and is from 7 to 16 feet wide. Its footwall rests directly on the smooth, even Livingston fault, beneath which is argillite. The hanging wall is rough and uneven and is almost entirely in the Scotch dike. (Fig. 4, Section C-C').

A short stope, with the appearance of a big glory hole, lies between the 2400 and 2500-levels, about 45 feet west of the east 2500 stope. It has a smooth, even hanging wall; and, when mapped, it becomes apparent that the argillite hanging wall is actually that of the main fracture surface of the Livingston fault. Thus the stope is entirely in the footwall; and, when studied closely, the ore found is a replacement of the footwall segment of the Scotch dike. The ore in this stope is predominantly sphalerite, but there are no assay records available to determine the value. The even hanging wall of the stope dips 44 degrees to the north, and this dip has influenced some observers to believe that the dip of the Livingston vein will increase with depth. However, the local increase does not afford sufficient evidence to postulate a continued increase in dip. As previously described, the vein on the 1800-level also dips 44 degrees but the increase is only a local variation and is not persistent; such may well be the case on the 2400-level.

Some observers postulate that the block of ground between the two stopes connecting the 2400 and 2500-levels represents a possible ore body with a large tonnage of potential ore reserves. The writer is dubious about this inferred ore body. There will undoubtedly be a certain amount of ore in this area, as the Livingston vein passes through there, but the vein in this block is enclosed on both hanging and footwall by argillite, thus it should have a narrow width. The fact that the two stopes are close together and that both form along the same vein does not substantiate the theory that a body of ore lies between. Detailed mapping shows the east stope to lie along the contact of the Livingston vein and the eastern, displaced Scotch dike, whereas the west stope lies on the contact of the Livingston and the footwall segment of the Scotch dike. Thus the two stopes have separate structural controls.

An interesting feature in the downward extension of the Livingston ore bodies is the progressive decrease in the distance between the faulted segments of the Scotch dike, particularly below the 2200-level. The distance decreases from 160 ft. on the 2200-level to about 60 feet below the 2400-level. The decrease may be explained by referring to Fig. 2. Here, the northern end of the outcropping Scotch dike, just before it passes under the glacial alluvium, strikes N. 40 degrees and dips 76 degrees SW., whereas the dike immediately west of the 2000-level portal strikes N. 22 degrees W. and dips 65 degrees SW. Thus from the 2000 portal northward there is a progressive northwest swing in the strike of the dike. As a study of the Livingston fault indicates that it is a reverse fault with the hanging wall displaced at a rake from the northwest to the southeast, it becomes apparent that in the area north of the 2000-level, the direction of movement along the Livingston fault has tended to parallel the strike of the Scotch dike. Such movement, while resulting in a displacement of the Livingston hanging wall, would not give much lateral displacement to the Scotch dike. Theoretically, if the strike of the Scotch dike paralleled the direction of movement on the Livingston fault, there would be no lateral displacement but rather a dike on dike fault contact.

The relationship between the strike of the Scotch dike and the direction of movement on the Livingston fault should be borne in mind in any future downward exploration for possible ore bodies. The contact of the dike and the Livingston vein controls the location of these ore bodies. This contact should receive priority during any future exploration.

Much exploratory work has been done on the 1800 and 2200-levels, in attempts to intersect the western continuation of the Livingston vein. Most of this work has been useless, for it extends beyond the pre-mineral West fault which limits the western extension of the Livingston vein. Many of the drifts and crosscuts have intersected numerous apophyses and stringers of rhyolite, porphyry, but these rocks have not been intersected by the Livingston fault, i.e., the feeding channel for mineralizing solutions, and are barren. There is, of course, a possibility that mineralizing fractures other than the Livingston may have intersected these rocks, but no such fractures have yet been found. Exploration of the ground west of the pre-mineral west fault should be discouraged.

The 1200 and 1200 Sub-Level Ore Bodies

On the 1200 and 1200 sub-levels are two rather small stopes that probably are on the Livingston vein. These stopes are considered to be on separate ore bodies, not as extensions of that found in the 1400 stope. The stopes are similar to the 1400 stope in that both have argillite footwalls and mineralized Scotch dike in the hanging wall, and in that both contain highly oxidized lead ores.

As mentioned earlier, the 1400 stope was caved and inaccessible. Therefore, for the purposes of this report, its boundaries were taken from another paper 1/and the dip observed at the base of the stope was projected through its plan length. This calculation gives the stope a dip-length of approximately 300 feet, and when projected in cross section, at a dip of 32 degrees, it should pass 47 feet above the 1200 sub-level. This projection, if it is correct, rules out the possibility of the 1200 and the 1200 sub-level stopes being a continuation of the vein which passes through the 1400 stope. (Fig. 4, Section A-A').

The prominent "A" fault cuts the 1200-level near the head of the 1200 transfer raise; it also cuts the 1200 sub-level near the stope entrance. The fault, which is normal, strikes N. 80 degrees W. and dips 68 degrees S. On the 1200-level it appears to have displaced the Scotch dike down the dip. Inasmuch as it displaces the Scotch dike it must also have displaced the vein on the under side of the dike. Assuming that the data compiled on the 1400 stope is correct the fault displacement should be about 90 feet. (Fig. 4, Section A-A').

A section drawn through the 1200 stope and the surface indicates that if the vein maintains its average dip of 32 degrees, it should be possible to follow it for 650 feet before intersecting the surface. However, various factors should be considered before any development of that block is contemplated. The short strike length of the stope makes the possibility of a large tonnage doubtful. Also, the oxidized condition of the ore creates milling problems that should not be overlooked. Another depressing factor is that the 1200 is connected to the 2200-level by a series of drifts, crosscuts, and raises, all of which makes the handling of ore and mining equipment cumbersome and inefficient.

