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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

PAPER 57-1

THE GEOLOGY AND GEOCHEMISTRY OF THE SILVER-LEAD-ZINC DEPOSITS OF GALENA HILL, YUKON TERRITORY

(Report, Map 4-1957, and six figures)

By

R. W. Boyle

OTTAWA
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Price, 50 cents

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INTRODUCTION

This report summarizes the author's 1955 field work on the silver-lead-zinc deposits of Galena Hill. The field research program in the Keno Hill-Galena Hill area which commenced in 1953 is now completed.

The structural pattern of the vein faults observed from the detailed field work on Galena Hill suggests that prior to cross-faulting all vein faults formed parts of three major vein fault systems, each striking northeast across Galena Hill. Individual vein faults in these major systems, however, branch and join to produce a ramifying pattern.

The three major vein fault systems are orebearing or are mineralized where they intersect each of three massive, thick-bedded members of the distinctive Central Quartzite formation which lies in a belt across Galena Hill. In addition, some mineralized zones occur where the vein faults intersect greenstones. In the thick-bedded quartzite members and in areas containing greenstone lenses the vein fault systems form a complex interlacing pattern with many mineralized junctions, but as the systems pass into thin-bedded quartzites and graphitic schists they become irregular and split up into many narrow, tight, and unproductive vein faults.

In the three systems ore forms locally at vein fault junctions and at sites in massive, thick-bedded quartzites or greenstones where the vein faults pass upward from these rocks into thin-bedded quartzites and schists.

A short account of the mineralization history and of the geochemistry of the deposits is given, but no attempt is made to discuss the genesis of the deposits because laboratory work on this problem is not yet complete.

Silver-lead-zinc deposits were discovered on Galena Hill in 1913 and mining operations and exploration have continued since that year. The principal producing mines on the hill are the Hector-Calumet operated by United Keno Hill Mines Limited, and the Mackeno mine. Former producing mines were the Silver King, Elsa, and Bermingham (Arctic and Mastiff).

During 1955 production and exploration were carried on continuously at the Hector-Calumet and Mackeno mines. In addition, United Keno Hill Mines continued deep exploration at the Elsa mine, and an adit was driven by private operators to intersect the downward extension of the Cream vein. Prospecting by Messrs. H. Colley and J.H. Giletzki in the area northwest of the Silver King mine resulted in the discovery of a vein carrying interesting amounts of zinc, lead, and silver.

ACKNOWLEDGMENTS

The author wishes to extend his thanks to many individuals and companies, who placed maps and data at his disposal during the 1955 season and helped in many other ways. He wishes especially to thank C.E. White, A.C. Carmichael and M. White, manager, chief geologist, and exploration manager, respectively, for United Keno Hill Mines Limited, and G. Campbell and W.R. McQuarrie, manager and geologist for Mackeno Mines Limited.

The writer had access to the lucid and informative annual reports written by the late Livingstone Wernecke for the Treadwell Yukon Company, Limited, former operators of the Hector-Calumet, Elsa, and Silver King mines. These reports, now in the geological files of United Keno Hill Mines, Limited, contain numerous geological maps and sections and cover in detail the old workings and prospects many of which are now caved or are otherwise inaccessible.

LOCATION

Galena Hill is in central Yukon 35 miles northeast of Mayo and some 220 miles due north of Whitehorse. Mayo is served by an all-weather road from Whitehorse and by Canadian Pacific Airlines. The two villages, Elsa and Calumet, and the Mackeno mine, can be reached by an all-weather road from Mayo.

TOPOGRAPHY, GLACIAL AND FROST ACTION, AND CLIMATE

Galena Hill lies in the northeastern part of the Yukon Plateau and the topography of the general area is mountainous with elevations ranging from 6,023 feet (Mount Haldane) to 2,500 feet (McQuesten River Valley).

Galena Hill (see Figure 1) has an elevation of 4,740 feet and has a moderately steep southwestern slope and steeper north, northwestern, and southeastern slopes. The terrain above 4,300 feet is relatively flat and rolling, and marked by several level grassy meadows. The north, northwestern, and southeastern slopes of the hill are traversed by several streams which have cut steep gulches into the rock strata. The principal streams responsible are Galena, Flat, Brefalt, Porcupine, and Sandy Creeks on the northwestern slope and Hinton and Fisher on the eastern and south-eastern slopes.

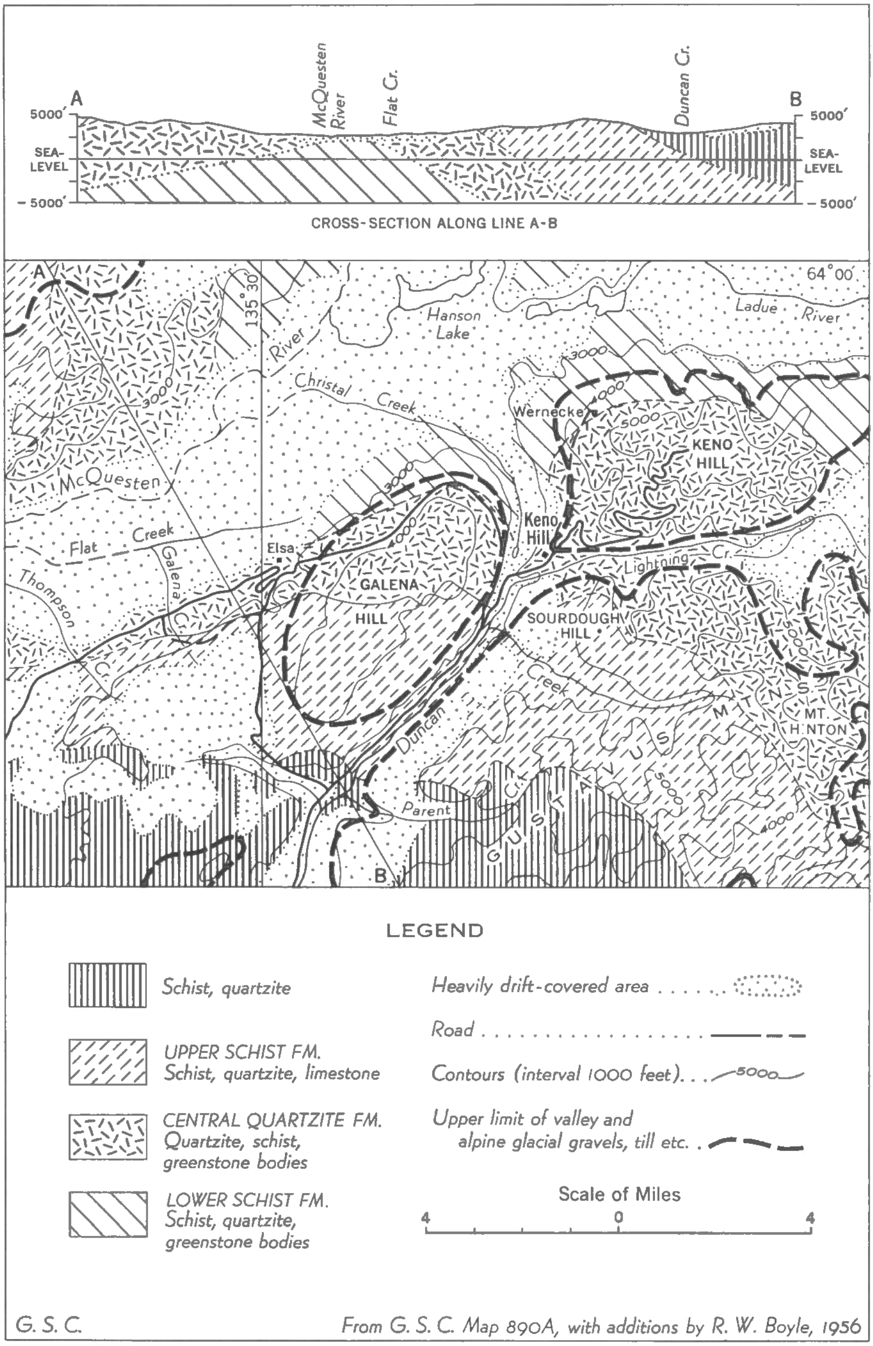

Figure 1. Geological map and cross-section of the Keno Hill-Galena Hill area, Yukon Territory

Rock outcrops are not numerous on any of the slopes and, with the exception of the gulches where relatively good geological sections are present, mapping can only be done by observations of float. Below an elevation of 4,400 feet the hill is covered with till, soil, rock float, muck, and muskeg in which conifers, birch, aspen, arctic blackbirch, and other vegetation grow abundantly. Above this elevation the soil is thin, the ground is covered with local rock float, the terrain is treeless, and vegetation is limited to alpine varieties and grassy meadows.

The lower slopes of the hill have been severely glaciated. Glacial till and gravel covered by muck and muskeg are widespread (see Figure 1) and in places are 20 feet thick or more. In the areas covered by till and muskeg there are sporadic outcrops of resistant greenstone lenses and, in places, a few outcrops of schist and thin-bedded quartzite.

Galena Hill is in the region of permanently frozen ground, and permafrost is present in underground workings down to depths of 200 feet or more. Some parts of the hill having a southern exposure are, however, relatively free of permafrost, and places where surface and underground water are flowing have been thawed out and form frost-free strips in the general permafrost. Frost action has had a marked effect on the rocks and soils especially at the higher elevations. There, the process of frost boiling has brought rock float and, in places vein float, to the surface, facilitating mapping the underlying bedrock and tracing vein faults. On steep slopes, however, frost action and land creep have moved float downhill 100 feet or more in places, making the accurate mapping of contacts and vein faults difficult.

The climate of the central Yukon is rigorous. The mean annual temperature at Mayo is 26°F, the average minimum temperature is 14°F, and the average maximum 37°F*. Temperatures as low as minus 80°F, and as high as 90°F have been recorded. The winters are long and cold with only a few hours of daylight each day, and the summers are short and warm with nearly continuous daylight.

The average annual precipitation at Mayo is 11.23 inches. The rainfall in the Galena Hill area during the spring and summer months is moderate with occasional torrential downpours. The snowfall is moderate and usually commences in mid-September or early October. Most of the snow has melted by the end of May, but local patches and small snowfields remain in sheltered places on northern slopes until early August.

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*Data, courtesy Dominion Meteorological Service, Department of Transport, Ottawa, Canada.

