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AND TECHNICAL SURVEYS

BULLETIN 111

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

(With short descriptions of the tin, tungsten,
and gold deposits)

R. W. Boyle

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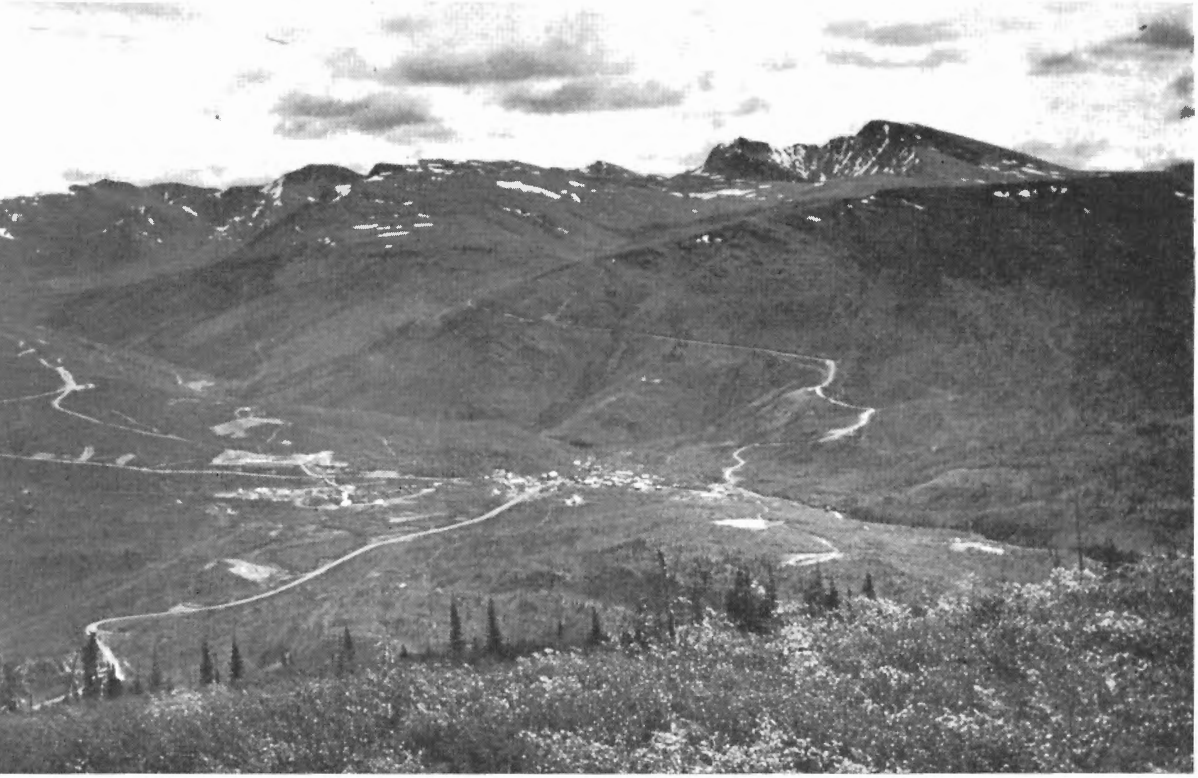

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PLATE I. The village of Keno Hill with Sourdough Hill and Bunker Hill in the background, looking northeast from Galena Hill.

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PREFACE

The lead-zinc-silver deposits of the Keno Hill-Galena Hill area were discovered in 1913 and since that time have produced a significant proportion of Canada's lead, zinc, silver, and cadmium.

The author describes the geology of these deposits and presents the results of detailed geochemical studies of the soils, waters, country rocks, and ores. He concludes that the hypogene deposits were formed by the diffusion of ore and gangue elements from the country rocks.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, June 18, 1962

Bulletin 111—Geologie, Geochemie und Ursprung der Blei-Zink-Silbervorkommen im Gebiete von Keno Hill und Galena Hill im Yukon-territorium.

Von R. W. Boyle

Verzeichnis der Elemente und Mineralien der verschiedenen Erze und angrenzenden Gesteine und Abriss der geochemischen Geschichte der Vorkommen.

Бюллетень 111 — Геология, геохимия и происхождение залежей свинца, цинка и серебра в районе Кено-Галена Хилл территории Юкон.

Р. У. Бойл

Дается элементарный и минералогический состав различных руд и смежных пород; прослеживается история геохимии рудных залежей.

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

Abstract

The sedimentary rocks underlying the Keno Hill-Galena Hill area belong to the Yukon Group and are probably of Precambrian or Palaeozoic age. They consist of graphitic and sericitic schists, phyllites, thick- and thin-bedded quartzites, argillites, and a few limestone lenses. The sedimentary rocks have been divided into three formations: a lower schist, a central quartzite, and an upper schist. The rocks in the three formations dip southeast and form the southern limb of a large open anticline.

Conformable lenses and sills of greenstone occur in the lower schist and central quartzite formations, and a few quartz-feldspar porphyry sills are present locally in all three formations. Granitic stocks of Mesozoic age outcrop northwest and southeast of the main mineral belt.

Two principal fault systems occur in the area: a northeast-striking system of vein faults which, together with numerous subsidiaries, contains all the orebodies, and a north-northeast to northwest-trending series of faults which cuts the orebodies and are barren.

The most favourable host rocks for the occurrence of lodes and veins are thick-bedded quartzites and greenstones. Structurally the principal lodes are localized in three sites (1) at the junction of two or more vein faults, (2) at the junction of a vein fault and subsidiary fracture, and (3) in quartzites or greenstones at or near the sites where vein faults pass upward from these rocks into schists or thin-bedded quartzites. Considered physico-chemically these three sites were dilatant zones into which the constituents of the ore and gangue minerals were drawn.

Six types of mineral deposits are represented in the area (1) cassiterite-tourmaline impregnation zones, (2) scheelite skarn lenses, (3) quartz-wolframite stringers in granites and sediments, (4) quartz-pyrite-arsenopyrite-gold lenses in vein faults, (5) siderite-galena-sphalerite-freibergite-pyrite-chalcopyrite lodes in vein faults, and (6) gold and scheelite placers. The siderite lodes and gold placers constitute the economic deposits of the area, yielding silver, lead, zinc, cadmium, and gold.

The siderite and quartz lodes are oxidized to depths ranging from 20 to 600 feet. In the oxidized zones the primary pyrite and siderite are altered to limonite and wad, arsenopyrite to limonite and scorodite, sphalerite to limonite and wad, galena to anglesite and cerussite, chalcopyrite to limonite, azurite, and malachite, and freibergite, boulangerite, and jamesonite to bindheimite, beudantite, malachite, native silver, and other secondary minerals. Oxidation of the siderite lodes has led to a marked enrichment of lead and silver and a strong depletion of zinc and cadmium.

In some siderite lodes the oxidation zones grade through a zone of reduction ranging from 2 to 20 feet in depth; in others the oxidation zones grade imperceptibly into the hypogene zones. The principal economic minerals formed in the zones of reduction are pyrargyrite and native silver.

Chemical evidence shows that the greenstones and sediments, especially the graphitic schists and quartzites, are adequate sources for the hypogene ore and gangue elements. It is suggested that all the deposits were formed by diffusion, and that the ore and gangue elements came from the country rocks. The diffusion of the various constituents was promoted by and was an integral part of the geological and physico-chemical events of regional metamorphism, granitic intrusion, and dilatancy of vein faults.

Résumé

Les roches sédimentaires de la région de Keno Hill-Galena Hill appartiennent au groupe Yukon; elles datent probablement du Précambrien ou du Paléozoïque. Elles se composent de schistes graphiteux et sériciteux, de phyllades, de quartzites en lits épais et minces, d'argilites et de quelques lentilles de calcaire. On les a divisées en trois formations: la formation schisteuse inférieure, la formation quartzitique intermédiaire et la formation schisteuse supérieure. Toutes ces roches ont un pendage vers le sud-est et forment le flanc sud d'un grand anticlinal évasé.

Dans la formation schisteuse inférieure et la formation intermédiaire, il y a des sills et des lentilles concordantes de roches vertes. Dans les trois formations, il y a çà et là quelques sills de porphyre à feldspath et quartz. Des stocks de granite mésozoïque affleurent au nord-ouest et au sud-est de la zone principale de minéralisation.

La région contient deux principaux faisceaux de failles: un faisceau de failles minéralisées à direction nord-est qui, avec ses nombreuses ramifications, contient tous les gîtes, et un faisceau de failles stériles à direction nord—nord-est—nord-ouest, qui coupent les gîtes.

Les roches hôtes les plus favorables à la présence de filons et de veines sont des quartzites en lits épais et des roches vertes. Du point de vue tectonique, les principaux filons sont localisés en trois endroits: 1) au point de rencontre de deux ou plusieurs failles minéralisées; 2) au point de jonction d'une faille minéralisée et d'une fracture subsidiaire; 3) dans les quartzites ou les roches vertes et aux, ou près des, endroits où les failles minéralisées passent peu à peu, vers le haut de ces roches, à des schistes ou à des quartzites en lits minces. Du point de vue physico-chimique, ces trois endroits sont considérés comme appartenant à des zones de dilatation où les minéraux du minerai et ceux de la gangue ont été attirés.

Six genres de gîtes de minéraux sont représentés dans la région: 1) des zones d'imprégnation de tourmaline-cassitérite; 2) des lentilles de skarn à scheelite; 3) des filonets de wolfram-quartz dans des granites et des sédiments; 4) des lentilles d'or-arsénopyrite-pyrite-quartz dans des failles minéralisées; 5) des filons de chalcopyrite-pyrite-freibergite-blende-galène-sidérose dans des failles minéralisées, et 6) des placers d'or et de scheelite. Les filons de sidérose et les placers aurifères constituent les gisements rentables de la région et renferment de l'argent, du plomb, du zinc, du cadmium et de l'or.

Les filons de sidérose et de quartz sont oxydés jusqu'à des profondeurs de 20 à 600 pieds. Dans les zones oxydées, la pyrite et la sidérose sont altérées en limonite et en wad, l'arsénopyrite en limonite et en scorodite, la blende en limonite et en wad, la galène en anglésite et en cérusite, la chalcopyrite en limonite, en azurite et en malachite, et la freibergite, la boulangérite et la jamesonite en bindheimite, en beudantite, en malachite, en argent natif et en d'autres minéraux secondaires. L'oxydation des filons de sidérose a augmenté sensiblement la teneur en plomb et en argent, mais a diminué fortement la teneur en zinc et en cadmium.

Les zones d'oxydation de certains filons de sidérose passent en profondeur à une zone de réduction de 2 à 20 pieds d'épaisseur; dans d'autres filons il y a passage insensible des zones d'oxydation aux zones hypogènes. Les principaux minéraux de valeur des zones de réduction sont la pyrargyrite et l'argent natif.

La chimie indique que les roches vertes et les roches sédimentaires, surtout les schistes graphiteux et les quartzites, constituent une source suffisante pour la formation du minerai hypogène et des minéraux de la gangue. D'après l'auteur, tous les gîtes auraient été formés par diffusion, et les éléments des minéraux de minerai et de la gangue proviendraient des roches encaissantes. La diffusion des différents composants aurait été favorisée, tout en faisant partie intégrante, par la succession des événements géologiques et physico-chimiques du métamorphisme régional, par l'intrusion granitique et par la dilatabilité des failles minéralisées.

Chapter I

INTRODUCTION

This report describes and discusses the detailed geology, mineralogy, geochemistry, and origin of the lead-zinc-silver-cadmium, tin-tungsten, and gold deposits of the Keno Hill-Galena Hill area. It is based on field work carried out during 1953, 1954, and 1955, and on laboratory work done during the period 1953-60.

According to Keele (1905),[1] the earliest record of prospecting in the Keno Hill area is mentioned by Ogilvie in his report on the Yukon (Ogilvie, 1890). In the autumn of 1887 Ogilvie met Alexander McDonald, a miner, who had spent the summer of that year prospecting and exploring on Stewart River and some of its tributaries. McDonald ascended Mayo River to Mayo Lake, thence up Duncan and Lightning Creeks to Keno Ladue River, down which he floated on a raft for two days. Finding this river flowing in a northeasterly direction and not south towards the main branch of the Stewart as he expected, he abandoned the raft and returned to the Mayo Lake area. After prospecting for a time in Gustavus Range, he crossed to McQuesten River and drifted down that river to Stewart River. McDonald named Mayo Lake and the river that drained it after Frank Mayo, one of the partners in the firm of Harper, McQuesten, and Company.

In the summer of 1898 many hundreds of prospectors made their way up Stewart River in search of gold placers, reported as early as 1894 to exist in the tributaries and bars of this river. This wave of prospecting led to the discovery during the period 1898–1903 of payable gold placers on Duncan Creek, Haggart Creek, Minto Creek, Highet Creek, and on the small creeks flowing into Mayo Lake. Production of placer gold from various creeks in the district has continued intermittently since that time.

As the placer miners spread farther afield the lode gold deposits of Dublin Gulch and elsewhere drew their attention, and these were explored, mainly during the years 1906-15. No production is known to have come from these deposits because most are too low grade for profitable exploitation.

In addition to the lode gold deposits interest also turned to the silver-lead veins of the area. The first discovery of one of these veins was on Galena Creek, the site of the present Silver King veins, and was made by H. W. McWhorter about the year 1906. It was not until 1913, however, that McWhorter and others commenced development of the Galena Creek vein, and in the following 6 years a small tonnage of high grade silver-lead ore was removed and shipped.

With the development of the silver-rich Galena Creek vein interest spread to Keno Hill where a discovery of galena carrying large amounts of silver was made by Louis Beauvette in July 1919. Following this a stampede to the hill took place and hundreds of claims were staked, covering numerous mineral prospects.

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[1] Dates in parentheses refer to the *Bibliography*, page 228.

The original discovery of Beauvette (now the No. 9 system of veins) near the summit of Keno Hill, as well as several other claims, were optioned and later purchased by the Yukon Gold Company, which began extensive development work in the winter of 1919-20. In 1920, a subsidiary company, Keno Hill, Limited, was formed to operate the original group and other holdings of the Yukon Gold Company. The first shipments of high grade lead-silver ore were made from Keno Hill in the winter of 1920-21.

In 1920 the Sadie-Friendship vein was located and a year later was acquired by Keno Hill, Limited. In the same year the Treadwell Yukon Company under Livingston Wernecke, geologist and later manager and a director of the company, entered the Keno Hill area, acquiring the Ladue and several other claims. During the following 20 years the Treadwell Company guided by the remarkable geological insight of Mr. Wernecke acquired several lead-silver veins on Keno and Galena Hills and developed producing mines. Chief among these were the Ladue, Sadie-Friendship, and Lucky Queen on Keno Hill, and the Hector-Calumet, Arctic and Mastiff, Elsa, and Silver King on Galena Hill. With the exception of the Hector-Calumet, all had ceased operation by the end of 1939.

Because of war conditions and the untimely death of Mr. Wernecke in a tragic aeroplane accident in Alaska, the Treadwell Yukon Company effectively suspended operations in 1941. From then on their properties remained idle until 1946 when the assets and claims of the company were sold to United Keno Hill Mines, Limited.

During the years 1949-53 mining exploration was stimulated by the finding of large lead-zinc-silver orebodies at the Hector-Calumet mine on Galena Hill by United Keno Hill Mines, Limited. Exploration spread to other parts of the area, and several ore shoots were discovered by a number of companies on Galena, Keno, and Sourdough Hills. Mackeno Mines, Limited, developed and mined ore shoots in the McLeod and subsidiary veins until 1958 when the properties and claims were sold to United Keno Hill Mines, Limited. On Keno Hill exploration by several companies succeeded in finding new ore shoots, but none of these proved to be large enough or of sufficient grade for profitable exploitation. On Sourdough Hill exploration during the same period by Bellekeno Mines, Limited, succeeded in finding two ore shoots in the Bellekeno vein system. Production of lead-silver concentrates from these shoots commenced late in 1952 and ceased in August 1954.

The Keno Hill-Galena Hill lodes are the richest silver deposits in Canada, and rank with the great silver-lead deposits of the world. These deposits up to 1960 produced more than 110 million ounces of silver, 353 million pounds of lead, 164 million pounds of zinc, and 1.8 million pounds of cadmium. In value this production amounted to more than $139 million, in addition to which about two million dollars worth of gold has been won from the placers of the area.

Despite the fact that the deposits of the Keno Hill-Galena Hill area have been known and exploited since the turn of the century, the mineralized belt is far from being exhausted. It will long remain one of Canada's principal sources of silver, as well as of lead, zinc, cadmium, and some gold and tungsten.

Scope of Research

The research on the deposits in the area consisted of both field and laboratory studies.

The field work consisted principally of mapping the rocks on Sourdough, Keno, and Galena Hills, tracing and examining all vein faults on the surface and in the accessible underground workings, and determining where possible the structural factors that controlled the localization of ore shoots. Limited mapping and an examination of deposits were also carried out on Mount Haldane and in the Dublin Gulch area.

During field work, samples of all rocks, soils, glacial materials, and underground waters were systematically collected for detailed geochemical work. In addition samples of all types of ores were collected for mineralogical and geochemical studies, and the alteration zones adjacent to the siderite lodes were sampled in all mines for thin-section work and chemical analysis.

During the 1954 and 1955 field seasons, a complete geochemical laboratory was operated in the field where geochemical studies of the surface and underground waters, soils, and glacial materials were carried out in detail.

In Ottawa the laboratory work consisted of thin- and polished-section studies of all rocks and ores, chemical and spectrographic analyses for both major and minor elements of soils, glacial deposits, rocks, ores and their oxidized equivalents, and X-ray determinations of the complex minerals.

Location

The Galena Hill-Keno Hill area 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 scheduled flights from Whitehorse and Dawson. The three villages, Keno Hill, Elsa, and Calumet, and the Galkeno mine, can be reached by an all-weather road from Mayo.

Topography, Glacial and Frost Action, and Climate

The principal mineral deposits occur on three adjacent hills, Galena, Keno, and Sourdough (*see* Map 1147A); smaller deposits occur on Mount Haldane and in the Dublin Gulch area. The mineralized belt as a whole lies within the northeastern part of the Yukon Plateau (Bostock, 1948), and the terrain is mountainous (Pls. I and II) with elevations ranging from 6,750 feet (Mount Hinton) to 2,300 feet (Keno Ladue-McQuesten River valley).

Mount Haldane (Pl. III) is one of the prominent features. It rises to an elevation of 6,032 feet and is flanked on the north by the McQuesten River valley, on the east by Haldane Creek, and on the southwest by Ross and Black Creeks. The slopes of the mountain are steep and are traversed by numerous gulches that cut deeply into the rock strata. Below an elevation of 4,500 feet the slopes are covered with thick deposits of soil, till, and muck, which sustain a good growth of timber. Above this elevation the slopes are covered with thin soils and rock debris which support scrub trees and alpine vegetation.

PLATE II
The Gustavus Range, looking southeast from Galena Hill.

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The Dublin Gulch area is dominated by the Potato Hills, Lynx Dome, and Haggart Dome. These features have elevations ranging from 4,900 to 5,050 feet. Conditions of vegetation are as described for Mount Haldane.

Galena Hill trends northeast between Duncan Creek and the McQuesten River valley. It has an elevation of 4,740 feet, 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 (Pl. IV). The north, northwestern, and southeastern slopes of the hill are crossed by several streams that have cut steep gulches into the rock strata. The principal streams responsible for these gulches are Galena, Flat, Brefalt, and Sandy Creeks and Porcupine Gulch on the northwestern slope and Hinton and Fisher Creeks on the eastern and southeastern slopes.

Keno Hill and Sourdough Hill are adjacent hills separated by Lightning Creek. Keno Hill trends northeast and lies between the Keno Ladue-McQuesten River valley and Allen, Faith, Lightning, and Christal Creeks. The hill has relatively gentle southern and southeastern slopes and a precipitous northern slope, marked by two cirques, Faro Gulch and Silver Basin Gulch. The terrain above 4,500 feet is relatively flat and rolling with five prominent rocky knolls known as Keno, Minto (Pl. V), Monument (the highest point on Keno Hill, elevation 6,065 feet), Caribou, and Beauvette. On the slopes of the hill several streams follow steep gulches in the rock strata, the principal ones being Gambler, Faro, McKay, and Silver Basin on the northern slope, Faith, Hope, and Charity on the northeastern and southern slopes, and Erickson on the western slope.

Sourdough Hill (Pl. VI) lies southwest of Keno Hill and trends north between Thunder, Lightning, and Duncan Creeks. The part of the hill described in this report is on the northern and northwestern slopes, which are gentle up to 4,200 feet and from there rise abruptly to a steep rocky hogsback that trends southwest for some 6,000 feet.

Extensive rock outcrops are uncommon on Galena, Keno, and Sourdough Hills, and with the exception of the gulches and cirques where relatively good geological sections are present, detailed mapping can only be done by observing float. Below an elevation of 4,400 feet rock outcrops are sparse, and the slopes are covered with till,

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PLATE III

The village of Elsa with Mount Haldane in the background, looking southwest from Galena Hill.

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PLATE IV

Flat, rolling topography, Galena Hill

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PLATE V

Greenstone knob, Minto Hill, east of Keno Summit.

RWB, 1-7-54

PLATE VI

Sourdough Hill, view southwest from Keno Hill. The workings are those of the Bellekeno mine.

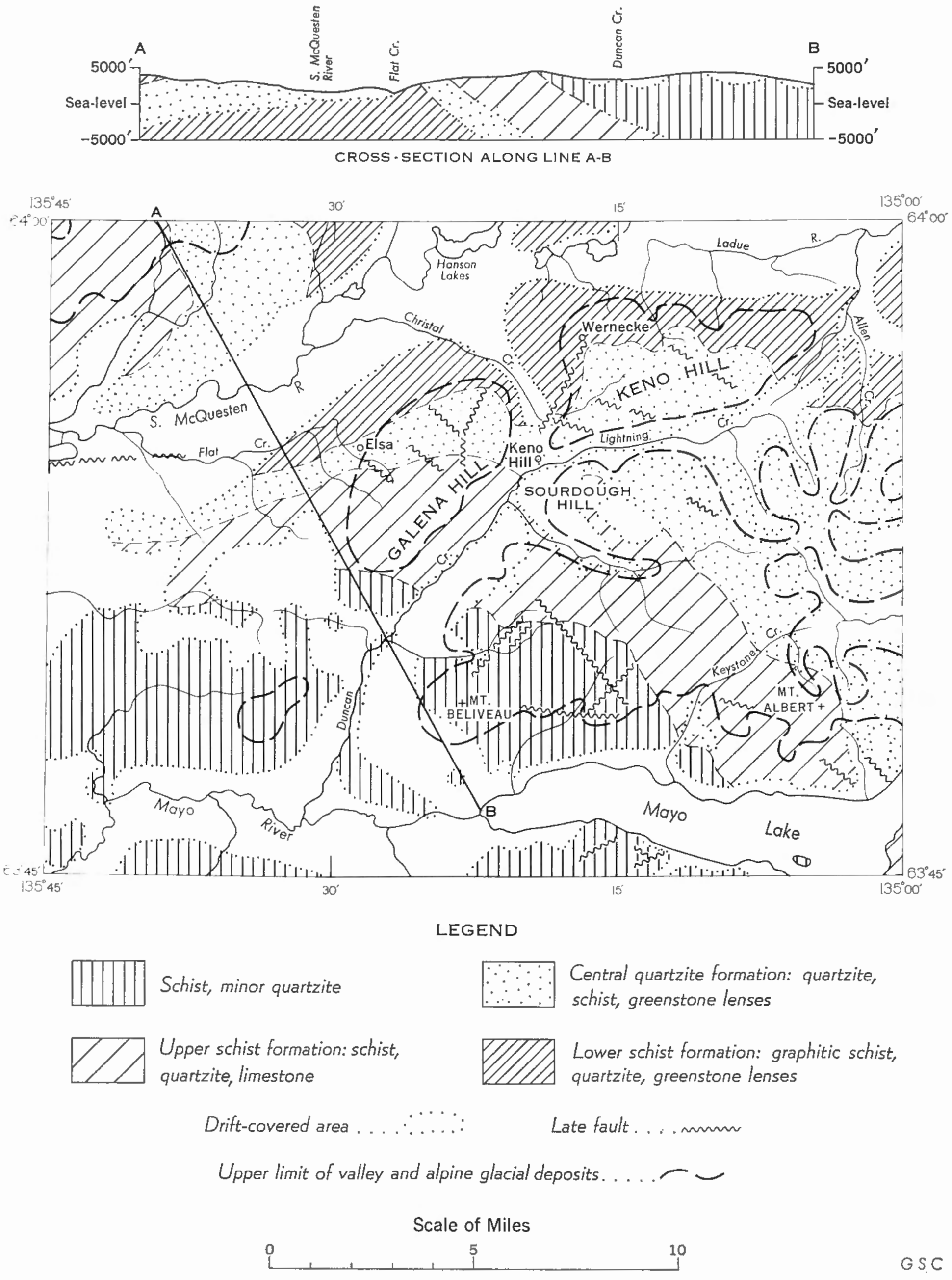

FIGURE 1. Generalized geological map and cross-section of the Keno Hill-Galena Hill area.

soil, rock debris, muck, and muskeg, in which conifers, birch, aspen, Arctic black-birch, and other vegetation grow abundantly. Above this elevation the soil is thin, outcrops are more numerous, the ground is covered with local rock float, the terrain is treeless, and the vegetation is limited to alpine species and grassy meadows.

The lower slopes of the hills were severely glaciated during Pleistocene time by ice-sheets that spread, from the east, over the entire area. Glacial till, gravel, and other debris lie in a series of benches on the slopes of the hills and floor the valleys (*see* Fig. 1). The deposits are generally 5 to 20 feet thick, but in some areas as on the southern slope of Keno Hill facing Lightning Creek and north of Christal Lake, they are 30 to 50 feet thick or more. Further details of the composition of the glacial deposits and soils are given in Chapters II and IV.

The Keno Hill–Galena Hill area is in the region of permanently frozen ground. Wernecke (1932) has given an interesting account of the permafrost conditions, and the present investigation has added further data. The permafrost is irregularly distributed and its occurrence is dependent upon the elevation, hillside exposure, depth of overburden, amount of vegetative cover, and presence of flowing underground and surface water. At high elevations and on slopes with a northern exposure it is generally present. Thus, on Keno Hill, the mine workings on the top of the hill and on the northern slope encountered permafrost some 400 feet below the surface. On the northern slopes of Sourdough Hill and Galena Hill a similar situation prevails, and frost and ice lenses have been encountered at depths of 250 feet or more in the mine workings. On the lower southern slope of Keno Hill, however, the workings of the Onek and Mount Keno mines show little evidence of permafrost. In places where surface and underground water are flowing the permafrost has been thawed out and frost-free windows and strips are present. These provide access and egress for waters that are oxidizing the lodes.

The effects of frost action, soil creep, and slope wash are marked on the hills, particularly at the higher elevations. Frost action is responsible for features such as stone rings and stripes, and produces a general 'boiling action' that brings rock float, mineralized float, and soil from deeper layers to the surface, thus facilitating the mapping of both the underlying bedrock and the tracing of vein faults. On steep slopes, however, frost action and land creep have transported float downhill in places, 100 feet or more, making the accurate mapping of contacts and vein faults difficult.

The climate of 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[1]. Temperatures as low as −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 Keno Hill area during the spring and summer 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 late August.

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[1] Data, courtesy Dominion Meteorological Service, Department of Transport, Ottawa, Canada.

Acknowledgments

The writer wishes to extend his thanks to numerous individuals and companies who placed maps and data at his disposal and who helped in many ways during the field seasons. He wishes especially to thank C. E. White and A. C. Carmichael formerly of United Keno Hill Mines, Limited; A. Pike, A. H. Manifold, and M. White now with that company; G. Campbell and W. R. McQuarrie formerly of Galkeno Mines, Limited; J. J. Hogan and J. D. Godfrey formerly of Mount Keno Mines, Limited; W. S. Ellis formerly in charge of exploration for Comstock Keno Mines, Limited; and J. Walli of Klondyke-Keno Mines, Limited.

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The geological maps of Keno and Galena Hills compiled by McTaggart (1950) were used as a guide throughout the investigation. These maps assisted and speeded the field work immeasurably.

The writer had access to the lucid and informative annual reports written by the late Livingston Wernecke for the Treadwell Yukon Company, Limited, former operators of the Hector-Calumet, Elsa, Silver King, Ladue-Sadie Friendship, Lucky Queen, and other 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.