Little Falls Vein

The Little Falls vein outcrops on a low argillite ridge cutting diagonally across the cirque immediately west of the Livingston mine buildings. It strikes N. 50 degrees W. and dips steeply to the SW. At the outcrop it appears as a brecciated quartz vein in a shear zone 1 to 2 feet wide, locally with scattered granules of galena.

The vein has been followed and crosscut on the 2200 and 2400-levels, but the 2400-level was flooded and inaccessible during the past summer's visit. On the 2200-level the vein follows a strong shear zone. It does not contain a consistent width, but here and there pinches completely out. At no place was the width found to exceed 2 feet. Stopes have been opened up at several points along the strike, but they are small. The heavy ground along the shear zone has made tight timbering mandatory; but even so, many of the working places are caved, making entry hazardous. There are reports that lead ore with a high silver content has been mined in these stopes, but there are no records to substantiate these claims. Judging from the condition of the stopes, their production has been limited.

In the writer's opinion, the Little Falls vein does not warrant any further exploration, certainly not in the immediate future. In the event that future production from the Livingston ore bodies should put the mine on a paying basis, then the downward continuation of the Little Falls vein might be explored by diamond drilling.

Scotch Vein

Past observers 6/ 7/ have referred to the hanging wall segment of the Scotch dike on and below the 2400-level as the Scotch vein. They point out that the Scotch vein apexes between the 2400 and 2200-levels. Present studies refute this theory. Detailed mapping proves that the eastern, displaced Scotch dike, i.e., in part the Scotch vein, can be traced to the outcrop, and that it is in contact with the Livingston fault from the 2500 to the 1200-levels. For this reason all ore deposits in the Scotch dike are regarded as belonging to the Livingston vein. Thus, in the 2500 east stope, the floor is on the Livingston fault, whereas, the ore body is a replacement of the dike. The same holds true for the 1400 stope and possibly for the 1200 and 1200 sub-level stopes.

Blumenthal Vein

In the 2402 crosscut, about 50 feet south of the winze station, is a 22-foot exposure of lightly mineralized porphyry dike known as the Blumenthal vein. This dike strikes N. 74 degrees W. and dips steeply to the southwest. The northern or footwall side of the dike, which is slightly mineralized, has been meagerly developed by a few rounds blasted from the east side of the crosscut. There are no assay reports from this dike, but judging from the ore displayed in the hand specimens, its value would be very low. If the ore had been promising it would undoubtedly have been more thoroughly explored at the time of discovery.

According to the attitude of the dike, it should have been intersected by the 2412 and the 2418 crosscuts. Such is not the case, nor is it intersected by any of the 2200 crosscuts. If projected downward, it should have been cut by the 2500 crosscut; however, that area was flooded at the time of the field examinations. Miners who were familiar with the 2500 crosscut report that it was not cut on that level. Good exposures of rhyolite porphyry occur in the face of the 2414 crosscut, but they are directly in the path of the Scotch dike and undoubtedly belong to it. If the strike of the Blumenthal dike were to swing sharply to the southwest, it is conceivable that it would merge with the Scotch dike somewhere between the 2402 and 2414 crosscuts; however, such a sudden turn seems improbable. It is more likely that the Blumenthal dike has been exposed at or near its apex and that it lacks sufficient length to reach the other crosscuts and drifts on that level. It is conceivable that it could merge with the Scotch dike at a lower level, and may even abut the Livingston vein. In that case it would be a likely location for ore bodies.

Small Offshoots from the Livingston Vein

There are a few places in the mine where small veins occur at variable distances away from the Livingston vein. These veins are controlled by small fractures in the Livingston hanging wall that were probably formed at the same time as the Livingston. The fractures are filled chiefly with quartz, pyrite and sphalerite which were introduced during the early stages of mineralization. One of the most conspicuous examples is the small sphalerite vein exposed in the 2200 winze station, and also cut by the winze between the 2200 and the 2400-levels. Another example is the small hanging wall vein cut by the 1806 crosscut. The small size, discontinous nature, and low grade of ore discourages exploration on these veins.

Mineralogy

The minerals that make up the Livingston ore are divided into three groups: (1) primary minerals, deposited by ascending hydrothermal solutions; (2) secondary minerals, derived from alteration of the primary minerals; (3) gangue minerals.

Primary Minerals

Jamesonite: The lead and iron, antimony sulphide ($Pb_4FeSb_6S_{14}$) is the dominant ore mineral at the Livingston mine, and has accounted for the bulk of the lead production. It occurs throughout the mine, from the outcrop to the lowest working places, without any noticeable change in physical characteristics or in quantity. It is characterized by its steel-gray color and tendency to form subparallel aggregates of prismatic crystals that are very brittle and easily broken across the elongation. Where exposed in the upper levels and on the outcrop, the Jamesonite is usually coated by a compact, earthy, yellow alteration product.

Galena: Lead sulphide (PbS) is present in variable amounts in the ores. It is particularily abundant on and above the 1400-level, often as relic cores enclosed by its oxidation products. Much of it has been broken and shattered by subsequent faulting, especially in those areas near the vein hanging wall. It is readily distinguished from jamestonite by its cubic cleavage and the bright metallic luster on its crystal faces. Polished sections reveal that the galena has been penetrated and replaced by jamesonite.