GENERAL GEOLOGY

The general geology of the Mayo area was described first by Keele (1905)[1] and later by Bostock (1947). The geology of Galena Hill was described by Stockwell (1926) and McTaggart (1950). Recently Kindle (1955) published a geological map with descriptive notes covering the area from Mayo Lake northward, including Keno Hill and Galena Hill.

The consolidated rocks underlying the Galena Hill area belong to the Yukon group and may be Precambrian or early Palaeozoic in age. They consist of sericitic, chloritic, and graphitic schists, thick- and thin-bedded quartzites, greenstones, and a few layers and lenses of limestone. Three formations, the Lower Schist formation, the Central Quartzite formation, and the Upper Schist formation, underlie Galena Hill, and on a regional basis appear to form the southern limb of a large anticline whose axis follows the McQuesten River Valley (see Figure 1). Conformable greenstone lenses occur in the Lower Schist and Central Quartzite formations, and limestone lenses and layers occur here and there through the Central Quartzite and Upper Schist formations. Quartz-feldspar porphyry float occurs at scattered points in the Upper Schist formation and marks a narrow sill. Granite and granodiorite masses outcrop 18 miles east and 8 miles north of Elsa townsite.

ROCK TYPES

Map 4-1957 shows the distribution of the rock types on Galena Hill, and the traces of the vein faults and faults. The author in a previous report (Boyle, 1956) described the various rock types in the general area, and only brief descriptions will be given here.

Schists, quartzites, and greenstones are the principal rock types, with here and there some limestone, quartz-feldspar porphyry and lamprophyre.

The schists are mainly black graphitic types. Many of these contain abundant pyrite, some have a limy matrix, and all are highly contorted and contain many bulbous masses of quartz. Other schists comprise essentially sericite, quartz, and chlorite, and are green in colour. These schists are also highly contorted and contain much quartz as stringers and bulbous masses. Quartz-mica schists are abundant in the Upper Schist formation. Under

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[1] Dates in parentheses refer to the Bibliography at the back of this report.

the microscope these rocks are composed principally of sericite with an abundance of white quartz eyes.

Thick-bedded and thin-bedded quartzites, consisting essentially of quartz and a little sericite and graphite, occur in the Lower and Upper Schist and Central Quartzite formations but are most abundant in the Central Quartzite. Some members of the Central Quartzite formation are composed of beds of quartzite up to 25 feet thick interbedded with thin-bedded quartzites and graphitic schists. These thick-bedded quartzites are generally grey to black, but one distinctive variety is light grey to white and has a cherty look. Beds of this white quartzite are good structural markers and can be traced across Galena Hill. All thick-bedded quartzites are highly jointed and yield large blocks during weathering and frost action. The thin-bedded quartzites are dark grey to black and occur in beds from an inch to a foot thick. Some have a limy matrix and others contain considerable amounts of pyrite; they are generally interbedded with graphitic schists. Assemblages of thin-bedded quartzites and graphitic schists make up most of the Lower Schist formation and form two members in the Central Quartzite formation.

The greenstones are sheared greyish green to dark green rocks and occur in conformable, elongated masses in the Lower Schist and Central Quartzite formations. They are more resistant to weathering than the schists and quartzites and form prominent precipices and knobs. They are highly jointed in most exposures and present a slabby appearance. Most greenstone bodies appear to be unconnected and have been interpreted by the author in a previous report (Boyle, 1956) to be boudins formed from once continuous sills during the severe thrusting and faulting that has taken place.

The quartz-feldspar porphyry is a light coloured rock that weathers buff to white. The phenocrysts of quartz and feldspar are set in a fine-grained groundmass of quartz, feldspar, muscovite, and chlorite. In some specimens, pyrite is abundant in the groundmass of the rock.

The limestones are grey on fresh surfaces and weather buff to brown. They occur principally in irregular layers and lenses in the Upper Schist formation, but there are a few beds up to a foot or more thick in the Central Quartzite formation. In this formation they are generally intercalated with thick-bedded quartzites.

The lamprophyres are light to dark brown rocks containing chloritized mica, quartz, feldspar, carbonates, and pyrite. They appear to form discontinuous sills that cannot be traced far.

DETAILED STRATIGRAPHY AND POSITION OF ORE-BEARING BEDS

Throughout the Galena Hill area the sedimentary strata have an average dip of 20 degrees to the south. Tops can rarely be determined and there is no clear evidence that extensive overturning or recumbent isoclinal folding has taken place on Galena Hill. The author has concluded therefore that the stratigraphic sequence, notwithstanding the presence of many low angle faults and other complexities, is a simple homoclinal succession.

Map 4-1957 was compiled during a detailed investigation of the vein deposits. Individual outcrop and float areas could rarely be shown; instead, where closely spaced, they have been grouped. Most of the contacts were interpreted from observations of rock float and, although the position of these contacts was mapped with great care, errors of 100 feet or more may be present in places.

The stratigraphy of the Lower Schist formation cannot be worked out in detail, because most of it is covered with heavy drift. However, the examination of scattered outcrops, mine adits, and float indicates that the bulk of the formation is composed of graphitic schist intercalated with thin-bedded quartzite, elongated greenstone bodies, limy schists, and a few thick beds of quartzite. This great mass of interbedded rocks is overlain by a distinctive layer of green sericite schist some 350 feet thick.

In general, the schists and thin-bedded quartzites of the Lower Schist formation are structurally incompetent and unfavourable for the occurrence of ore shoots. The greenstones, on the contrary, are favourable. On Keno Hill several rich ore shoots were mined where vein faults intersected greenstones, and it is logical to expect that the greenstones on Galena Hill are similarly favourable sites for shoots. The lens-like nature of the greenstones, that is their tendency to pinch out on strike and dip, should, however, be kept in mind when evaluating the extent and continuity of orebodies in these rocks.

The Central Quartzite is the most important ore-bearing formation on Galena Hill and an attempt was made to piece together its detailed stratigraphy from surface and underground mapping. Some gaps are present but distinctive horizon markers can be traced across the hill. Three ore-bearing members are present; the Mackeno, the Hector-Calumet, and the Silver King. All three are composed principally of thick-bedded quartzites and are separated from one another by thin-bedded quartzites and graphitic schists. A tabulated description of the stratigraphy of the Central Quartzite formation follows.

Table I

STRATIGRAPHY OF CENTRAL QUARTZITE FORMATION

Member	Description	Approximate thickness in feet (section through Hector-Calumet mine)	Mines and prospects
	Green sericite schist (base of Upper Schist formation)	100	
Silver King member	Grey, thick-bedded quartzites, beds up to 15 feet thick at Silver King mine; bed of white, cherty quartzite near top. In places two greenstone sills, at other places two zones containing greenstone lenses. Member appears to thin northeastward.	350	Silver King mine Coral and Wigwam prospect Arctic and Mastiff (Bermingham mine)
	Thin-bedded quartzites interbedded with graphitic schists. A few beds of quartzites 3 feet or more thick.	550	
Hector-Calumet member	Massive pale grey to grey, thick-bedded quartzites; beds from 5 to 25 feet thick; centre of sequence marked by two or more beds of white to pale grey, thick-bedded, cherty quartzite interbedded with two highly sheared greenstone sills or lenses. Member thins southwestward.	800	Hector-Calumet mine Elsa mine Dixie prospect

Member	Description	Approximate thickness	Mines and prospects
	Grey to black, thin-bedded quartzites interbedded with graphitic schists; most beds 1 foot to 2 feet thick; some up to 5 feet thick.	350	
Mackeno member	Massive, pale grey to black, thick-bedded quartzites; most beds 5 to 10 feet thick, some up to 25 feet thick or more; a few interbedded graphitic schist layers. Member thins southwestward.	300	Mackeno Mine Dragon prospect No Cash prospect
	Green sericite schist (Top of Lower Schist formation)	350	

The thicknesses given for the individual members in the Central Quartzite formation are approximate. They have been computed principally from mine sections and diamond drill logs and check reasonably well with surface mapping. It should be noted, however, that some of the members seem to be thickened in places by faulting, and appear to thin or thicken along strike as a result of original sedimentation.

It should be particularly noted that the orebodies and mineralized zones in the Central Quartzite formation occur predominantly in the thick-bedded quartzite members. Where vein faults pass into members composed of thin-bedded quartzites and schists they are narrow, tight, and only sparingly mineralized.

The Upper Schist formation is composed principally of quartz-mica schist, graphitic schist, minor amounts of quartzite, and a few limestone lenses. Despite the presence of numerous faults this formation appears to be barren of orebodies and extensively mineralized zones.

THE VEIN FAULT AND FAULT SYSTEMS

Two types of faults occur in the area; those that contain veins and lodes of economic minerals and are designated by the term "vein fault" in this report; and those that contain only small amounts of economic minerals, generally of supergene origin and are called bedding faults, cross faults, etc.

Field investigations indicate that there are faults of three main ages. These are, the oldest first:

1. Early bedding and low-angle faults; some of these may show small late movements offsetting the vein faults and cross faults.

2. Vein faults; these may show evidence of two or more periods of movement and mineralization.

3. Cross faults, that cut and offset 1 and 2 above.

The early bedding faults are formed by slipping along and between beds, and mashed and contorted schist beds between more competent greenstones and quartzites may result. The low-angle faults are somewhat similar structures that follow bedding planes or schist beds for some distance and then cut across the strata. The cross-cutting part of the fault is marked by a breccia zone commonly over 25 feet wide. Movements along these faults are generally small, and they are thought to have resulted from thrusting along bedding planes and incompetent beds during the regional folding of the sedimentary strata.

The vein faults occur in all types of rocks but differ in their internal nature in greenstones, quartzites, and schists. In greenstones and thick-bedded quartzites the vein faults occupy zones 5 to 50 feet in width composed of parallel to subparallel gouge- or breccia-filled fractures along which recurrent movement has taken place. Slips and fractures abound throughout a single fault zone. Some parallel the zone and cut through the breccia, gouge, and mineralized parts; others branch from and rejoin the main vein faults, or diverge into the foot-wall or hanging-wall and die out.

In schists and thin-bedded quartzites the vein fault zones are narrow, rarely exceeding a foot or so in width, and contain slips and fractures filled with gouge and breccia. In many places the vein faults in these rocks are difficult to trace, because they may be no more than a single fracture or slip an inch or so wide along which the wall-rocks have been dragged, contorted, and mashed.