Chapter II

GENERAL GEOLOGY

Summary of Geological Features

The general geology of the Mayo district, of which the Keno Hill-Galena Hill area is a part, was described first by Keele in 1906 and later by Cairnes (1916) and Bostock (1947). The geology of Keno Hill was described by Cockfield in 1920 and 1923, and that of Galena Hill by Stockwell in 1925. More recently McTaggart (1950, 1960) published detailed geological maps of both Keno and Galena Hills, and Kindle (1955, 1962) provided a description of the geology of the area comprising Mayo Lake, Galena Hill, and Keno Hill. Other geological investigations of the area may be found in the present writer's preliminary papers (1956, 1957b), in the compilation by Bostock (1957), and in the recent report by McTaggart (1960).

The consolidated rocks (Map 1147A, Fig. 2, and Table of Formations) underlying the Keno Hill-Galena Hill area are mainly sedimentary and include various types of argillites, phyllites, slates, schists, and quartzites of Precambrian or early Palaeozoic age (Yukon Group)[1]. Conformable greenstone lenses and sills, probably of Cretaceous age, occur in profusion in places in the sedimentary strata, and a few narrow lamprophyre and quartz-feldspar porphyry sills (probably Cretaceous or younger) are present locally. Granitic masses cut the sedimentary rocks and greenstones at several places; east and northeast of Mayo Lake, northwest of Hanson Lake, and south and east of Dublin Gulch. Near these granitic masses, characteristic skarn zones are developed in the calcareous rocks of the sedimentary sequence. The age of the granitic rocks is uncertain; it is generally assumed that they are Cretaceous.

On Keno and Galena Hills the sedimentary rocks dip gently south and are cut by early and late brecciated fault zones. Most of the early faults strike northeast, generally dip steeply southeast, and contain the lead-zinc-silver lodes. Most of the late faults strike northwest, dip southwest, and offset the early faults and the lodes. The age of the faults is uncertain, but as they cut the quartz-feldspar porphyry dykes and sills, they are probably Cretaceous or younger.

Soils and Glacial Deposits

The soils in the Galena Hill-Keno Hill area fall into two general types: (1) residual soils, and (2) muck, peat, and half-bogs. Over much of the area the soils and glacial deposits are permanently frozen below the top few inches.

The residual soils were developed mainly from the bedrocks on which they lie but in places they may be decomposed remnants of an old till. They occur mainly above the 4,000-foot contour, and have poorly developed profiles which are greatly disturbed by

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[1] When this report was prepared the rocks in the Yukon Group were thought to be of Precambrian and/or Palaeozoic age. Later work by Green and Roddick (1962), however, suggests that the sequence is greatly interrupted by thrust faults and that some of the rocks may be late Palaeozoic or early Mesozoic.

frost action. The muck, peat, and half-bogs are developed extensively on the north slopes of the hills and on low-lying poorly drained ground. Their profile development is poor or absent.

The glacial deposits, as shown on Figure 1, floor the principal valleys and form benches on the lower slopes of the hills. They range in thickness from a few feet to 50 feet or more and consist mainly of till, glacio-fluvial deposits, glacio-lacustrine gravel, sand and silt, and a few layers of peat.

A more detailed description of the soils and glacial deposits, their geochemistry, and the part they play in the fixation of various metallic elements during exogene (weathering) processes is given in Chapter IV.

Rock Types

Figure 2 shows the distribution of the various rock types on Galena, Keno, and Sourdough Hills, and Map 1147A gives the general distribution of those within the district.

The geological maps of Galena, Keno, and Sourdough Hills were compiled during a detailed investigation of the deposits. As it was difficult to portray on these maps all outcrop and float areas, the writer has grouped many small closely adjacent outcrops, and has assumed that in other areas float overlies outcrops. Bulldozing and trenching in recent years have shown that these assumptions can be made with some confidence on and near the tops of the hills. Most contacts were located by observing rock float, and although the position of these contacts was mapped with great care, errors of 100 feet or more may exist in places.

The descriptions that follow are concerned mainly with the rocks on Galena, Keno, and Sourdough Hills. Brief descriptions are given of the rocks in adjacent areas, as some of these have a bearing on the ore-forming processes.

The principal sedimentary rocks in the area are quartzites, phyllites, slates, schists, argillites, and limestones. The intrusive rocks comprise meta-gabbro, meta-diorite, and meta-diabase (greenstones), quartz-feldspar porphyry, granite, granodiorite, diorite, syenite, and a few dykes of biotite lamprophyre.

Most of the sediments and greenstones fall into the low-grade greenschist or sericite facies. Next to granitic masses, skarn and hornfels are developed.

Chemical analyses of the principal rock types and a discussion of their geochemistry are given in Chapter IV.

Argillites, Phyllites, Slates, and Schists

Of this group of rocks, schists are the most abundant, followed by phyllites and argillites; slates have a limited local occurrence.

The *argillites* occur in beds ranging in thickness from a few inches to 10 feet or more and are generally interbedded with the various types of schists, phyllites, and quartzites. All varieties of argillite exhibit a poorly developed cleavage approximately parallel with the bedding. In many occurrences they are crumpled, fractured, or crushed and contain numerous carbonate and quartz stringers.

Table of Formations

Era	Period or Epoch	Group	Formation (Keno, Galena, and Sourdough Hills only)	Lithology
Cenozoic	Pleistocene and Recent			Soils, half-bog soils, muck, peat, glacial till, sand, and gravel; rock float and talus
Mesozoic	Cretaceous (?)			Quartz-feldspar porphyry, biotite lamprophyre, granodiorite, granite, diorite, syenite. The age relationships of the porphyry, lamprophyre, and granitic rocks are uncertain
	Intrusive and granitized contact			
	Cretaceous (?)			Meta-gabbro, meta-diorite, meta-diabase (greenstone)
Precambrian or Palaeozoic	Intrusive contact			
		Yukon Group		Pebbly quartzite, phyllitic quartzite, slate; minor limestone
				Slate, schist, pebbly quartzite; minor limestone
				Pebbly quartzite, quartz-mica schist, slate; minor limestone
				Quartz-mica schist, pebbly quartzite; minor limestone
			Upper schist formation	Quartz-mica schist, quartzite, graphitic schist; minor limestone
			Central quartzite formation	Thick-bedded quartzite, thin-bedded quartzite, phyllite, argillite, slate, graphitic schist, calcareous quartzite, calcareous schist
			Lower schist formation	Graphitic schist, argillite, thin-bedded quartzite, calcareous schist, phyllite, slate, sericite schist; minor thick-bedded quartzite

In hand specimens most argillites are grey, but some are dense black and contain much carbonaceous matter and pyrite.

In thin sections the grey argillites are seen to contain white mica (sericite) and/or brown mica (biotite), microcrystalline quartz and leucoxene, chlorite, isotropic colloidal material, and pyrite. Some contain a little carbonate. Accessory minerals are tourmaline, zircon, and rutile. The texture is commonly banded, with layers containing essentially sericite, leucoxene, and a little quartz alternating with layers containing quartz, carbonate, and subordinate sericite and/or biotite. In most sections the small irregular masses of pyrite are strung out along particular bands.

The black argillites are composed mainly of layers of carbonaceous material containing much fine-grained pyrite and minor amounts of carbonate minerals, quartz, and sericite. These generally alternate with layers containing quartz, sericite, carbonate minerals, some carbonaceous material, and a little pyrite.

Mineralogically, the *phyllites* are essentially the same as the argillites. They are, however, a little coarser grained and exhibit a silky sheen on cleavage surfaces. Most are greyish or buff; some are black and contain much carbonaceous material and pyrite. In the field many of the phyllites are warped, dragged, or crushed, and such rocks generally contain numerous stringers of quartz and carbonate. Boudins of quartz may also occur in these rocks but are rarely as abundant as in the schists.

The *slates* generally occur in highly disturbed zones, particularly on the noses of small folds. In most occurrences the slaty cleavage is not well developed. Mineralogically, the slates are similar to the argillites and phyllites.

There is little evidence of residual clastic grains in any of the argillites, slates, and phyllites. Most of these rocks are also remarkably devoid of original sedimentary features such as grain gradation, crossbedding, concretions, etc. Some argillites and phyllites, however, exhibit a fine bedding lamination.

The varieties of *schist* found in the area include graphitic schist, quartz-sericite schist, and chlorite schist. All are highly foliated and locally exhibit wrinkle lineations, many small drag-folds, and innumerable crenulations. Most contain an abundance of stringers, irregular masses, and bulbous lenses (boudins) of white quartz in small fractures, between schist layers, in dragged and crenulated zones, and along bedding planes.

The graphitic schists weather easily to a crumbly mass of small black schistose fragments and hence only rarely form good outcrops. In drill-cores and underground exposures they occur in beds ranging from a fraction of an inch to a few feet in thickness and are everywhere intercalated with phyllites, slates, or thin- and thick-bedded quartzites. In hand specimens they are black or greyish black, and exhibit well-developed schist planes that possess a dull to bright sheen when wet.

Under the microscope the principal mineral constituents are dense opaque carbonaceous matter (graphite), quartz, sericite, carbonate minerals, feldspar, chlorite, isotropic colloidal material, and numerous metacrysts of pyrite. The accessory minerals, where identifiable, are tourmaline, rutile, and zircon. The texture is schistose with interlaced laminae, strands, and wisps of graphite and sericite enclosing elongated micro-lenses containing quartz, carbonate minerals, sericite, and minor feldspar.

The pyrite metacrysts, mostly cubes or distorted cubes, tend to be concentrated in the quartz micro-lenses or in the wavy and crumpled zones of the graphite laminae. In some sections microcrystalline pyrite is strung out along the graphitic laminae. Micro-boudins of quartz, many containing a cube of pyrite, are common in nearly all sections.

The quartz-sericite schists also weather easily and form few prominent outcrops. All occurrences exhibit a marked schistosity and where dragged, crenulated, or crushed contain numerous stringers, masses, and boudins of white quartz. In hand specimens they are greenish or mottled greenish yellow, and have a silvery lustre when wet.

In thin sections the quartz-sericite schists are seen to consist essentially of quartz and sericite with subordinate amounts of carbonate minerals and leucoxene. The leucoxene consists of a felted aggregate of rutile needles and is invariably concentrated in swirling masses in the laminae of sericite. The main accessories are apatite, zircon, and tourmaline, and a few pyrite metacrysts are also present in most sections. The texture is schistose with laminae, shreds, and wisps of sericite and leucoxene enclosing irregular elongated lenses and bands composed principally of quartz with some shreds of sericite and a few cubes of pyrite.

Quartzites

Quartzites occur throughout the sedimentary sequence, but tend to be concentrated in well-defined bands in the various formations. Both thick- and thin-bedded varieties are present. The thick-bedded variety comprises beds ranging from 3 to 25 feet in thickness; thin-bedded varieties occur in beds from an inch to a foot or more thick. Both varieties are interbedded with assemblages of schist, argillite, and phyllite. All thick-bedded quartzites are well jointed and yield large blocks during weathering and frost action. The thin-bedded varieties are generally contorted, warped, and locally drag-folded (Pl. VII). Stringers, irregular veinlets, and small lenses of quartz are abundant in both varieties (Pl. VIII).

In hand specimens the fresh quartzites are white to grey to black, and have a gneissoid to schistose appearance. Some are very fine grained and resemble recrystallized cherts. On weathered surfaces most of the quartzites are buff, but others are grey or white.

Thin sections show that the quartzites consist essentially of quartz, with minor amounts of white mica (sericite) and, locally, carbonate minerals. Calcareous varieties contain up to 30 per cent carbonate minerals. The black quartzites contain much carbonaceous material. Accessory minerals in all varieties include irregular patches and specks of leucoxene, tourmaline, zircon, apatite, and pyrite. The pyrite occurs mainly as cubes, distorted cubes, and crystal groups.

Most of the quartzites are fine grained, the cherty variety being very fine grained. Typical specimens have a gneissoid to schistose mosaic texture with the quartz grains showing a pronounced elongation. Most of the sericite flakes and wisps and the carbonaceous material occur at the border of the quartz grains, and both exhibit parallelism. Some varieties of white quartzite are banded, with relatively pure quartz laminae alternating with laminae of quartz and sericite or quartz, sericite, and carbonate minerals.

RWB, 5-5-55

PLATE VII. Drag-folded quartzites, Galena Creek, near Silver King mine.

RWB, 3-8-55

PLATE VIII
Stringers and small lenses of white quartz in quartzite.

Some of the quartzites exhibit crossbedding, bedding laminations, and other original depositional features, and a few show faint overgrowths of silica on the quartz grains. These were undoubtedly originally fine-grained orthoquartzites. Other quartzites, especially the nearly pure white cherty varieties as well as some fine-grained grey varieties, exhibit no observable original clastic features but have a banding similar to certain recrystallized cherts. These appear to have originated mainly by the precipitation of silica from the water of the basin in which they were laid down, a conclusion that is amplified in Chapter IV.

Limestones

Limestones are relatively rare in any of the formations. They occur principally in irregular layers, lenses, and boudins in the upper schist formation, and a few beds up to a foot or more thick are interbedded with quartzites in the central quartzite formation. Most limestone beds and lenses are highly contorted and fractured and are in places seamed by numerous ramifying veinlets and irregular lenses of later white to buff carbonates.

In hand specimens the fresh limestones are grey to black; some varieties are banded with greyish layers alternating with irregular lens-like layers of white to buff carbonate. Some specimens exhibit a schistose appearance, due to the presence of much sericite. Most bodies weather buff, but a few, particularly the black varieties, weather either greyish or black.

Under the microscope the normal limestones are seen to contain carbonate minerals with minor amounts of quartz and sericite. Accessory minerals include leucoxene, pyrite, and limonite. Siliceous varieties contain more quartz and sericite. The grey limestones are fine grained with a slight schistose texture and are composed of relatively clear carbonate minerals. Banded and mottled varieties contain grey bands of relatively fine-grained carbonate alternating with bands containing coarser grained clear carbonate and quartz. The black limestones are nearly opaque to transmitted light. They have a microcrystalline groundmass in which is set much carbonaceous matter in wisps, bands, whorls, and irregular patches. Some black varieties have a brecciated appearance and consist of irregular fragments of dense black microcrystalline limestone intersected by patches, veinlets, and ramifying areas of relatively clear fine-grained carbonate containing some quartz.

There is no indication of any original sedimentary features such as well-marked laminae, oölites, fossils, or concretions in any of the limestone beds or lenses seen by the writer.

Skarn

Skarns are developed in the vicinity of granitic masses at several places in the area, but they are generally so poorly exposed that an accurate idea of their nature is difficult to obtain. Indeed most of the remarks made here are based on information derived from a study of the skarn rocks in the contact zone southeast and east of the Dublin Gulch stock.

The skarns occur as irregular bodies, boudins, beds, and in discontinuous lenses that appear to have resulted mainly from the contact metamorphism of limestone. Some bodies may have been derived from calcareous schist and calcareous quartzite.

The rocks are greenish or greenish brown, coarse to medium grained, and mostly massive, dense, and hard. Some bodies show a faint banding and others are slightly schistose in appearance.

In thin sections the skarns exhibit a wide variety in quantity and types of minerals. The predominant minerals are diopside, fibrous amphibole, scapolite, quartz, carbonate minerals, plagioclase, and epidote. In some bodies these minerals are coarse grained, and euhedral to subhedral. In others they are fine grained, highly intergrown, and irregular. Accessory minerals include sphene and apatite. Scheelite, as subhedral to anhedral crystals, occurs in many of the bodies. This mineral is generally disseminated through the groundmass but tends to occur in the carbonate or quartz rich parts. Many of the scheelite crystals are poikilitic and enclose particles of carbonate, quartz, and other minerals. Pyrrhotite is abundant in a few beds and lenses of skarn. It occurs as ramifying patches and blebs in the fine-grained groundmass. Where pyrrhotite is present in quantity, the lenses carry up to 0.10 ounce gold/ton.

Greenstones

The greenstones are schistose, greyish green to dark green rocks that occur in conformable elongated lenses and sills, principally in the schistose formations and to a lesser extent in the quartzite formations. The greenstones weather differentially compared with the schists and quartzites and form prominent precipices and knobs (Pl. V). In most occurrences they are jointed and present a slabby appearance (Pl. IX). In some bodies narrow shear zones, joints, and irregular fractures contain small lenses and masses of quartz, epidote, and calcite.

In Chapter III it is shown that ore shoots are localized in some vein faults where greenstone forms one or both walls, and that they terminate when the vein faults pass into schist. This feature makes an understanding of the geometry of the greenstone bodies imperative in attempting to assess the extent and continuity of the ore shoots.

Blackadar (1951) has described the form of the greenstone bodies and discussed their origin. He suggests that the greenstone lenses are (1) remnants of a highly faulted series of pipe-like intrusions or (2) are due to shearing of tabular bodies with consequent formation of boudins; he favours the first hypothesis.

Field and underground investigations by the present writer show that most greenstone bodies occur in the lower schist formation and in the schist members of the central quartzite formation. In the schist members the bodies are lens-like and discontinuous both along the strike and down the dip, but appear to follow certain definite horizons. Where greenstone occurs in quartzite, as on the northern slope of Sourdough Hill and on parts of Galena Hill, the bodies are fairly continuous and appear to be sills. In both schist and quartzite the greenstone lenses and sills are cut by numerous shear zones and are highly sheared at their contacts with both quartzite and schist. This suggests that the discontinuous lens-like bodies of greenstone along specific horizons were once sills that were fractured and sheared, both along and oblique to their contacts. The sills were thus disrupted into separate entities which were compressed and sheared into lens-like bodies (boudins) as illustrated in Figure 3. The details of the process by which boudins are formed have been outlined by Cloos (1946) and De Sitter (1958), who also give several references. Once formed the boudins were further cut and displaced by an extensive series of bedding plane faults, low-angle thrust faults, shear zones, vein faults, and cross-faults. The fact that most of the greenstone bodies (competent rocks) in the schists (incompetent rocks) show well-developed boudinage strongly supports the boudinage hypothesis. In the quartzites where the competency of the two rocks (greenstone and quartzite) is nearly the same, surface and underground mapping suggest that the greenstone bodies are faulted sills.

RWB, 1-6-55

PLATE IX. Jointed greenstone body, Keno Summit, Keno Hill.

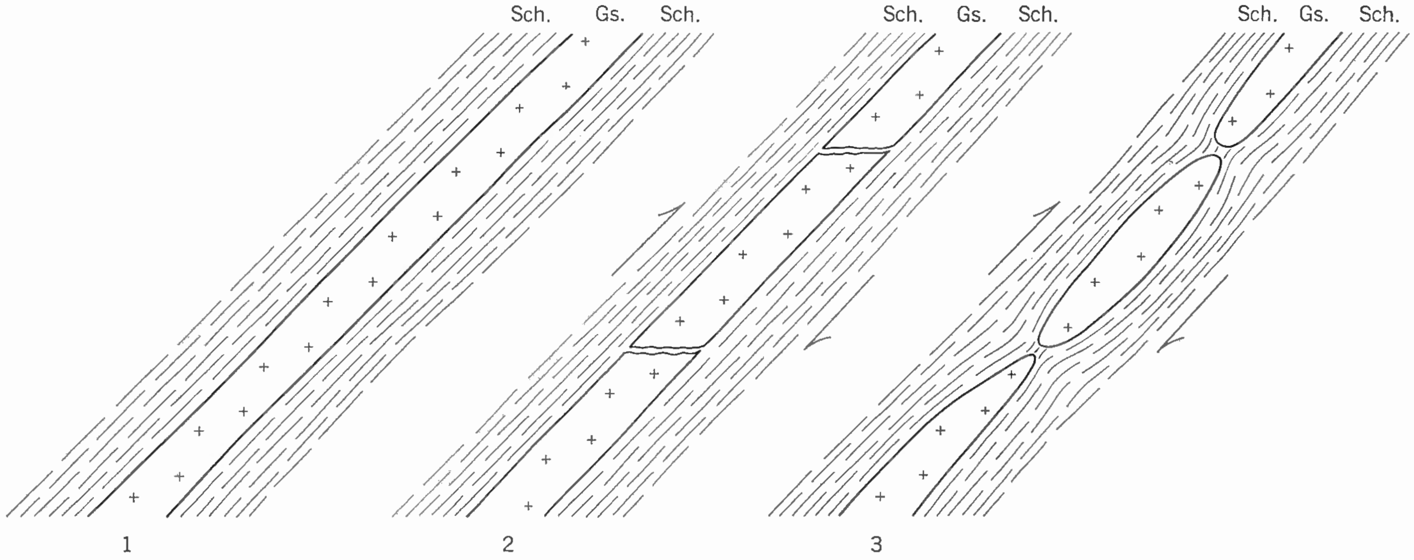
In thin sections the greenstones present considerable variety both in mineral composition and texture. All are highly altered, and it is rare to find bodies with any original minerals. Remnants of original textures are, however, preserved in most bodies.

The principal minerals now present in the greenstones are hornblende, actinolite, saussurite (zoisite, epidote, albite, sericite, carbonate), plagioclase (oligoclase to andesine), chlorite, stilpnomelane, biotite, white mica (sericite), leucoxene, and carbonate minerals. Quartz, potash feldspar, ilmenite, magnetite, limonite, and apatite are common minor constituents, and pyrite is present in some bodies. All these minerals are not necessarily found in any one greenstone mass.

The texture of most of the larger greenstone bodies is diabasic with amphibole in various degrees of alteration as large lath-like crystals. In a few sections pyroxene (augite?) is present. Most of the feldspars are so highly saussuritized that their precise original composition is impossible to decipher. Original magnetite and ilmenite crystals are rimmed or pervaded by leucoxene and limonite. Apatite occurs in small euhedral crystals. Chlorite is generally present, commonly in considerable amounts, and biotite, sericite, quartz, and carbonate minerals are found in some bodies. Some of the quartz may be primary, but most appears to have originated from alteration processes.

Smaller greenstone bodies and the borders of the large lenses have a schistose texture. In these the amphibole, saussurite, carbonates, and other minerals are fine grained, highly intergrown, and drawn out into bands, streaks, and elongated lenses and trains.

A few greenstone bodies have a pseudo-porphyritic texture due to the presence of large, irregular, commonly somewhat angular, masses of leucoxene and/or saussurite set in a fine-grained, felted groundmass of amphibole, feldspar, chlorite, carbonates, and saussurite.



1. *Greenstone sill is intruded into schist*
2. *Tension fractures form across greenstone sill due to shearing action*
3. *Shearing of greenstone rounds off edges and schist flows into spaces between lenses*

Incompetent schist . . . . . Sch. *Competent greenstone* . . . . Gs.

GSC

FIGURE 3. Sketches illustrating formation of greenstone boudins.

Granitic Rocks

A detailed investigation of the granitic rocks was not carried out as (1) most of the bodies lie outside the map-area, and (2) most are so poorly exposed that systematic sampling was not possible. During the investigation, however, representative samples of the Dublin Gulch granitic bodies were obtained and studied, and other samples from the Granite Creek area were provided by L. H. Green.

The granitic masses appear to be intrusive into the various formations, and, as mentioned previously, have produced a certain degree of metamorphism in the sediments. The most characteristic of the metasediments are the skarn rocks.

The granitic bodies range in composition from granodiorite to quartz diorite. Most are medium to fine grained and equigranular; a few have porphyritic and aplitic phases. Associated pegmatite bodies occur locally.

The northwest contact zone of the granitic body between Dublin Gulch and Lynx Creek is marked by numerous apophyses and granite dykes. In places these are cut by veins containing arsenopyrite, pyrite, and gold. Within the granite mass proper, and near its contacts, small stockworks of quartz veins carrying crystals of scheelite, and locally wolframite, occur sporadically. These and other occurrences are described in greater detail in the next chapter.

The granitic rocks are grey to dark grey on fresh surfaces and tend to weather light or dark grey, or buff. The Dublin Gulch bodies are deeply weathered and decomposed in places to depths of 10 feet or more.

The principal mineral constituents of the granitic masses are quartz, plagioclase (oligoclase to andesine), potash feldspar, biotite, muscovite, and hornblende. The plagioclase may be zoned and the cores are commonly altered to saussurite and sericite. The biotite generally shows an alteration to chlorite, and in some thin sections the hornblende is seen to be similarly affected. Pyroxene is common in some of the Dublin Gulch bodies and is generally accompanied by some carbonate. The common accessory minerals in most of the granitic bodies are sphene, apatite, epidote, allanite, pyrite, and magnetite.

Quartz-Feldspar Porphyry

The quartz-feldspar porphyries occur as poorly exposed sills on the north and northeastern slopes of Keno Hill, on the south and western slopes of Galena Hill, and on the southern slope of Mount Haldane, as well as at other scattered points throughout the district. They cut the greenstones and are, therefore, younger than these rocks. In a few places the porphyries are cut and offset by the siderite veins, and hence were completely consolidated bodies before the veins were formed. The age relationships of the porphyries and various granitic bodies are unknown.

Most of the porphyries are light coloured rocks; some are grey and others are speckled with plates of biotite. On weathered surfaces they are buff.

Thin sections reveal a well-developed porphyritic texture in most specimens. The phenocrysts of quartz, feldspar, biotite, and chlorite are set in a fine- to medium-grained groundmass of quartz, plagioclase, myrmekite, muscovite, and chlorite. Accessory minerals include apatite, sphene, epidote, carbonate, magnetite, hematite, zircon, and pyrite. The quartz crystals are generally clear and many are fractured. The feldspar crystals are zoned with calcic cores (andesine) and sodic rims (albite-oligoclase). The cores are commonly saussuritized. The biotite usually contains oriented rutile needles or patches of leucoxene or sphene and is more or less altered to chlorite. Pyrite is relatively abundant in some bodies.

A few of the bodies on Galena Hill are fine grained and equigranular with only a few random phenocrysts of quartz. They contain much sericite, myrmekite, some carbonate, quartz, altered feldspar, leucoxene, epidote, and zoisite and appear to represent altered fine-grained granites or rhyolites.

Lamprophyre

The lamprophyres are light to dark brownish grey rocks that occur as a few discontinuous sills and dykes in the schist and quartzite formations. Their relationships to the granitic rocks and greenstone bodies are unknown as they are not found near or cutting one another. They are cut and altered by the siderite-sphalerite-galena lodes and hence are older than these bodies.

Most of the lamprophyres are the porphyritic biotite variety. The biotite, now highly altered to chlorite containing remarkable gridworks of rutile needles, is set in a fine- to medium-grained matrix composed essentially of carbonate minerals, chlorite, quartz, and white mica. The principal accessory minerals in the matrix are pyrrhotite, pyrite, marcasite, apatite, and rutile. Some of the lamprophyres contain rounded fragments of quartzite.

Stratigraphy of Sedimentary Rocks

On Keno and Galena Hills the sedimentary strata have an average dip of 20° S. Tops cannot be determined with accuracy and there is no clear evidence that extensive overturning or recumbent isoclinal folding has taken place. The writer has concluded, therefore, that the stratigraphic sequence on these two hills, notwithstanding the presence of many low-angle faults and other complexities, is a simple homoclinal succession. According to Bostock (1947) this homocline forms the southern limb of a large anticline whose axis follows the McQuesten River valley (*see* Fig. 1).

The reader should not assume, however, that this view is entirely correct for the region as a whole. There are many inconsistencies in the simple picture suggested above, and further detailed work may well show that the rocks in the Keno Hill-Galena Hill area are thrown into a series of complex recumbent isoclinal folds. For an exposition of this interesting hypothesis the reader is referred to the published account by Green and McTaggart (1960).

The rocks on Keno and Galena Hills can be subdivided into three units on a lithological basis: the lower schist formation, the central quartzite formation, and the upper schist formation. Each of the units can be further subdivided, again on lithological grounds, into distinctive members. The generalized picture is shown in Figure 4, the details in Figure 2.

On Keno Hill the *lower schist formation* includes a lower sequence of rocks composed mainly of graphitic schists, phyllites, argillites, and thin-bedded quartzites, followed by a sequence made up of thick-bedded quartzites, thin-bedded quartzites, phyllites, and sericite schists. All these rocks, particularly the lower sequence, contain numerous elongated lenses and discontinuous bodies of greenstone that follow definite horizons.

The most distinctive member in the lower schist formation is the No. 9 quartzite, which is composed of thick-bedded quartzites interbedded with graphitic schists and phyllites. This member underlies Monument Hill and extends westward to the vicinity of the Keno Hill-Wernecke road, where it either pinches out as a result of a facies change or is truncated by a flat fault. The first hypothesis seems the more probable as the member has not been found in the lower schist formation to the westward on Galena Hill.

The No. 9 quartzite is overlain by sericite and graphitic schist beds and underlain by graphitic schist and three series of thick-bedded quartzites each interbedded with sericite schist. Westward, the thick-bedded quartzites appear to pinch out as a result of a facies change, but low-angle faults or a complicated fold may be partly responsible for their disappearance.

On Galena Hill the stratigraphy of the lower schist formation cannot be worked out in detail, because most of it is covered with 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, phyllites, and a few thick beds of quartzite.

The upper part of the lower schist formation is a distinctive layer of green sericite schist some 350 feet thick. This layer can be traced from Hope Gulch across the southern slope of Keno Hill and thence from the Christal Creek area westward across the northern slope of Galena Hill.