Sphalerite: Zinc sulphide (ZnS) is abundant from the 1800 on down through the lower mine levels. In places it comprises as much as 70 per cent of the ore, e.g., on the west side of the 2200 Christmas stope and the western 2400 stope. The mineral is almost completely absent in the oxidized ores above the 1400-level. It has a dark brown color, is coarse-grained, and has a resinous to submetallic luster.

Chalcopyrite: The copper iron sulphide ($CuFeS_2$) is present, but in very small amounts. It adds nothing to the value of the ores.

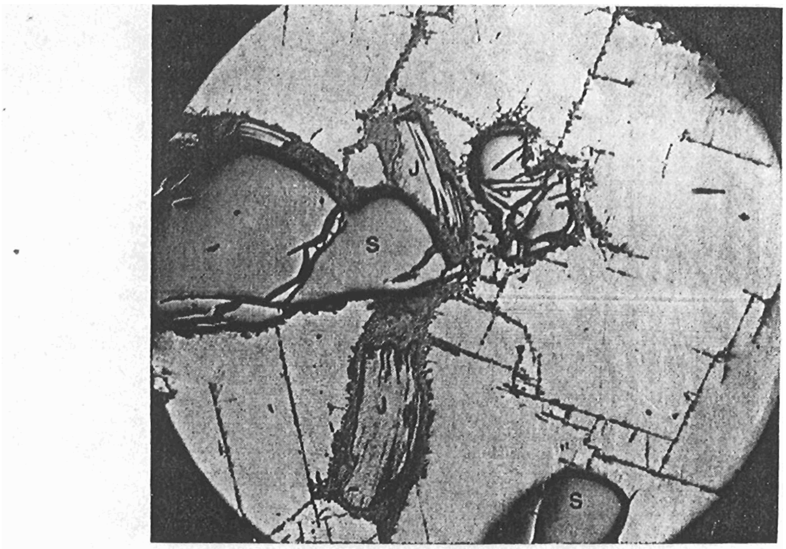
Wurtzite: Wurtzite (ZnS) has been identified in the ores on the 2400 and 2500-levels. It is identifiable only in a polished section where it is recognized as forming a coating or as grains intergrown with sphalerite. It is dark brown, extremely fine-grained, and is without crystal boundaries. The wurtzite is cut and replaced by younger galena and jamesonite, and appears to have been deposited simultaneously with or closely following the sphalerite.

Tetrahedrite: Tetrahedrite ($(Cu,Fe)_{12}Sb_4S_{13}$) occurs sparingly as microscopic grains in the galena and jamesonite. As no other silver-bearing minerals, seem to be present, it is probably the source of much, if not all of the silver in the ore.

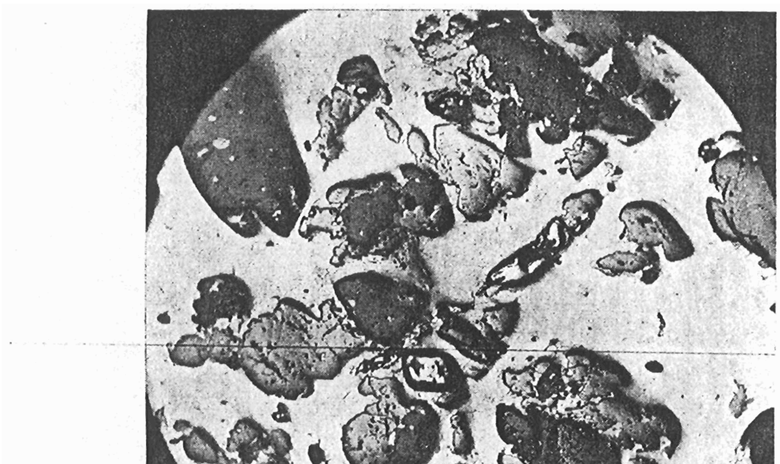
Pyrite: The iron sulphide (FeS_2) is present in small amounts in the ore. Most of it occurs as corroded, relic cores in the other sulphides, and as it has been more or less extensively replaced by all the other sulphides, it obviously has been the first metallic mineral deposited.

Pyrrhotite: The bronze colored, faintly magnetic iron sulphide $Fe_{11}S_{12}$) is very abundant in the veins of the district. It is most prominent in the rhyolite porphyry dikes, particularly those in contact with the Livingston vein, where it occurs as

P-88



A. Photomicrograph of ore from the 1400-level showing progressive oxidation of sulphides. Jamesonite (J) is strongly affected, in places being entirely oxidized. Galena (white) is oxidizing along cleavage and sphalerite (S), protected by the other minerals, is fresh and unaltered. X 50.



B. Photomicrograph of ore from a pillar in the Christmas stope showing the typical ore texture. The white background is jamesonite, light gray bunches are sphalerite, and dark blebs are quartz. Other minerals present include pyrrhotite, arsenopyrite, and tetrahedrite. X 40.

Fig. 6

a replacement of the dike minerals. It is one of the earlier deposited sulphides.

Arsenopyrite: The sulpharsenide of iron (FeAsS) occurs in all the ore. It forms small scattered crystals that are unrecognizable by the unaided eye, but are very evident in polished sections. It accounts for the arsenic content of the ore.

Gold: Assays of the ores show a trace of gold, but native gold was not observed in the polished sections.

Bismuth: It has been reported 7/ that bismuth occurs in the ores; however, current investigations have failed to identify any bismuth-bearing mineral. Chemical analyses also have failed to reveal the presence of bismuth.