The amount and direction of movement on vein faults can rarely be estimated because of the general absence of horizon markers and the presence of late faults following the same course as the vein faults. Where the amount of horizontal and vertical movements can be ascertained, maximum displacement rarely exceeds a few hundred feet.

Below the oxidized zone the breccia fragments and fractures in the vein fault zones are in places cemented by siderite and some quartz, and, in the mineralized parts and orebodies, by sphalerite, galena, and freibergite. In the oxidized zone the cement is limonite, manganese oxides, galena, supergene carbonates, and various sulphates.

The change in the nature of the vein faults, where they pass from one rock type to another, is an important factor in the structural control of some ore shoots. Vein faults in greenstones or thick-bedded quartzites differ little in character; in both rocks they are generally complex breccia zones that are favourable sites for orebodies. Where a vein fault passes from either of them into schist or thin-bedded quartzite a sharp narrowing generally takes place, and the breccia disappears, either partly or totally. The strikes and dips of individual fault and slip planes constituting the fault zone become erratic, and the structures tend to branch and follow bedding planes and finally die out in a drag-folded or crenulated part of a bed. Such zones are generally too tight and irregular to be favourable sites for ore shoots.

Cross faults are generally recognized by offsets on contacts, or on vein faults. They generally appear as a series of slips and fractures ramifying through a crushed and brecciated zone which may be 150 feet or more wide.

On Galena Hill the late cross faults form a herring-bone pattern with the McLeod fault forming the main trunk fault. This fault strikes southwest and dips 60 degrees southeast. The subsidiary faults on the northwest side of the McLeod fault strike northwest and dip about 45 degrees southwest at the surface and gradually flatten at depth. Those on the southeast side strike east or northeast and appear to dip south or southeast.

The northwest striking cross faults west of the McLeod fault are right-hand faults with most of the movements taking place horizontally. The amount of movement on individual faults differs - the Hector, Jock, Arctic, and Porcupine Creek faults show a horizontal movement of only a few hundred feet, whereas the Brefalt Creek fault has an apparent horizontal displacement of 2,000 feet.

The majority of faults east of the McLeod fault are, like the McLeod fault itself, left-hand faults, and the movements appear to be mainly horizontal, rarely exceeding a few hundred feet.

The late cross faults have been regarded by some as the channelways for the hypogene ore solutions. This is, however, improbable. It is a fact that late cross faults occur at nearly every mine, but this seems to be purely fortuitous as there are so many cross faults cutting the rocks of Galena Hill that it would be remarkable if nearly every mine working did not intersect one at least of these structures. It is clear that the cross faults offset the vein faults and ore shoots at many places, and although the cross faults may have aided the supergene processes by making channelways available for circulation of underground water, they could not have had any part in the hypogene processes.

VEIN FAULT SYSTEMS

Summary

An analysis of the pattern of the various individual vein fault systems suggests that prior to cross faulting all formed parts of three major systems as follows:

Central System; includes the Coral and Wigwam, Arctic and Mastiff, Hector-Calumet, Dragon, and Mackeno vein faults, and probably the Formo and Bluebird vein faults.

Western System; includes the Silver King, Elsa, Dixie, and No Cash vein faults.

Eastern System; includes the Eagle, Tin Can, and other vein faults.

The three major systems strike northeast, and, with few exceptions, nearly all veins dip steeply to the southeast. Individual vein faults form a ramifying pattern and branch and join throughout their extent. Late cross faulting has disrupted the continuity of the vein faults in many places, resulting in a complex segmented pattern.

All three major systems are orebearing or are mineralized where they intersect the massive, thick-bedded quartzites of the Silver King, Hector-Calumet, and Mackeno members. Some mineralized zones also occur where the vein faults intersect greenstones in the Lower Schist formation. In the thick-bedded quartzite members the systems form a complex interlacing pattern with many favourable vein fault junctions, but as the systems pass into thin-bedded quartzites and graphitic schists they become irregular and split up into many narrow, tight, unproductive vein faults.

The local ore controls in the vein fault systems are (1) vein fault junctions and (2) at sites in massive thick-bedded quartzites or greenstones where the vein faults pass upward from these rocks into thin-bedded quartzites and schists. Both these sites were dilatant zones in which quartz, siderite, galena, sphalerite, freibergite, and other minerals were precipitated to form the productive ore shoots.

Central System

Mackeno System

The Mackeno system (4 and 5)[1] consists of two intersecting vein faults (McLeod and Sime veins), and two faulted segments of a cross-over vein fault (Sugiyama vein) (see Figure 2). The McLeod vein is the most important vein fault of the system and has produced most of the ore found to date. The Sime vein has produced ore from only one small stope, and only a few small mineralized pods have been found in the Sugiyama vein. The McLeod vein fault is marked by a zone of breccia and gouge in places over 50 feet wide. At least two periods of movement and brecciation have taken place. The sequence of structural events in chronological order can be summarized as follows:

1. Formation of early vein fault probably marked by brecciation over widths 10 to 20 feet.

2. Deposition of siderite, galena, sphalerite, and tetrahedrite.

3. Late faulting (McLeod fault) marked by extreme brecciation. Parts of some ore shoots were crushed, brecciated, and dragged along the fault zone; in other places the late fault movement and brecciation followed the hanging-wall or foot-wall of the ore shoots.

The two ore shoots in the McLeod vein fault are localized in the part of the fault zone where one or both walls are

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[1]Numbers in parentheses are those of properties shown on the geological map.

a favourable series of massive thick-bedded quartzites. The shoots moreover rake northeast nearly perpendicular to the bedding. The shoot in the Sime vein is, likewise, localized where the vein fault cuts the same favourable series of massive thick-bedded quartzites.

The loci of the ore shoots in the Mackeno system appear to be at or near the points where the vein faults pass upward from competent thick-bedded quartzites into sites where schist forms one or both walls of the vein fault. This is a familiar structural site for ore shoots in the area, and the reasons for ore deposition at these loci have been discussed at length by the author in a previous report (Boyle, 1956).

Galena, sphalerite, and freibergite are the principal hypogene ore minerals in the ore shoots of the Mackeno system, and the gangue minerals include pyrite, quartz, and siderite. All ore shoots are oxidized down to the lowest levels of mining. The supergene minerals are mainly limonite, jarosites, and manganese oxides, derived from siderite, sphalerite and pyrite.

The relationship of the Mackeno system to the Hector-Calumet system is not clear. The McLeod vein fault may be an extension of a bifurcating vein fault of the Hector-Calumet system. If so the southwestern extension of the McLeod vein fault should lie in the foot-wall of the McLeod fault, that is the side next the Hector-Calumet. The other possibility is that the McLeod vein fault is entirely separate from the Hector-Calumet system and follows the same course as the McLeod fault. Whichever is the case, it should be noted that the southwestern extension of the McLeod vein fault on the surface enters the favourable Hector-Calumet member approximately 2,500 feet southwest of the road to Calumet. Other favourable exploration possibilities in the McLeod and Sime vein faults occur down the dip where, on both the hanging-wall and foot-wall, they intersect the favourable series of massive quartzite beds outlined on Figure 2.

Hector-Calumet System

The Hector-Calumet system comprises the most extensive and productive vein faults in the Keno Hill-Galena Hill area. These extend northeast to the Dragon claim and southwest to the Coral and Wigwam claims, a distance of 3 miles. All along these vein faults bodies of lead-zinc-silver ore occur, but by far the largest production has come from the Hector-Calumet mine situated near the mid-point of the system.

The system is covered with drift and rock rubble along most of its extent, and the vein faults are exposed at only a few places. In addition, the presence of many cross faults makes accurate mapping of the system difficult and exploration costly.

The northeastern extension of the system at the Dragon prospect (7), consists of two or more vein faults, and as noted above the Mackeno vein faults may also represent the extension of certain vein faults of the Hector-Calumet system.

At the Dragon prospect the principal vein fault dips 65 degrees southeast, is 5 to 8 feet or more in width, and has been prospected by pits, sluices, and shafts for a distance of 1,000 feet or more. In the vicinity of the main shaft the hanging-wall and foot-wall are quartzite and schist, respectively. According to Stockwell (1926) the main vein is interrupted just northeast of the main shaft by a northwest trending fault carrying some quartz, arsenopyrite, galena, and pyrite. On the surface this fault is not recognizable, but several lineaments are present which may mark the surface traces of this and other faults.

Northeast of the main shaft the principal vein fault appears to split into two or more components as it passes into sericite schist, graphitic schist, and thin-bedded quartzites. There, a few pits have exposed several fracture zones with some oxidized material, but ore minerals are sparse or lacking. Farther to the northeast the vein faults pass into graphitic schist and cannot be traced on the surface.

Near the main shaft the vein minerals are oxidized siderite, galena, freibergite, quartz, limonite, manganese oxides, jarosites, cerussite, and anglesite. According to Stockwell (op. cit) and from local reports the ore minerals are high in silver, but are only sparsely distributed through the siderite gangue.

Southwest of the Dragon prospect the vein faults are drift covered and cannot be traced accurately. In this area they enter the unfavourable series of thin-bedded quartzites overlying the thick-bedded quartzites of the Mackeno member, and the general fractured and broken nature of the rock float suggests that there the vein faults are narrow and form an irregular ramifying pattern. It is also probable that in this region the vein faults of the Mackeno system coalesce with those of the Hector-Calumet, and a general shattering and brecciation over a wide area is to be expected. In addition to these structural complexities several lineaments suggest the presence of north-west cross faults which would further disrupt the continuity of the vein faults.

To the southwest the system enters the Calumet claims (8) where one vein fault has been well defined by surface and underground workings. In addition the short faulted extension of another vein fault is known, and probably, projecting from underground data, a third vein fault is present southeast of the main one, although no evidence for its existence can be found on the surface.

Before entering the Hector claim (9) the vein faults are offset by the Hector fault and, farther to the southwest across the Hector claim, by the Jock fault (see Map 4-1957). Between these two faults the system consists of three interlaced vein faults, two of which are productive. The details of these and their faulted extensions will be considered in the description of the Hector-Calumet mine.

The vein faults are not exposed for some 3,000 feet southwest of the Jock fault. However, the existence of a strong topographic lineament and the presence of abundant manganese stained float suggest that the traces of the vein faults are as shown on the map. It is apparent, from the stratigraphic succession in this region, that the vein faults at the surface traverse a series of thin-bedded quartzites and schists, and from the known behaviour of vein faults in such rocks it is probable that they are narrow, have a general anastomosing pattern, and are unlikely to contain large, continuous orebodies. Favourable conditions should exist, however, where the downward extension of the veins intersect the underlying thick-bedded quartzites of the Hector-Calumet member.