In the lower schist formation, most of the productive lead-zinc-silver lodes are localized in the thick-bedded quartzites, particularly in the No. 9 quartzite member. This member contained the No. 9, Lucky Queen, Shamrock, and several other smaller lodes. In general, the various schists, phyllites, argillites, and thin-bedded quartzites are structurally incompetent and unfavourable for the occurrence of ore shoots. The greenstones, on the contrary, should be regarded as favourable. On Keno Hill a number of rich ore shoots were mined at the Ladue-Sadie-Friendship property where vein faults cut greenstones. It is logical to expect, therefore, that the greenstones throughout the formation are similarly favourable sites for shoots where the proper fracturing and faulting has taken place. 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 in the Keno Hill-Galena Hill area, and an attempt was made to piece together its detailed stratigraphy from surface and underground mapping. There are some gaps, but distinctive horizon markers can be traced across the two hills. The three orebearing members are the Galkeno, the Hector-Calumet, and the Silver King. All are composed principally of thick-bedded quartzites and are separated from one another by thin-bedded quartzites, phyllites, and graphitic schists. A description of the characteristic members of the central quartzite formation is given in the following table.

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	350	Silver King mine Coral and Wigwam prospect Arctic and Mastiff (Bermingham mine) Bellekeno mine
	Thin-bedded quartzites interbedded with graphitic schists and phyllites. A few beds of quartzites 3 feet or more thick	550	
Hector-Calumet member	Massive pale grey to grey, thick-bedded quartzites interbedded with minor thin-bedded quartzites, phyllites, and graphitic schists; beds of quartzite 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	800	Hector-Calumet mine Elsa mine Dixie prospect Onek mine Mount Keno mine
	Grey to black, thin-bedded quartzites interbedded with graphitic schists and phyllites; most beds 1 foot to 2 feet thick; some up to 5 feet thick	350	
Galkeno member	Massive, pale grey to black, thick-bedded quartzites; most beds 5 to 10 feet thick, some 25 feet thick or more; a few interbedded graphitic schist layers and thin-bedded quartzites	300	Galkeno mine Dragon prospect No Cash prospect
	Green quartz-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 also appear to thin or thicken along strike as a result of primary 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 quartzite, phyllites, and schists they are narrow, tight, and only sparingly mineralized.

The *upper schist formation* is composed principally of quartz-mica schist, graphitic schist, thin-bedded quartzites, a few beds of thick-bedded quartzite, and a few limestone lenses. Despite the presence of numerous faults, orebodies and extensively mineralized zones appear to be absent.

Chapter III

VEIN FAULT AND FAULT SYSTEMS

The orebearing and non-orebearing faults in the Keno Hill-Galena Hill area are described in this chapter, and a short description is given of the numerous mines and prospects on Sourdough Hill, Keno Hill, Galena Hill, Mount Haldane, and in the Dublin Gulch area.

Two types of faults occur: those that contain major concentrations of economic minerals, called 'vein faults' in this report; and those with small amounts of ore minerals, generally of supergene origin, called cross-faults, bedding faults, etc. The surface traces of both types of faults are shown on Figures 2 and 18.

Field studies indicate that faults of three principal ages are present. From oldest to youngest these are:

(1) Early bedding faults and low-angle faults.

(2) Vein faults. These may show evidence of two or more periods of movement and mineralization.

(3) Late cross-faults, low-angle faults, and bedding faults that cut and offset 1 and 2 above.

Fractures and joints are widespread and occur in nearly all types of rocks, but particularly in thick-bedded quartzites and massive greenstones. Sets of several ages are present. Some are offset by the vein faults and others cut across both the vein faults and late faults. Most joints and fractures contain only quartz and carbonate minerals.

INTERNAL NATURE, STRUCTURE, AND PATTERN OF FAULTS

Vein Faults

The vein faults occur in all types of rocks but differ in their internal nature where cutting through greenstones, quartzites, phyllites, and schists respectively. In most greenstones and all thick-bedded quartzites the vein faults are breccia zones or sheeted zones, or transitions between these two types; in a few greenstones they are shear zones and some chlorite schist is developed along them. In the schists, phyllites, and thin-bedded quartzites the vein faults are represented by narrow fractures, slips, crenulated zones, or narrow breccia zones.

The breccia and sheeted zones, which constitute the vein faults in the greenstones and thick-bedded quartzites, range from 5 to 50 feet in width and can be traced with ease along strike and dip. The breccia zones (Pl. X) are composed of rock fragments that are generally angular. Some are however rounded indicating considerable attrition during fault movements. In some faults the fragments have been ground into a clay or sandy gouge. The breccia-type vein fault is widespread; those at the Bellekeno,

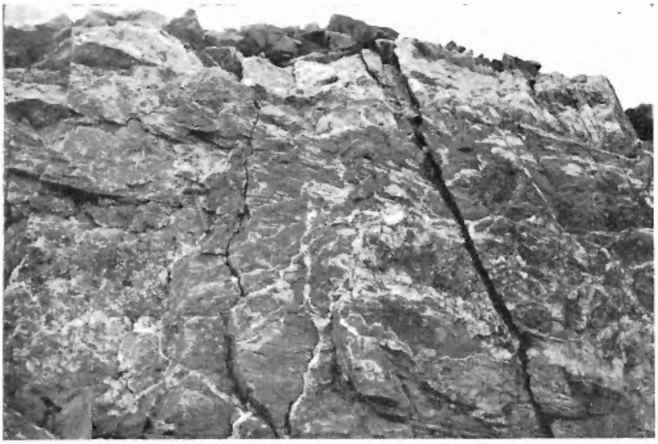


PLATE X

Early quartz vein and associated stringers (light grey to white) in breccia vein fault, Main vein, Faro Gulch, Keno Hill.

RWB, 6-6-54

Ladue-Sadie-Friendship, Onek, Galkeno, Hector-Calumet, and Silver King mines are of this type. The sheeted-zone type (Pl. XI) consists of rectilinear slabs of quartzite or greenstone separated, in most occurrences, by small breccia- or gouge-filled fractures a fraction of an inch to a few inches wide. Faults of this nature are not abundant, but good examples occur in the surface pits at the Black Cap prospect and in the Lucky Queen mine.

Below the oxidation zones the breccia fragments and rectilinear slabs in the vein fault zones are cemented, in places, by siderite and some quartz, and, in the mineralized parts and orebodies, by sphalerite, galena, and other ore minerals. Barren parts show little cementation except by some carbonate minerals. In the oxidized zones the fragments and slabs are cemented by limonite, manganese oxides, galena, carbonates, and sulphates in mineralized parts and orebodies. Barren sections contain only breccia, gouge, and limonite.

PLATE XI

Mineralized sheeted zone, Black Cap prospect, Keno Hill.

RWB, 2-8-54

In the schists, phyllites, and thin-bedded quartzites individual vein faults are narrow, rarely more than a foot wide, and contain some gouge and breccia. In many places the vein fault is difficult to trace because it is a simple fracture or slip an inch or so wide along which the walls of schist or phyllite have been dragged, contorted, and mashed. Such vein faults rarely contain more than a small amount of ore and gangue minerals.

The structural details of vein faults are complex in all occurrences. In no place do they exhibit a simple fault plane, but rather several parallel to subparallel gouge or breccia-filled surfaces 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 sections. Others branch from, and rejoin the main vein fault, or branch into schists in the foot-wall and hanging-wall and die out. Slickensides on wall-rock, siderite, and sphalerite along fault and slip surfaces are common in many fault zones, and in some mineralized sections near late slips, the galena exhibits a fine-grained or schistose appearance (steel galena).

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.

The change in the nature of the vein faults as they pass from one rock type to another is important in mining and in understanding the structural control of some ore shoots. Figure 5 is an idealized sketch showing the nature of vein fault in the various types of rocks. Vein faults that pass from greenstone into thick-bedded quartzite in most places show little change in character or in strike and dip; in both rocks they tend to be breccia or sheeted zones that are favourable sites for orebodies. The passage of a vein fault from greenstone or thick-bedded quartzite into schists, phyllites, and thin-bedded quartzites is marked, however, by a sharp reduction in the width of the fault zone and a gradual or total disappearance of breccia. Strikes and dips of individual fault and slip planes constituting the vein fault zone become erratic with a general tendency for these structures to branch and follow bedding planes and finally die out in a drag-folded or crenulated part of a bed. The schists or phyllites adjacent to individual slips are contorted and mashed, and the fault zone as a whole is difficult to follow during mining.

Field studies indicate that the degree of competency and the tendency to form breccia or sheeted zones favourable to mineralization decrease according to the rock type in the following order: thick-bedded quartzites, greenstones, thin-bedded quartzites, phyllites, and schists. This does not mean that members composed of thin-bedded quartzites, phyllites, and schists should be neglected during exploration. On the contrary, if these members contain greenstone lenses or a few thick beds of quartzite, conditions may be favourable for ore shoots. The orebodies of the Ladue-Sadie-Friendship mine, for example, occurred in a complex of this type.

From the foregoing description of the differences in the vein faults from rock type to rock type, the question of the continuity of the vein systems arises. Not only is it everywhere difficult to trace extensions of vein systems along strike on account

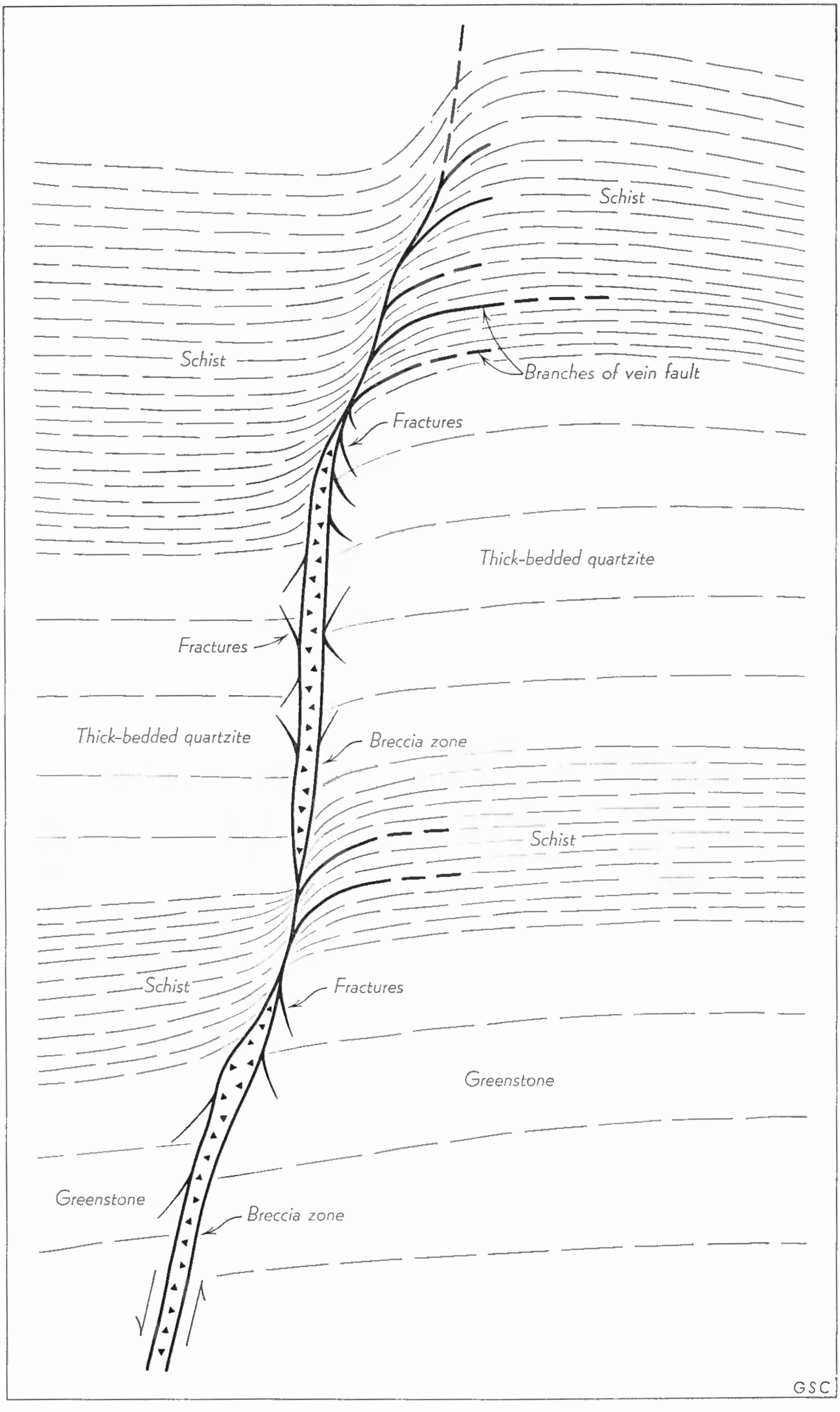


FIGURE 5. Sketch illustrating the nature of a vein fault in various types of rocks.

of the heavy drift, but also because of the narrow and unpretentious nature of the vein faults in schist and thin-bedded quartzite. Underground work and extensive bulldozing at the surface on the projected extensions of vein systems, however, show beyond a doubt that the vein faults continue through the schist as tight fractures and contorted zones, and, barring the presence of offsets on cross-faults, the vein faults may reappear along strike, again as wide breccia zones in quartzites and greenstones. The No. 6 system affords an example of this particular feature.

The pattern of the vein faults is complex and difficult to systematize. Nearly all strike northeast and dip southeast. Viewed in a broad sense, the principal vein faults appear to constitute a series of parallel to subparallel faults with strikes ranging between N35°E to N80°E on Galena, Keno, and Sourdough Hills (Fig. 4). These were originally termed longitudinal faults by early investigators (Cockfield, 1924a). Associated with the longitudinal faults are a number of cross-over or transverse vein faults whose strikes range from slightly west of north to N35°E. The age of these faults is uncertain. They may be subsidiaries of the longitudinal faults and hence formed at the same time, or they may have been developed during a later period of movement along the longitudinal faults.

Cross-faults, Low-angle Faults, and Bedding Faults

These faults are not unlike vein faults, and in some places it is difficult to distinguish members of this group from vein faults unless they are crossing one another. Faults of two ages are present—those formed prior to the vein faults and those formed later.

The early bedding faults are marked by mashed and contorted schist beds between more competent greenstones and quartzites and were probably formed by early shearing along and between beds during folding. 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 severe thrusting, partly along bedding planes and incompetent beds during the regional folding of the sedimentary strata.

Locally some early bedding faults may contain a little quartz, siderite, galena, sphalerite, and other ore minerals. In general, however, they are tight structures and were not amenable to mineralization.

The late cross-faults, low-angle faults, and bedding faults are generally recognized by offsets on contacts, or on vein faults. Most appear as a series of slips and fractures ramifying through a crushed and brecciated zone which may range from 20 to 100 feet or more wide.

The most characteristic of these faults are the northwest-striking cross-faults, which have been recognized in nearly all the underground workings on Keno and Galena Hills and on the surface by offsets on vein faults and contacts. Many lineaments on the ground and on air photographs probably mark the traces of many of these faults, and the straight parts of streams in the gulches on the northern slope of Keno Hill and northwestern slope of Galena Hill may be controlled by them. On Figure 2 a few of these cross-faults are shown, but it is probable that there are a great many more in the parts obscured by drift and rock float.

On Keno Hill, the cross-faults strike northwest and dip southwest at about 60 degrees. They appear to splay off a northeast-trending fault whose trace passes through the Wernecke area and the Christal Creek valley (*see* Fig. 4).

In surface and underground exposures the cross-faults on Keno Hill consist of zones 10 to 50 feet wide of highly comminuted and brecciated rock through which run numerous fractures and slips with irregular dips and strikes. The fault zones dip at from 45 to 70 degrees. Drag features in some faults suggest that they are thrust faults. The horizontal displacement of the earlier vein faults and ore shoots along the cross-faults varies from a few feet to 500 feet. The amount of vertical displacement can rarely be determined.

On Galena Hill the late cross-faults have similar characteristics and form a herring-bone pattern, the McLeod fault forming the main trunk fault. This fault strikes northeast and dips 60° SE. The subsidiary faults on the northwest side of the McLeod fault strike northwest and dip about 45° SW 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 dominant horizontal displacements. The amount of displacement on individual faults differs—the Hector, Jock, Arctic, and Porcupine Gulch 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.

Most 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 northwest-striking faults rarely contain the hypogene gangue or ore minerals found in the earlier vein faults, but hypogene drag-ore derived from adjacent veins may be present in places. Most of the faults are the courses for underground waters carrying various elements found in the vein faults. In the oxidized zone the faults may contain pockets and seams of supergene minerals.

The late cross-faults have been regarded by some as the channelways for the hypogene ore solutions. This, however, seems improbable. It is so that late cross-faults occur at nearly every mine, but this appears to be purely fortuitous because so many cross-faults cut the rocks of the Keno Hill-Galena Hill area that it would be remarkable if nearly every mine working did not intersect at least one of these structures. It is clear from underground and surface mapping 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 played any part in the hypogene processes

DESCRIPTION OF VEIN FAULT SYSTEMS

Despite a considerable amount of geological mapping and geochemical work it has not been possible to correlate the vein fault systems on adjacent hills, because of the presence of thick intervening drift-covered valleys and complex cross-faults. It is the writer's opinion that the No. 6 vein fault is the main trunk fault in the Keno Hill-Galena Hill area and that the others are parallel with, and in part subsidiary to it. There is, however, no sure evidence to support this opinion.

The lodes in the vein faults are localized structurally in three sites (1) at the junction of two or more vein faults, (2) at the junction of a vein fault and subsidiary fracture, and (3) in quartzites or greenstones at or near where a vein fault passes from these rocks into overlying schists, phyllites, or thin-bedded quartzites.

Keno Hill, Sourdough Hill, and Bunker Hill

Vein faults in the Keno Hill-Sourdough Hill area can be classified into two groups as follows:

(a) Vein faults that strike N 35 to 80° E (longitudinal vein faults).

(b) Vein faults that strike north to N 35° E (transverse vein faults).

Both transverse and longitudinal faults appear to be normal faults with dips varying from 60° to 80° SE.

No precise data on the age relationships of the two classes of vein faults have been obtained. However, the longitudinal vein faults are mineralized by a suite of minerals that have been fractured and cemented by a suite of minerals predominating in the transverse vein faults. This suggests that the longitudinal faults are older than the transverse faults if one assumes successive stages of faulting and mineralization.

On the other hand, the longitudinal vein faults appear to truncate the transverse vein faults (*see* Fig. 2), and the two types generally intersect at angles greater than 45 degrees. These relationships suggest that the transverse vein faults may be subsidiary to the longitudinal vein faults, but until certain critical intersections are investigated thoroughly underground this assumption will remain in doubt.

Longitudinal Vein Faults

Several well-defined vein fault systems in this group have been explored and their nature and mineral deposits are relatively well known. Of these the following are the most important and have been responsible for a large part of the production of lead-zinc-silver concentrates in the past years—Ladue-Sadie-Friendship system, Lucky Queen system, Nabob-Main Fault system, Number 6 system, Comstock-Porcupine system, Onek system, Mount Keno system, and Bellekeno system. The vein faults of these systems are essentially parallel or subparallel both in strike and dip. In addition several other vein faults, that are poorly exposed or of only limited extent, belong in this category. These include the No. 1 vein fault, Shamrock-Gambler vein fault, Helen Fraction vein fault, the Faith system of vein faults, and others.

The internal nature and mineralization of these vein faults are similar in nearly all occurrences. In quartzites and greenstones they are breccia or sheeted zones and can be traced easily; in schists they are narrow fractures, slips and crenulated zones that are difficult to follow by surface or underground exploration.

Many of the veins were mineralized during two principal stages described in detail in Chapter V. During the first stage quartz, arsenopyrite, pyrite, gold, and various sulphosalts were deposited. This stage was followed by fracturing and deposition of siderite, galena, sphalerite, pyrite, and freibergite.

Ladue-Sadie-Friendship System

Vein float from the Ladue-Sadie-Friendship system (24, 25)[1] was discovered in the autumn of 1920 by David A. Cunningham, who in July of the following year located the Ladue vein. About the same time or shortly afterward (August?) the Sadie-Friendship veins were found. Development of the Ladue veins began in 1921 and mining was carried out there and on the Sadie-Friendship vein by the Treadwell Yukon Company until the ore shoots were exhausted in 1932.

The system consists of at least two parallel vein faults that strike from N 30° to 40° E and dip southeast. Other parallel vein faults occur between this and the Lucky Queen system and are described separately. The system is poorly exposed in the surface pits and caved stopes of the Ladue and Sadie-Friendship mines. However, the annual reports of Livingston Wernecke, former manager of the two mines, provide an accurate description of the principal vein fault of the system, and much of the data given below was obtained from a study of these reports and their accompanying maps and sections.

The principal vein fault has been followed in the underground workings of the Ladue and Sadie-Friendship mines to a depth of 600 feet and along the strike from the northern contact of the large greenstone body at Wernecke southwesterly for 2,500 feet, where the vein fault intersects graphitic schists and phyllites. At this point the main vein fault narrows and splits into several branches that contain small siderite lenses with a little galena. The southern extension beyond this point is not known with certainty, but diamond drill holes on the property of Klondyke Keno Mines, Limited, intersected narrow fractures containing some siderite and galena, suggesting that the main vein fault may extend at least 1,500 feet to the southwest.

Along its extent the main vein is disrupted in places by northwest-striking cross-faults that dip from 15 to 25° SW. These faults produce a general westerly offset to the vein as it is followed to the southwest. The main vein is further sliced by a subparallel, northeast-trending, late fault, which also offsets the cross-faults.

The vein fault explored at the Klondyke Keno mine (23) strikes north, dips steeply east, and may represent the southern extension of a vein fault either parallel with or subsidiary to the main Ladue-Sadie-Friendship vein. The northern extension of this vein fault has, however, not been found. In the Klondyke Keno mine the vein fault is of the breccia type, from 2 to 5 feet wide, and along its northern extension interbedded greenstone lenses and phyllites form the hanging-wall and foot-wall.

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[1] Numbers in parentheses refer to those on Figures 2 and 4.

Southward the vein fault passes into graphitic schist, narrows to a few inches, and probably divides into several branching fractures. Deep bulldozer-cuts in the graphitic schist on the assumed southern extension failed to locate its presence. No orebodies were found during the exploration of this vein fault.

Northeast of the Ladue mine, the principal vein fault of the system weakens as it passes into graphitic schists and within a few hundred feet no trace of it is discernible on the surface. Deep bulldozer-cuts in the graphitic schist on the assumed northern extension expose only narrow unmineralized fractures. Some vein float was found along the assumed extension, but the schists are structurally unfavourable, and it is doubtful if a strong vein fault exists in these rocks.

On the Lake property (35) immediately west of Gambler Gulch two parallel vein faults, containing a little siderite, quartz, galena, sphalerite, freibergite, chalcopyrite, and pyrite, have been explored by cuts and an adit. These vein faults are 3 to 8 feet wide, have a northeast strike, a southeast dip, and may represent the northern extension of the system. East of Gambler Gulch no vein faults are known to occur on the strike of the system.

The productive part of the main vein fault occurred where it cut greenstones, thin-bedded quartzites, phyllites, and interbedded schists. The vein fault in this part dips 60 to 70° SE and consists of a breccia and sheeted zone 5 to 40 feet wide with several subsidiary faults that branch from and rejoin the plane of the main vein fault. Late northwest-striking cross-faults cross this complex, offsetting the ore shoots to the west as mentioned above. These faults are in turn cut and offset by a northeast-striking late fault, which also slices through the shoots. These complex conditions made mining and exploration difficult.

According to Wernecke the ore shoots, which consisted of irregular bodies of siderite, galena, sphalerite, and freibergite, tended to occur where the vein fault crossed quartzites and phyllites or where greenstone formed one or both walls. The latter relationship is well shown on the 100-foot level of the Ladue mine (*see* Fig. 6), where greenstone forms both walls of the No. 2 orebody, and on the surface and underground at the Sadie-Friendship mine (*see* Fig. 7), where greenstone forms the foot-wall and graphitic schist the hanging-wall of a large ore shoot. Another favourable site for pods of ore was at the intersection of the main vein fault and branches that strike northward into the foot-wall or hanging-wall.

Two complex orebodies (*see* Fig. 6) occurred in the Ladue part of the vein fault. No. 1 orebody near No. 1 shaft had an average length of 120 feet and an average width of 5 feet. Its northeastern part was tabular; its southwestern part split into two branches, one of these followed the main vein fault and the other a southwestward-striking fracture in the foot-wall. The orebody as a whole raked north at approximately 40 degrees for some 450 feet down the dip before it tapered down and ended. Both hanging- and foot-wall rocks were phyllite, thin-bedded quartzite, and graphitic schist. The foot-wall was rough and irregular with numerous branch faults and slips, the hanging-wall was smooth and marked by a post-ore fault. The vein filling was principally galena, sphalerite, and freibergite. No. 2 orebody lay north and south of No. 2 shaft and had a length of 550 feet on the 200-foot level. The average width was 7 feet. It was roughly saddle-shaped, the eastern limb following the main vein fault and the western limb a north-striking fracture in the foot-wall. The rake of this saddle-shaped body was steeply north; the rake length approximated 400 feet. The wall-rocks were highly shattered greenstones (chlorite schists) and phyllites, and the orebody consisted of a stock-work of reticulating veinlets containing principally siderite, galena, sphalerite, freibergite, and small amounts of quartz.

Three ore shoots were found in the Sadie-Friendship part of the main vein fault (*see* Fig. 7). Two of these were north of a prominent northwest cross-fault and the other south of the fault. The most northerly shoot was 160 feet long on the 200-foot level, and 2 to 3 feet wide. The wall-rocks were mainly schist and phyllite. The shoot just north of the northwest cross-fault was 100 feet long and 3 to 4 feet wide on the 200-foot level. The foot-wall was schist, phyllite, and thin-bedded quartzite and the hanging-wall was mainly greenstone. The shoot south of the cross-fault was a complex stock-work some 40 feet wide composed of siderite, galena, and sphalerite veins in crushed and fractured greenstone and schist. It consisted of two parts separated by a longitudinal late fault. The foot-wall was greenstone and the hanging-wall graphitic schist.

The rake of the three shoots in the Sadie-Friendship mine was slightly north to vertical. No ore was found below the 400-foot level.

In the Ladue mine the ground was frozen to a depth of 260 feet whereas at the Sadie shaft no permafrost was encountered. The oxidized zone at the Ladue mine was only 10 feet deep, and at the Sadie-Friendship from 5 to 10 feet. Native silver and ruby silver were found only sparingly in the oxidized zones and in the zones of reduction.

The primary ore shoots at both mines exhibited a mineral zoning both laterally and vertically. The flanks, and particularly the ends, of the shoots were marked by numerous stringers of siderite containing pyrite and minor amounts of sphalerite and galena. These extended in places as far as 75 feet out from the main vein fault into the country rock. Inward the amount of pyrite decreased and the main parts of the shoots contained essentially siderite, galena, sphalerite, freibergite, minor amounts of other sulphosalts, and quartz.

The vertical sequence of vein minerals in the ore shoots was as follows. Galena predominated at the top of the shoots giving a high lead content (*see* Table 1). Within a comparatively short distance down the dip (100 to 200 feet) the content of galena decreased and sphalerite was the principal mineral constituent. With increasing depth (400 feet) sphalerite decreased in turn, and siderite became the predominant mineral. Freibergite also decreased with depth, but its vertical range was much greater than that of galena, a feature which kept the silver to lead ratio in the lower parts of the shoots relatively uniform (Table 1). On their lower extensions, the shoots were composed mainly of siderite with a considerable amount of freibergite and small quantities of galena and sphalerite. This assemblage gradually gave way to siderite containing only pyrite and small amounts of the ore minerals.

During the lifetime of the Ladue mine its ore shoots produced about 200,000 tons of ore averaging 54.5 ounces Ag/ton, 12.6% Pb, and 3.9% Zn. The shoots in the Sadie-Friendship mine produced approximately 113,000 tons of ore assaying 55.3 ounces Ag/ton, 7.8% Pb, and 4.7% Zn. Zinc and cadmium were not recovered from the ores.

Table 1

Variation in Lead and Silver Content of Primary Ores, Ladue Mine, Wernecke, Yukon[1]

Location	Tons mined	Metal recovered[2]		Ratio Ag oz/Pb lbs
		Ag oz	Pb lbs	
Ore shoots above 100′ level	64,508	4,097,000	1,064,500	3.85/1
" " 100′—200′ level	26,162	1,004,000	156,800	6.40/1
" " 200′—300′ level	12,164	502,000	122,400	4.10/1
" " 300′—400′ level	10,659	681,000	124,200	5.48/1
" " 400′—500′ level	2,920	78,300	10,000	7.83/1
" " 500′—600′ level	1,535	39,700	6,600	6.02/1
Totals	117,948	6,402,000	1,484,500	

NOTES: 1. Data from Annual Reports Treadwell Yukon Co.
2. Zinc was not recovered from the concentrates.