Secondary Minerals

The secondary minerals listed below occur in those areas where the primary minerals have been oxidized, i.e., the upper mine workings and on the outcrop.

Anglesite: The ash-gray ($PbSO_4$) is formed by the oxidation of galena. It is the first oxidation product formed and commonly occurs as a fine compact coating or shell about the residual galena crystal. It has been abundant in the 1200, 1200 sub-level, and 1400 stopes. In places, much of it remains on the walls.

Cerussite: Cerussite, the lead carbonate ($PbCO_3$) is abundant in the 1200 and sub-level stopes, closely associated with anglesite. Some of it occurs as small crystals and crystalline masses in openings in the ore, but most of it forms earthy masses and incrustations on residual grains and lumps of galena, largely as a replacement of the earlier-formed anglesite. The crystals and earthy masses are generally discolored to a pale yellow or light brown by admixed iron oxides.

Bindheimite: A hydrous antimonate of lead, formed by the oxidation of jamesonite, is widespread in the upper workings and at the outcrop. The material varies from light to dark yellow in color, and has a fine earthlike texture. It commonly occurs as an incrustation on residual jamesonite. Although this material is referred to as bindheimite, it may actually be a mixture of several unidentified antimony ochres.

Goslarite: The hydrous zinc sulphate, goslarite ($ZnSO_4 \cdot 7H_2O$) is very evident at the base of a small sphalerite ore shoot in the 1802 west crosscut. Several large piles of broken ore, containing sphalerite mined in the 1920's and left on the drift floor, have undergone rapid oxidation and are not incrusted with the acicular, light colored, astringent, goslarite.

Limonite: The hydrated iron oxide, limonite ($2Fe_2O_3 \cdot 3H_2O$) is conspicuous on the vein outcrops and in the upper mine workings. It is a brownish-red to dark yellow, rust-like substance that forms coatings and stains on the inclosing rocks. It results from oxidation of the various iron-bearing sulphides.

Gangue Minerals

The various gangue minerals are not described in detail as they are all common and well known. They include among others: quartz, the feldspars--orthoclase and albite, sericite, and calcite. Of these, quartz is the most abundant. The feldspars are an inheritance from the dike rock.

Epitome of Mineralization

The groundwork for mineralization apparently was laid with the intrusion of rhyolite porphyry dikes and the formation of the Livingston fault which served to direct the mineral-bearing solutions from their deep magmatic sources into the openings along the fault. These solutions were very hot as they left the source region but as they encountered the cooler rock above, they lost heat and arrived at the site of mineral deposition at lower temperatures. However, temperatures were still high enough at the start of mineral deposition to permit formation of pyrrhotite and arsenopyrite, minerals ordinarily regarded as having fairly high heats of formation; but, by the time the other sulphides were deposited, temperatures had declined to levels low enough to permit deposition of wurtzite and jamesonite, minerals of rather low heats of formation. As the minerals attained their respective saturation points and precipitated, they not only filled the available openings but also entered into and replaced the bordering rocks. Inasmuch as the argillite walls were quite impermeable, the solutions could not enter and the ore was restricted to fillings along the plane of the fault, but where the fault cut the relatively brittle rhyolite porphyry the solutions were able to penetrate into the fractured rock and replace it with ore, thus forming the larger ore bodies.

Quartz was the first mineral deposited. It not only filled openings in the fractures but diffused into and replaced the inclosing wall rocks, particularly the much fractured dike rock. Following quartz; pyrite, arsenopyrite, and pyrrhotite were successively introduced. These sulphides diffused into the shattered rock and have in places replaced more than 40 per cent of the rock. As they were the first sulphides deposited they had unobstructed access to fracture openings, thus they commonly extend to a considerable distance from the main vein. Examples of pyrrhotized zones extending beyond the main ore body occur on the 2200-level.

The deposition of the iron sulphides was followed by that of sphalerite, wurzite, chalcopyrite, tetrahedrite, galena, and jamesonite, in part in an overlapping sequence. Sphalerite and wurtzite were probably deposited simultaneously. The chalcopyrite-tetrahedrite sequence is doubtful; it may be reversed. As veinlets of jamesonite cut and replace all of the other sulfides, it was certainly the last ore mineral to be deposited. Some minerals such as quartz, pyrite and pyrrhotite, have been deposited either continuously over a period of time, or at two or more successive stages. Calcite, which locally fills scattered fractures in the ore, was the last mineral to be deposited.

Secondary Enrichment

Oxidation effects do not extend below 200 feet (vertical distance) from the surface; however, because of the gentle dip of the Livingston vein, the effects are evident throughout the upper several hundred feet. In general, oxidation has been intense in those areas on and above the 1400-level. There, galena and jamesonite have been largely converted to anglesite, cerussite, and bindheimite. These secondary minerals have remained in place with little or no downward migration, thus the secondary enrichment in lead content has been negligible. The bulk of the sphalerite in these upper areas has been oxidized and carried away in solution; this accounts for the low zinc assays in the oxidized zone.

Unoxidized sulphides do occur in the vein outcrop on the precipitous mountain side, because there the headward erosion of the canyon has kept pace with oxidation and has removed the oxidized ore as fast as it was formed. As the outcrop in general represents a cross-section of the vein, it is only on the extreme southern end, on top of the mountain, that extensively oxidized ore is found.