On the Ruby fraction and Arctic and Mastiff claims the system has been exposed by several shafts, open cuts, and by the Bermingham cross-cut and connecting drifts.

The vein on the Ruby fraction (13) strikes north 50 degrees east and dips 65 degrees southeast and varies in width from 1 foot to 3 feet. According to Stockwell the vein is mineralized with siderite, galena, and pyrite. Alteration products include limonite, manganese oxide, and cerussite. The galena is said to carry from 250 to 385 ounces of silver to the ton and earthy cerussite, anglesite nodules, oxidized freibergite, etc. carry as high as 700 ounces of silver to the ton. No orebody of workable size was found during the early prospecting work, and as far as known no work has been done since 1935. The northeast extension of the Ruby vein has not been definitely established by mapping. The southwest extension may be represented in the Bermingham cross-cut by a crushed zone containing small amounts of siderite and galena, some 500 feet from the portal.

On the Arctic and Mastiff claims (12) are two vein faults repeatedly offset by northwest trending cross faults. Only one of these vein faults, the southeasterly, is known in in detail; the other is inferred as a possible extension of the vein fault on the Ruby fraction.

The principal vein fault has been offset by at least five faults, the main ones being the Arctic and Mastiff, with a combined horizontal movement of 400 feet. According to Wernecke and Visel early underground development during the years 1923-26 disclosed a vein with a maximum width of 6 feet between the Arctic and Mastiff faults. About 2,100 tons of ore assaying 144 ounces silver, 55 per cent lead, and 0.6 per cent zinc a ton were removed from a tabular shoot, 90 feet long, 50 feet down the dip, and 5 feet in average thickness. This shoot extended above the 70-foot level to within 20 feet of the surface. On and below the 70-foot level the vein was considerably wider and showed irregular streaks of ore over widths of 55 feet. Both vein and shoot were highly oxidized and contained galena, freibergite, cerussite, anglesite, limonite, manganese oxides, jarosites, altered siderite, some oxidized pyrite, and small amounts of quartz.

During 1929 and 1930 work by the Treadwell Yukon Company on the downward extension of the vein and its faulted extension southwest of the Arctic fault failed to find any bodies of ore large enough to mine. In 1951 United Keno Hill Mines drove the Bermingham cross-cut and drifted beneath the old workings but met with no better success, and the operation was abandoned.

According to Wernecke, the hanging-wall of the productive part of the vein fault is soft black graphitic schist and thin-bedded quartzite, and the foot-wall alternating thick- and thin-bedded quartzite. From the map and the stratigraphic table of the Central Quartzite formation it can be seen that the vein fault, where productive, cuts the Silver King member. This thick-bedded quartzite member appears to be less than 100 feet thick on the Arctic and Mastiff claims, a feature which would account for the relatively short vertical extent of the ore shoots.

Southwest of the Arctic fault the easterly vein fault enters the Upper Schist formation, through which it has not been traced. A vein fault striking north 55 degrees east and dipping 70 degrees southeast is exposed on the Coral and Wigwam claims (14) at the head of Porcupine Gulch which may be the extension of the most westerly vein fault of the Hector-Calumet system, that is the vein fault that passes through the Ruby fraction.

The vein fault at the Coral and Wigwam prospect lies astride the contact between the Silver King member and Upper Schist formation. Although part of the fault cuts quartzite, the mineralization is irregular and, according to local reports, tends to occur in small bunches. The primary minerals are galena, freibergite, quartz, sphalerite, and pyrite. Alteration products including limonite, manganese oxide, jarosite, cerussite, and anglesite are present in the surface exposures. No ore shoots have been found.

The most productive part of the Hector-Calumet system is on the Calumet and Hector claims, where United Keno Hill Mines Limited have investigated the system along strike for some 3,500 feet and to a depth of 1,300 feet. To date, the Hector-Calumet mine has yielded over a million tons of ore averaging 45 ounces silver a ton, 9 per cent lead, and 6.5 per cent zinc. In addition the ore averages 0.09 per cent cadmium, and 1,109,634 pounds of this metal have been recovered. The annual production of the mine for the years 1954 and 1955 is tabulated below:

Metal	1955	1954
Silver, ounces	5,670,137	5,878,791
Lead, pounds	26,350,198	30,663,549
Zinc, pounds	24,035,999	26,134,700
Cadmium, pounds	302,297	312,931

The known reserves at the end of 1955 were 587,830 tons of ore averaging 37.7 ounces silver a ton, 8.7 per cent lead, and 8.0 per cent zinc[1]; with further underground development more ore will undoubtedly be found.

In the underground workings of the Hector-Calumet mine the system comprises several anastomosing vein faults which vary markedly in strike and dip. The names of the vein faults are shown on Figure 3. Only four, Nos. 1, 2, 3, and 4 veins, have been productive; other vein faults, as far as known, are only sparsely mineralized.

The vein faults have been sliced into segments and offset by two major northwest cross faults, the Hector and Jock faults. These appear as zones of highly fractured rock up to 150 feet or more wide. Both zones dip at 45 degrees southwest, but individual faults and slips within the zones may be steeper. The horizontal movement on the two faults is right hand, judging from drag effects and the offset position of the veins. The amount of horizontal movement is some 250 feet on the Hector fault and probably 400 feet on the Jock fault. The magnitude of the vertical movement is not known accurately but appears to be less than 100 feet.

Prior to cross faulting the productive part of the vein faults at the Hector-Calumet mine formed a cymoid loop about a highly fractured horse of country rock (see Figure 4). Two features control the location of the ore shoots; 1, vein fault

[1]All data from annual reports, United Keno Hill Mines Limited.

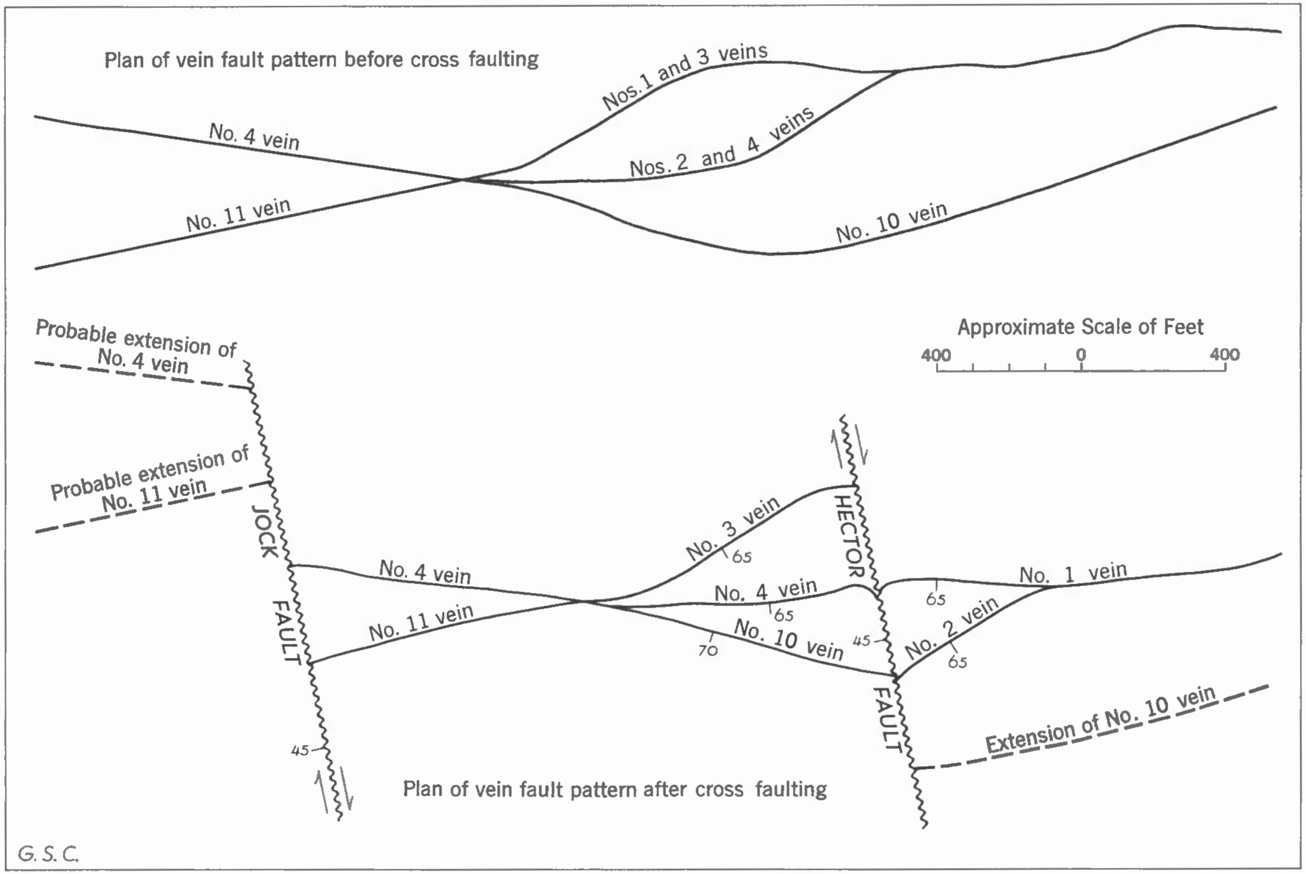

Figure 4. Sketches illustrating the vein fault pattern at the Hector-Calumet mine, Galena Hill, before and after cross-faulting.

junctions and 2, the presence of massive thick-bedded quartzites (Hector-Calumet member).

The largest shoot in the mine occurs at the junction of the No. 3 and 4 veins. The rocks at this junction are severely brecciated on some levels over widths of 75 feet or more and have been mineralized extensively over much of this width. The shoot is developed at the junction and along No. 3 vein fault on the 100-foot level for some 800 feet, and along No. 4 vein fault for a short distance. It can be seen in longitudinal section (see Figure 3B) that this shoot comes to an apex downward. The southwestern margin follows the general plunge of the junction of the two vein faults straight down and the northeastern margin cuts obliquely back, following in a general way the trace on the fault plane of the base of distinctive white cherty quartzite beds. In other words, the extent of the shoot is controlled not only by the fault junction but also by the presence of favourable, brittle competent beds.