Between the Sadie-Friendship workings and the Lucky Queen system two prominent lineaments represented by quartzite bluffs occur on the ground and are clearly visible on vertical aerial photographs. Another series of lineaments occurs in the greenstones east of the Ladue workings, and a narrow vein fault in greenstone and schist is exposed midway between the Ladue and Lucky Queen workings. Fractures in the quartzite along the western lineament contain siderite and some galena, and the vein fault in the greenstone and schist contains a little siderite. Geochemical work (Boyle, *et al.*, 1955) carried out on water from springs issuing below the western quartzite bluff indicates that a metal source lies nearby. The existence of lineaments and known mineralized fractures and the presence of a geochemical anomaly warrant some prospecting in this area.

Lucky Queen System

The discovery of the vein fault that ultimately led to the development of the Lucky Queen mine was made by Hector Morrison near the northeast boundary of the Lucky Queen claim. The actual date of discovery is uncertain, but according to some reports it was in the summer of 1920. Development of the Lucky Queen veins commenced in 1927, and mining by the Treadwell Yukon Company continued until 1932 when the ore shoots were exhausted.

The Lucky Queen system (34) is some 5,000 feet east of the Ladue-Sadie-Friendship system and consists of two breccia vein faults and sheeted zones that intersect in the area southwest of the main Lucky Queen shaft. The vein faults strike from N 20°

to 45° E and dip steeply southeast. Only one of the vein faults, the main Lucky Queen break, contained sizable orebodies. This break is strong and can be traced for a considerable distance.

The main Lucky Queen break is exposed in caved stopes and pits for a distance of 1,200 feet southwest from the main shaft. In these is a breccia fault and sheeted zone from 5 to 40 feet wide, which along strike is cut into several segments by a series of flat, parallel northwest-striking cross-faults. These faults cause a general westward offset of the breccia fault and sheeted zone as it is followed south.

Southwest of the southernmost shaft on the Lucky Queen property the vein fault does not outcrop, but a strong lineament to the west of the projected strike of the structure suggests that the main vein fault is slightly offset to the west and its trace is probably marked by the lineament shown on Figure 2. Geochemical work (Boyle, *et al.*, 1955) carried out along this lineament indicated an anomalous zinc content in water from springs, evidence also suggesting the presence of a vein fault.

This lineament, when traced southwest from the south shaft on the Lucky Queen property passes into the Black Cap and Shepherd claims (Brewis Red Lake Mines, Limited) (33). There, several pits, a shaft, and an adit expose a vein fault. The pits expose two sheeted zones 50 feet apart. These dip 75° SE, are from 2 to 10 feet wide, and contain some siderite, galena, and freibergite. Southwest of the pits an adit has been driven to the vein fault, and a drift follows a sheeted zone and breccia zone for about 150 feet to the northeast. Along this drift the vein fault is a foot or so wide and difficult to trace because it has been offset by both bedding plane faults and northwest-striking cross-faults. The northern part of the vein fault is in quartzite; traced south it passes into sericite schist where it forms horsetails and dies out in a series of slips and crenulations in the schist. In the quartzite the vein fault contains limonite, siderite, quartz, galena, and a little freibergite. No orebodies were found during exploration.

Southwest of the Brewis Red Lake adit the continuity of the system is uncertain. Two shafts sunk many years ago in the schist south of the adit appear to have followed a subsidiary south-striking fracture or narrow vein fault carrying a little siderite. On the Kijo (31) claim a narrow breccia fault carrying a little siderite and galena may represent the southwestern extension of the Lucky Queen break. However, bulldozer-cuts in the intervening area between this exposure and the outcrops on the Black Cap property have failed to find a vein fault.

In the vicinity of the Lucky Queen mine the system consists of two intersecting vein faults. One of these strikes N 20° E the other N 45° E. North of the main Lucky Queen shaft the more northerly passes first into schist and then into an area of interlayered schist and greenstone. Where greenstone formed the foot-wall of the vein fault there was a small ore shoot containing quartz and freibergite; other parts of the vein fault were barren. The main N 45° E vein fault enters a zone of schist north of the main Lucky Queen shaft. There outcrops are so scattered that the structure cannot be traced. It is probable that northeastward along strike the main vein fault is offset back and forth by a series of northwest-trending faults. In one exposure on the Highlander claim (39) a series of open-cuts has been excavated and a shaft sunk. These workings are now inaccessible, and little data could be obtained from a surface examination.

However, Cockfield (1924a), in his description of the vein fault at this prospect, says that some ore was won from a small orebody in quartzite, containing siderite, pyrite, galena, freibergite, and sphalerite.

Northeast of the pits on the Highlander claim the system is not exposed for 1,500 feet. On the Stone claim (41) a vein fault striking N 50° E and dipping to the southeast may be the northeastern extension of the Lucky Queen system. This vein fault has been investigated by pits, open-cuts, and adits, all of which were caved or ice-filled at the time of the writer's examination of the area. According to Matt Butyer, owner of the claim, exploration work disclosed a vein fault 10 feet wide with a greenstone and schist hanging-wall and schist foot-wall. A small amount of ore was removed from the vein fault. The minerals in the ore shoot were siderite, quartz, galena, freibergite, sphalerite, and chalcopyrite. The mineralized part of the vein fault was apparently in greenstone below a schist capping. Many post-mineral faults were encountered. In 1952 Jersey Yukon Mines, Limited, investigated the vein fault by driving an adit southward between the two adits driven during early exploration. This adit was started in graphitic schist and phyllite and the material on the dump suggests that it was in graphitic schist and phyllite throughout. From reports it would appear that the tunnel passed through the vein without it being recognized, and, if so, illustrates the difficulty in recognized vein faults in schists.

Northeast of Faro Gulch the system has not been exposed. In this area it passes into unfavourable graphitic schists and phyllites, and unless the vein faults were to intersect greenstones, orebodies are not likely to occur.

Two parallel vein faults occur on the Cub and Bunny (40) claims 1,000 and 1,500 feet southeast respectively of the Highlander open-cuts. The western vein fault occurs in greenstone and contains siderite, galena, freibergite, and sphalerite. A little ore was probably removed from this vein fault. The eastern vein fault occurs in sericite and graphitic schists and is not clearly defined despite the large number of bulldozer-cuts and pits dug to explore it. No ore is known to have been taken from this vein fault.

The vein fault that contained the orebodies at the Lucky Queen mine (34) was explored on three levels. Several ore shoots (*see* Fig. 8) were mined to a depth of 300 feet. Below this depth the vein fault was barren. It was severely disrupted by northwest-striking faults, and the ore shoots were cut by a number of longitudinal slips. The wall-rocks of the vein fault were principally quartzites with interbedded graphitic schists, and a greenstone lens was intersected at the northeastern end of the drift on the 300-foot level. Surface investigations and a study of the maps and plans of the Lucky Queen mine indicate that the two ore shoots were localized in the main N 45° E vein fault near its intersection with the N 20° E vein fault.

The ore shoots consisted of veins, stringers, and bunches of ore and gangue minerals. Siderite, galena, sphalerite, and freibergite were the principal primary minerals. The shoots were highly oxidized to depths of 60 feet or more and contained essentially limonite, jarosites, beudantite, cerussite, anglesite, manganese oxides, and nodules of oxidized siderite, galena, and freibergite. Assays of this material averaged 485.3 ounces Ag/ton, 42 per cent Pb, and 4.5 per cent Zn in some stopes. Ruby silver and native silver were common below the 100-foot level and were found as deep as 250 feet. Assays of stopes containing these secondary minerals averaged 87.9 ounces Ag/ton and 7.7 per cent Pb. Below the secondary silver zone the ore averaged 74.1 ounces Ag/ton and 7.3 per cent Pb.

The ore shoots in the Lucky Queen mine yielded approximately 123,000 tons of ore averaging 97.8 ounces Ag/ton, 8.7 per cent Pb, and 4.0 per cent Zn. Zinc and cadmium were not recovered.

No. 1 Vein Fault

This vein fault (47) outcrops in the headwall of Faro Gulch 600 feet north of the Main vein fault (Fig. 9). It dips 60° SE, is 5 to 10 feet wide, and has been investigated by three adits 230, 140, and 150 feet long, now all caved. According to Cockfield (1924a), a small ore shoot was encountered in the vein fault on the upper levels. It was 60 feet long and high, 14 inches thick, and pinched out on the lower levels.

Material on the dumps of the three adits consists principally of quartz, oxidized siderite, sphalerite, galena, freibergite, and pyrite. Some of the quartz contains arsenopyrite, indicating a mineralization like that described below for the No. 6 and Comstock-Porcupine systems.

The northeastern extension of the No. 1 vein is covered by extensive scree and has not been located. The southwestern extension is also obscured by rock float and drift. Geochemical work done in an attempt to trace the vein fault to the southwest suggests that it may extend as shown on Figure 2.

Shamrock-Gambler System

The Shamrock vein fault (38) has been prospected principally in the head-wall of Erickson Gulch and the Gambler vein fault (48) in the western wall of Faro Gulch. It is probable that they link up in the intervening area, although they cannot be traced on the surface.

Both the Shamrock and Gambler have had a long history, but only from the Shamrock has a significant amount of ore been produced.

Cockfield (1920) described the early work on the Shamrock vein in 1919 as follows:

> Promising showings also occur on two claims owned by T. McKay and Axel Erickson. One of these claims is situated at the head of a small gulch tributary to Christal creek about a quarter of a mile to the east of the Heather claim. The vein was uncovered by a small open-cut running into the hillside, but owing to slumping no particulars concerning it could be obtained other than that the vein strikes in a general northerly direction. A good showing of vein material occurs on the dump and grab samples taken by the owners and assayed by the Territorial Assay office at Whitehorse run from 100 to 1,000 ounces in silver.

Underground work continued in 1920 and Cockfield (1921a) reported,

> Mining work is in progress on two groups of claims owned by McKay, Erickson, and Beauvette. One of these groups situated at the head of Erickson gulch, comprises the Shamrock, Reno, Kid, Lion, and Tiger claims. Development work consists of 200 feet of drifts and a 15-foot winze. There are two main veins varying in width from 2 feet maximum to a seam, the dips varying from 45 to 90 degrees. There are in addition a number of small slip faults. The mineralization consists chiefly of galena, carbonates, and iron oxide. About three tons of galena was stoped from these workings and shipped, but returns were not available at the close of the season's work. Very little unaltered galena was encountered in these workings which are, however, within 40 feet of the surface.

Work up to 1923 on the Shamrock and intersecting veins was summarized by Cockfield (1924a) as follows:

> The Shamrock group, consisting of seven claims and two fractions, owned by Messrs. A. Erickson, T. McKay, L. Beauvette, and A. Nickol, is situated near the summit of Keno hill, immediately to the west of the original holdings of Keno Hill, Limited. The workings consist of an adit 240 feet in length with three crosscuts, and three prospect shafts, from the bottom of one of which a drift was run. These working are all on the Shamrock claim. On the Reno are two open-cuts, and one on the Maple Leaf.
>
> The adit taps a vein 80 feet from the entrance, which is followed to the end of the workings. This vein varies from 6 inches to 3 feet in thickness. The mineralization consists of galena, with lead carbonate. Three tons of ore were stoped from above the drift and shipped.
>
> The prospect shafts above the adit apparently encountered two parallel veins; the workings, however, had caved at the time of the writer's visit and very little could be seen. New shafts being sunk to the north encountered float from the same veins. From these workings a shipment of 60 tons was taken which assayed 170 ounces of silver and 74.8 per cent lead.
>
> On the Maple Leaf claim an open-cut partly exposes a vein which is thought to be the continuation of Keno Hill, Limited, No. 1 vein. On the Reno claim two new veins were discovered during the past summer. These were only partly exposed, but showed heavy galena mineralization.

Reporting on the Shamrock group in 1929, Cockfield (1930) said:

> This group has been one of the most consistent producers of the claims held by individuals in the area. It lies near the head of Erickson gulch, adjoining the original holdings of Keno Hill, Limited, on the west, and is being worked under lease from the owners, by McIvor, McKay, and Formo. To date it has shipped 1,900 tons of sorted ore, of which amount 565 tons were shipped during the season of 1928–29.
>
> The workings lie on what is believed to be one of the major veins, sometimes called the Gambler vein, which crosses Faro gulch and swings southwest across the broad flat at the summit above this gulch and consist of a shaft 120 feet deep and inclined at 60 degrees. This shaft has levels driven from it at depths of approximately 65 and 110 feet. The upper level is approximately 580 feet long, and drifts along the vein for about 250 feet to the south of the shaft to form an adit tunnel, and continues 330 feet to the north of the shaft. The lower level follows the vein for about 240 feet north from the shaft, and about 90 feet south. A number of streaks of ore have been encountered and stoped in these workings. As a general rule these have not been large, seldom exceeding 4 feet in width. Although the ore-shoots discovered to date have not been large, it is interesting to note that this property is one that has paid for its development by the ore extracted, and the chances seem very favourable that as development work goes on, other shoots of ore will be discovered.

A few hundred tons of ore was removed from the Shamrock vein in 1930 and a few tens of tons again in 1934 and 1938, after which all work appears to have ceased until the prospect was acquired by United Keno Hill Mines, Limited.

In the summers of 1954 and 1955 this company drove an adit in the head-wall of Erickson Gulch 100 feet below the old workings to intersect the vein fault 200 feet below the surface. Drifting on the vein fault developed an ore shoot 119 feet long which averaged 71.4 ounces silver a ton and 22.0 per cent lead over an average width of 3 feet. Limited raising and diamond drilling did not establish the outlines of this shoot. Work was suspended in the autumn of 1955, and no further work has been done.

Surface and underground examination by the writer revealed the following:

The Shamrock system of vein faults consists of a main vein fault and at least two subsidiaries that branch from the main vein fault into the foot-wall as shown on Figure 2. The strike of the main vein is N 40° E and the dip is 60° SE. The strikes of the subsidiary veins are a little east of north; the dips are unknown. All veins lie in massive quartzite with interbeds of graphitic schist and phyllite (No. 9 quartzite member).

The main vein fault is of the breccia type, 4 to 10 feet wide, and is severely disrupted by cross-fractures and longitudinal slips. The ore shoots favour the hanging-wall of the fault and tend to be sporadic and small, seldom more than 3 feet wide. They are highly oxidized and contain mainly galena, cerussite, limonite, malachite, and manganese oxides.

The ore shoots in the main vein fault appear to be localized beneath the sericite schist band, that formerly overlay the No. 9 quartzite but is now removed by erosion. In this respect the structural control is similar to that in the No. 9 system. In the area south of the adits on the main vein one small shoot occurred at or near the junction of the main vein and a branch vein in the foot-wall.

The Gambler vein crosses the western part of Faro Gulch and outcrops at intervals in its steep western wall. Shafts have exposed it on the flat area southwest of the gulch.

The Gambler vein was found early in 1920 and development work commenced in 1921. The early work is described by Cockfield (1924a) as follows:

> Two adits have been driven on this vein on the Gambler claim. The upper is 50 feet above the lower and 81 feet south of it, and is 50 feet in length. An underhand stope 18 feet long and 12 feet deep is situated 18 feet from the entrance. The lower adit is 40 feet in length.
>
> The vein, which varies in width from 4 to 6 feet, is mineralized with quartz, arsenopyrite, galena, zinc blende, freibergite, and siderite. The ore-shoot mined in the stope varied from 2 feet in width at the top to 3 feet 10 inches at the bottom. This stope yielded 53 tons of ore, about half of which assayed 230 ounces of silver and 34 per cent lead, and the remainder 135 ounces silver and 46 per cent lead. The ore in the stope is not yet exhausted. In the face of the lower adit, which lacks some 40 feet of being under the stope, is a seam of galena 16 inches thick.

The property was acquired by Comstock Keno Mines, Limited in 1951, and the vein was investigated in the next two years by extending the workings from the lower adit to a total of 510 feet. Work was suspended in 1953 and nothing further has been done at the property.

In the new workings the vein fault dips 50° to 65° S and varies in width from 5 to 15 feet. It cuts through thick-bedded quartzites with interbeds of graphitic schist and phyllite (No. 9 quartzite member). It is mainly a breccia type fault with local sheeted zones in the quartzites. Spur fractures are also numerous and the whole complex is interrupted frequently by narrow longitudinal and cross-slips.

Locally the breccia and sheeted zones contain small stringers and pods of quartz, pyrite, arsenopyrite, siderite, calcite, galena, and freibergite. One of the larger mineralized parts of the fault, some 360 feet from the adit portal, was investigated by means of a 40-foot raise, and a few tons of shipping ore was removed. The mineralized sections appear to be localized near rolls in the vein fault, particularly where the vein fault steepens.

Nabob-Main Vein Fault System

This system (49) outcrops in the head-wall of Faro Gulch (Fig. 9) and can be traced northeast across Silver Basin (Fig. 2). The system strikes N 75° E and dips from 65 to 70° SE. The principal vein fault of the system varies from 5 to 10 feet in width.

In this system the only workings of any consequence are those of Comstock Keno Mines, Limited, on the Nabob claim, where pits, an adit, crosscut, and drift investigated the vein fault. Underground the vein fault was a breccia and sheeted zone and contained quartz, some oxidized siderite, limonite, anglesite, cerussite, and a little galena. No orebodies were found.

Northeast of the Comstock-Keno workings, the vein fault is poorly exposed and appears to be faulted in at least one place. On the Ladue Fraction (54), astride the rim of the western part of the head-wall of Silver Basin Gulch, an adit has been driven on the presumed extension of the vein. In the adit some siderite, quartz, limonite, cerussite, anglesite, galena, freibergite, and arsenopyrite were present. Northeastward, across Silver Basin Gulch, bits and pieces of mineralized float may mark the position of the vein fault.

The southwestern extension of the Main vein fault has not been located, chiefly because no work has been done on it. On Figure 2 it will be noted that the fault passes from the No. 9 quartzite into a thick bed of overlying schist, a favourable structural location for ore shoots. It would seem that early work carried out on the surface in the schist failed to find anything, thus discouraging further work. Underground work or diamond drilling in the quartzites immediately below the schist might be more rewarding.

No. 6 System

The principal vein fault of this system is exposed intermittently from the Dorothy prospect (30) to a point some 2,000 feet northeast of the No. 6 shaft (43). The northeast extension beyond this point is not known with certainty, but the presence of float indicates that the principal vein fault may join the Comstock-Porcupine system in the vicinity of the Gold Hill No. 2 prospect (53). The southwest extension does not outcrop, but a pronounced lineament suggests that it may continue for at least 3,000 feet southwest of the most southwesterly of the Dorothy shafts.

The principal vein fault strikes N 65° E, dips 75 to 85° SE, and varies in width from a foot or so in schists and phyllites to 15 feet or more in greenstones. At the surface it is significantly mineralized with quartz, pyrite, arsenopyrite, siderite, sphalerite, and galena at three known localities—in the vicinity of the Dorothy shafts, at the No. 6 shaft, and 1,500 feet southwest of this shaft.

The Dorothy shafts have caved and the vein is so poorly exposed on the surface that no detailed description at this locality can be given. Material on the dumps includes some massive and coarsely crystalline siderite with a little galena and freibergite, and some quartz with pyrite and arsenopyrite. According to local reports no ore was removed from the workings.

The mineralized zone southwest of the No. 6 shaft has been exposed along its length by a deep bulldozer-cut (Fig. 2). In the cut the vein fault is a complex of ramifying fissures and brecciated zones 10 or more feet wide, mineralized locally with quartz, pyrite, arsenopyrite boulangerite, meneghinite, siderite, galena, and sphalerite. Oxidation is extensive and has yielded much powdery limonite with some azurite, malachite, manganese oxides, anglesite, cerussite, and beudantite. The foot-wall of the vein fault is greenstone and the hanging-wall graphitic schist and phyllite. No ore shoots are known at this locality, and no ore has been removed. Immediately southwest of the No. 6 shaft the vein fault was explored in 1948 and 1949 by United Keno Hill Mines by means of several bulldozer-cuts. The cuts revealed lenses containing quartz, pyrite, arsenopyrite, and boulangerite, and others containing siderite, galena, and sphalerite, over a length of 450 feet and an approximate width of 11 feet. These carried relatively low values in gold, silver, lead, and zinc.

The No. 6 shaft was sunk to a depth of 42.5 feet in 1952 by United Keno Hill Mines, and a drift was driven northeast for some 16 feet on the vein. About thirteen tons of ore was removed at that time. During the summer of 1956 the same company drove an adit 1,364 feet long from the southeast side of Keno Hill and crossed the vein at right angles to its strike. A hanging-wall drift 249 feet long and a foot-wall drift some 79 feet long were run southwest and northeast respectively along the vein. According to the 1956 annual report of United Keno Hill Mines, Limited, the No. 6 vein fault was fairly well mineralized but assays were below ore grade.

According to Zajac (1957), who has studied the No. 6 vein in the vicinity of the No. 6 shaft area, the following features are apparent:

1. The No. 6 vein fault may be classified as a normal oblique-slip fault with a small left-handed displacement. It strikes N 60° to 68° E and dips 81° SE to 85° NW with somewhat greater local variations of attitude where the vein fault cuts greenstones.

2. In the greenstone, the No. 6 vein fault is about 13 feet wide and consists of several parallel to subparallel shear planes, the most prominent of which is along the hanging-wall of the zone. The greatest amount of movement occurred along the hanging-wall shear plane, as indicated by the greatest amount of gouge (up to 3 inches) and breccia. The other shear planes are less prominent, more irregular, branching, and discontinuous in places.

3. The greenstone wall-rocks are closely jointed by shear and tension joints. In the greenstones the most prominent joints near the fault can be grouped into two sets as follows:

(a) Those striking N 10 to 15° E and dipping 80 to 90° SE.

(b) Those striking N 65 to 70° E and dipping 10 to 20° SE.

Zajac was unable by means of a stereonet to relate the joints to the fault movement.

4. Where the schist forms one of the walls, the vein fault consists of a single shear plane and lacks gouge. Where schist forms both walls, the fault is poorly developed and can only be traced in surface trenches.

5. The mineralized parts are confined within the vein fault, and only a few tension joints contain some hypogene minerals. The mineralized parts are widest in greenstone, narrower where schist forms one of the walls, and practically non-existent where

both walls are schist. In greenstone the mineralized parts consist of parallel to subparallel veins and lenses branching and converging along the different shear planes and fissures of the fault zone.

6. The veins and lenses have sharp contacts with the wall-rocks and range in width from 1 inch to 6 feet, the widest of which pinches and swells along the vein fault.

7. The veins and lenses are of two types: early quartz veins and lenses containing mainly pyrite and arsenopyrite, and later siderite veins and lenses containing mainly sphalerite, galena, and freibergite. Most of the siderite veins occur as separate irregular, pinching bodies along the main vein fault, either adjacent to or separated from the earlier quartz veins by sheared greenstone.

The mineralized parts of the No. 6 vein fault system are restricted principally to sites where the wall-rocks are quartzites or where greenstones form one or both walls. This is particularly notable at the No. 6 shaft and at the other locality southwest of this shaft. Exploration in this system should, therefore, be restricted to the favourable quartzites and greenstones, particularly below the sites where the vein fault passes upward into schists.

Comstock-Porcupine System

This system is exposed in the workings of the Porcupine (44) and Comstock Keno mine (45). From the latter the principal vein fault (originally known as the Kinman vein) can be traced northeast through the Gold Hill No. 2 (53) prospect to its probable extension, the Gold Queen vein (57) in the Silver Basin area. The southwest extension passes through the Apex claim (37) where it is faulted as shown on Figure 2. The faulted extension has not been located with certainty, but factors such as location, strike, and dip suggest that the Hogan vein of the Mount Keno system described below may be the southern extension of the Comstock-Porcupine system.

Cockfield (1930) described early work on the system as follows:

> On the Kinman vein, representation work being done on the Porcupine claim near the head of Hope gulch encountered a shoot of ore 4 feet wide, which where exposed in the open-cut consisted of massive galena. Data with regard to the length of this shoot have not yet been obtained. The extension of this vein has also been discovered on the Teresa claim near the head of Charity gulch. This property is owned by Smith, Corp, and Ryan, and is leased to a group of individuals. The workings here consist of a shallow shaft, which at the time of the writer's visit had not quite reached bedrock, but which was yielding the float of the vein, making it apparent that the outcrop was not far off. This float was mineralized with quartz and arsenopyrite but contained none of the ore minerals.

The same author describing the Apex prospect wrote:

> This property is on the southern slope of Keno hill, on the southwest side of Charity gulch, and is owned by T. McKay, and worked under option by F. Hoffman and J. Grenier.
>
> The development work includes an open-cut terminating in an adit with a winze sunk near the face. The general course of the vein is north 45 degrees east, and it is composed mainly of manganese oxide and siderite. Most of the workings do not permit of obtaining an idea of the mineralization owing to the timbering that was necessary in the adit. At 35 feet the adit encountered a slip striking north 77 degrees east, and dipping to the northwest on which a winze was sunk 18 feet. This slip was mineralized with calcite and zinc blende. The workings to date have not encountered any ore-shoots of value.

Visel visited the Porcupine prospect in 1930 and described it in his private report as follows:

> The Porcupine vein follows a previously unknown vein of the older series which has been re-opened. It is 4 to 5 ft. wide in its widest point, not including the quartz of the older vein, which is about two feet. In places the width reduces to two and three feet, but this is probably due to post-mineral slip movement, as the vein matter and ore is badly crushed and 'chewed up'. The ore in this vein is of milling grade, averaging about 60 to 70 ounces silver to 10 to 12% lead per ton, with a gangue of siderite and crushed quartz.

According to the underground plan accompanying Visel's report, the Porcupine vein was explored by a 50-foot shaft, an adit some 200 feet long, and a drift 160 feet long. The wall-rocks of the vein are sericite schist, limy schist, and greenstone. The best assays occurred in the section of the vein fault where the foot-wall was shattered greenstone. Examination of dump material and inspection of Visel's plan indicate two major periods of mineralization—an initial deposition of quartz, pyrite, and arsenopyrite lenses followed by a second stage of siderite lenses containing galena, sphalerite, and freibergite. Near the surface the hypogene minerals are highly oxidized yielding mainly limonite, manganese oxides, anglesite, cerussite, and secondary copper carbonates.

The northeast extension of the Porcupine vein was investigated by Comstock Keno Mines, Limited, in the summer and autumn of 1954. An adit was driven 300 feet northeast to the vein, and drifts were run along the vein 75 feet southwest and 240 feet northeast, respectively. Work was suspended late in 1954.

The vein fault, as exposed in the Comstock Keno drift, dips 70 to 85° SE and is a breccia zone 8 to 10 feet wide. As in the Porcupine prospect, two main periods of mineralization occurred. The first is represented by small quartz-pyrite-arsenopyrite veins and lenses and the second by pods of galena, in places a foot or more wide. These pods together with disseminated sphalerite, siderite, and oxidation products such as limonite, anglesite, malachite, and cerussite form a small ore shoot whose dimensions were not fully investigated. The shoot appears to be restricted principally to those parts of the vein fault where greenstone forms one or both walls.

Small mineralized zones occur in the Comstock-Porcupine vein fault 1,600 feet southwest of the Porcupine shaft, on the Apex property (37), at the Gold Hill No. 2 shaft (53), and on the Gold Queen (57), and other claims. No ore shoots have been found at these places, but it should be noted that a favourable site for ore shoots exists in the No. 9 quartzite below the overlying sericite schist, southwest of the Gold Hill No. 2 shaft. This favourable locus rakes into the Comstock Keno and Porcupine properties and merits some investigation.

Onek System

The Onek system (22) consists of a principal vein fault with subsidiary intersecting and subparallel vein faults and fractures. The system outcrops northeast of Keno Hill townsite, strikes N 45° E, and can be traced from a point a few hundred feet northeast of the townsite, northeast for 3,000 feet. Both extensions on the surface are covered by drift.