Tenor of the Ore

Haley 6/ reports that from the beginning of active mining operations in 1923 until Sept. 1, 1928, 76,155 tons of ore were mined at the Livingston. This ore averaged as follows:

Lead	Zinc	Silver	Gold
11.6%	8.52%	5.54 oz per ton	Trace

Locally there have been rich spots in the ore bodies where the tenor has not conformed with those figures as above the 1400-level, where there was an abundance of galena. There, some assays have gone as high as 55 per cent lead and 25 ounces of silver per ton. Also, some places in the Christmas stope have yielded high lead values. For the most part, former miners were attracted to those areas rich in lead and silver. Wherever possible they bypassed places with a high sphalerite content for they were penalized for zinc in the lead concentrate.

The ore values throughout the mine workings have remained fairly uniform, and have not departed from the above mentioned assay values. In 1948, the 2500 east stope produced ore that carried from 6 to 12 per cent lead, 7 to 10 per cent zinc, and about 7 ounces in silver per ton. These values dropped off when the stope swung eastward and down-dip, away from the raking ore body.

There is some evidence that the zinc content is increasing with depth. This fact is suggested by the increase in zinc content in the ore shoot on the west side of the Christmas stope on the 2200-level, and by the west ore body between the 2400 and 2500-levels. However, the lead values remain strong in these lower areas, and generally conform with those values obtained above.

The following table represents analysis of selected ore specimens from the various mine levels. It shows that while there are enriched spots throughout the mine, there is no sudden increase of one metal at the expense of another.

TABLE 2

Analysis of selected specimens*

Specimen	Au. Oz.	Ag.Oz.	Pb%	Zn%	Cu%	Sb%	As%	Bi%
1. Outcrop on hilltop	Tr.	4.8	--	--	--	--	--	--
2. Outcrop at 1400 portals	Tr.	10.6	45.1	0.11	--	16.0	1.7	--
3. 1200 sub-level stope	Tr.	22.0	63.4	0.08	Tr.	8.2	4.1	--
4. 1400 stope	Tr.	28.0	66.0	6.5	Tr.	0.35	0.05	--
5. 1802 W. zinc shoot	--	----	0.05	50.9	--	0.1	0.05	--
6. 2000 stope pillar	Tr.	17.6	26.1	0.62	--	4.1	1.8	--
7. 2264 W. stope	Tr.	11.4	9.0	18.8	--	1.0	0.6	--
8. 2414 W. crosscut	0.05	142.8	40.0	7.6	Tr.	3.1	1.0	--
9. 2500 East stope	Tr.	10.0	11.5	26.4	Tr.	1.8	0.7	--
10. 2500 crosscut	Tr.	21.2	34.5	6.3	--	5.2	2.0	--

*Analyzed by C. R. Kurtak, chemist for the Idaho Bureau of Mines and Geology

In table 2, number 2, 3, and 4 are from the galena-rich areas on and above the 1400-level. Number 2 owes its high antimony content to incrusted antimony ochres. Number 5 is from an early formed zinc offshoot from the Livingston vein that was not affected by later mineralization. Number 8 is from a 5-inch vein on the Scotch dike hanging wall, well away from the Livingston ore body.

Suggestions for Future Development

There is only one target area in the Livingston mine promising enough to warrant exploration. That is the downward continuation of the raking ore shoots formed by the intersection of the Livingston vein and the Scotch dike. As previously described, this ore shoot has largely been on the contact of the vein and the under segment of the dike; however, the change in the strike of the dike suggests that the hanging wall and footwall ore bodies come fairly close together with increasing depth, as evidenced by their positions between the 2400 and 2500-levels.

During the summer of 1948, mining in the 2500 east stope ceased largely because of two reasons (1) the stope encountered low values as it swung down dip to the east, away from the raking ore body; (2) continued mining necessitated sinking operations. The stope at its lower extremity was 25 feet long and averaged 12 feet in width. The eastern wall was quite barren, but ore on the lower western wall was encouraging. This ore assayed about 8 per cent lead, 12 per cent zinc, and 7 ounces in silver per ton. It conformed with ore mined in upper levels, both in tenor and in physical characteristics. The ore did not terminate abruptly, nor was it faulted out. It gave every indication of continuing with depth.

Diamond drilling offers the simplest means for exploring the downward continuation of the ore bodies. A good site for drilling would be in the 2414 crosscut about 180 feet west of the 2400-level station, where the intersection of 4 drifts provides adequate working space. The site is almost in line with the raking ore bodies, which could be reached with fairly short holes. A possible drilling program, to be based at this site, is suggested in table 3. The location of the drilling site and the projected bottoms of the holes are given in Fig. 3.

This drilling program is designed to bracket the target area. It takes into consideration possible changes in the dip of the Livingston vein; changes in the strike of the Scotch dike; and variations in the strike length of the raking ore bodies. The holes should be drilled in the order listed and the cores should be carefully logged and studied. Should ore be encountered in any of the first three holes, suitable adjustments could be made in the continuation of the drilling program, depending upon the data obtained during drilling.

In the event that ore found in the drill cores should prove encouraging, a tonnage factor of 8.3 cu. ft. per ton should be used to compute the inferred tonnage. This factor is derived from the volume percentages of minerals comprising the ore. Without drilling, any estimate of tonnage lying below the 2500-level would be guesswork; however, if an ore body 10 feet thick is encountered in any two of the above listed holes, it could indicate a probable 15,000 tons and possibly more.

There are other sites in the mine that warrent investigation by lessees or small operators. They may not yield a large tonnage, but should prove profitable under small-scale mining operations. Two 70-foot diamond drill holes from the face of the 2408 crosscut; one at a bearing of S. 85 degrees E., and upward at an angle of 55 degrees; and the other at a bearing of S. 87 degrees W., and upward at an angle of

45 degrees, will explore the ground between the 2200 and 2400-levels. This area, especially west of the 2400 east stope, should be productive.