Two ore shoots have been formed along No. 1 and No. 2 vein faults, near their mutual junction. This junction rakes 55 degrees east and is followed by the two ore shoots. The ore shoots are principally contained in a series of massive thick-bedded quartzites lying immediately below the characteristic cherty white quartzite.

The No. 1 vein contains two other ore shoots, one 500 feet and the other 1,600 feet northeast of the junction of No. 1 and No. 2 veins. The reasons for the localization of these shoots are obscure, but they occur in highly brecciated parts of the vein faults, perhaps at the junctions of other cymoid loops that have not yet been investigated.

The primary mineralization in the Hector-Calumet mine is essentially the same as that elsewhere in the Galena Hill area. Masses and lenses of an early generation of quartz with a little pyrite fill some of the vein faults. These lenses have been brecciated and later cemented by siderite, pyrite, sphalerite, galena, and tetrahedrite. Pyrite tends to form predominantly on the borders and ends of the ore shoots, and galena, sphalerite, and tetrahedrite in the central parts. Lenses and pods, 10 feet or more wide, of sulphides with siderite are common. Oxidation effects are observable down to 600 feet in No. 1 and 2 veins and to 400 feet in No. 3 and 4 veins. There is no observable difference in the porosity of these two sets of veins and oxidation should have therefore proceeded to the same depth in each. They are separated by the Hector fault and, as the main period of oxidation was probably in the Tertiary, it is probable that some of the movement on this cross fault occurred after this. The oxidation minerals developed are mainly limonite, manganese oxides, jarosites, cerussite, anglesite, and calcite. Some ore shoots are relatively high in silver bearing jarosites, plumbojarosite, and cerussite. As in other veins there has been a general enrichment of silver and lead and depletion of zinc in the oxidized zones.

In summarizing the main features of the Hector-Calumet system it should be pointed out that the vein faults are productive or mineralized only where they cut one or more thick-bedded quartzite members in the Central Quartzite formation. Thus, whereas, only small ore shoots are present in the lower Mackeno and upper Silver King members the favourable circumstance of several vein fault junctions in competent thick-bedded quartzites in the Hector-Calumet member has led to the formation of several large ore shoots. As the vein faults pass from the thick-bedded quartzite members into thin-bedded quartzites or graphitic schists the vein faults become a series of narrow fractures that are scarcely traceable, and have been unfavourable sites for ore deposition.

Ore deposition in the system has been principally localized at the junctions of vein faults(Hector-Calumet mine) or at sites in the vein faults where they pass from thick-bedded quartzites upward into graphitic schists or thin-bedded quartzites (Arctic and Mastiff claims). These two positions, especially the junctions, and the tendency of the vein faults to form loops, should be watched for carefully during exploration.

Formo Vein

This vein (3) was explored by H.E. Formo during the period 1925-30 and about 40 tons of high grade silver ore ~~were~~ was mined. In 1950 Yukeno Mines Limited obtained an option on the property and during 1952 and 1953 explored the vein by two adits and connecting drifts on two levels. The results of this exploratory work were disappointing as no orebody large enough to be mined was found.

The vein outcrops beside a greenstone knob, strikes north 17 degrees east, and dips 60 degrees east. Its north-eastern extension is offset a short distance to the east by a northwest trending cross fault which strikes north 40 degrees west and dips 35 degrees southwest. The southwestern extension of the vein has not been traced.

In the underground workings the vein flattens slightly and becomes irregular. The maximum width is 4 feet and the wall-rocks are predominantly thin-bedded quartzites and graphitic schists with a few narrow lenses of greenstone and a sill of lamprophyre. Several small lenses and pods of ore are scattered along the vein fault. These lenses are irregular and contain much sphalerite and pyrite. Other minerals present are galena, tetrahedrite, siderite, and quartz.

The general setting of this vein is not promising for the occurrence of large persistent orebodies because of the general tightness and irregularity of vein faults in the schists and thin-bedded quartzites of the Lower Schist formation. The vein may, however, be productive where it cuts greenstone either on its strike or dip, and these special conditions should be sought during exploration.

Bluebird Vein

The Bluebird vein (2) strikes north 20 degrees east and dips 65 degrees southeast. It has been investigated by two shafts sunk many years ago. The rocks on the foot-wall are greenstone and those on the hanging-wall, graphitic schist and thin-bedded quartzites. The vein is irregular and varies in width from 1 foot to 5 feet. It is mineralized with galena, sphalerite, and pyrite in a gangue of ankerite, calcite, quartz, limonite, and manganese oxides. The galena assays high in silver.

The Bluebird vein fault probably represents the northeast extension of one of the vein faults of the Mackeno system.

Western System

Silver King System

The vein faults of the Silver King system (17) were first prospected in 1913 by H. W. McWhorter and represent the initial discovery of silver ores in the Galena Hill-Keno Hill area. A small tonnage of ore was shipped from the veins during the years 1915 to 1928 by several individual operators. In 1929 the Treadwell Yukon Company purchased the properties covering the productive part of the system, and extensive development resulted in the discovery of three ore shoots (Silver King, Hawthorne, and Webfoot) which yielded 11,700,000 ounces of silver during the years 1929-39. The known ore shoots in the system are now exhausted.

The system consists of two vein faults, the Silver King (204 and 206 veins) and Hawthorne (202 vein) which intersect in the vicinity of the No. 3 shaft (see Figure 5). The rake of the intersection of these two vein faults is 75 degrees to the southeast. Both vein faults contained productive orebodies.

The principal vein fault (Silver King fault) strikes north 50 degrees east and dips 70 degrees southeast. To the northeast it transects massive, thick-bedded quartzites of the Silver King member of the Central Quartzite formation. To the southwest it crosses Galena Creek where it is probably offset to the northwest by a northwest striking cross fault. From this point the exact location of the vein fault is unknown, but 2,000 feet southwest of the point where the road crosses Galena Creek a few pits and shafts have traced a vein fault which is probably its farthest southwest extension. There, the vein fault cuts thin-bedded quartzites and schists of the Upper Schist formation and is only sparsely mineralized with siderite and galena.

The Silver King vein fault contained three ore shoots -- one in the vicinity of the Aitken shaft and the other two northeast of the No. 3 shaft.

The shoot below the old Aitken shaft contained 2,700 tons of ore assaying 215 ounces of silver a ton, 30.42 per cent lead, and 0.10 ounce of gold a ton. The dimensions of this shoot are not known in detail, but the approximate outline is shown on Figure 5. It is localized in thick-bedded quartzites below the region where the vein fault enters thin-bedded quartzites and schists on both hanging-wall and foot-wall.

The Silver King orebody was immediately northeast of No. 3 shaft. Although discontinuous in part, it had a horizontal length of 360 feet on the No. 1 level and a maximum vertical extent of 200 feet. The average width was 7.8 feet and the average assay 90.2 ounces silver per ton and 17.5 per cent lead. Sphalerite was not shipped and there is no record of the average zinc content. From random assays zinc apparently ranged in amount from 2 to 15 per cent, and probably averaged 9 per cent.

The Webfoot orebody adjoined the Silver King orebody on the northeast. It had a horizontal length of 190 feet on the 100-foot level and a maximum vertical extent of 140 feet. The average width was 15.8 feet and the average assay 60.7 ounces silver a ton and 3.6 per cent lead. The zinc content was lower than that of the Silver King orebody.

The subsidiary vein fault (202 vein) strikes north 75 degrees east, dips 70 degrees southeast, and contained the Hawthorne orebody. This orebody had a horizontal length of 440 feet on the No. 2 level, and a total vertical extent of 270 feet. It had an average width of 3 feet, and averaged 197.8 ounces silver a ton and 17.6 per cent lead. The zinc content is unknown. The shape of the orebody was roughly elliptical with the major axis some 680 feet in length raking 30 degrees to the southwest.

The vein faults in which orebodies of the Silver King system occurred are extensive brecciated and sheeted zones 15 feet or more wide. Three stages in the mineralization history can be recognized after the vein faults were formed. These are in chronological order:

(1) Deposition of early quartz and some pyrite, followed by that of cream-coloured siderite, galena, sphalerite, pyrite, and tetrahedrite.

(2) Brecciation of galena-sphalerite-siderite lodes followed by deposition of microcrystalline quartz, pyrite, calcite, ruby silver, native silver, and resinous sphalerite. Part or all of these minerals may be due to the supergene processes outlined in stage 3.

(3) Oxidation of the lodes. This resulted in a general enrichment of silver and lead and the oxidation of sphalerite, pyrite, and siderite to limonite, manganese oxides, and jarosites. Much zinc was removed, and it is apparent that some silver, calcium, silica, and other elements migrated downward to the region immediately below the oxidized zone where they were precipitated as sphalerite, ruby silver, native silver, calcite, and microcrystalline quartz.

The upper part of the oxidized zone at the Silver King mine was removed during the glaciation of the McQuesten Valley leaving only the bottom 25 feet. This remaining part was considerably enriched in silver and lead, and assays of 300 ounces or more of silver a ton and 25 to 30 per cent lead were common. Below the enriched oxidized zone the assays dropped to 100 ounces or less of silver a ton and less than 20 per cent lead.

It will be noted that the principal ore shoots of the Silver King system are localized on the two limbs of a Y junction in the system, and the smaller shoot below the Aitken shaft occurred in the favourable locus beneath the thin-bedded quartzites and schists of the Upper Schist formation. Two of the ore shoots (Silver King and Webfoot) are where the massive, thick-bedded quartzites of the Silver King member form the foot-wall, and it is probable that the ore bearing part of the system as a whole owes its presence to this brittle, competent member. At the Silver King mine this member is some 350 feet thick, and it is apparent that the ore shoots bottomed on the dip where the vein faults passed into the underlying thin-bedded quartzites and schists.

The prospecting possibilities in the vicinity of the Silver King mine are limited. One favourable site is where the vein fault cuts the thick-bedded quartzites beneath the schists and thin-bedded quartzites southwest of the Aitken shaft. Another deep possibility is in the Hector-Calumet member which the downward extension of the vein faults should intersect.

The southwest extension of the Silver King vein at the surface passes into thin-bedded quartzites and schists of the Upper Schist formation and only sparse mineralization can be expected in these rocks. The northeast extensions of the two vein faults have not been traced, but both must pass into thin-bedded quartzites--the Silver King vein into the thin-bedded member underlying the Silver King quartzites, and the Hawthorne into the overlying thin-bedded quartzites and schists of the Upper Schist formation. Both these series of thin-bedded quartzites and schists are unfavourable for the occurrence of ore shoots.