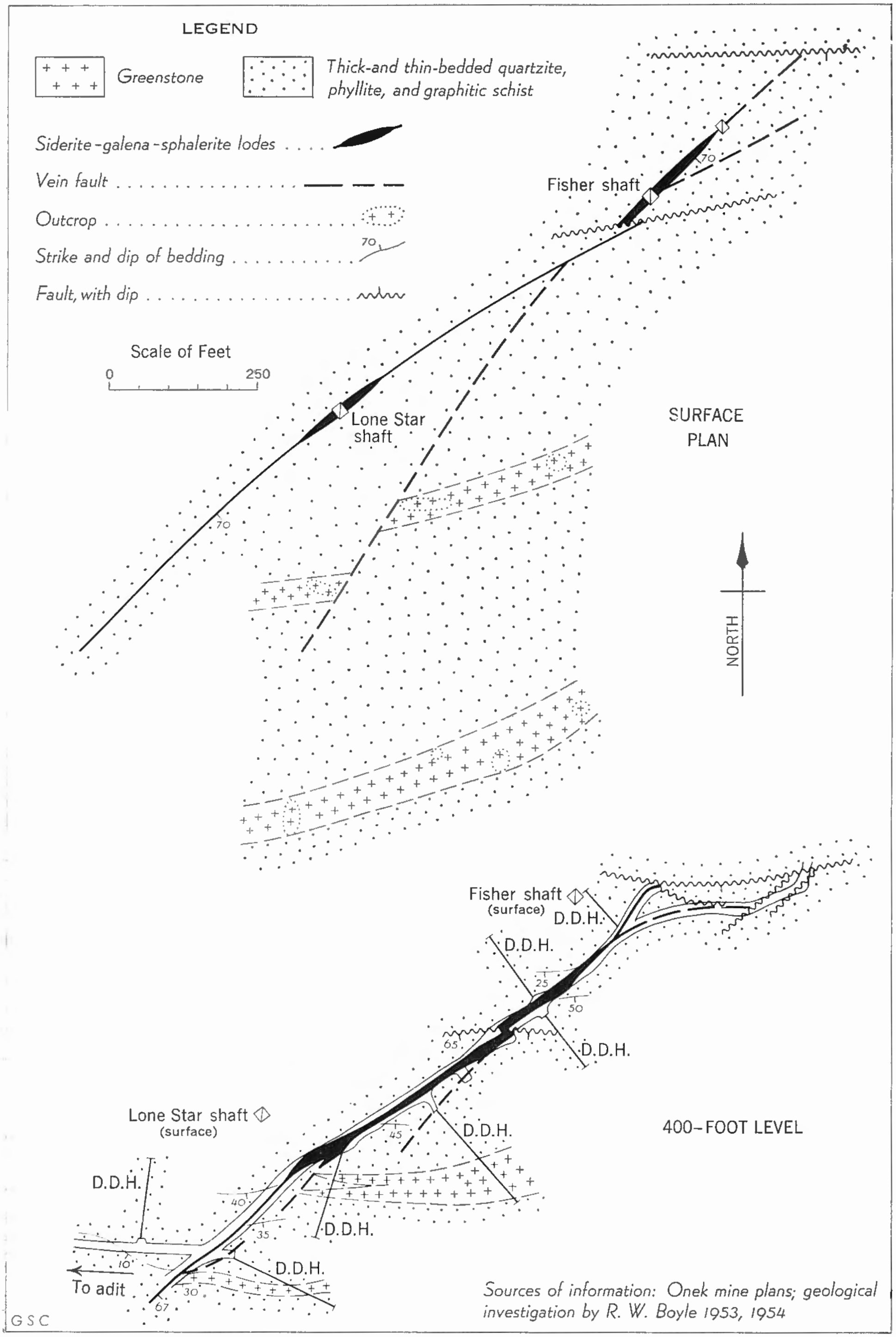
The early exploration of the principal vein fault is described by Cockfield (1924a) as follows:

> The Onek Mining Company, Limited, was organized in 1922 to secure options on a number of claims in the Keno Hill area. This company was under the control of the Slate Creek Mining Company. A number of claims were prospected, but the chief work was done on a group, the Fisher, Lone Star, Galena Farm, and Rando, situated on the southern and western slope of the hill close to Keno Hill townsite. Operations were discontinued in 1922 and have not since been resumed.
>
> A vein has been traced by means of a number of open-cuts across the Fisher, Lone Star, and part of the Galena Farm claims. On the Lone Star claim it is faulted about 100 feet to the north as shown by the line of open-cuts. The underground workings consist of a vertical shaft 135 feet deep and two levels at 50 and 100 feet, which are 30 and 97 feet long respectively. The vein gives evidence of continuity on the surface, and there is no evidence of change in mineralization to the depth that workings have been carried. The mineralization consists of siderite, galena, and lead carbonate. A fairly persistent streak of galena varying from 2 to 20 inches in thickness is exposed in the workings. The values shown by a number of assays range around 80 ounces of silver to the ton. On the 50-foot level the galena averaged 80 ounces of silver; on the 100-foot level assays across a face of 12 inches yielded as high as 140 ounces. In the bottom of the shaft across a face of 8 inches the galena assayed as high as 165 ounces. On the 50-foot level the galena averages 20 inches in thickness; on the 100-foot level it varies from 3 inches up to 20 inches, and between the 100-foot level and the bottom of the shaft the vein flattens somewhat, and splits into two branches; the northern branch gave the assay referred to above, whereas the south branch has 4 to 5 inches of galena assaying 6 to 10 ounces. The values contained in the galena on this property are considerably lower than the average of the shipping ore from other properties which are shipping.

There is no adequate record of the amount of ore removed during the early development and mining. From local reports and the size of the workings only a few thousand tons of oxidized ore were probably won from the vein in the vicinity of the Fisher shaft. Judging from the writer's near-surface sampling of the vein at the Fisher shaft the ore averaged 88.1 ounces Ag/ton, 42 per cent Pb, and 0.67 per cent Zn.

During the period 1950–52 United Keno Hill Mines, Limited, investigated the system by reopening the two shafts (Lone Star and Fisher) and driving an adit from a point north of Keno Hill townsite eastward 1,566 feet. At this point the adit intersects the main vein fault at a depth of 400 feet and connects with a drift that explored the vein fault along its strike for about 1,300 feet. Raises driven at intervals along the drift connect with other drifts that investigated the upward extension of the vein fault. According to the 1952 annual report of United Keno Hill Mines, Limited, these workings developed a series of ore shoots containing 148,750 tons of ore averaging 10.27 ounces Ag/ton; 4.4 per cent lead; and 13.0 per cent zinc. Of this ore, some 25,263 tons was removed as development ore. No mining has been done since September 1952.

At the surface the vein fault pattern of the system (*see* Fig. 10) is not clear because of thick overburden and the presence of many cross-faults and slips. Surface mapping by the writer suggests that to the south the main vein fault branches into two closely spaced vein faults; to the northeast it is probably joined by a subsidiary vein fault northeast of the Lone Star shaft. This subsidiary structure is narrow and appears to offset a greenstone sill a few feet. It is not known to carry any ore shoots. Southwest of the Fisher shaft the vein fault is offset by a cross-fault; northeast of the shaft the main vein fault is joined by several small subsidiary vein faults and spur faults which are barren.



Sources of information: Onek mine plans; geological investigation by R. W. Boyle 1953, 1954

FIGURE 10. Plan of surface and 400-foot level, Onek mine, Keno Hill.

On the 400-foot level the main vein fault is a breccia zone 10 to 20 feet wide dipping 65 to 70° SE. The sedimentary beds and greenstone bodies in the access adit dip at 10 to 20° S and steepen to 40° S or more as they enter the vein fault zones. Judging from the drag on the beds, the hanging-wall of the main vein fault moved northeast with respect to the foot-wall. Neither the amount of horizontal nor vertical movement can be estimated.

Two hundred and seventy-five feet northeast of the intersection of the adit and drift on the 400-foot level the main vein fault is joined by a series of easterly dipping spur fractures trending at S 40° W into the hanging-wall. A similar situation exists at a distance of 600 feet, and at 800 feet the vein fault splits into two branches. At each of the junctions with spur fractures and southwest of the point where the vein fault splits into two branches, mineralized zones and ore shoots are present as shown on Figure 10.

On the 400-foot level the ore shoots are mineralized, chiefly with siderite, sphalerite, and a little quartz; galena and freibergite are less common. Near the surface galena, freibergite, chalcopyrite, anglesite, cerussite, oxidized siderite, and various other secondary minerals constitute the ore.

The northern extension of the Onek system terminates against a fault zone some 20 feet or more wide. The data from an examination of the drag effects in this fault zone on the 400-foot level suggest that the main vein fault is offset an unknown distance to the east. It is possible that the fault offsetting the Onek system is the same as that offsetting the Hogan vein fault of the Mount Keno system. However, so many of these faults are present in the Onek-Mount Keno area that precise correlations cannot be made.

The position and strike of the Onek system suggest that it may be the southern extension of the Comstock-Porcupine system. The presence of some mineralized rock in isolated cuts on the northern extension of the Onek system suggests that a continuous vein may exist, but the common occurrence of northwest-trending cross-faults and the general heavy drift make it impossible to trace the Onek system beyond its extent as shown on Figure 2.

Mount Keno System

This system consists of two well-developed parallel vein faults 2,000 feet apart and striking N 40° E. Other small vein faults and fractures occur in the vicinity of these main faults.

The western or Hogan vein fault (27) was investigated by an adit, crosscuts, and drifts at an elevation of 3,300 feet by Mount Keno Mines, Limited, and by an adit, crosscut, and drift at an elevation of 3,800 feet by Ankeno Mines, Limited, during the period 1952–54. Cuts and pits expose the vein at several places.

The Hogan vein fault, as exposed in the Mount Keno and Ankeno workings, is a strong break 5 to 10 feet wide, dipping 60 to 80° SE. The vein fault consists of highly brecciated and comminuted quartzite, graphitic schist, and some greenstone. The hanging-wall of the break has moved northeast about 100 feet relative to the foot-wall. Along its exposed length, the vein fault is cut by longitudinal and cross-slips and by two northwest-striking faults that dip at about 45° SW. These faults offset the vein to the west as it is traced south.

The Hogan vein fault contains much coarse siderite now partly oxidized to limonite and manganese oxides, massive pyrite lenses, and a little sphalerite and galena. No ore bodies were located during the exploration work.

The eastern or Runer vein fault (29) was first explored in the twenties and a little ore was probably removed. In the period 1952–54 the vein was further investigated by Mount Keno Mines by means of two adits and connecting drifts, one at an elevation of 3,800 feet, the other at 3,900 feet. In addition to these workings numerous pits, bulldozer-cuts, and shafts expose the vein at several places.

In the quartzites the vein fault is a breccia zone from 1 foot to 5 feet wide; in the greenstones it forms a sheeted zone about the same width. The dip is irregular, varying from 45° to 70° W, and many branches and rolls are present both along the strike and dip of the vein fault. Many longitudinal and cross-slips occur, and northwest-trending cross-faults offset the vein fault in two places. The extensions of the vein fault north and south of these faults are not known with certainty.

The minerals in the Runer vein are oxidized siderite, limonite, galena, sphalerite, freibergite, pyrite, anglesite, and cerussite. Two small ore shoots, containing not more than 100 tons of high grade ore, were found during exploration. One of these, on the 3,900-foot level, occurred in thick-bedded quartzites below a series of graphitic schist and phyllite beds.

The northern extension of the Runer vein fault is not exposed, but the position and similarities in strike and dip of the Vanguard (36) vein fault suggest that it may be the northern extension. This vein fault has a steep western dip and locally contains siderite, limonite, and a little galena and freibergite. The Vanguard vein is probably cut off by a fault on both its southern and northern ends, but the offset parts have not been found.

Bellekeno System

The Bellekeno system (26) occurs on the northern slope of Sourdough Hill, and consists of two main parallel vein faults and several other smaller parallel and intersecting vein faults (*see* Fig. 11). These vein faults are on the Tundra, Whipsaw, Apex Fraction, Eureka, Ram, Chance, and Extension mineral claims. All have been investigated by numerous shafts, adits, sluices, and bulldozer-cuts.

The Tundra claim was originally staked in 1920 by Andrew Johnson. In 1923 it was owned by M. Mellish who had it leased to J. Gillis, J. McHugh, and J. Curley. The Whipsaw and Eureka claims lie immediately southwest of the Tundra; they were originally staked in 1921 by Alex Gordon, who removed about 100 tons of high-grade silver ore from one of the veins (No. 50 vein) on the Whipsaw claim during the period 1921–26, and about 175 tons from the veins on the Eureka claim between 1921 and 1929. The Ram claim adjoins the Tundra claim to the south; it was originally staked in 1920 by Andrew Johnson. According to local reports, about 300 tons of high-grade silver ore averaging 200 ounces Ag /ton and 40 per cent Pb was won from the

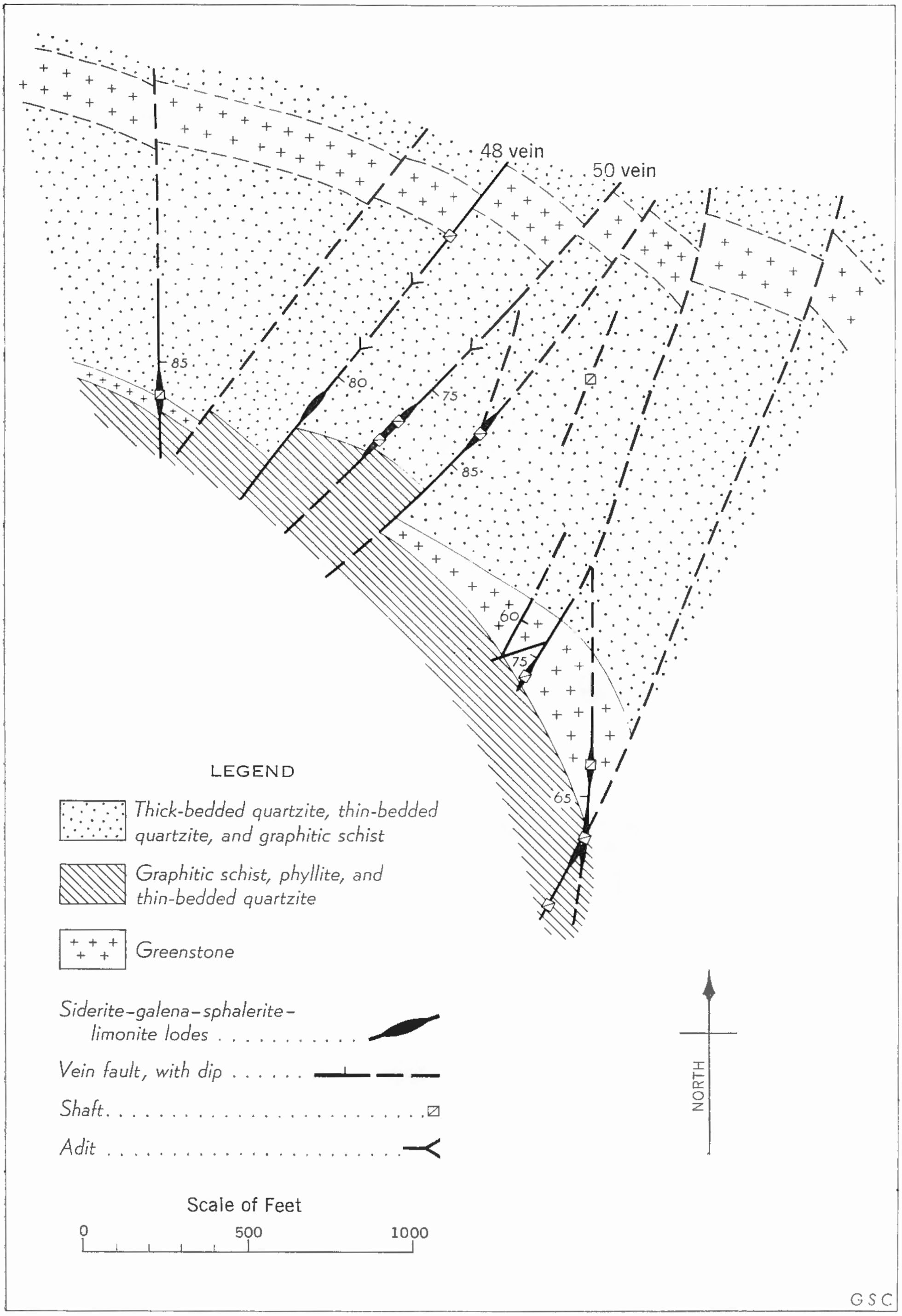


FIGURE 11. Generalized plan showing location of ore shoots and mineralized zones, Bellekeno system, Sourdough Hill.

various veins on the Ram claim. During the boom in the early fifties the Ram claim was purchased by Mayo Mines Limited, who developed and mined a small shoot of unknown tonnage.

Work on the veins during the early twenties is described by Cockfield (1924a) as follows:

> The Thunder (Tundra) mineral claim is situated on Sourdough hill, which lies south of Keno hill across Lightning creek. It is owned by M. Mellish and is under lease to J. Gillis, J. McHugh, and J. Curley.
>
> The workings, in addition to several open-cuts, consist of a shaft and incline 8 feet deep and a drift south from the shaft of 65 feet. There is also a crosscut 6 feet long about 15 feet south of the shaft. The vein was originally discovered in two open-cuts; in the upper cut galena and siderite were found, and in the lower cut, siderite. The shaft lies about midway between the two cuts, and the underground workings are being driven towards the upper cut.
>
> The vein as exposed in the underground workings varies considerably in strike, dip, and thickness. The average strike is about north 30 degrees east astronomic and the dip from 70 degrees to the southeast to vertical. The vein has a thickness of from a few inches to 7 feet. The greater part of the vein filling is siderite. The chief ore minerals are freibergite and galena. These both occur in small bunches, the former apparently favouring the hanging-wall, whereas the latter occurs at random in the vein and also impregnating the wall-rock. Associated with the freibergite are the oxidation products, malachite and azurite. Pyrite, arsenopyrite, and chalcopyrite also occur in small amounts, the pyrite occasionally enclosing the galena. Where the freibergite is present high values in silver are obtained.

Later, in his report on the Mining Industry of Yukon for 1929 Cockfield (1930) refers to the veins as follows:

> A number of promising showings have been located on Sourdough hill, which lies immediately to the south of Keno hill, and a considerable amount of work has been done on these in the past few years. Unfortunately, however, the ownership of this ground has been the subject of litigation, and in the meantime the work has not been proceeded with. Such workings as exist are full of water and, therefore, inaccessible.

In 1953 Bellekeno Mines, Limited, acquired the principal showings on Sourdough Hill, and during 1953 and 1954 investigated and developed two ore shoots on one of the strongest vein faults (48 vein) and exposed a parallel vein fault (50 vein) on one level. Figure 12 shows the disposition of the ore shoots and other geological features of the 48 and 50 veins. All the vein faults in the system are similar in structure but differ in width and continuity. A description of the 48 vein will suffice as an example for the system.

The 48 vein is a brecciated zone some 5 to 15 feet wide in the thick-bedded quartzites, but narrows abruptly to a series of horsetail fractures and slips containing gouge and comminuted schist in the graphitic schist and phyllite overlying the quartzite. It strikes N 35° E, dips 80° SE, and the northwest wall has moved up and southwest with respect to the southeast wall. Numerous longitudinal slips cut both the barren parts and ore shoots, and cross-slips with small displacements offset the vein fault at many places along its exposed length.

As shown by Figure 12, two main ore shoots and other mineralized zones are present in the vein fault. The ore shoots contain limonite and manganese oxides, galena, sphalerite, freibergite, siderite, calcite, anglesite, cerussite, smithsonite, gypsum, and quartz. Mineralized zones contain limonite and other oxides, siderite, and small amounts of galena and sphalerite.

Before exhaustion in October 1954, the two ore shoots produced approximately 11,000 tons of ore averaging 65 ounces Ag/ton, 25 per cent Pb, and 3.5 per cent Zn.

The principal ore shoots of the Bellekeno mine were localized in the Silver King quartzite member directly beneath the upper schist formation. Thick-bedded quartzites generally form the walls of the ore shoots, but the upper part of the largest ore shoot in the Bellekeno mine occurred where the foot-wall and hanging-wall were quartzite and graphitic schist respectively. No ore shoots were found in the upper schist formation. The mineralized zones and ore shoots rake 45° NE.

The Bellekeno system affords an excellent example of the localization of ore shoots and mineralized zones at quartzite-schist or greenstone-schist contacts. This relationship is shown clearly by Figure 11. Similar relationships also exist at the Moth property (21) and at several other properties on Keno and Galena Hills. During exploration it is, therefore, important to examine all places where vein faults pass from thick-bedded quartzite or greenstone into overlying schists, phyllites, and thin-bedded quartzites.

Other Vein Faults

Numerous other vein faults with strikes parallel or subparallel to those described above occur on Keno Hill. Most of these vein faults have short strike lengths and cannot be traced far owing to heavy overburden or poor development in schists and phyllites.

The east-west vein at the Klondyke-Keno property (23) cuts greenstone. It is a few inches to 3 feet wide, strikes N 80° E, and probably dips about 70° N. Its northeastern extension appears to be cut off by the main north-south vein; it has not been found. The southwest extension of the vein passes into graphitic schist and phyllite and cannot be traced beyond the pits shown on Figure 2.

Two periods of mineralization have produced: first, quartz (both massive and prismatic), arsenopyrite, and pyrite; and second, galena, sphalerite, siderite, meneghinite, bournonite, chalcopyrite, and tetrahedrite. The main secondary minerals are anglesite, azurite, malachite, covellite, and limonite. The hypogene minerals occur principally in massive or brecciated quartz veins and lenses. Some fill clear prismatic quartz vugs. No ore shoots are known to occur in the vein.

The vein fault on the Helen claim (52) has been prospected by three adits, a shaft, and an open-cut. Where exposed in these workings, the vein fault appears to strike about N 80° E and probably dips about 65° S. It may extend eastward on the lower slope of Monument Hill and may be the western extension of the northern vein fault on the Divide (61) and other claims.

In places the Helen vein fault is 2 to 5 feet wide and contains lenses of fractured quartz, and some siderite, galena, freibergite, arsenopyrite, and meneghinite. Much of the galena fills prismatic quartz-lined vugs and crushed zones in the lenses. The main secondary minerals are anglesite, cerussite, limonite, manganese oxides, and beudantite. No ore shoots are known in the Helen vein fault.

On the Lake View claim (50) a vein fault has been investigated which may be the northeastern extension or a spur of the Shamrock-Gambler system. The workings include cuts and an adit now all sloughed in and caved. Vein material in the cuts and on old dumps suggests that the vein fault contains pods of quartz, siderite, galena, freibergite, and sphalerite. Secondary minerals are mainly limonite, azurite, malachite, anglesite, and cerussite.

On the Nabob No. 2 claim (51) a poorly exposed vein fault has been investigated by three or more prospect shafts, now all caved. This vein appears to strike about N 50° E and intersects graphitic schist, thin-bedded quartzite, phyllite, and perhaps greenstone on its northeastern extension. Vein material on the dumps includes oxidized siderite, galena, freibergite, limonite, azurite, malachite, anglesite, and cerussite. There is no record of any ore shoots having been found in this vein fault.

The two subparallel vein faults on the Fox claim (55) are poorly exposed and difficult to trace. They appear to strike about N 40° E, cut through quartzites and schists, and offset a quartz-feldspar porphyry sill. Vein material on the dumps includes brecciated quartz, oxidized siderite, calcite, galena, freibergite, and sphalerite. No ore shoots are known in these and associated vein faults.

On the Silver Basin claims (56), the strikes of a number of narrow vein faults range from N 50° E to N 75° E. Associated with these are others that strike N 50° W to N 25° W. These veins were originally staked and prospected by R. Rasmusen.

Cockfield (1921a) described the early work on the Silver Basin claims as follows:

> Rasmusen's claims are situated on the western side of Silver Basin gulch and consist of the Silver Basin, Silver Basin IV, Diorite, and Silver Gulch. A main longitudinal fault striking north 30 degrees east and dipping 65 degrees to the southeast cuts across the property. This has the typical quartz-arsenopyrite mineralization, with some galena. Four transverse faults intersect this main fault and pass upward from the quartzites into the schists. The chances for mineralization at these points have already been pointed out. The work done consists of some open-cuts and trenches, but is insufficient to show the true value of the property.

Later developments were summarized by Cockfield (1924a) in the following terms.

> The Silver Basin claim is owned by R. Rasmusen and lies on the western slope of Silver Basin gulch. Development consists of one short adit and a number of open-cuts and trenches. Five veins, numbered in the order of their discovery, have been exposed in these workings. No. 1 vein is exposed in an adit which lies several hundred feet from the western boundary of the claim. It strikes north 67 degrees east astronomic and dips to the southeast at 60 degrees. The vein where exposed cuts quartzite, but a short distance above passes into schist. The mineralization is typical comprising galena, siderite, and freibergite. In running the adit a small shoot of ore was encountered which, however, was passed through. Further work on this vein is desirable, but this should not be carried into the overlying schist. No. 2 vein strikes north 74 degrees east astronomic and dips 37 degrees to the southeast. It is exposed in a small open-cut to the northeast of the adit, where it has a width of about 1 foot. The mineralization is mainly quartz and arsenopyrite, but a small amount of galena occurs. Vein No. 3 is exposed in several open-cuts at the top of the quartzite band referred to above, and a short distance below a sill of quartz porphyry. The strike and dip are variable, but the strike averages north 48 degrees west and the dip 75 degrees to the southwest. The mineralization is practically the same as vein No. 1. Vein No. 4 is one of the most important showings on the property. It is exposed in a series of open-cuts near the eastern boundary of the claim, and has a width of 4 feet. It strikes north 23 degrees west and dips to the southwest at 50 degrees. The mineralization shows quartz, galena, siderite, and freibergite. This vein has been traced over 100 feet by means of open-cuts, and also appears on the adjoining claim, Silver Basin No. 4, owned by M. Michie. The ore minerals are disseminated. Vein No. 5 lies 150 feet east of No. 3 above the quartz porphyry sill referred to. It is only partly exposed in an open-cut where it has a width of 8 feet and is mineralized with quartz, arsenopyrite, galena, freibergite, siderite, barite, and occasional flakes of native silver. It is cut off in the open-cut by a steeply dipping normal fault, the throw of which is small.

> Four of the five veins discovered on this claim belong to the earlier or quartz-arsenopyrite type. There is ample evidence that transverse veins also occur, and it is likely that these are mineralized. These transverse faults are well shown in the upper bed of the quartzites which cross the property, and it is believed that further trenching will uncover veins other than those described.

In 1952 Yukeno Mines, Limited, did some work on one of the veins by extending the adit but failed to find any substantial orebodies. Since then no work has been done and all of the workings are now caved and inaccessible.

The position of the longitudinal veins on the Silver Basin claims suggests that they may be the northeastern extension of either the Shamrock-Gambler or No. 1 vein fault system. The veins are favourably situated, as pointed out by Cockfield, in quartzites below a schist capping, and furthermore there are several transverse veins with the possibility of some favourable vein fault junctions.

On the Gold Queen claim (57), two or more veins, representing the probable northeastern extension of the Porcupine-Comstock system, are exposed in open-cuts, trenches, and a short inaccessible adit. In the open-cuts the veins contain limonite, black siderite, sphalerite, galena, and some freibergite. No ore has been removed from any of the veins, but they are favourably situated in quartzites below schist and seem to warrant further prospecting.

Two subparallel vein faults are exposed by several cuts on the Divide (61) and other claims on the flat area between the heads of Hope and Faith Gulches. These vein faults cut phyllite and sericite schist, are irregular, and difficult to trace beyond the limits shown on Figure 2. Locally, they contain pods and short irregular veins of quartz (some massive and some prismatic), with siderite, galena, arsenopyrite (?), and sphalerite. No ore shoots are known to occur.

On the Faith group of claims (63) a vein fault that may be a subsidiary of the southern vein fault on the divide claims has been prospected by several cuts. This vein fault strikes about N 70° W through quartzites and phyllites and contains a few small pods of siderite and galena, limonite, cerussite, and anglesite. Prismatic quartz crystals up to 2 inches long are present locally. No ore shoots have been found in the vein fault.

The Homestake group of claims (42) lies on the north slope of Bunker Hill, at an elevation of 4,500 feet. They were originally staked by J. Walsh in 1928 (?) and were owned in the early fifties by G. Lee of Whitehorse and A. C. Bleiler.

Early work on the claims is summarized by Cockfield (1930) as follows:

> The work done consists of two open-cuts, and a shaft 43 feet deep with a drift 15 feet long in a southerly direction from the bottom of the shaft. The shaft at the time of the writer's visit was filled with water to within 6 feet of the surface, so that very little of the vein could be seen. The strike of the vein is approximately north 30 degrees east astronomic, and the dip 70 degrees to the southeast. It is reported that at the bottom of the shaft the vein had a width of 7 feet; composed of a little over 3 feet of siderite, and somewhat over 2 feet of shattered quartzite with siderite, followed by 1 foot of siderite with streaks of the ore minerals through it. South in the drift the vein narrowed to 5 feet, and was about half siderite and half country rock; towards the end of the drift the siderite appeared to pinch out. The siderite is coarsely crystalline with blebs and streaks of galena and grey copper in it. To the north of the shaft a width of 4 feet of siderite was encountered in an open-cut, and still farther to the north a second open-cut, which had not reached bedrock, showed heavy siderite float. Further surface prospecting is desirable on this property, before underground work is undertaken, but prospecting is difficult, as the overburden is about 12 feet thick.