Another site for exploration would be the ground above the 1400 caved stope. At its face, this stope was supposed to have been 8 feet thick, composed of high-grade lead ore. A 45-foot raise, driven from the face of the 1202 sub-level drift, at a N. 60 degrees W. bearing and at an angle of 70 degrees, should intersect the vein slightly above the face of the 1400 caved stope. This entry would develop the ground between the faces of the 1400 stope and the "A" fault. (Fig. 4, Section A-A').

Conclusions

There is a favorable outlook for the Livingston mine as an active producer. Such production will require further exploration, but this is fully warranted. It is doubtful if the mine will ever be a large producer, comparable with some mine in the Coeur d'Alene district, because the ore bodies are restricted to too small an area; however, the mine should supply at least a 100-ton mill. In the past, most of the profits were returned to the mine as exploration work, much of it ill-advised and unwarranted. However, some of the work has provided a means for observing the structural control of the ore bodies. Now that these relationships are better understood, future exploration can proceed with more assurance. If exploration is restricted to those areas which fall in line with the continuation of the present known ore bodies, i.e., those formed at the intersections of the Livingston vein and the Scotch dike, it should prove remunerative.

HERMIT MINE

The Hermit mine is about a mile north of the Livingston, beyond Railroad Ridge, at the headwaters of Silver Rule Creek. Two tunnels and a connecting inclined winze have been driven on the property, all of which were accessible in 1948. The camp contains an abandoned blacksmith shop and two dilapidated mine cabins. It has been idle for several years.

Reports of mining activity during 1916 9/ mention a high grade ore-streak carrying good values in lead and silver. A small shipment of lead is reported to have been made from the bottom of the winze, but there are no records of its value. The bottom of the winze was flooded at the time of the recent visit.

The lower tunnel is about 900 feet long and is entirely in the thin-bedded, carbonaceous argillite of the Milligen formation. (Fig. 7). It cuts a large shear zone at 205 feet from the portal. The zone strikes N. 38 degrees W. and has an average dip of 45 degrees SW. It varies in width from 18 to 24 inches, but locally swells to 6 feet. The shear zone has a smooth, slickensided hanging wall but the footwall is brecciated and irregular. Some small brecciated quartz pods on the footwall carry traces of pyrite, sphalerite, and possibly other sulphides, although they are so scattered and minute that they are unrecognizable in the hand specimen.

The inclined winze follows the shear zone from the upper tunnel to about 60 feet below the lower tunnel. A short intermediate level has been driven from the winze but failed to reveal any ore bodies. Search on other drifts and crosscuts has also proved fruitless.

TABLE 3

Data for a diamond drilling program to be based in the 2414 west crosscut
(See Fig. 3.)

Hole	Angle of dip	Bearing	Minimum length of hole	Maximum length of hole	Vert. dist. from drill site	Slope length of ore, inter-sected*
1.	70 degrees	S. 60 degrees E	175	250	165	215
2.	45 degrees	S. 30 degrees E	175	250	125	175
3.	70 degrees	Due E	200	290	190	240
4.	75 degrees	S. 40 degrees W	175	260	170	270
5.	90 degrees	________	190	300	190	322
6.	60 degrees	Due W	220	340	190	320

*Slope length calculated from a mean dip of 34 degrees and a rake of 27 degrees, measured from the horizontal. It is measured from the bottom of the 2500 east stope. (measured in feet.)