From the positions of the Silver King and Elsa systems (see below), and assuming the presence of northwest cross faults in the area between the two systems, it is possible that they represent faulted extensions of each other. If so the surface extension of the Silver King system cuts the favourable Hector-Calumet member at the Elsa. If, however, the two are not faulted parts of the same system, then the surface extension of the Silver King vein fault may intersect the Hector-Calumet member some 6,000 feet northeast of No. 3 shaft, and this should be a favourable place to prospect.

Elsa System

Development of the Elsa system (16) commenced in 1928, and during the ensuing 15 years some 55,000 tons of ore containing more than 5,500,000 ounces of silver were won from its ore shoots. During 1948 and 1949 United Keno Hill mines carried out some lateral exploration and more recently have been exploring the veins at depth.

The productive part of the system consists of three vein faults which form Y junctions (see Map 4-1957 and Figure 6). An additional narrow vein fault lies 670 feet from the portal of the 400-foot level adit. This vein fault has been investigated by short drifts, but only scattered ore minerals with a low silver content were encountered.

The three productive vein faults cut the favourable Hector-Calumet member which is composed of massive thick-bedded grey quartzites, siliceous white quartzites, and greenstone lenses in the Elsa mine. The vein faults are fractured and brecciated zones 10 to 30 feet wide which have been mineralized, principally near their junctions. The Brefalt vein is the most persistent and appears to be the trunk vein of the system. It strikes north 65 degrees east and dips 65 degrees southeast. The dips and strikes of the other veins and their relationship to the Brefalt vein are shown on Figure 6.

Many late slips and narrow faults occur along the vein faults of the system. Some of these offset the vein faults slightly; others parallel the vein faults and cut through fault breccia and ore shoots.

The ore shoots have an irregular lenticular outline and have a maximum width of 15 feet. Some follow the junctions of the vein faults closely and rake at approximately the same angle, others appear to be controlled by other unknown features. All ore shoots are intensely oxidized, down to the lowest level of mining, and only in a few places were primary sulphides present. Sphalerite was practically absent in the upper parts of the veins being almost completely removed by oxidation. The minerals in the ore included highly altered galena and freibergite, cerussite, anglesite, native silver, argentite, silver bearing jarosites, limonite and manganese oxides, and altered siderite. The shoots near the surface were enriched in silver, assays of 200 ounces or more a ton being not uncommon. On the lower levels the silver values were less, ranging from 50 to 100 ounces a ton in the various ore shoots.

The northeast and southwest extensions of the Elsa system have been offset by the Porcupine Creek and Brefalt Creek faults, respectively.

Northeast of the Porcupine Creek fault a vein fault, which probably represents the faulted extension of one of the vein faults of the system, has been traced as shown on Map 4-1957. This vein fault is narrow and irregular and contained one small ore shoot holding a few tons of ore. Still farther northeast the extension of the system should enter the unfavourable series of thin-bedded quartzites and schists separating the Hector-Calumet and Mackeno members. In these rocks the vein faults would be poorly developed and ore shoots unlikely. Finally, before entering the Mackeno member at the No Cash property, the system probably coalesces with the Dixie vein fault.

The extensions of the vein faults southwest of the Brefalt Creek fault have not been found, and two possibilities should be considered in searching for them. First, the Silver King system may be the southwest extension of the Elsa system; or secondly, the two may be separate and parallel, in which case the extension of the Elsa system may pass into the favourable Silver King member in the area between Flat and Galena Creeks.

Dixie Vein

This vein (15) probably forms a part of the Elsa system and extends northeast to join the other vein faults of this system in the area north of the Elsa-Calumet road. The exposed part of the vein has been investigated by a shaft and several pits, but none of the underground workings was accessible at the time of the author's visit.

Where seen the Dixie vein strikes northeast, dips steeply southeast, and cuts a series of cherty white quartzite beds of the Hector-Calumet member. The principal minerals are altered siderite, galena, freibergite, sphalerite, pyrite, limonite, manganese oxides, and anglesite. Only one small shoot, containing a few tons of ore, was found during underground exploration.

The Dixie vein, it should be noted cuts the favourable Hector-Calumet member and hence warrants further investigation. It should also be borne in mind that the vein exposed may be only one of several because there is a general tendency for veins to occur in a complex ramifying pattern in the brittle rocks of this member. Lateral work to the east and west of the exposed vein should prove or disprove this possibility.

No Cash Vein

The No Cash vein (11) probably represents the northeast extension of the Elsa system, including the Dixie vein. It has been investigated by a series of pits, shafts, and underground workings for a distance of 3,000 feet along strike. The most important workings occur in the vicinity of the main shaft, southwest of Star Creek.

This shaft, some 100 feet deep, connects with a footwall drift 80 feet in length and a hanging-wall drift 45 feet in length on the 50-foot level. On the 100-foot level a single drift follows the vein for some 700 feet to the southwest and 420 feet to the northeast where it connects with an adit driven westward to Star Creek gulch.

The drifts on the 50-foot level were driven by early operators in 1928 or 1929, and a small tonnage of high grade ore was removed. The drift on the 100-foot level together with the adit and several raises was driven by United Keno Hill Mines in the period 1948-52. During these operations some 4,500 tons of ore containing over 70 ounces of silver a ton were mined.

The drifts expose a complex fractured zone varying in width from 5 to 15 feet which has been offset by several cross faults with small horizontal displacements. Both the hanging-wall and foot-wall are irregular and many fractures branch from and join the fractured zone. The general dip of the fractured zone is 60 degrees southeast, but there are many irregularities. The wall-rocks are massive thick-bedded quartzites (upper part of the Mackeno member) interbedded with several beds of graphitic schist and thin-bedded quartzite.

Several narrow shoots of ore occur along the drifts and appear to be localized where either the foot-wall or hanging-wall is massive thick-bedded quartzite. Beyond this generalization there are insufficient openings to determine the structural setting of the mineralized parts. The ore minerals include galena and tetrahedrite and their oxidation products anglesite, cerussite, and silver-bearing iron oxides and sulphates; the gangue is limonite, manganese oxides, altered siderite, some quartz, and pyrite.

Structurally the No Cash vein is favourably situated in the Mackeno member and the position of the ore shoots may, therefore, be similarly controlled to those in the Mackeno mine. Other vein faults may also be present in the general area of the No Cash vein and may form the characteristic anastomosing pattern so common in the vein fault systems of Galena Hill.

Eastern System

Tin Can and Rico Veins

The Tin Can veins (1) cut greenstone, thin-bedded quartzites, and graphitic schists. The principal vein fault has been investigated along strike by several pits and shafts. It is regular in the greenstones, but irregular where it passes into thin-bedded quartzites and graphitic schist, and apparently splits into several branches along strike.

The well-defined part of the vein in the greenstones is 2 to 5 feet in width and has been mineralized with ankerite, calcite, quartz, sphalerite, and pyrite. Small amounts of siderite, limonite, manganese oxides, and altered galena lie on the dumps. No ore shoots were found during early exploration.

Traced southwest the main vein fault crosses the Yukeno road as shown on Map 4-1957. Beyond this point it appears to have been repeatedly faulted and is impossible to trace. However, along the projected strike a vein fault occurs in siliceous quartzites of the Hector-Calumet member about 2,000 feet due south of the main Mackeno adit. This vein fault has been investigated by an adit which is now caved. Material on the dump consists of altered siderite, manganese oxides, limonite, and some galena. The adit appears to have been driven along a mineralized, shattered zone in the quartzite.

The Rico vein fault is 2,700 feet southeast of the main adit of the Mackeno mine. It has been investigated by a shaft now caved and an adit that extends for 200 feet into the hillside. The vein fault is a poorly developed shattered zone striking north 60 degrees east and dipping 65 degrees southeast. It is cut off and faulted by late slips and faults. Limonite, manganese oxides, some ankerite, and small amounts of quartz and pyrite occur at irregular intervals.

The Rico vein fault probably forms a part of the Tin Can and Eagle system of vein faults.

Eagle Vein Faults

The Eagle vein faults (6) are exposed at the head of Hinton Creek and have been investigated by four shafts and several open cuts. The two vein faults may represent faulted parts of a once continuous vein fault or they may be part of a ramifying system. The westerly vein fault has a maximum width of 3 feet, strikes north 50 degrees east, and dips steeply southeast. The eastern vein fault has a similar strike and dip. The foot-wall of the western vein fault is quartzite to the northeast and sericite schist to the southwest; the hanging-wall is mainly quartzite. The eastern vein fault occurs mainly in quartzite.

The mineralized material on the dumps and in the exposed parts of the vein faults consists of siderite, quartz, pyrite, galena, sphalerite, arsenopyrite, limonite, and freibergite. No ore shoots are known to occur.

It is probable that the Eagle vein faults are part of a system comprising the Rico, Tin Can, and other vein faults that cut the quartzites south of the Mackeno Mine.

Cream Vein Fault

The Cream vein fault (10) is an isolated vein fault and is exposed on the lower northwest slope of Galena Hill, at an elevation of 3,000 feet. It has been investigated by open cuts and an inclined shaft which is said to reach a depth of 106 feet and to connect with three drifts. At the time of the author's visit an adit was being driven by lessees to intersect the vein fault at depth. The shaft was inaccessible, and hence most of the description of this vein fault is from surface observations and private reports.

The wall-rocks are principally thin-bedded quartzites and graphitic schist with thin lenses of greenstone and a few thick beds of quartzite. The main vein fault has an average strike of north 25 degrees east and dips 50 degrees southeast. It pinches and swells along strike, and presumably behaves in a similar manner down its dip. The mineral content is erratic and consists of galena, sphalerite, and chalcopyrite in a gangue of siderite, calcite, quartz, pyrite, and limonite. The mineralization differs somewhat from other vein faults of the district in being relatively high in chalcopyrite. It is reported that about 50 tons of ore have been removed from small shoots in the vein.

Two hundred feet southeast of the main shaft another shallow shaft has been sunk on a fracture in thin-bedded quartzites. The dump material shows pyrite, quartz, and arsenopyrite. Probably this fracture is one of many associated with the Cream vein fault.

GEOCHEMISTRY OF THE DEPOSITS

The Galena Hill deposits are similar in most respects to those on Keno Hill, which have been described in a previous report (Boyle, 1956), and it is, therefore, unnecessary to repeat the details of the mineralogy and geochemistry. Only a brief summary will be given of the course of mineralization and the salient points of the geochemistry of the processes of hypogene and supergene mineralization.