The workings, all now inaccessible, consist of a shaft, a short adit, and numerous open-cuts, prospect pits, and sluices. The material on the dumps consists of coarse-grained manganiferous siderite, cementing fragments of quartzite, and some coarse- and fine-grained galena, freibergite, and black sphalerite. Quartz is present on some of the dumps, suggesting that quartz veins may form part of the mineralized sections of the veins.

According to local reports, a few tons of high-grade lead-silver ore were removed from the property in the mid-thirties.

The relationship of the Homestake veins to others on Keno Hill is not clear. Their position suggests that they may be the southwestern extension of the veins exposed on the Divide and other claims. They are favourably situated in a series of thick-bedded quartzites that seem to be equivalent to those at the Onek mine. At the intersection of the southwestern projection of the veins and the upper schist formation a situation similar to that at the Bellekeno mine may obtain.

Transverse Vein Faults

The best known systems in this category are the No. 9 and Moth. Here also belong the Croesus vein, the Caribou vein, the vein fault on the Devon claim, and several other vein faults in the vicinity of the Lucky Queen and Bellekeno mines.

The No. 9 system was mainly responsible for the production of lead-silver concentrates during the early twenties, and its high-grade shoots stimulated the later development of the Keno Hill camp. The Moth system contains an orebody high in zinc but low in silver, making it uneconomic at present.

In the overall fracture pattern of the vein faults, the transverse systems are probably subsidiaries of the more persistent longitudinal vein faults.

The internal nature and mineralization of the transverse vein faults are similar to those in the longitudinal systems. In quartzites and greenstones they are breccia or sheeted zones and can easily be traced; in schists they are narrow fractures, slips, and crenulated zones that are difficult to follow at the surface or underground.

The mineral assemblage in most vein faults is complex and is described in detail in Chapter V. Siderite, galena, sphalerite, freibergite, quartz, and pyrite, are the principal hypogene minerals, and limonite, wad, anglesite, cerussite, beudantite, calcite, dolomite, and copper carbonates are the main supergene minerals in the oxidized zones.

No. 9 System

Galena float and mineralized vein material were noted on Keno Hill as early as 1910, but the high-grade silver veins of the No. 9 system were not discovered until July 1919, by Louis Beauvette. His discovery led to a stampede during which more than a hundred claims were staked and recorded on Keno Hill. In 1919 Keno Hill Limited, a subsidiary of the Yukon Gold Company, secured options on a number of claims, and development and mining on several veins in Faro Gulch and vicinity was commenced. By the autumn of 1923 the main ore shoots were exhausted.

The No. 9 system (46) consists of several parallel to subparallel vein faults that outcrop in the head-wall of Faro Gulch and on the greenstone knob known as Keno Summit. These vein faults strike from N 30° to 40° E, dip steeply southeast, and appear to be small displacement cross-over faults between the two longitudinal faults known as the Main fault and No. 6 system. Field mapping of the vein faults of the system indicates that they occur only between these two longitudinal faults.

The vein faults are of the breccia and sheeted type in quartzite and greenstone, and narrow fractures and crenulated zones in the schists which cannot be followed with any continuity. The numeration and situation of the vein faults and the location of ore shoots in the principal vein faults are shown on Figure 9.

Of the numerous vein faults in the system, the No. 9 was the most productive and was investigated to a depth of 300 feet by shafts and adits and below 300 feet by an internal inclined shaft. In these workings and on the surface the vein fault dips 70° SE, varies from 2 to 8 feet wide, and is a strong breccia fault zone in the quartzites; in the schists it is a series of closely spaced fractures that cannot be traced far with confidence. Near the surface the ore shoots were highly oxidized and contained galena, limonite, beudantite, jarosites, cerussite, anglesite, manganese oxides, and oxidized siderite, freibergite, and sphalerite nodules. Some native silver was found on the second and third levels. An average assay of this material, taken from the records of Keno Hill Limited, was as follows:

Ag — 203.0 oz. per ton
Pb — 58.9%
Cu — 0.25%
Fe — 3.5%
Zn — 0.5%
S — 6.9%
SiO_2 — 12.25%

In the lower parts of the ore shoots the main minerals were siderite with disseminated galena, sphalerite, and freibergite. Assays of this material probably averaged 60 ounces Ag a ton, 10 per cent Pb, and 7 per cent Zn. The ore shoots were localized below the line on the vein fault above which both walls are schist. They were irregular in outline with a southeast rake and had either a quartzite foot-wall and schist hanging-wall or quartzite on both walls. Post-mineral fractures sliced through the shoots in several places and cross-faults offset the vein a few feet. The ground in the workings was frozen to a depth of 400 feet.

The No. 3 vein fault was investigated by a shaft to a depth of 150 feet and three levels at 30, 75, and 150 feet. According to Cockfield (1924a), the first level was 140 feet long and reached the surface on the steep side of Faro Gulch. The second level was 180 feet long and was connected with the first by a winze with an intermediate level. The winze also connected the second and third levels. Five small ore shoots were found in the vein fault, which dips 80° SE, varies in width from 2 to 5 feet, and shows a strong development of breccia where it cuts quartzites. A study of the longitudinal section of this vein fault indicates that the ore shoots were localized where one or both of the walls were quartzite. Where the vein fault had schist on both walls it was narrow and irregular, and no ore shoots were found. The mineral assemblage of the No. 3 was similar to that of No. 9. The ore shoots were irregular in outline and raked flatly southeast following the schist-quartzite contact.

According to Visel, No. 12 vein fault yielded only a very small shoot of ore near the portal of an adit driven along the vein fault for some 350 feet to the schist-quartzite contact. A winze was driven on the shoot and exposed some milling-grade ore.

Number 2 vein fault is probably the continuation of No. 9. It occurs in greenstone, dips 75° SE, is 2 to 5 feet wide, and is mineralized locally with siderite, some galena, and freibergite. No ore shoots of any size were found. Numbers 5 and 5-2 vein faults contained a few hundred tons of highly oxidized and enriched ore in greenstone. Numbers 4 and 6 vein faults also occurred in greenstone and contained ore shoots comparable in size to those of Numbers 5 and 5-2.

The No. 9 system as a whole contained only small ore shoots. Records show that about 9,000 tons averaging 200 ounces silver a ton and 60 per cent lead was taken from the No. 9 vein, and Visel estimated that 10,000 to 12,000 tons of disseminated ore remain in the mine. The other veins produced small ore shoots of which only a few contained more than 500 tons.

The ore shoots in all vein faults of the system were localized just below the line above which both walls are schist, and no ore shoots were found at more than 200 feet perpendicularly from this line. In the greenstones, siderite was an important primary gangue mineral, whereas in the quartzites it was not abundant. The ore was highly oxidized and enriched and could be sacked and shipped without concentration.

Moth System

The Moth system (21) is west of Keno Hill in the low-lying area between the townsite and Christal Lake. It consists of one principal vein fault and other narrow vein faults and fractures that cannot be traced far because of thick overburden. In the early twenties some of the veins were prospected, and a little development ore was probably removed.

The principal vein fault strikes N 30° E, dips 65° SE, and has been traced northeast from Lightning Creek for 2,000 feet. The vein fault is a breccia and sheeted zone from 5 to 20 feet wide in the quartzites and a shattered breccia zone of the same width in the greenstone. Longitudinal faults, cross-faults, and slips interrupt its continuity.

The mineral content, which is somewhat different from that of other transverse veins, consists of quartz, pyrite, arsenopyrite, dark sphalerite, a little galena and chalcopyrite, and some siderite and calcite.

Two mineralized zones in the main vein fault are known. In 1950 United Keno Hill Mines, Limited, investigated the one on the Moth claim by an inclined shaft, crosscuts, and a 140-foot drift at a depth of 100 feet. An ore shoot relatively high in zinc and low in lead and silver (average assay—Ag-10 ounce/ton, Pb-1.6 per cent, Zn-5 per cent) was outlined. On the 100-foot level the explored part of the shoot has an average width of 10 feet; its horizontal and vertical extent are unknown. The shoot occurs in a highly brecciated part of the vein fault where greenstone and quartzite form the foot-wall and quartzite the hanging-wall. Several cross-fractures and longitudinal slips cut the shoot along its length.

The other mineralized zone in the main vein fault occurs 800 feet northeast of the Moth shaft. This zone is small, contains mainly pyrite and a little arsenopyrite, and has greenstone on the hanging-wall and quartzite on part of the foot-wall.

Other fractures and vein faults occur in the system, but these are poorly exposed and little is known about them. One, however, is a sheeted zone that occurs some 1,000 feet southeast of the principal vein. Along most of its length this zone is marked by lineaments, of which perhaps the most striking is the straight part of Lightning Creek between the two sharp bends in the stream. No mineralized parts of this sheeted zone have been found. Another vein fault, with small mineralized zones containing siderite, outcrops a few hundred feet southeast of the Galkeno mill. This vein fault can be traced only a few feet on the outcrop, and both extensions are hidden beneath overburden.

The ore shoot at the Moth property is localized near the contact of the Silver King quartzite member and the upper schist formation. This contact is a particularly favourable one for localizing ore shoots not only in the Moth system but also in the Bellekeno, Silver King, and other systems.

Other Vein Faults

On the Croesus property (32) a series of bulldozer-cuts, pits, shafts, and two caved adits investigated what appears to be a south-striking subsidiary vein fault with greenstone on the east wall and graphitic schist on the west wall. Coarsely crystalline siderite filled part of the vein fault, and a little galena and freibergite are reported to have occurred in the siderite. Across Erickson Gulch the vein fault is not exposed, but presumably it joins the No. 6 system in the region of the Dorothy (30) prospect.

A number of veins and fractures cut schists and quartzites in the head-wall of Silver Basin on the Duncan claim (58), originally staked and prospected by the late David Sparks. In 1952 the claim was under option to Yukeno Mines, Limited.

The workings on the claim consist of a number of open-cuts, a caved adit, and an inaccessible shaft. None of the veins can be followed far, and their strikes and attitudes are uncertain. One appears to strike about N 35° E and has a steep dip. Vein material on the dumps consists of limonite, wad, siderite, galena, and freibergite.

Most of the veins and fractures on the Duncan and adjacent claims appear to be of the transverse type, lying between longitudinal vein faults.

On the Caribou claim (60) near the summit of Caribou Hill, a vein has been investigated by three or more shafts, an adit, and a number of prospect cuts. None of these workings is now accessible.

Early work on the Caribou claim is summarized by Cockfield (1921a) as follows:

> The Caribou claim is situated on Caribou hill. The workings consist of surface trenchings. On the summit of the hill the vein is about 5 feet in width striking south 45 degrees east and dipping 72 degrees to the northeast. The mineralization consists of 5 to 8 inches of galena in a gangue of carbonates, oxides, and quartz. The outcrop may be traced along the northern slope of Caribou hill. A considerable body of disseminated ore is found below the intersection of this vein with a flat-dipping one.

On the dumps there is an abundance of limonite, wad, cerussite, oxidized siderite, galena, some freibergite, and a little brecciated quartz. According to local reports, about 120 tons of high-grade oxidized lead-silver ore was shipped in the period 1925–27. No work seems to have been done on the veins on this and adjoining claims for many years.

On the nearby Alice claim (59), originally owned by the late Bill Williamson, there is an old caved adit that extends southeast into the quartzite and schist just to the northwest of the summit of Caribou Hill. Vein material on the dump consists of limonite, wad, siderite, sphalerite, and galena. No vein was seen on this claim, but local accounts and old reports (Cockfield, 1921a) suggest the presence of a vein or veins as shown on Figure 2.

The vein fault on the Devon (62) claim has been investigated by several open-cuts and an adit, now caved. The strike of the vein fault appears to be about N 10 to 15° E; the dip is unknown. The wall-rocks are quartzites with some phyllites and graphitic schist. The material on the dumps includes mainly quartz, siderite, galena, limonite, wad, anglesite, and cerussite. No ore shoots are known to occur in the vein fault.

Several transverse vein faults and spur veins are associated with the Ladue-Sadie-Friendship, Lucky Queen, Shamrock-Gambler, and Bellekeno systems. These are described above under their respective systems.

Galena Hill

An analysis of the pattern of the various individual vein faults on Galena Hill suggests that, prior to cross-faulting, all faults formed parts of three major systems as follows (Fig. 2):

Central system; includes the Coral and Wigwam, Arctic and Mastiff, Hector-Calumet, Dragon, and Galkeno 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 vein faults dip steeply to the southeast. Individual vein faults form a ramifying pattern and anastomose throughout their extent. Late cross-faulting has disrupted the continuity of the vein faults in many places, resulting in a complex segmented pattern. None of the systems can be correlated satisfactorily with those on Keno Hill. If, however, they are classified according to their strike directions the major vein faults, such as the Hector-Calumet and Silver King, correspond more or less to the longitudinal systems on Keno Hill, and the others, of which the Sugiyama is an example, correspond to the transverse systems.

All three major systems are ore bearing or are mineralized where they intersect the massive, thick-bedded quartzites of the Silver King, Hector-Calumet, and Galkeno 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 into many narrow, tight, unproductive vein faults.

Ore is localized in the vein fault systems at, 1) vein fault junctions, and 2) in massive thick-bedded quartzites or greenstones where the vein faults pass upwards 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

Galkeno Vein Faults

These vein faults (14) occur principally on the Rio claim originally owned by Mrs. W. C. Sime, on the Keno claim staked in 1926 by Angus McLeod, on the Happy Fraction originally owned by J. Sugiyama, and on the Verna claim.

Cockfield (1930) described the early work on the Rio claim as follows:

> On the Rio claim, owned by Mrs. W. C. Sime, a vein is exposed by an incline driven down the strike of the vein. The incline is about 30 feet deep, and follows a stringer of galena which widens to 3 feet. The vein strikes north 37 degrees east and dips at 63 degrees to the southeast. Immediately below the large showing the incline is filled with water. Some 65 feet lower in elevation an adit was started with the intention of striking the vein, in which all told 140 feet of drifting and crosscutting was done, but the workings were not driven sufficiently far to intersect the vein.

For many years the Keno claim was prospected by McLeod by means of numerous prospect shafts and trenches, and a main shaft some 100 feet deep, which connected with drifts and crosscuts near the bottom. A small tonnage of ore was removed between 1926 and 1949.

The Rio, Keno, Verna and other adjoining claims were initially optioned by Yukon Galena Mines, Limited, in 1948. In 1949 this company merged with Silver Basin Yukon Mines, Limited, and Yukeno Silver-Lead Mines as Consolidated Yukeno Mines. In 1950 Mackeno Mines, Limited, acquired the claims and an intensive development program was carried out, culminating in the discovery of two ore shoots from which production began in 1953. In 1957 the name was changed from Mackeno to Galkeno Mines, Limited, and in 1958 the property was sold to United Keno Hill Mines, Limited.

The workings at the time of the writer's examination consisted of adits and shafts on the Sime, Sugiyama, and McLeod veins and an access adit and crosscut driven to connect the workings in the Sime and McLeod veins and to develop the latter (Fig. 13). Drifts have been driven on five levels in the McLeod vein and on two levels in the Sime vein. In the McLeod vein the levels are connected by raises and a winze. In the early part of 1957 a new adit was started at the base of Galena Hill to cut the McLeod vein fault at a depth of about 1,200 feet below the surface.

Up to the end of 1956 the Galkeno vein faults yielded some 66,000 tons of ore; the ore reserves on February 28, 1957 were stated to be 61,399 tons averaging 36.1 ounces Ag a ton, 8 per cent Pb, and 8 per cent Zn.

Two intersecting vein faults (McLeod and Sime veins), and two faulted segments of a cross-over vein fault (Sugiyama vein) are present on the Galkeno property. The McLeod vein fault strikes N 25° E and dips 60° SE; the Sime vein strikes N 65° E and dips about 55° SE; the Sugiyama vein strikes N 10° W and dips 85° W.

The McLeod vein is the most important of the vein faults and has produced the bulk of the ore to date. The Sime vein has produced ore from only one small stope, and the small mineralized pods in the Sugiyama vein have yielded about 25 tons of ore. The McLeod vein fault is marked by a zone of breccia and gouge in places over 50 feet wide. At least three periods of movement and brecciation have taken place. The sequence of major structural events in chronological order can be summarized as follows:

1. Formation of an early vein fault probably marked by brecciation over widths of 10 to 20 feet. Deposition of quartz with some pyrite and arsenopyrite.
2. Fracturing and brecciation followed by deposition of siderite, galena, sphalerite, pyrite, 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 a favourable series of massive thick-bedded quartzites. They 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 Galkeno vein faults appear to be at or near the points where the vein faults pass upwards from competent thick-bedded quartzites into localities where schist forms one or both walls of the vein fault. This is a familiar structural site for ore shoots on both Galena and Keno Hills. The reasons for ore deposition at these loci are discussed in the last section of this chapter.

Galena, sphalerite, and freibergite are the principal hypogene ore minerals in the ore shoots of the Galkeno vein faults and the gangue minerals include quartz, siderite, pyrite, and small amounts of arsenopyrite. All ore shoots are oxidized down to the lowest levels of mining. The supergene minerals are mainly limonite, manganese oxides, anglesite, cerussite, beudantite, and jarosites, all derived from siderite, sphalerite, galena, freibergite, and pyrite.

The relationship of the Galkeno vein faults to those of the Hector-Calumet is not entirely clear. The McLeod vein fault may be an extension of one of the bifurcating Hector-Calumet vein faults, and 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 to the Hector-Calumet. The other possibility is that the McLeod vein fault is an entirely separate vein fault unrelated to the Hector-Calumet vein faults, and if so it probably follows the same course as the McLeod fault. Whichever is so, it should be noted that the southwestern extension of the McLeod vein fault on the surface enters the favourable Hector-Calumet member about 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 13.

Hector-Calumet Vein Faults

The Hector-Calumet vein faults (10, 11) are the most extensive and productive in the Keno-Galena Hills area. These extend northeast to the Dragon (U.N.) claim and southwest to the Coral and Wigwam claims, a distance of 3 miles. Along these vein faults, bodies of lead-zinc-silver ore occur, but the Hector-Calumet mine, midway between the known northeast and southwest limits, is the largest producer.

Most of the vein faults are covered with drift and rock rubble, and only at a few places are they exposed. In addition, the many cross-faults make accurate mapping of the vein faults difficult and exploration costly.

At the Dragon prospect (12) the northeastern extension is exposed in places and consists of two or more vein faults. Early work at the Dragon prospect is summarized by Stockwell (1926) as follows:

> This property, owned by O. Miller, is situated on the northern slope of the hill about a mile northeast of the highest point. During the past four years a great deal of work has been done on the property. A vein has been prospected along its strike for a distance of 500 feet by means of three shafts, 20, 24, and 42 feet deep respectively, five open-cuts, and two sluices. Many open-cuts and two sluices have also been made to the northeast of the main workings.
>
> The vein, which is reported to be from 5 to 7 feet or more in width, strikes north 16 degrees east and dips 66 degrees southeast. The hanging-wall is quartzite and the foot-wall in most places black schist. The minerals in the vein are siderite, limonite, manganese oxide, galena, cerussite, freibergite, and a little quartz. The ore minerals carry high values in silver, but are only sparsely distributed through the siderite, which is the main constituent of the vein.
>
> Near the northeast end of the vein the siderite ends abruptly and the mineralization is quartz, arsenopyrite, galena, and pyrite. Assays are said to show some gold values. It is assumed that this mineralization is in a cross-fault, the surface trace of which strikes north 82 degrees west. It is not known whether the fault is older or younger than the siderite vein.
>
> To the northeast of this cross-fault and along the strike of the siderite vein there is apparently a brecciated quartz vein, but no siderite has been found. In a ground-sluice 950 feet northeast of the end of the siderite vein some galena float is present.

So far as is known from local reports only a few tons of ore has been removed from the veins.

Investigations made by the present writer in 1955 are summarized in the following:

At the Dragon prospect the principal vein fault dips 65° SE, is 5 to 8 feet or more wide, 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. The main vein is interrupted just northeast of the main shaft by a northwest-trending fault (probably the fault referred to by Stockwell) carrying some quartz, arsenopyrite, galena, and pyrite. On the surface this fault is not recognizable, but several lineaments are present that 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 expose 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 on the dumps are coarse-grained siderite, quartz, galena, freibergite, boulangerite, sphalerite, limonite, manganese oxides, jarosite, bindheimite, cerussite, and anglesite. According to local reports the ore minerals are only sparsely distributed through the gangue in the vein underground.

Southwest of the Dragon prospect the vein faults are drift covered and cannot be traced with certainty. In this area they enter the unfavourable series of thin-bedded quartzites overlying the thick-bedded quartzites of the Galkeno member, and the general fractured and broken nature of the rock float suggests that the vein faults are narrow and form an irregular ramifying pattern. It is also possible that some of the Galkeno and Hector-Calumet vein faults coalesce in this area, and a wide zone of general shattering and brecciation is to be expected. In addition to these structural complexities several lineaments suggest the presence of northwest cross-faults that would further disrupt the continuity of the vein faults. One of these cross-faults (Calumet fault) has recently been exposed in the underground workings of the Calumet mine, and the faulted extension of the vein system has been traced northeast of it for some 1,500 feet.

To the southwest of the Calumet fault an anastomosing vein fault has been clearly delineated by surface and underground workings on the Calumet claims (11) (Fig. 14). In addition the short faulted extension of another vein fault is known, and probably, projecting from underground data, a third vein fault (No. 10 extension) is present southeast of the main one, although no evidence for its existence can be found on the surface. Number 10 extension could be the faulted southwest extension of the McLeod vein (Galkeno system).

Before entering the Hector claim (10) the vein faults are offset by the Hector fault, and, farther to the southwest across the Hector claim, by the Jock fault. Between these two faults are three interlaced vein faults, two of which are productive. The details of these and their faulted extensions is 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, a strong topographic lineament and the presence of abundant manganese-stained float suggest that the traces of the vein faults are as shown on Figure 2. It is apparent, from the stratigraphic succession in this region, that the vein faults at the surface cross a series of thin-bedded quartzites and schists, and from the known behaviour of vein faults in such rocks, they are probably narrow, have a general anastomosing pattern, and are unlikely to contain large, continuous orebodies. Favourable conditions should exist, however, where the downward extension of these vein faults intersects the underlying thick-bedded quartzites of the Hector-Calumet member.

On the Ruby Fraction (6) and Arctic and Mastiff (Bermingham) (5) claims the probable southwest extensions of the vein faults of the Central system are exposed by several shafts, open-cuts, and by the Bermingham crosscut and connecting drifts.

The vein on the Ruby (Darwin) Fraction strikes N 50° E, dips 65° SE, and varies in width from 1 foot to 3 feet. According to Stockwell (1926) the vein is mineralized with siderite, galena, freibergite, and pyrite. Alteration products on the dumps 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, 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 crosscut by a crushed zone containing small amounts of siderite and galena, some 500 feet from the portal.

On the Arctic and Mastiff (Bermingham) claims are two vein faults repeatedly offset by northwest-trending cross-faults. Only one of these vein faults, the southeasterly, is known in any detail; the other may be the possible extension of the vein fault on the Ruby (Darwin) Fraction.

The Arctic and Mastiff claims were among the first important lead-silver producers on Galena Hill. They were staked by C. H. Bermingham and C. R. Settlemier in 1921 and about 3,000 tons of ore averaging about 195 ounces silver a ton and 60 per cent lead was mined from them at various times from 1925 to 1941.

The workings are numerous and include several old shafts, drifts, and crosscuts all now inaccessible, and an accessible adit (Bermingham adit) and crosscut that connects with a drift some 1,000 feet long.

The principal vein fault on the claim has been offset by at least five faults, the main ones being the Arctic and Mastiff, with a combined horizontal movement of about 350 feet. According to Wernecke and Visel, early underground development between the Arctic and Mastiff faults during the years 1923–26 disclosed a very complex anastomosing vein fault with a maximum width on the 100-foot level of 55 feet. Above the 100-foot level the vein fault contained three bands of ore, separated by crushed bodies of country rock; on the 100-foot level six bands of ore totalling 22.4 feet in width were present. Below the 100-foot level the bands apparently pinched out as they were not found on the 200-foot level. In this complex of irregular shoots about 2,100 tons of ore assaying 144 ounces silver, 55 per cent lead, and 0.6 per cent zinc was removed. Both the vein fault and shoots were highly oxidized, and judging from the dumps contained galena, freibergite, boulangerite, chalcopyrite, cerussite, anglesite, limonite, manganese oxides, beudantite, bindheimite, jarosite, altered siderite, some oxidized pyrite, and a little quartz.

During 1929 and 1930 the Treadwell Yukon Company sank a shaft to a depth of 200 feet, and drove crosscuts and drifts to explore the downward extension of the vein fault between the Arctic and Mastiff faults. This work failed to find any bodies large enough to mine. Work done at the same time to test the extension southwest of the Mastiff fault similarly met with no success. During the years 1948–51 United Keno Hill Mines, Limited, drove the Bermingham crosscut and drifted beneath the old workings, but the results were disappointing 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 Figure 2 and the stratigraphic table of the central quartzite formation given in Chapter II, 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 200 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 Mastiff fault the easterly vein fault enters the upper schist formation, through which it has not been traced. A vein fault striking N 55° E and dipping 70° SE is exposed on the Coral and Wigwam claims at the head of Porcupine Gulch. This vein 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.

Early work at the Coral and Wigwam prospect (4) was summarized by Stockwell (1926) as follows:

> This property, part of a large block of claims owned by R. Fisher and Dr. W. E. Thompson, is situated at the head of Porcupine gulch on the northwest slope of Galena hill. The claims were staked in 1921, but the main work on the property was done in 1924. The owners state that 7 or 8 tons of ore, assaying 258 ounces of silver to the ton and 61 per cent lead, were shipped. No mining was done on the property during the summer of 1925.
>
> The workings consist of a few open-cuts and three shafts along the strike of a vein. The centre shaft is 26 feet deep and from the bottom a drift has been run a short distance northeast along the vein; from near the end of the drift a short crosscut was driven southeast. The other shafts were filled with water at the time of the writer's visits. On adjoining claims belonging to the same owners, three ditches, two of which are shown on the map, were dug during the summer of 1925 in preparation for ground-sluicing in the following spring.
>
> The centre shaft, drift, and crosscut are in a shear-zone striking north 53 degrees east and dipping 65 to 75 degrees southeast. The foot-wall is mica and graphite schist and the hanging-wall is chiefly quartzite with some schist. Mineralization is irregular and occurs chiefly near the foot-wall of the shear zone. The primary minerals are galena, associated with a considerable amount of freibergite, in a gangue of siderite and minor quantities of quartz and pyrite. Alteration products observed are limonite, manganese oxide, and cerussite. It is reported that native silver occurred near the surface at the shaft.
>
> Similar gangue minerals and their alteration products were observed on the dumps of the other two shafts, and in addition to these minerals a little galena was seen at the northeast shaft.
>
> Just northwest of the latter shaft brecciated quartzite is mineralized with quartz and stibnite. The deposit is said to carry only low values in silver.

The claims are now owned by United Keno Hill Mines. In recent years this company has searched without success for the northeast extension of the vein fault, by means of several bulldozer-cuts.

At the time of the writer's examination all the workings were caved. Surface mapping revealed that 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 was irregular and the ore minerals appear in small bunches. The primary minerals on the dumps are galena, freibergite, quartz, sphalerite, and pyrite. Alteration products, including limonite, manganese oxides, jarosite, cerussite, and anglesite, are present in the surface exposures. According to local reports only a few tens of tons of ore have been won.

The most productive parts of the Hector-Calumet vein faults are on the Calumet, Hector, and Jock claims. The history of these claims is long and varied, facets of which have affected the present importance and prominence of the silver camp as a whole.

The Hector claim was staked by C. Sinyard and M. S. McCowan sometime between 1923 and 1925 and after ten years of prospecting an ore shoot was outlined in the Hector veins in 1935. In the same year prospecting to the east by J. Boone resulted in the discovery of the Calumet veins. The Treadwell Yukon Company acquired mining rights to both the Hector and Calumet claims in 1935, and by 1936 an extensive underground program had proved a sizable tonnage of ore on the two claims. After a small production from the Hector mine in the following 2 years the financial arrangements between the owners of the Hector claim and the Treadwell Yukon Company proved unsatisfactory, and the company transferred all operations to the Calumet ore shoots from which nearly all the production came until operations ceased in 1941 due to war conditions and exhaustion of ore.

In 1945 United Keno Hill Mines, Limited, acquired the assets of the Treadwell Yukon Company and an option on the Hector and adjoining claims. Extensive underground development in the years following outlined several ore shoots which have provided most of the post-war production of the camp.

The workings of the Hector-Calumet mine extend along strike for more than 3,500 feet and to a depth of 1,300 feet. An adit some 1,900 feet long was driven southeast from the road passing through the Calumet townsite and provides the main entry to the mine.