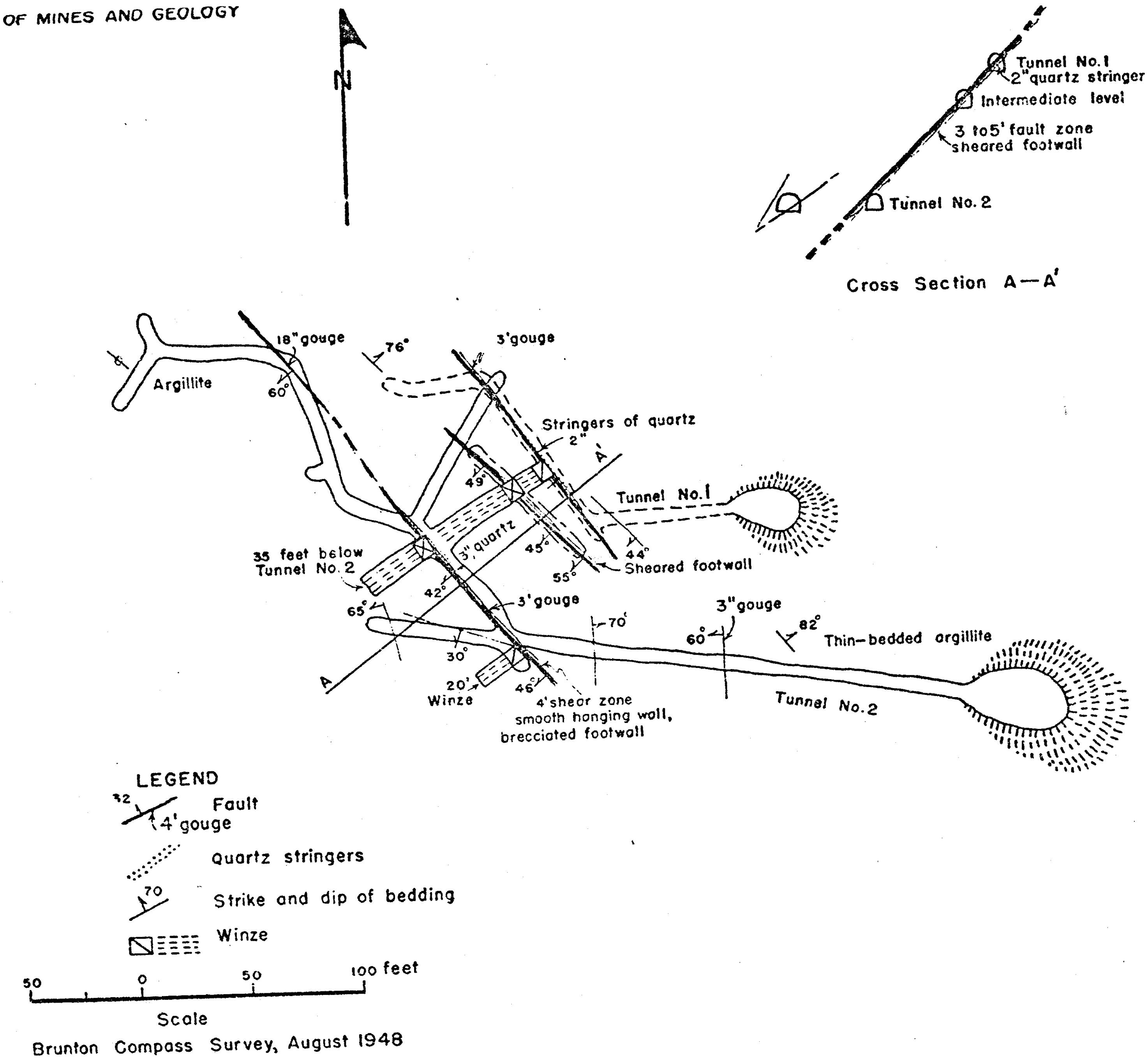


Fig. 7 GEOLOGIC MAP OF THE HERMIT MINE

249

DEL YANTE PROPERTY

The Del Yante property lies about a mile southeast of and on the same mountain side as the Livingston mine. It is explored by three short tunnels, all of which were caved at the time of the visit. In addition, there are several open cuts and exploratory trenches on the surface.

Surface examinations show that the workings explore a fault zone that strikes N. 12 degrees W. and dips 78 degrees W. The zone is about 4 feet wide; it cuts calcareous argillite of the Milligen formation. About 100 yards to the west, up the mountain side, this formation contacts the Boulder Basin quartz monzonite. The wall rock on both sides of the fault is brecciated and cemented by calcite. It is a major fault and traced up the hillside, forms a small bench-like structure. A thin quartz stringer, which in places is 16 inches wide, lies along the hanging wall of the fault. It contains abundant lamellar, iron-stained calcite and traces of oxidized sulphides. Ore specimens collected on the dump, although partially oxidized, contain copper-stained quartz, fine-grained galena, sphalerite, jamesonite, chalcopyrite, and pyrrhotite.

Judging from the small size of the dumps and surface workings, there has not been much mining activity on this property. It has been idle for several years.

LAKEVIEW MINE

The Lakeview, formerly known as the Crater mine, comprises 6 unpatented claims owned by the Fisher brothers of Clayton, Idaho. The mine lies on the south shore of Crater Lake, small tarn occupying the bottom of a glacial cirque, at the head of Livingston Creek about 1 mile northwest of the Livingston mine. The property is explored by a tunnel, some open cuts, and two winzes that were filled with water at the time of the visit.

The country rock is carbonaceous argillite and thin-banded quartzite of the Milligen formation. The beds trend N. 12 degrees W and dip steeply to the southwest. There are several ore-bearing veins on the property, some of which follow fractures, others appear to conform with the bedding of the country rock. The main quartz vein may be traced from the lake shore southward for about 700 feet. It has a maximum width of 6 feet, elsewhere it narrows to a mere stringer. It has been drifted on by the main tunnel, and about 40 feet from the portal, it has a good showing of jamesonite. (Fig. 8). At this point a short crosscut was driven and a 60-foot winze sunk to develop possible ore bodies. The ore was found to occur as parallel stringers along the bedding planes of the country rock. None of the stringers are more than a few inches thick. Continued crosscutting and drifting intersected and followed the main quartz vein to the south. The southern exposure is brecciated and iron-stained. It contains some sulphides, chiefly pyrrhotite, sphalerite, and jamesonite; however, on the whole the vein is quite barren. The main quartz vein may be traced on the surface for 460 feet to the south, where it is explored by a 15-foot shaft and a short drift. Some jamesonite and sphalerite are exposed at the face of the short drift. These minerals are unoxidized.

At the time of the 1948 visit, the Fisher brothers had just completed a road up Livingston Creek, making the mine accessible to motor transportation. They were also cleaning several tons of previously mined ore from the dump, and mining from some