The rocks in which the deposits occur are mainly sedimentary in origin and include quartzites, sericitic, chloritic and graphitic schists, and graphitic phyllites, all of which are interbedded with greenstone lenses and sills. Although chemical analyses are not yet available for the sedimentary rocks, thin section studies show that their main characteristic is the high silica, alumina, and carbon content. The schists, phyllites and some quartzites contain in addition large amounts of pyrite and carbonate minerals that are original sedimentary constituents and not introduced subsequently. The greenstones are highly altered rocks that probably had an original dioritic or gabbroic composition. Both the sedimentary rocks and greenstones have been extensively altered during regional metamorphism and fall into the chlorite-sericite or greenschist facies.

The vein faults cut and offset all ages of rocks in the Galena Hill-Keno Hill area and both greenstones and quartz-feldspar porphyries have been altered by the mineralizing solutions. It is improbable, therefore, that any of the near-surface intrusive rocks are responsible for the mineralization. It is difficult to see how the greenstones or porphyries could have given rise to magmatic, metal-bearing solutions that found their way into the vein faults because they were completely crystallized, solid bodies before the vein faults cut through them.

An adequate source for both gangue elements and the metals exists in the sedimentary rocks and consolidated igneous rocks as shown by preliminary analyses. For instance it is known that enormous amounts of sulphur, carbon dioxide, silica, iron, and manganese, the principal constituents of the deposits, are present in the Lower Schist formation underlying the deposits. Furthermore, trace analyses indicate that much zinc, copper, arsenic, and antimony are available in these rocks and that lead and silver are also present. The source of the elements is, therefore, not so much of a problem as the processes whereby they were concentrated in the deposits. On this latter subject little can be said until the completion of laboratory work.

MINERALIZATION HISTORY

The mineralization history of Galena Hill has been long and complex, involving at least three hypogene stages followed by a supergene stage which is still in progress. The structural history and stages of mineralization are enumerated below, the oldest first.

1. Formation of early quartz stringers and lenses containing some pyrite and carbonate minerals along bedding planes, fractures, shear zones, drag-folds, and contorted zones in sedimentary rocks and greenstone. These are cut by all structures listed below.

2. Development of early faults with a general northeast strike. These are the vein faults and their formation was followed, in some places, by the deposition of quartz and some pyrite as veins occupying them. On Keno Hill arsenopyrite is a typical mineral of this stage but is absent or present in only small amounts on Galena Hill. The quartz-pyrite veins of this stage generally carry low gold and silver values. In a few vein faults some galena and sphalerite may have accompanied the quartz.

3. Continued movement along the vein faults followed by the deposition of siderite, galena, sphalerite, pyrite, freibergite, and chalcopyrite in dilatant zones at or near the junctions of the vein faults, in subsidiary fractures striking off the main faults, and at sites in the vein faults where they cut thick-bedded quartzites and greenstones and pass upward into schists and thin-bedded quartzites.

4. Brecciation in places of the lodes formed in stages 2 and 3, resulting in the crushing of the siderite and pyrite and the production of steel and gneissic galena. This was followed in some lodes by deposition of dolomite, calcite, grey quartz, quartz crystals, and some sphalerite and galena. Some of these minerals may be due to re-working and leaching of the minerals formed during stage 2, but most are probably supergene (see stage 7).

5. Formation of late faults striking northeast, northwest, and southwest. The principal of these is the McLeod fault which followed the McLeod vein fault. During this period of faulting northwest and northeast striking faults such as the Hector, Jock, and many others, were formed, subsidiary to this main trunk fault. Several periods of movement apparently affected the Hector and other faults, some of which were later than the early stages of the oxidation of the lodes.

6. Development of fractures, slips and minor narrow faults that cut across and slice through the vein faults and lodes. Some minor faults that follow the vein faults cut across the northwest striking cross faults and may be mistaken for the continuation of vein faults.

7. Processes of supergene oxidation.
   - (a) Oxidation of pyrite, sphalerite, siderite, galena, and freibergite. This resulted in the formation of limonite, hydrous manganese oxides, anglesite, hawleyite, cerussite, calcite, azurite, quartz, malachite, plumbojarosite, silver-bearing jarosites, and native silver. During this period many soluble salts of iron, manganese, zinc, silver, and lead were formed which migrated downward into the lodes. In vein faults not sealed by permafrost these oxidation processes are active at present.

   - (b) Precipitation of supergene calcite, quartz, sphalerite, native silver, pyrargyrite, and galena in brecciated lodes, late faults, and fractures in the zone of reduction below the temporary water-table. The amount of supergene galena and sphalerite is small and has little effect on the economics of the lodes. The amount of native silver and pyrargyrite formed in some lodes is considerable and influences the silver tenor of the lodes. In vein faults not sealed by permafrost the processes in the zone of reduction are active at present.

(c) Formation of ice lenses in the veins, fractures, and faults in the permafrost zone. Most of these lenses were formed during Pleistocene time, but in some faults they are apparently still being formed.

HYPOGENE PROCESSES

The early stringers, boudins, and irregular bodies of quartz are small and are restricted to contorted parts of schist beds or fractures in quartzites and greenstone. They are isolated bodies in the rocks, unconnected and unrelated to any fault or fracture system, and contain minerals the elemental components of which are abundantly present in the rocks enclosing them. Godfrey (1954), who has studied these bodies in detail, has concluded that they have a metamorphic origin. With this conclusion the author is in agreement, and it seems logical that these bodies represent concentrations of SiO_2, CO_2, Ca, S, and other elements mobilized during the earliest stage of metamorphism of the area. These compounds and elements have evidently migrated into low pressure dilatant zones (fractures and contorted schist zones) where they have been precipitated as a consequence of free energy (equilibrium) differences.

During the first stages of the mineralization of the vein faults silica, with small amounts of iron, sulphur, arsenic, calcium, magnesium, manganese, carbon dioxide, and a little gold were introduced to form the early quartz lenses containing pyrite and some carbonate minerals. Relatively little lead, silver, or zinc was introduced during this period. The second stage of mineralization followed during the brecciation of the early quartz lodes and the formation of extensive dilatant zones in the vein faults. During this stage the composition of the solutions differed from those responsible for the early quartz bodies, and large amounts of CO_2, S, Fe, Mn, Ca, Mg, Pb, Ag, Zn, Cd, Cu, As, and Sb were introduced to form the economic siderite lodes containing pyrite, galena, sphalerite, and freibergite. At this stage relatively little silica was introduced. Some siderite lodes show a tendency for alternate banding of siderite and ore minerals, but regardless of these occurrences there is little general evidence to suggest that the elements or compounds were deposited in successive waves. The gangue and ore minerals are generally so intergrown that the conclusion seems inescapable that they were precipitated during a period when the solutions fluctuated but slightly in composition.

The wall-rock alteration has not as yet been sufficiently studied to draw many conclusions. In most places alteration in quartzites and schists has had little if any effect, but in some a bleaching and leaching process, mainly of carbonate minerals, has taken place leaving the quartzites white and in places a mass of crumbly incoherent grains. The alteration of the greenstones adjacent to mineralized lodes is profound in most places, and chlorite, zoisite, plagioclase, and other minerals are altered to a soft, confused, schistose mass of carbonate minerals, sericite, leucoxene, pyrite, and quartz.

SUPERGENE PROCESSES

The supergene processes in the vein faults are primarily due to the action of meteoric water containing dissolved oxygen and carbon dioxide of atmospheric origin. During these processes the mobility of the various elements is a function of their solubility, generally as the oxygen salts (sulphates, carbonates, etc.), the pH of the migrating solutions, the availability of free oxygen, and the presence of reactive gangue minerals.

Complete chemical analyses of oxidized and unoxidized ores are not yet available, and hence only qualitative statements can be made. The results of three years of geochemical research in the area (Boyle, 1955, 1957) show that meteoric water removes Fe, Mn, Ca, Mg, Al, Si, Ni, Na, Co, Ba, Sr, Cs, Zn, Cu, Ag, Pb, Sb, As, and Cd from the oxidizing zones. These are carried principally as sulphates and carbonates and probably in some cases (e.g. silicon) as complex ions. The migration of these elements may follow two courses: if the circulating system is an open one they may be removed completely from the deposits and dispersed in streams and soils; if the circulation is slow or nearly stagnant the elements migrate downward slowly passing from an oxidizing to a reducing environment at the temporary water-table whereupon they precipitate as new minerals in fractures, faults, and brecciated parts of the lodes.

The principal manifestations of the supergene processes are the oxidation of siderite, pyrite, sphalerite, and freibergite to limonite, silver-bearing jarosites, and various black manganese oxides. In addition galena has been oxidized to anglesite, and in some veins secondary reactions involving carbonate solutions and lead have produced cerussite. Plumbojarosites has also formed by the reaction of ferric sulphate solutions with galena or solutions carrying lead. During these oxidation processes much iron, manganese, calcium, and magnesium have been released and have migrated downward as soluble sulphates and carbonates. Some silica has also been mobilized and carried downward, together with a little lead, silver, arsenic, antimony, and much zinc.

Where the circulation system has been an open one these elements and compounds have been dispersed through springs into the drainage systems of the area. In other cases, however, the circulating system has been nearly stagnant, and supergene carbonates, quartz, and sulphates have formed in fractures and cavities at or just below the water-table. Some supergene galena and sphalerite have also been formed in this environment, but not enough to affect the lead and zinc tenor of the ores to any marked degree.

As shown by the analyses in Table II the oxidized zones are enriched in silver and lead and depleted in zinc. Most of this enrichment has resulted from the nearly complete removal of the gangue minerals, pyrite and siderite, leaving the silver bearing galena and freibergite as oxidized nodules coated with anglesite and other minerals, which prevents complete oxidation. The rest of the silver enrichment is the result of chemical processes after the release of silver from its host minerals, galena and freibergite. In the upper parts of the veins this silver migrates downward with increasing oxidation, and gradually the oxidized zones become highly enriched in silver bearing jarosites, anglesite, and other oxidation products. Some silver was carried on downward to the region of the water-table where it was precipitated as native silver, or pyrargyrite in some veins, as at the Silver King mine.

SUMMARY

The rocks underlying Galena Hill include chloritic, sericitic, and graphitic schists, quartzites, and lenses and sills of greenstone. These rocks belong to the greenschist facies. A few quartz porphyry sills are the only evidence of granitic intrusions.