Up to 1958, the Hector-Calumet mine had yielded more than 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, 1,831,823 pounds of which had been recovered up to 1960. Annual production for the years 1955, 1956, and 1957 was:

Metal	*1957*	*1956*	*1955*
Silver, ounces	5,694,850	5,582,979	5,670,137
Lead, pounds	22,569,908	25,083,145	26,350,198
Zinc, pounds	18,119,454	24,107,851	24,035,999
Cadmium, pounds	236,271	322,379	302,297

The known ore reserves at the end of 1957 were of the order of 550,000 tons averaging 36.8 ounces silver a ton, 7.3 per cent lead, and 6.0 per cent zinc[1].

Geological descriptions and the historical development of the Hector-Calumet vein faults and orebodies have been published by Stockwell (1926), Cockfield (1930), Bostock (1936), (1938), (1939), (1941), Hicks (1949), (1952), Smitheringale (1950), Johnston and Powelson (1951), Pike (1957), Carmichael (1957), and Boyle (1957b).

The underground workings of the Hector-Calumet mine disclose several anastomosing vein faults which vary markedly in strike and dip. The names of the vein faults, their strikes, dips, and contained orebodies, are shown on Figure 14. Only five veins, Nos. 1, 2, 3, 4, and 15 and the extensions of No. 1 vein (Nos. 18 and 19) northeast of the Calumet fault, have been productive; other vein faults, so far as known, are only sparsely mineralized.

The vein faults have been sliced into segments and offset by three major northwest cross-faults, the Jock, Hector, and Calumet. These appear as zones of highly fractured rock up to 150 feet or more wide. Each zone dips at about 45° SW, but individual faults and slips within the zones may be steeper. The horizontal movement on each fault is right hand, judging from drag effects and the offset position of the veins. The amount of horizontal movement is some 270 feet on the Hector fault,

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[1] Annual report, United Keno Hill Mines, Limited, 1957.

320 feet on the Calumet 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 most productive part of the vein faults at the Hector-Calumet mine formed a cymoid loop about a highly fractured horse of country rock (*see* Fig. 15). Two major features control the location of the ore shoots: 1) vein fault junctions, and 2) the presence of massive thick-bedded quartzites (Hector-Calumet member).

The largest shoot in the mine occurs near the junction of the Nos. 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 fractured 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* Fig. 14) that this shoot tapers at depth. The trace of the southwestern margin follows the general plunge of the junction of the two vein faults and the northeastern margin cuts obliquely back, following in a general way the trace on the fault plane of the base of a series 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° E and is followed by the two ore shoots. These ore shoots are contained principally in a series of massive thick-bedded quartzites lying immediately below the characteristic cherty white quartzite.

The No. 1 vein contains several other ore shoots particularly in the vicinity of loops and junctions, e.g., No. 1 and No. 15 veins. Northeast of the Calumet fault ore mineralization is associated with a probable loop formed by Nos. 18 and 19 veins.

The primary mineralization in the Hector-Calumet mine is essentially the same as that elsewhere in the Galena Hill area. Small 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 freibergite. 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 galena, sphalerite, and siderite, often in alternating bands, are common. In individual ore shoots galena and freibergite, and hence the lead and silver contents, decrease with depth, and there is a noticeable increase in sphalerite and pyrite. The lead-silver ratio, however, remains nearly constant throughout the pitch length of the shoots, and in this respect the ore mineralization is similar to that in the Ladue-Sadie-Friendship mine on Keno Hill.

Oxidation effects are observable down to 600 feet in No. 1 and No. 2 veins and to 400 feet in No. 3 and No. 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, however, by the Hector fault, and as the main period of oxidation was in the Tertiary, it is probable that some of the movement on this cross-fault occurred after this. The supergene minerals developed are mainly limonite, manganese oxides, beudantite, bindheimite, jarosite, cerussite, anglesite, and

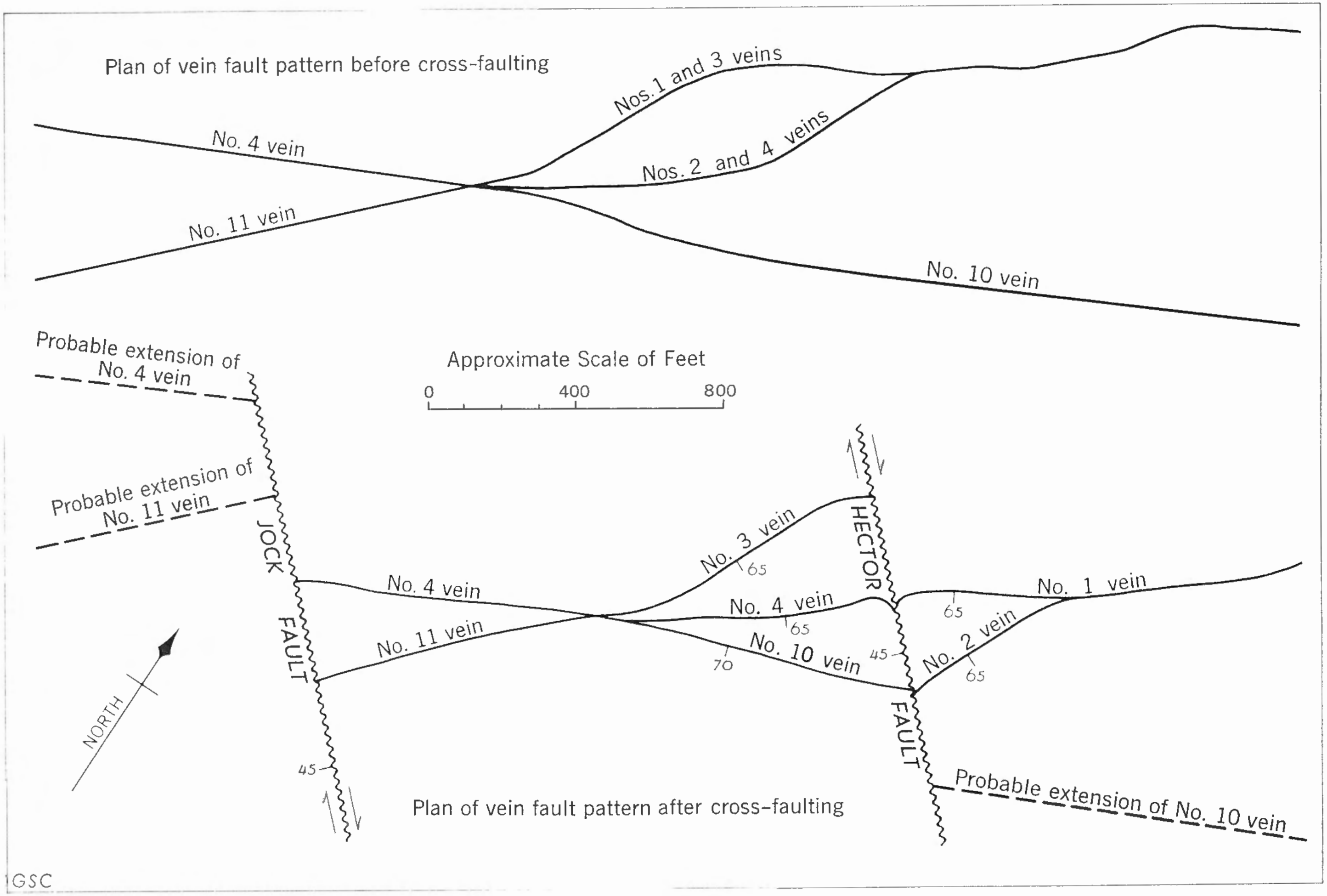

FIGURE 15. Sketches illustrating the vein fault pattern before and after cross-faulting, Hector-Calumet mine, Galena Hill.

calcite. Some ore shoots contain much silver-bearing jarosite, plumbojarosite, and cerussite. As in other veins on Keno and Galena Hills there has been a general enrichment of silver and lead and a depletion of zinc in the oxidized zones.

In summarizing, the Hector-Calumet vein faults are productive or mineralized only where the vein faults 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 a number of 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 narrow to a series of thin fractures that are scarcely traceable, and have been unfavourable sites for ore deposition.

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

Formo Vein

This vein (13) occurs on the Tyee and Rocket claims originally worked by H. E. Formo. Cockfield (1931a) described the early work as follows:

> *Tyee Claim.* This claim is owned by H. E. Formo who has also an option on the adjoining claim, the Rocket. These claims are situated on the northern slope of Galena hill near the mouth of Christal creek. A considerable amount of work has been done improving the trail to the property. The workings consist of an incline shaft 80 feet deep; the dip of the vein is somewhat flatter than normal, being about 35 degrees, and the strike is north 17 degrees east. There is a drift to the south at the bottom of the shaft and another drift to the south at 60 feet with a raise connecting the two. Both these drifts are 15 feet long. At the bottom of the shaft there is a 15-foot drift to the north. The ore is 20 to 28 inches wide in a vein which shows a maximum width of 4 feet in the shaft. In the bottom of the shaft the ore increases to 36 inches, but is of much lower grade, containing much pyrite and zinc blende. In the north drift the vein is cut off by a northwesterly trending fault and no attempt has been made to pick it up beyond this fault. The best ore was found 25 to 30 feet down in the shaft and 40 tons of this were sorted and shipped. The smelter returns on this shipment were not available, but assays of the ore made before shipment indicated a content of between 225 and 250 ounces of silver and 60 per cent lead.

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 mine was found.

The vein outcrops beside a greenstone knob, strikes N 20° to 50° E, and dips about 50° SE. Its northeastern extension is offset a short distance to the southeast by a northwest-trending cross-fault which strikes N 55° W and dips 35° SW. The southwestern extension of the vein has not been traced.

In the underground workings the vein flattens slightly and becomes irregular, in places splitting into several branches. The maximum width of any branch 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. These lenses are irregular and contain much brecciated sphalerite and pyrite. Other minerals present are galena, freibergite, siderite, calcite, 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 bodies on either its strike or dip, and these special conditions should be sought during exploration.

Bluebird Vein

The Bluebird vein fault (17) is exposed on the Bluebird claim. The workings consist of several pits and two shafts now caved. No work has been done in recent years.

The following early reports by Stockwell and Cockfield trace the history of the vein and outline its significant features:

> This claim[Bluebird] owned by A. McLeod, H. Rhor, and S. Turpin, is situated low down on the northeast slope of the hill. A vein striking north 25 degrees east and dipping 62 degrees southeast was exposed during the spring of 1925 by means of two open-cuts. The vein is mineralized with galena, sphalerite, and pyrite in a gangue of ankerite, calcite, quartz, limonite, and manganese oxide. The country rock is greenstone and along the foot-wall it contains disseminated pyrite. The galena is reported by the owners to assay 292 ounces of silver to the ton and 77 per cent lead. (Stockwell, 1926)
>
> *Bluebird Claim.* This claim is owned by O'Sullivan and Nicholson. On it a vein striking north 27 degrees east and dipping 62 degrees southeast was exposed by means of open-cuts. The vein is mineralized with galena, sphalerite, and pyrite, in a gangue of ankerite, calcite, quartz, limonite and manganese oxide. Two shafts have been sunk, the lower of which is 40 feet deep, and hit the vein at 22 feet. The upper shaft is 23 feet deep. Both shafts were filled with water at the time of the writer's visit. (Cockfield, 1930)

The Bluebird vein probably represents the northeast extension of one of the Galkeno vein faults.

Western System

Silver King Vein Faults

The Silver King vein faults (1) occur on the Webfoot and Silver King claims and probably extend westward through the Mabel and Adam claims. The veins outcrop in the canyon of Galena Creek and in pits near the main road from Elsa to Mayo. All workings are now inaccessible. The early history and development of the veins was summarized by Cairnes (1916):

> The Galena Creek vein is believed to have been discovered and staked by H. W. McWhorter and partner about the year 1906, but the claim was afterwards allowed to lapse. The deposit was relocated in 1912 or 1913 by Mr. McWhorter who gave a lay [lease] on the ground to Jack Alverson and Grant Hoffman. These layees [lessees] did the first real development on the property, and proved it to be of importance. They shipped 59 tons of ore to the smelter at Trail, B.C., the smelter returns for which amounted to $269 per ton, in gold, silver, and lead, the gold being very low, but the lead amounting to 45 per cent. In the spring of 1914 the property was acquired by Thomas P. Aitken and Henry Munroe, Mr. Aitken being the principal owner. During the winter of 1914-15 these owners shipped 1,180 tons of ore to San Francisco. The smelter returns for this shipment according to a statement kindly furnished by Mr. Aitken, included $3 per ton in gold, and for about half of the ore, 39 per cent lead and 280 ounces of silver, and for the other half 23 per cent lead and 260 ounces of silver per ton.

> The vein outcrops in the walls of the canyon on Galena creek, but to either side along its strike is not exposed, being covered with a heavy mantle of drift. Thus all that is known concerning the vein is derived from the mine workings and the exposures in the canyon which at this point has a depth of about 70 feet. The vein occurs in a fissure, or in places really in a compound fissure traversing old altered sediments probably of Pre-Cambrian age. These where exposed in the canyon are greyish to greyish-green schistose, quartzitic, sericitic rocks which in places occur in heavy massive quartzite beds with relatively little sericite, but also grade into more finely laminated phases that become typical sericite schists. All these rocks have been much contorted and broken, and contain a great amount of secondary quartz which occurs in lenses, stringers, and irregular bunches. These have been deposited for the most part along the planes of schistosity of the enclosing rocks; but in places stringers and veinlets occur intersecting the foliation surfaces at various angles.
>
> The vein strikes about astronomic north 65 degrees east and dips to the southeast at angles ranging generally from 55 to 80 degrees, although in places it has an almost vertical attitude. The extension of this vein on the northeast side of the canyon comprises really a fault zone about 5 feet in thickness, which includes crushed and sheared wall-rock interspersed with small quartz stringers, the most prominent of which is 6 to 8 inches in thickness and is only slightly mineralized. An adit 100 feet long has been driven in on this zone from an elevation only a few feet above the creek level, and along this adit, the quartz and all other evidence of mineralization gradually disappear, until at the end, there is only about 2 feet of barren, sheared, country rock.
>
> On the southwest side of the canyon, the vein is very highly mineralized chiefly with galena and ruby silver, although a certain amount of iron pyrites also occurs, and in one place a band of zinc blende about 2 inches or even more in thickness, which contains about 30 per cent zinc, follows the foot-wall. An incline shaft on the vein had been sunk 185 feet below the level of the upper edge of the canyon walls, when the property was visited about the middle of August (1915); and from this incline, stopes had been opened up from which the ore was being mined. In the mine workings, one main shoot of highly mineralized rich ore had been encountered, which in most places consists mainly of galena and ruby silver with only subordinate amounts of quartz gangue; it is claimed to average over $150 per ton in gold, silver, and lead. This shoot dips to the northeast along the vein, is about 30 to 35 feet long, and has been found to persist downward to at least the level of the bottom of the incline, the lowest point reached by the mine workings in August. Near the middle, the shoot is 40 to 48 inches thick, but it narrows to 6 or 8 inches at the edges.
>
> Another shoot or pocket of ore was encountered to the southwest of the main shoot, in a short drift run to the southwest from the bottom of the incline. . . . . .

From 1915 to 1928 the veins were prospected by several individual operators and a small tonnage of ore was shipped. In 1928-29 Messrs. Ferguson, Hawthorne, and MacPherson, prospecting along the northeastern extension of the veins, found high-grade ore, and both the Silver King and Webfoot claims were optioned by the Treadwell Yukon Company in June of 1929. Extensive development followed, resulting 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. In 1939 the Silver King mine was closed on the exhaustion of the known orebodies. In 1947-48 a small amount of underground exploratory work was carried out by United Keno Hill Mines, Limited with negative results.

On the Silver King and Webfoot claims are 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* Fig. 16). The rake of the intersection of these two vein faults is to the southwest at a steep angle. Both vein faults contained productive orebodies.

The principal vein fault (Silver King vein) strikes N 50° E and dips 70° SE. 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

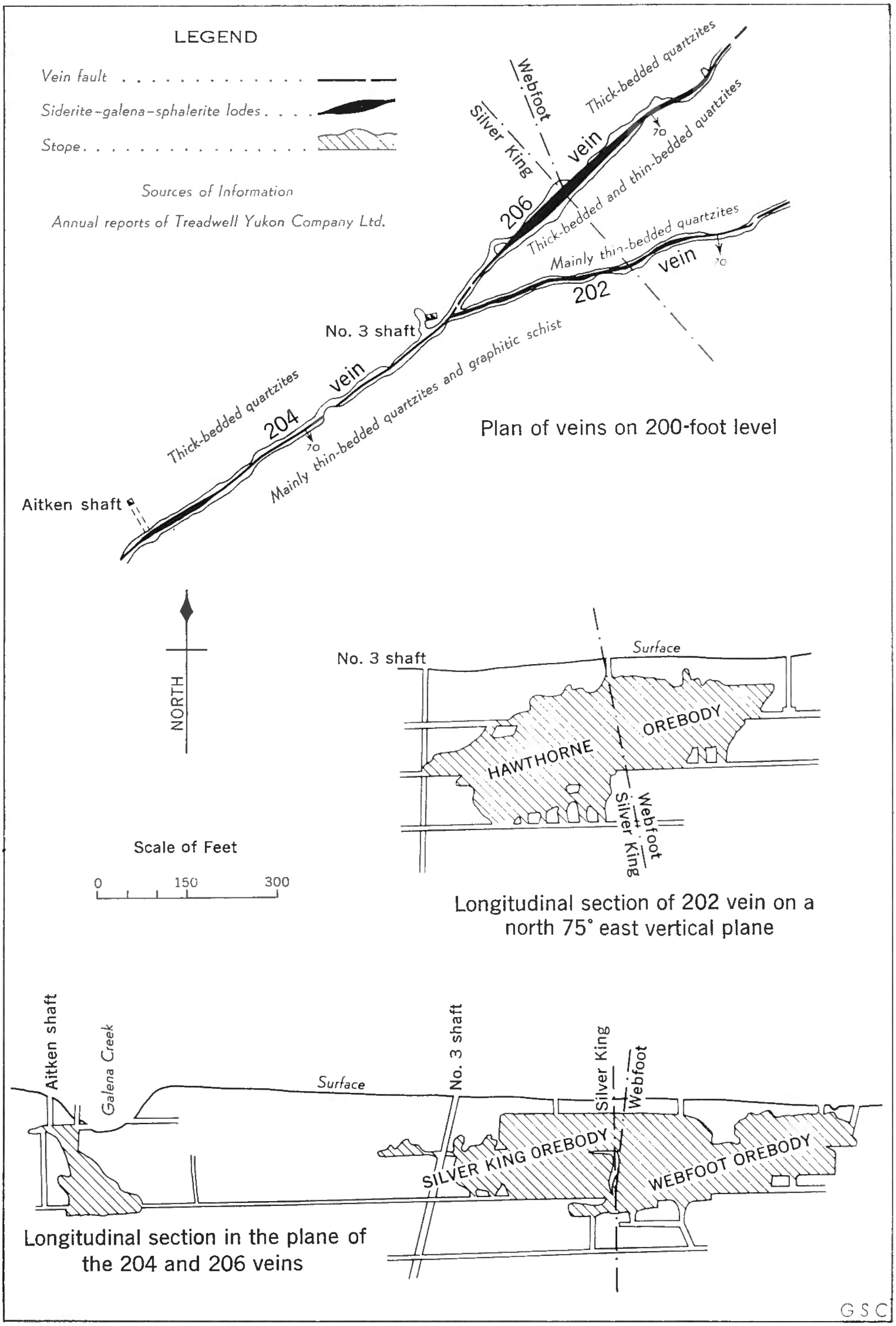

FIGURE 16. Plan and longitudinal sections, Silver King mine, Galena Hill.

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 on the Mabel and Adam claims 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 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 per cent lead, and 0.10 ounce of gold a ton. The dimensions of this shoot are not known in detail, but its approximate outline is shown on Figure 16. 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 a 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.

Both the Silver King and Webfoot orebodies had a flat rake to the southwest.

The subsidiary vein fault (202 vein) strikes N 75° E, dips 70° SE, 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 orebody was roughly elliptical with the major axis some 620 feet long raking 25° SW.

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 after the vein faults were formed can be recognized. These in chronological order are:

1. Deposition of early quartz and some pyrite, followed by cream coloured siderite, galena, sphalerite, pyrite, and tetrahedrite.
2. Brecciation of siderite-galena-sphalerite 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, galena, freibergite, pyrite, and siderite to limonite, manganese oxides, beudantite, bindheimite, jarosites, cerussite,

anglesite, malachite, and azurite. 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, pyrite, 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 in the Silver King vein faults are localized on the two limbs of a Y junction, 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 parts of the vein faults as a whole owe their 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 except where vein faults might intersect greenstone masses.

From the positions of the Silver King and Elsa systems, 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 in which to prospect.

Elsa Vein Faults

The Elsa vein faults (2) occur principally on the Porcupine, Elsa, and Jean claims and were discovered in 1925 by C. Brefalt and D. Tolmie. In 1928 the Elsa and adjoining claims were acquired by the Treadwell Yukon Company, which began development of the vein faults in that year. During the next 14 years some 55,000 tons of ore containing more than 5,500,000 ounces of silver was won from ore shoots in the vein faults.

After acquiring the assets of the Treadwell Yukon Company in 1946, United Keno Hill Mines, Limited, carried out diamond drilling and underground development work in the Elsa vein faults from 1948–51 and a small tonnage of ore was removed. In 1955 United Keno Hill Mines, Limited, sank an underground shaft 171 feet below the 400-foot level. In the following year a limited program of development on the 525-foot level disclosed several lenses of ore some of which were of exceptionally high grade. Production from the development of these lenses totalled 3,713 tons carrying 75.44 ounces silver a ton. In 1957 development and mining yielded 10,043 tons of ore averaging 72.24 ounces silver a ton. This ore came mainly from two intersecting vein faults (Nos. 5 and 15) lying between the 200- and 525-foot levels.

The workings of the Elsa mine consist of a main access adit (401 adit) and two old adits (101 and 201), both now inaccessible, several prospect shafts, all now caved, and a number of drifts with connecting crosscuts, raises, and an internal shaft (Fig. 17).

In the Elsa mine there are two principal vein faults which form a Y junction. 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 productive vein faults cut the favourable Hector-Calumet member which in the Elsa mine is composed of massive thick-bedded grey quartzites, siliceous white quartzites, and greenstone lenses. In the 401 access adit this member and its associated rocks are much contorted, with local recumbent drag-folds, boundinage structure, and numerous slips and small faults following the bedding planes.

The vein faults are fractured and brecciated zones 10 to 40 feet wide. On the 200-foot level the Brefalt vein appears to be the trunk fault. It strikes N 65° E and dips from 50 to 75° SE. The 415 and 203 veins appear to be parts of a single subsidiary vein fault striking N 45° E and dipping 70° SE or steeper. Associated with this vein fault is another, the No. 15 vein, which strikes N 20° E and dips from 40 to 65° W. In addition there are other short spur veins that strike N 15 to 30° E and dip steeply northwest. These veins probably represent tension fractures. They change attitude abruptly over short distances and on entering schist and phyllite they weaken and die out.

The ore shoots are irregular in outline and have a maximum width of 40 feet. Some rake to the southwest at about the same angle as the line of intersection of the two main faults. These shoots are probably controlled by the junction of the two faults. Other shoots appear to be controlled by the junctions of the southeasterly dipping 415 and 203 veins and the northwesterly dipping spur faults, with ore occurring both in the spurs and in the main fault. In the new workings, in the foot-wall of the Porcupine Gulch fault (525-foot level), the ore shoots are localized at and near the junction of the No. 15 and No. 5 vein faults.

All ore shoots are intensely oxidized, down to the lowest level of mining in the old workings, and only in a few places were primary sulphides present[1]. Sphalerite was

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[1] Recent development work at the Elsa mine has shown that the oxidation extends to about 400 feet.

practically absent in the upper parts of the veins, being almost completely removed during oxidation. The minerals in the ore included highly altered siderite, galena, pyrite, freibergite, cerussite, anglesite, native silver, pyrargyrite, argentite, beudantite, bindheimite, silver-bearing jarosites, quartz, limonite, and manganese oxides. The shoots near the surface were enriched in silver, assays of 250 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. In the shoots in the new workings, in the foot-wall of the Porcupine Gulch fault, the principal primary minerals are siderite, galena, pyrite, chalcopyrite, and freibergite. There is relatively little sphalerite. Freibergite is particularly abundant, occurring in almost solid veinlets in places, or as coarse irregular masses in siderite and galena.

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

Northeast of the Porcupine Gulch fault a vein fault has been investigated by pits, a shallow shaft from the surface, and a raise from the 202 drift of the Elsa mine. This vein fault is narrow and irregular and contained a small ore shoot with a few tons of high-grade ore. Its correlation with the Elsa vein faults is uncertain, but it seems probable that it represents the extension of the 415-203 vein. The northeast extension of the Brefalt vein may be represented by the Dixie vein described below.

The extensions of the Elsa 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 veins may represent the southwest extension of the Elsa veins, or secondly, the two may be separate and parallel, in which case the extensions of those at the Elsa mine may pass into the favourable Silver King member in the area between Flat and Galena Creeks.

Dixie Vein

The Dixie vein (3) probably represents the northeast extension of the Brefalt vein, and may extend northeastward by a series of faulted segments to link up with the No Cash veins.

Early work on the Dixie vein is described by Stockwell (1926) as follows:

> This claim, [Dixie] owned by J. V. Sullivan, is situated on the northwestern slope of Galena hill; the workings are at an elevation of about 3,900 feet and are 2,000 feet northeast of Porcupine gulch.
>
> The country rock is quartzite intruded by a sill of greenstone. In two open-cuts in quartzite 300 feet north of the greenstone some siderite float has been found. The siderite contains a little pyrite and is partly altered to limonite and manganese oxide.
>
> In an open-cut near the greenstone a quartz vein sparsely mineralized with arsenopyrite is exposed. It strikes roughly east-west and dips about 40 degrees south.
>
> A ditch has been dug in preparation for ground-sluicing in the spring of 1926.

In 1928, eleven tons of ore averaging 172 ounces silver and 52 per cent lead was extracted from the vein.

The Dixie claim is owned by United Keno Hill Mines, Limited. The workings, now caved or flooded, consist of several prospect shafts and pits, and a shaft some 75 feet deep, from which short underground drifts were run on the 40-foot level.

Where seen by the writer the Dixie vein strikes northeast, dips steeply southeast, and cuts a series of grey and cherty white quartzite beds of the Hector-Calumet member. Mapping to the southwest and northeast of the main shaft suggests that the vein is cut off by cross-faults, but no definite indications for these postulated faults were found.

The principal minerals in the Dixie vein are altered siderite, galena, freibergite, sphalerite, pyrite, and limonite, manganese oxides, cerussite, and anglesite. Only small shoots, containing a few tons of ore, were found during the underground exploration of the vein.

It should be noted that the Dixie vein 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 (7) probably represents the northeast extension of the Elsa and Dixie veins. It was discovered by C. Brefalt and D. Tolmie, about 1928, and is now owned by United Keno Hill Mines, Limited.

Early work on the No Cash claim is described by Cockfield (1931a) as follows:

> This claim is owned by Brefalt and Tolmie and worked under lease by E. Bjonnes. There is a shaft 50 feet deep with two drifts, one slightly higher than the other, at the bottom. These drifts are connected by cross-cuts. One drift is on the foot-wall and the other on the hanging-wall side of the vein. The hanging-wall drift is 60 feet long, it extends 15 feet to the north and 45 feet to the south of the shaft. The foot-wall drift is 22 feet long on either side of the shaft. The hanging-wall of the vein shows a dip of 55 degrees and the foot-wall varies from 60 to 75 degrees. Between the two drifts there is a streak of low-grade ore. The ore on the hanging-wall is 5 feet wide and is fairly high grade; the lean ore between the two drifts is 3½ feet wide; and the foot-wall streak is well mineralized and about 3 feet wide. Very high assays have been secured from the ore as hand-sorted for shipment. The lessee shipped 21 tons during 1930, but the actual returns for this were not available. Mr. Bjonnes states that a channel sample cut across the whole width of the deposit assayed 75 ounces.

From 1930-38 about 400 tons of ore averaging 400 ounces silver a ton and 50 per cent lead was won from the vein by Bjonnes, Tolmie, and Brefalt.

At the time of the writer's investigation the workings consisted of a series of pits, shafts, and underground workings along the strike of the vein for a distance of 3,000 feet or more. The most important workings occur in the vicinity of the main shaft, southwest of Star Creek.

This shaft, some 90 feet deep, connects with a foot-wall drift 80 feet long and a hanging-wall drift 45 feet long 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. A 50-foot winze sunk 115 feet northwest of the main shaft connects with a short subdrift on the vein.