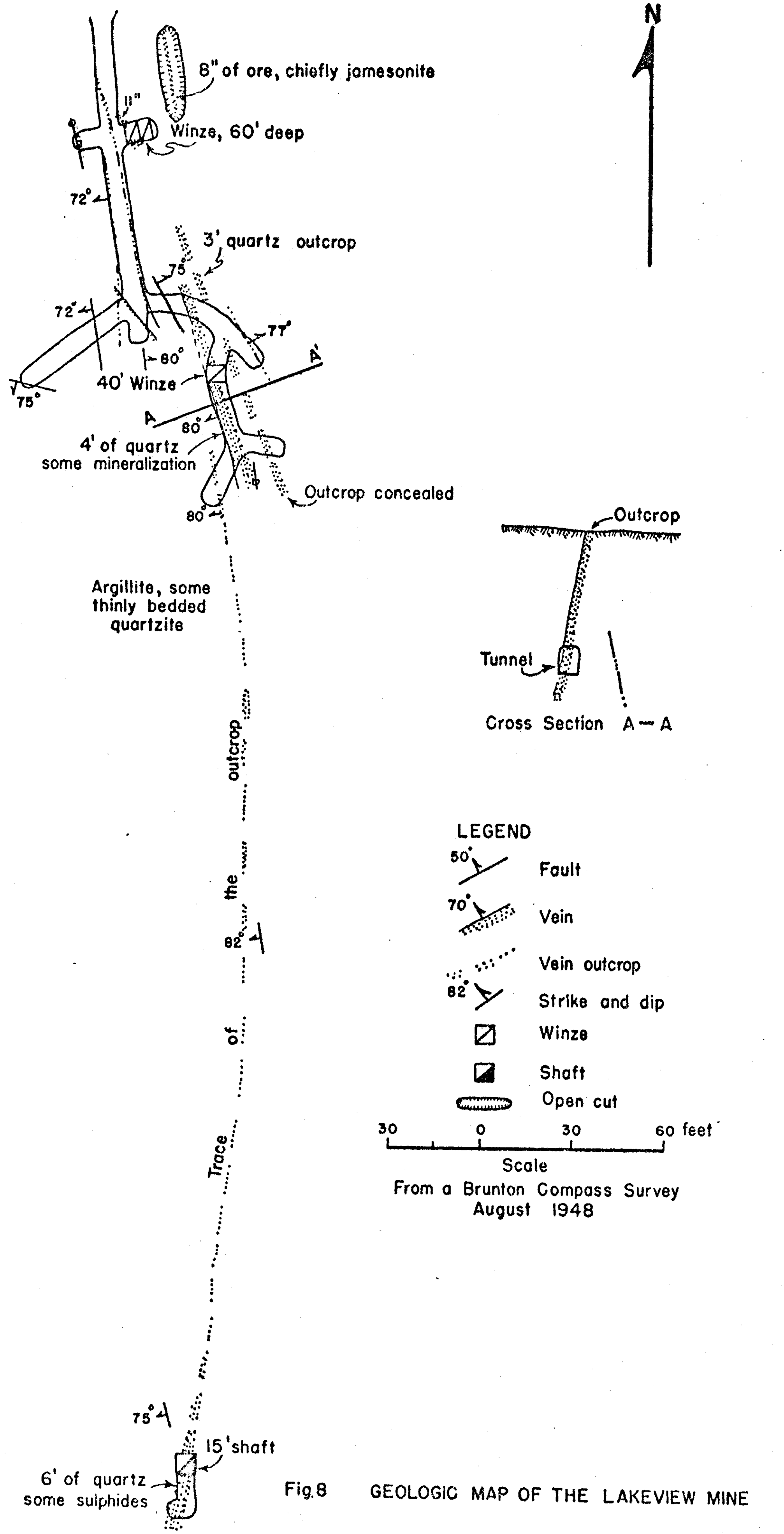


Fig.8 GEOLOGIC MAP OF THE LAKEVIEW MINE

open crosscuts. They reported that an average sample of ore went 15 per cent lead and 17 per cent antimony. They had intended to make some ore shipments, but the high antimony content created some lead-smelting problems, causing the ore buyers to offer lower prices for their product. Therefore, they were withholding shipment, seeking a better market for their antimony.

Development of the Lakeview mine has previously been hindered by its isolated and inaccessible location. The vein, where exposed on the surface and in the tunnel is promising. Diamond drilling on the lower extensions of the vein might prove the existence of valuable ore bodies.

LITTLE LIVINGSTON

The Little Livingston mine is owned by the Livingston Mines, Inc. It is high on the east canyon wall of Livingston Creek at the northwest end of Railroad Ridge. The property has been explored by 7 tunnels, with approximately 300 feet between the upper and lower workings. In 1948, one of the upper tunnels was open for about 50 feet, all others were caved at the portal.

People familar with the mine say it was an active early day producer, and that high-grade lead-silver ores were packed by mule to the old smelter at Clayton. Several lessees are also reported to have made rich shipments at later dates. There are no records of the amount of ore produced or of its value. All mine maps have been lost, or else were never compiled, and there is no record of the mine workings; however, the fairly large dumps indicate that some of the tunnels may have been several hundred feet in length.

The mine workings are in the Milligen formation, which is mainly thinbedded argillite, although some beds are calcareous. Ore on the dumps is highly oxidized, but some fragments of unaltered jamesonite are occasionally found. The oxidized minerals are chiefly cerussite and bindheimite; some oxidized silver ores are undoubtedly present but were not recognized.

Commonly the oxidized lead-ores have a copper-stained blue or bluish-green coloration and are called "silver bromides" by the local miners. This is in error for the color is imparted by the copper stain, not by silver. The ore is in a fairly crystalline, brecciated quartz gangue. Some fragments accompany what appears to be a highly altered granitic rock.

Bell 8/ describes the ore as occurring in a thin, gently eastward dipping vein which accompanies a narrow highly mineralized porphyry dike. The dike is from 1 to 5 feet wide, and the vein closely adheres to the trend of the dike. From his description it appears as though the ores are like those of the Livingston mine in that they are chiefly the result of dike replacement.

The mine has been idle for many years.

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