Three formations are recognized and have been named as follows: Lower Schist formation, Central Quartzite formation, and Upper Schist formation. The Central Quartzite formation is the principal focus for mineralization. This formation contains three favourable members, the Mackeno, Hector-Calumet, and Silver King. Each consists of massive thick-bedded quartzites which contain the main orebodies.

In general the schist formations are incompetent and unfavourable for the occurrence of ore shoots. The Lower Schist member, however, contains numerous competent greenstone lenses that are worth exploring.

The ore-bearing vein faults cut all the rocks of the area. They consist of extensive brecciated and sheeted zones in the thick-bedded quartzites and greenstones and a network of narrow fractures in the schists and thin-bedded quartzites. The vein faults on Galena Hill appear to fall into three major anastomosing systems which strike northeast and dip southeast. Each of these systems is cut into segments by late faults and fractures that offset individual vein faults and in many places cut through the ore shoots.

The ore shoots are localized in two structurally favourable sites: At sites in massive thick-bedded quartzites, where the vein faults pass upward into schists and thin-bodied quartzites; and at or near junctions of the vein faults. The latter sites are especially favourable for the formation of large and continuous orebodies.

The sequence of mineralization is complex, entailing both hypogene and supergene processes. The hypogene mineralization consists of three distinct types, representing three periods. The earliest is the formation of small quartz lenses and stringers distributed at random in quartzites, schists, and greenstones. These bodies probably formed as a result of a local secretion process during metamorphism of the enclosing rocks. The other two periods are restricted to the vein faults. The first of these resulted in the deposition of quartz lenses carrying a little pyrite and gold, and the second, which cuts the first, in the formation of lodes containing siderite, galena, sphalerite, and freibergite. These lodes are high in silver and from them most of the lead, zinc, silver, and cadmium has been won.

The siderite lodes are highly oxidized near the surface and down to a depth of 600 feet or more in some vein faults. In most vein faults the oxidation has led principally to the formation of limonite, jarosites, and various manganese oxides from siderite, pyrite, and sphalerite. During these processes much zinc has been removed, and some galena has been oxidized to anglesite or cerussite. In addition, the oxidation has led to an enrichment of silver in the oxidized parts of some lodes by the removal of siderite, pyrite, and other gangue minerals and by the chemical solution of silver in the higher parts of the oxidized zones and its precipitation in the lower parts.

At or near the water-table some supergene sphalerite and galena have been formed in many lodes, but it is doubtful if any marked enrichment of lead and zinc has resulted. Secondary enrichment of silver, by the formation of the native metal or ruby silver in the zone of reduction, has, however, increased the silver tenor of the ores in a few lodes.

Table II

LEAD, ZINC, AND SILVER CONTENTS OF OXIDIZED AND UNOXIDIZED LODES, GALENA HILL

Location	Description	Pb %	Zn%	Ag oz/ton
Hector-Calumet mine	Average assay of oxidized ore	9.87	4.29	51.18
"	Average assay of unoxidized ore	9.2	8.4	38.4
Elsa mine	Average assay of near surface, oxidized ore	25.39	0.5	467.4
"	Average assay of oxidized ore on 160-foot level	11.8	-	173.6
Silver King mine	Oxidized ore near surface	61.4	1.7	374.2
"	Unoxidized ore 80 feet below surface	22.3	6.8	156.8
"	Unoxidized ore 100 feet below surface	3.9	8.7	38.5

Notes: 1 All analyses in Table II from various mining reports, annual reports, and company assay plans.

2 Dash indicates no assays available.

BIBLIOGRAPHY

Annual Reports, United Keno Hill Mines Limited, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955.

Blackadar, R.G.
1951: The Greenstone Intrusions of the Mayo District, Yukon Territory; Unpub. M.A. Thesis, Univ. Toronto, Toronto, Canada.

Bostock, H.S.
1933: The Mining Industry of Yukon, 1932; Geol. Surv., Canada, Sum. Rept. 1932, part AII, pp. 1-14.
1935: The Mining Industry of Yukon, 1934; Geol. Surv., Canada, Memoir 178.
1936: The Mining Industry of Yukon, 1935; Geol. Surv., Canada, Memoir 193.
1937: The Mining Industry of Yukon, 1936; Geol. Surv., Canada, Memoir 209.
1938: The Mining Industry of Yukon, 1937; Geol. Surv., Canada, Memoir 218.
1939: The Mining Industry of Yukon, 1938; Geol. Surv., Canada, Memoir 220.
1941: The Mining Industry of Yukon, 1939 and 1940; Geol. Surv., Canada, Memoir 234.
1943: Preliminary Map Upper McQuesten River, Yukon; Geol. Surv., Canada, Paper 43-9.
1947: Mayo, Yukon Territory; Geol. Surv., Canada, Map 890A.
1948: Mayo District, Yukon; In Structural Geology of Canadian Ore Deposits; A Symposium arranged by a Committee of the Geology Division, Canadian Institute of Mining and Metallurgy, pp. 110-112.
1948: Physiography of the Canadian Cordillera, with special reference to the Area North of the Fifty-fifth Parallel; Geol. Surv., Canada, Memoir 247.
1953: Potential Mineral Resources of Yukon Territory; Geol. Surv., Canada, Paper 50-14.

Boyle, R.W.
1955: Geochemical Prospecting in the Yukon; Can. Min. J., Vol. 76, No. 6, pp. 51-55.
1956: The Geology and Geochemistry of the Silver-Lead-Zinc Deposits of Keno Hill and Sourdough Hill, Yukon Territory; Geol. Surv., Canada, Paper 55-30.

Boyle, R. W., Illsley, C. T., and Green, R. N.
1954: A Geochemical Investigation of the Heavy Metal Content of the Streams in the Keno Hill-Galena Hill Area, Yukon Territory; Geol. Surv., Canada, Paper 54-18.
1955: Geochemical Investigation of the Heavy Metal Content of Stream and Spring Waters in the Keno Hill-Galena Hill Area, Yukon Territory; Geol. Surv., Canada, Bull. 32.

Boyle, R. W., Pekar, E. L., and Patterson, P. R.
1955: Geochemical Investigation of the Heavy Metal Content of the Streams and Springs in the Galena Hill-Mount Haldane Area, Yukon Territory; Geol. Surv., Canada, Bull. 36.

Boyle, R. W., and Cragg, C. B.
1957: Soil Analyses as a Method of Geochemical Prospecting in the Keno Hill-Galena Hill Area, Yukon Territory; Geol. Surv., Canada, Bull. 39. (In press.)

Cairnes, D. D.
1916: Mayo Area; Geol. Surv., Canada, Sum. Rept. 1915, pp. 10-34.

Cockfield, W. E.
1919: Mayo Area, Yukon; Geol. Surv., Canada, Sum. Rept. 1918, pt. B, pp. 1B-15B.
1921: Silver-lead Deposits of the Keno Hill Area, Mayo, Yukon; Geol. Surv., Canada, Sum. Rept. 1920, pt. A, pp. 1A-6A.
1922: Silver-lead Deposits of Davidson Mountains, Mayo District, Yukon; Geol. Surv., Canada, Sum. Rept. 1921, pt. A, pp. 1A-6A.
1924: Geology and Ore Deposits of Keno Hill, Mayo District, Yukon; Geol. Surv., Canada, Sum. Rept. 1923, pt. A, pp. 1A-21A.
1924: Silver-Lead Deposits of Beaver River Area, Yukon; Geol. Surv., Canada, Sum. Rept. 1923, pt. A, pp. 22A-28A.
1930: The Mining Industry of Yukon, 1929; Geol. Surv., Canada, Sum. Rept. 1929, pt. A, pp. 1A-15A.
1931: The Mining Industry in Yukon and parts of Northern British Columbia in 1930; Geol. Surv., Canada, Sum. Rept. 1930, pt. A, pp. 1A-16A.

Godfrey, J.D.
1954: The Origin of Ptygmatic Structures; J. Geol., vol. 62, No. 4, pp. 375-387.

Green, L.H.
1956: Mayo Lake, Yukon Territory; Geol. Surv., Canada, Prelim. Ser. Map 5-1956.

Hicks, H. Brodie
1949: The United Keno Hill Mines, Western Miner, vol. 22, No. 11, pp. 46-56.
1952: Exploration, Development, and Production Practices at United Keno Hill Mines, Limited; Can. Min. Met. Bull., vol. 45, No. 486, pp. 587-597.

Johnston, A.W. and Powelson, J.M.
1951: Development of Mayo Mining District, Mayo, Yukon Territory; Proc. Geol. Assoc. Can. vol. 4, pp. 41-48.

Keele, Joseph
1905: The Duncan Creek Mining District; Geol. Surv., Canada, Sum. Rept., 1904, pp. 18-42.

Kindle, E.D.
1955: Keno Hill, Yukon Territory (map with marginal notes); Geol. Surv., Canada, Paper 55-12.

McTaggart, K.C.
1950: Keno and Galena Hills, Yukon Territory (Preliminary Maps); Geol. Surv., Canada, Paper 50-20.

Smitheringale, W.V.
1950: Geology of the Keno Hill Area; Western Miner, vol. 23, No. 6, pp. 43-46.

The Staff - United Keno Hill Mines Limited
1949: United Keno Hill; Western Miner, vol. 22, No. 1, pp. 37-40.

Stockwell, C.H.
1926: Galena Hill, Mayo District, Yukon; Geol. Surv., Canada, Sum. Rept., 1925, pt. A, pp. 1A-14A.

Traill, R.J., and Boyle, R.W.
1955: Hawleyite, Isometric Cadmium Sulphide, A New Mineral; Amer. Mineral, vol. 40, pp. 555-559.

Visel, C.E.
Undated: Private report to American Smelting and Refining Corporation and now in the Geological files of United Keno Hill Mines, Elsa, Yukon.

Wernecke, Livingstone
1932: Glaciation, Depth of Frost, and Ice veins of Keno Hill and Vicinity, Yukon Territory; Eng. Min. J., vol. 133, pp. 38-43.

__________ Annual reports of Manager on operations of the Treadwell Yukon Company Limited. These reports are now in the geological files of United Keno Hill Mines, Elsa, Yukon.

Williams, C.F.
1922: The Mayo District Yukon; Eng. Min. J. Press; vol. 113, No. 24, pp. 1039-1046.