The drifts on the 50-foot level were driven by the early owners of the No Cash claim and are those referred to by Cockfield. The drift on the 100-foot level, together with the adit, winze and subdrift, and several raises, were driven by United Keno Hill Mines during 1948 to 1952. According to the 1952 annual report of the company, this work developed 600 feet of ore with an average width of 3.0 feet and an average silver content in excess of 100 ounces a ton. Ore won during the development work amounted to some 4,600 tons carrying 70 ounces silver a ton, 7.2 per cent lead, and 1.6 per cent zinc. No work was done on the vein from 1953 to 1958.

The underground workings expose a complex fractured and brecciated 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 main fractured zone. The general dip of the fractured zone is 60° SE, but there are many irregularities. The wall-rocks are massive thick-bedded quartzites (upper part of the Galkeno member) interbedded with several beds of graphitic schist, phyllite, 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, openings are too few to allow the structural setting of the mineralized parts to be determined. The ore minerals include galena, sphalerite, and freibergite and their oxidation products anglesite, cerussite, and silver-bearing iron oxides and sulphates; the gangue is limonite, manganese oxides, altered siderite, some crushed and crystalline quartz, pyrite, and arsenopyrite.

The No Cash vein is favourably situated in the Galkeno member, and the ore shoots may, therefore, have a similar structural control to those in the Galkeno 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.

Betty Vein

The Betty vein (8) lies on the Betty claim, situated northeast of the No Cash claim. The vein probably represents the northeast extension of the No Cash vein. No work has been done on the vein in recent years, and the following account is from Stockwell (1926):

> This claim [Betty] is situated at an elevation of about 3,700 feet just east of Sandy creek on the northwest slope of the hill. It is owned by A. Wightman.
>
> Two small open-cuts in greenstone have exposed a narrow vein which strikes about north 58 degrees east and dips to the southeast. The minerals present are quartz, calcite, galena, sphalerite, arsenopyrite, pyrrhotite, cerussite, and limonite. The owner states that near the top of one of the open-cuts the chief ore mineral was galena; at greater depth sphalerite was most abundant and in the bottom some pyrrhotite was found. These changes took place in the vertical distance of only 3 to 4 feet.

Eastern System

Tin Can and Rico Veins

Early work on the Tin Can claim (18) is described by Stockwell (1926) as follows:

> This claim, owned by A. McLeod, H. Rhor, and S. Turpin, is situated low down on the eastern slope of the northeast end of Galena Hill. The workings consist of a ground-sluice, two shafts, and a few open-cuts. The shafts have exposed a vein which strikes about north 50 degrees east and dips steeply southeast. Judging from the material on the dumps, the vein is mineralized with ankerite, calcite, quartz, sphalerite, pyrite, and a small amount of siderite, limonite, and manganese oxide. A small amount of galena is reported to have

> been found also. The owners report that the two shafts, which were filled with water at the time of the writer's visit, are 32 and 15 feet deep, that in the deeper shaft the vein is well-defined and about 3 feet wide, and that the hanging-wall is greenstone and the foot-wall is schist.

A small amount of exploration work has been done on the veins since 1925 but no ore shoots have been found.

The Tin Can veins cut greenstone, thin-bedded quartzites, phyllites, 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 strikes about N 60° E, dips steeply southeast, is 2 to 5 feet wide, and has been mineralized principally with ankerite, calcite, quartz, sphalerite, and pyrite. Small amounts of siderite, limonite, manganese oxides, cerussite, anglesite, and galena lie on the dumps.

Traced southwest, the main vein fault crosses the Yukeno road as shown on Figure 2. Beyond this point it appears to have been repeatedly faulted and is impossible to trace. However, along the projected strike a vein fault occurs on the Viola claim in the siliceous quartzites of the Hector-Calumet member about 2,000 feet due south of the main Galkeno 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 (19), originally staked by H. A. Stewart circa 1924, lies 2,700 feet southeast of the main adit of the Galkeno mine. It has been investigated by a shaft now caved and an adit that extends for 120 feet into the hillside. At the end of the adit the vein fault shows as a poorly developed shattered zone striking N 60° E and dipping 65° SE. It appears to be 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. No ore minerals were seen in the workings or on the dumps.

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 (15) were originally owned by A. McLeod, S. Thurber, and Miss J. Stewart and were staked about 1924. They are exposed at the head of Hinton Creek and were investigated during the period 1924 to 1929 by four shafts and several pits. More recently in the early 1950's Jersey Yukon Mines, Limited, investigated the veins by means of a shallow shaft and several bulldozer-cuts.

There are two vein faults. These may represent faulted parts of a once continuous vein fault or the two may be part of a ramifying system.

The westerly vein fault has a maximum width of 3 feet, strikes N 50° E, 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, massive pyrite, galena, sphalerite, arsenopyrite, freibergite, limonite, and manganese oxides. 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 Galkeno mine.

Other Vein Faults

Cream Vein

The Cream vein (9) occurs on the Cream claim, originally staked and owned by Choketa Phillipovich. The vein lies on the lower northwest slope of Galena Hill at an elevation of 3,000 feet. It is an isolated vein, but further work may show it to be part of the western system of vein faults.

This vein 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 writer's examination 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.

In the vicinity of the vein the wall-rocks are thin-bedded quartzites, phyllites, and graphitic schist with thin lenses of greenstone and a few thick beds of quartzite. The main vein fault has an average strike of N 25° E and dips 50° SE. It pinches and swells along strike, and presumably behaves in a similar manner down its dip. The mineral content is erratic; material consists of galena, dark freibergite, pyrargyrite, and chalcopyrite in a gangue of siderite, massive calcite, quartz, pyrite, and limonite. The mineral assemblage differs somewhat from that of other vein faults in the district, in being relatively high in chalcopyrite. It is reported that about 60 tons of ore was removed by lessees from small shoots in the vein during the period 1948–49.

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, arsenopyrite, and scorodite. Probably this fracture is one of many associated with the Cream vein fault.

Fisher Creek Veins

These veins (16) occur on the David and Joan claims owned by I. S. McKay and on the Bluebell and Dan claims owned by Frank White. These claims are on the southeast slope of Galena Hill, southwest of Fisher Creek.

The workings consist of many pits and prospect shafts, all now inaccessible. All the veins are poorly exposed and little information could be gained from a surface examination.

The lower vein on the Joan claim, at an elevation of about 3,100 feet, appears to strike about N 30° W, judging from the position of the prospect pits. The dip is uncertain but may be southwest. Vein material consists of galena, sphalerite, and freibergite in a gangue of quartz, calcite, pyrite, and altered siderite.

The veins on the David and other claims appear to strike both northeast and northwest and, judging from the numerous small dumps, contain some galena, siderite, quartz, limonite, and manganese oxides.

The correlation of these veins with other vein systems is uncertain. Their strike is very different from that of the other veins on Galena Hill, except for the Sugiyama vein at the Galkeno mine. Probably the Fisher Creek veins are cross-over vein faults related to northeast-striking vein faults that are poorly developed in the phyllites and schists. However, if these northeast-striking vein faults continue and cut the favourable quartzite formation at depth, they could produce ore shoots.

Duncan Creek Vein

The Duncan Creek vein (20) is exposed on one of the Overtime claims, owned by United Keno Hill Mines, Limited. It has been exposed by stripping and trenching, mainly on the east side of Duncan Creek. The vein material consists of siderite, pyrite, pyrrhotite, galena, and sphalerite. The wall-rocks are phyllite, graphitic schist, limestone, and thin-bedded quartzites. The extent of the vein is unknown and its attitude is uncertain.

The position of the Duncan Creek vein suggests that it may be the southwestern extension of the Onek system or perhaps the Moth system.

Cairnes (1916) mentions the presence of a similar vein farther up Duncan Creek Canyon. This vein could not be found.

Mount Haldane

On Mount Haldane (Map 1147A) are numerous mineralized vein faults that are similar to those on Galena and Keno Hills. Most of these tend to be narrow and discontinuous, but it should be pointed out that relatively little work has been done on any of the showings. The writer did not examine the geology and veins on Mount Haldane in detail, but a geochemical survey carried out under his direction suggests that mineralization may be widespread. Several streams and springs carry anomalous amounts of zinc, and both siderite and galena float were found at several places. The results of the geochemical survey can be found in the publication by Boyle, Pekar, and Patterson (1956).

In the period 1918–20 some prospecting and exploration work was done on Mount Haldane, principally on Bighorn Creek. Nearly all the workings on the various claims are now inaccessible, and the writer can add little to the report by Cockfield (1919) which summarizes the features and mineralization of the veins on the Lookout and Wolf properties as follows:

> A number of claims are situated on Mt. Haldane, but serious work looking to the opening up of the deposits has been done on only one group, known as the Lookout property. This group, consisting of five claims, was staked by A. Johnson and bonded over to Messrs. J. E. Pickering, J. Greenfield, J. Anderson, and R. MacLennan. It is situated on a spur of Mt. Haldane on the western side of Bighorn creek, a tributary to the south fork of McQuesten river at an elevation of 3,500 feet, or 125 feet above the level of the creek in this vicinity. A road has been constructed to the property and comfortable buildings erected.

The development work includes two adits, an upper and a lower, both of which lie on the Lookout or central claim of the group. The upper adit is 50 feet in length and is terminated by a shaft following the inclination of the vein. The depth of this shaft is 25 feet measured on the slope. The lower adit lies 39 feet in elevation below and somewhat to the right of the upper. It is 59 feet long to the point where it taps the vein and from this point a drift follows the vein along the hanging-wall until immediately below the shaft, a distance of 87 feet. At this point a crosscut is being run to the foot-wall of the vein and it is intended to connect up the two sets of workings by a raise.

The country rock is a gneissoid quartzite and quartz-mica schist on the Lookout claim, i.e., to the west of the creek, and on the eastern side of the creek gneissoid quartzites and greenstone schists occur. Farther to the east a small body of greyish granite porphyry intrusive into schist is to be found.

The vein follows a well-defined but slightly irregular fracture in the quartzites, striking from 120 degrees to 150 degrees (magnetic) and dipping from 45 degrees to 50 degrees to the southwest. The thickness of the vein where first encountered in the lower workings is 7 feet, but it widens continuously towards the shaft. The outline is thus probably lenticular, but insufficient work has been done to permit of an exact determination of the shape. The vein has been explored in length for only 87 feet, but various considerations render it almost certain that it is much longer.

The vein-filling consists of galena, limonite, manganite, pyrolusite, anglesite, quartz and occasional specks of copper minerals, usually oxidation products. Angular fragments of the shattered country rock are also included. The hanging-wall is sharply defined and is marked by 1 inch to 6 inches of gouge, frequently showing an inch or more of impure graphite. The foot-wall is not very well marked, the mineralization extending into the country rock as much as 10 feet beyond the vein proper, in veins or tongue-like fissures. The distribution of the minerals in the vein is exceedingly irregular and follows no definite rule that has been recognized. The galena occurs plentifully along the foot-wall associated with limonite and manganese minerals. In such places it is coarsely crystalline and not particularly rich in silver. At intervals through the vein, but most frequently close to the hanging-wall, are small, irregular streaks of finely crystalline galena high in silver. The limonite is found throughout the vein. Manganese minerals such as pyrolusite and manganite are confined to the foot-wall.

The workings lie entirely within the oxidized zone. Owing to the frozen condition of the ground oxidation must have been accomplished prior to the formation of the frost zone, in which the present workings lie, as the frozen ground prevents the circulation of meteoric waters necessary to accomplish the alteration. It is, therefore, unlikely that the depth of the zone of oxidation bears any relation to the present ground water-level and probably very little to the present topography. Further the oxidation has been very incomplete.

Six samples were taken. No. 1 is a sample of all the material up to one foot from the hanging-wall; No. 2 of all material up to 2 feet from the floor of the shaft, the foot-wall not being visible; No. 3 to include the remainder of the vein lying between these two. These three samples were taken at the bottom of the shaft. No. 4 is a sample to give an idea as to the content of the foot-wall taken where the vein was first encountered in the lower adit. No. 17 is a sample of the working face taken arbitrarily on August 6. No. 18 is a sample of highly manganiferous material from the foot-wall. These were assayed and the results are listed below*.

No.	Gold	Silver	Lead	Remarks
	Ozs. per ton		%	
1	0.02	34.38	20.06	
2	Trace	26.20	25.15	
3	0.03	62.85	30.14	
4	Trace	11.10	7.20	High in manganese
17	Trace	8.20	10.66	
18	Trace	4.50	1.09	High in manganese

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*All assays by Wm. Sime, Territorial Assay Office.

In addition to the vein on the Lookout claim two and possibly three other veins as yet undeveloped occur on the Wolf claim on the eastern side of the creek. These extend up over the ridge on to adjoining claims. As no development work had been done it was impossible to obtain full particulars, especially as the surface was covered with superficial accumulations. Only the weathered outcrop of two of the veins was visible and was found to be made up of limonite and manganese minerals, such as pyrolusite and manganite, like the outcrop of the Lookout vein. From the outcrop, the veins were traced up hill by means of float for a distance of over 2,000 feet. The two veins where exposed are thin and strike about magnetic north, and dip at 45 and 60 degrees to the west respectively. They probably intersect, therefore, a short distance below the surface.

Three samples were taken—Nos. 19, 20, and 21—to represent all the vein matter in sight near the outcrop, including both float and material in place. These gave the following results on assay.

No.	Gold	Silver	Lead	Mn.
	Ozs. per ton		%	%
19	Trace	5.60	0.20	Not determined
20	Trace	Trace	0.25	Not determined
21*	Nil	12.66	Not determined	

*Assay by Mines Branch, Dept. of Mines, Ottawa.

These results on the whole are encouraging. Though it appears that the greater part of the ore will require concentration before shipping, the orebodies appear to be of sufficient size to warrant the erection of a small plant for milling. With very little more work the size of the orebodies can be determined and then it would be possible to decide if the erection of a mill was justified. Owing to the superficial accumulations the outcrop could not be traced for any distance save by means of float which is unsatisfactory, but the Lookout vein appeared to be persistent.

The work done on the Lookout property up to 1920 was summarized by Cockfield (1920) in the following description:

The Lookout property has been taken over by the Yukon Silver-Lead Mining Company, an organization of local capitalists. The property consists of a group of five claims and several fractions, situated on a spur of Lookout mountain, on the western side of Bighorn creek, a tributary of McQuesten river. The outcrop is situated at an elevation of 3,500 feet or 174 feet above the level of the creek.

The development includes about 930 feet of underground work. The upper adit is 50 feet in length and is terminated by a winze 25 feet deep, following the inclination of the vein. A second adit 39 feet below the upper and 90 feet to the north of it, is 59 feet long to the point where it taps the vein, and from this point a drift follows the vein until directly below the winze, and an upraise has been stoped to within 6 feet of the bottom of the winze. The third adit is 125 feet below the second, and 320 feet to the north. It is 135 feet long to the point where it taps the vein, and a drift following the vein has been run in a southerly direction for a distance of 305 feet. Forty feet from the point where the adit taps the vein, a winze was sunk on the vein to the fourth level, a distance of 55 feet measured along the slope, and 100 feet beyond an incline has been sunk to a depth of 90 feet. The fourth level was driven from the incline to the winze and extended north a few feet.

The vein follows a well-defined but irregular fracture in a gneissoid quartzite and quartz-mica schist. It strikes from 120 degrees to 150 degrees magnetic and dips from 45 to 55 degrees to the northeast. The filling consists of manganite, pyrolusite, limonite, cerussite, anglesite, galena, and quartz. The hanging-wall is usually well-defined and marked by gouge, frequently showing an inch or more of impure graphite. The ore is of a disseminated character, the galena occurring in small streaks and masses. There are, however, several zones in which the streaks of galena occur in sufficient numbers to permit of sorting a shipping grade of ore. The uppermost of these was encountered in the prospecting shaft sunk from the upper adit. The size of this zone has not been determined, as it does not appear in the lower workings. In the second adit there are no well-defined zones, and although galena occurs plentifully along the foot-wall in a gangue of manganese minerals, it is as a rule more coarsely crystalline and carries less silver. In the third level there are two streaks of carbonate ore carrying very high but somewhat erratic values in silver. These streaks vary from 1 inch to 12 inches in thickness. Two zones occur between the third and fourth levels, one being in the winze and the other in the incline. Neither of these has been fully blocked out, but the ore-shoot occurring in the incline is probably the largest yet found. Five samples were cut across the portion of the ore-body that is exposed in the workings, four of the samples (Nos. 1 to 4) being taken in the incline, two above and two below the fourth level, the intervals between samples being 10 feet. Both sides of the incline were sampled and the material from the two cuts included in the one sample. No. 5 is a sample taken from the fourth level 10 feet from the incline. The samples were assayed* and the results are listed on next page.

No.	Gold	Silver	Lead
	Ozs. per ton		%
1	0.02	43.48	29.80
2	0.01	34.34	28.20
3	Trace	37.20	40.60
4	0.03	45.57	36.60
5	Trace	28.80	23.20

Development work at this mine is still proceeding. The incline is being sunk to water-level, and it is the intention of the owners to stope out and sort for shipment the ore occurring between the third and fourth levels.

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*Assays by W. C. Sime, Territorial Assay Office, Whitehorse.

A small amount of prospecting and some exploratory work on the Lookout and other claims was done in the late forties and early fifties, but the results were disappointing in that no ore shoots of any size or grade were discovered.

Dublin Gulch Area

Dublin Gulch is particularly noted for its gold and scheelite placer and residual deposits (Pls. XII, XIII) which have been recently described by Bostock (*in* Little, 1959). In addition to these deposits the Dublin Gulch area contains quartz-arsenopyrite-pyrite-scorodite-gold veins, siderite veins (?), pyrite-jamesonite veins, cassiterite veins, scheelite and wolframite veins and pegmatite bodies, and skarn deposits containing scheelite. Some of these varied deposits are shown on Figure 18. The descriptions that follow are based on only brief examinations by the writer and are included primarily to provide a complete framework of data for the discussion of the origin of the mineral deposits in the Keno-Galena Hills area.

Quartz-Arsenopyrite-Pyrite-Scorodite-Gold Veins

These veins occur principally in the metasediments along the northwest contact zone of the Dublin Gulch granodiorite mass. They are similar in most respects to the quartz-arsenopyrite veins on Keno and Galena Hills and are probably of the same age. Detailed descriptions of the deposits in the Dublin Gulch area can be found in the

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PLATE XII
Dragline operation, Waddco gold placer, Haggart Creek, 1953.

publications by MacLean (1914), Cairnes (1916), and Cockfield (1919). Most of the prospecting and development work on the veins was carried out between 1912 and 1918, and since that time only sporadic prospecting by individuals has been done. There are no records of any ore having been produced from the veins. All the workings are now caved and little remains to be seen on the surface.

Most of the veins tend to occur in clusters and have a northeasterly strike, which varies between N 10° E and N 60° E. In this respect they resemble the quartz-arsenopyrite veins on Keno and Galena Hills. The dip of the veins is varied and somewhat irregular. Some dip southeast and others are vertical or dip to the northwest. In thickness the veins range from 1 inch to 4 feet, but well mineralized deposits more than 2 feet wide are exceptional.

The veins occur in vein faults, irregular shattered zones, and fissures that cut through schistose quartzites, phyllites, graphitic schist, quartz-mica schist, and locally granite and granodiorite dykes and apophyses of the granodiorite mass. The walls of the veins, particularly the granitic rocks, are altered to a soft mass of sericite, carbonate, and quartz. Some or all of this alteration may be due to supergene processes.

The veins consist dominantly of a primary quartz gangue, which is mineralized chiefly with arsenopyrite, pyrite, and gold. In addition, some veins probably contain boulangerite and other sulphosalts, judging from the occurrence of these minerals in pieces of float taken from the sluice boxes of placers below the veins.

All veins are highly oxidized to an unknown depth. The minerals in the oxidized parts are residual quartz gangue, greenish scorodite, limonite, residuals of arsenopyrite and pyrite, calcite, and free gold. The latter occurs principally in the form of minute dust and occasionally as plates and wires mainly in the scorodite-limonite mixture. Panning of the surface exposure of the veins, particularly where scorodite is present, yields gold readily.

Records of the assays of the veins indicate that the gold content ranges from 0.10 to 0.50 ounce a ton. The silver content rarely exceeds one ounce a ton. As these assays were from samples of the enriched near-surface parts of the veins it is probable that the primary vein material contains smaller amounts of both gold and silver.

Siderite-Galena-Sphalerite Veins (?)

Nodules and lumps of siderite containing small amounts of sphalerite, galena, jamesonite, and other sulphosalts appear from time to time in the heavy concentrates from the Dublin Gulch placers. The presence of these minerals suggests that siderite veins similar to those on Keno Hill, Galena Hill, and Mount Haldane may occur somewhere in the drainage basin of Dublin Gulch.

Pyrite-Jamesonite Veins

In recent years E. H. Barker has exposed several veins by bulldozer-cuts on the right bank of Haggart Creek near its junction with Dublin Gulch.

These veins occur in shattered zones, probably vein faults, which appear to have a northeast strike. Their attitude is not known. The primary minerals in the veins are pyrite, jamesonite, and quartz. Near the surface these minerals are altered to limonite, senarmontite, anglesite, and native sulphur. The content of gold and silver in the veins is low.

Cassiterite Veins

Two cassiterite-tourmaline veins occur near the top of the hill overlooking Haggart Creek and Dublin Gulch. According to Bostock (pers. com.) these veins were found by E. R. Sheppard and H. Ray in August 1943 by painstaking panning of samples of soil. Consolidated Mining and Smelting Company, Limited, investigated the veins in 1945 by trenching and driving a crosscut below the surface outcrops, but the work failed to find orebodies large enough to mine and the prospect was abandoned. No work has been done on the veins since 1945. Thompson (1945) has published an early description of the prospect.

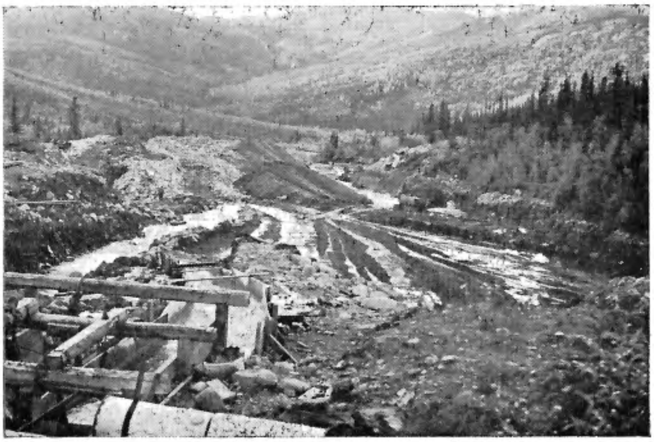


PLATE XIII

Taylor gold-scheelite placer, Dublin Gulch, looking west, 1953.

RWB, 9-6-52

The veins are extremely irregular and are more in the nature of impregnations in intensely shattered and brecciated fault zones. One of the mineralized shattered zones trends N 45° W, and the other, judging from pits that cross it, trends N 20° E. The dip of the mineralized zones is unknown, but appears to be steep. The width of the zones is uncertain but seems to vary from 1 foot to 25 feet. The wall-rocks are quartzites, phyllites, graphitic schist, and quartz-mica schist.

The mineralized zones consist essentially of highly brecciated rock impregnated with microscopic green tourmaline, quartz, microcrystalline cassiterite, and chlorite. Small crystals and masses of pyrite are common in the primary mineralized material, and locally some chalcopyrite is present. The near-surface parts of the mineralized zones are oxidized and are composed of disintegrated breccia fragments containing tourmaline and cassiterite, powdery greenish brown soil composed of limonite, tourmaline, and cassiterite, and cellular fragments of rock containing quartz, limonite, altered pyrite, cassiterite, and tourmaline.

According to Thompson a channel sample across one of the zones contained 1.53 per cent Sn. Two other channel samples taken by Bostock, across 30 inches, assayed 1.53 and 0.83 per cent Sn, a trace of gold, and 0.04 ounce of silver a ton for both samples. Bostock (pers. com.) states that the average of the samples assayed by the Consolidated Mining and Smelting Company was less than 0.3 per cent Sn.

Tungsten Deposits

The tungsten deposits in the Dublin Gulch area are of four types, as follows:

1. Quartz veins containing scheelite and/or wolframite.
2. Pegmatite bodies containing scheelite and/or wolframite.
3. Skarn bodies carrying scheelite.
4. Placer and residual deposits carrying scheelite and wolframite.

These deposits have been described by Cairnes (1917) and Cockfield (1919), and more recently by Bostock (*in* Little, 1959).

The quartz veins containing scheelite and wolframite occur sporadically in the granitic rocks, in the quartzites, phyllites, and schists, and in some of the skarn zones developed in limestone bands.

In the granitic rocks the quartz veins tend to form small stockworks in which individual veinlets range from 1 inch to 6 inches in width. None of the stockworks is extensive, and none of the individual quartz veins seen by the writer appears to continue far. The scheelite occurs as crystals in the quartz gangue and in the adjacent granitic rock. Calcite and muscovite are the only other common minerals, and wolframite is present in some quartz stringers. Stockworks of this type occur near the head of Bawn Boy Gulch and in the granitic rocks to the northeast.

Quartz veins carrying scheelite and wolframite and cutting the quartzites, schists, and skarn rocks are not numerous. Where found they tend to be within the contact zone of the granodiorite mass, particularly along the north and northeast contacts. Mineralogically, the veins are similar to those that cut the granitic rocks.

The pegmatite bodies containing scheelite are also rather rare. A few of these bodies occur near the head of Dublin Gulch both in the contact zone and in the granodiorite mass. The pegmatites are composed mainly of quartz, muscovite, and small amounts of feldspar. Tourmaline and wolframite occur in a few dykes.

Scheelite in skarn has a widespread though sporadic distribution in the eastern contact zone of the granodiorite mass, particularly near the head of Ray Gulch.

The skarn occurs in irregular bodies, boudins, beds, and in discontinuous lenses, and appears to have been formed by contact metamorphism of limestone, calcareous schist, and calcareous quartzite. The principal minerals are diopside, fibrous amphibole, scapolite, quartz, carbonate minerals, plagioclase, epidote, sphene, and apatite. The scheelite occurs as subhedral to anhedral crystals disseminated through the groundmass and is commonly concentrated in the carbonate or quartz-rich parts of the skarn. Analyses of selected samples of some of the skarns indicate contents of WO_3 ranging from 0.0 to 2.43 per cent.

The gold-scheelite placers and eluvial deposits of the Dublin Gulch area occur principally along the lower and central reaches of Dublin Gulch and near the head of Bawn Boy Gulch. In addition, Haggart Creek carries both gold and scheelite and the two minerals can be panned in the gravels of Olive Pup, Stewart Pup, Eagle Pup, Ray Gulch, and other streams draining into Lynx Creek.

The principal heavy minerals in the placers are gold, scheelite, wolframite, hematite, arsenopyrite, garnet, native bismuth, cassiterite, magnetite, and pyrite. Only gold and scheelite are present in economic quantities. Bostock estimated in 1943 that 176,400 pounds of scheelite could be recovered from the various placers along Dublin Gulch and Haggart Creek. Since this estimate a considerable amount has been removed.

STRUCTURAL CONTROL OF ORE SHOOTS AND MINERALIZED ZONES

Details of the influence of vein fault junctions and schist cappings in localizing ore shoots and mineralized zones have been discussed in the earlier descriptions of the major systems. Table 2 summarizes these details and facilitates an analysis of the influence of certain geological features on the localization of the ore shoots.

In the Keno Hill-Galena Hill area 63 deposits were examined in detail. Of these the structural elements localizing ore shoots and mineralized zones are unknown in 24, mainly because of poor exposures or inaccessibility of abandoned workings. In 32 deposits ore shoots and mineralized zones are located below actual schist cappings or were below these cappings before erosion removed the schist. In 12 deposits, observed or suspected vein fault junctions are favourable sites. Five properties have both features present.

Thick-bedded quartzites are the most favourable host rocks, forming the wallrocks of the ore shoots and mineralized zones in 41 cases, and greenstones are next with 24. Thin-bedded quartzites, phyllites, and schists form part or all of the wallrocks in 41 deposits but only in three are the ore shoots wholly enclosed and hence probably controlled by these rocks.

The ore shoots of the most productive mines—Silver King, Galkeno, Sadie-Friendship, Ladue No. 2 orebody, Bellekeno, Shamrock, and No. 9—were in quartzite or greenstone below schist cappings, and those of the Silver King, Elsa, Hector-Calumet, Onek, Ladue No. 1 orebody, and Lucky Queen occurred mainly in quartzites at vein fault junctions. In certain deposits, as at the Ladue, No. 9, Silver King, and others, both schist cappings and vein fault junctions were present, making the conditions for mineral deposition especially favourable.

The structural reasons for localization of the ore shoots below schist cappings and at junctions can be logically explained by recourse to the dynamics of faulting.

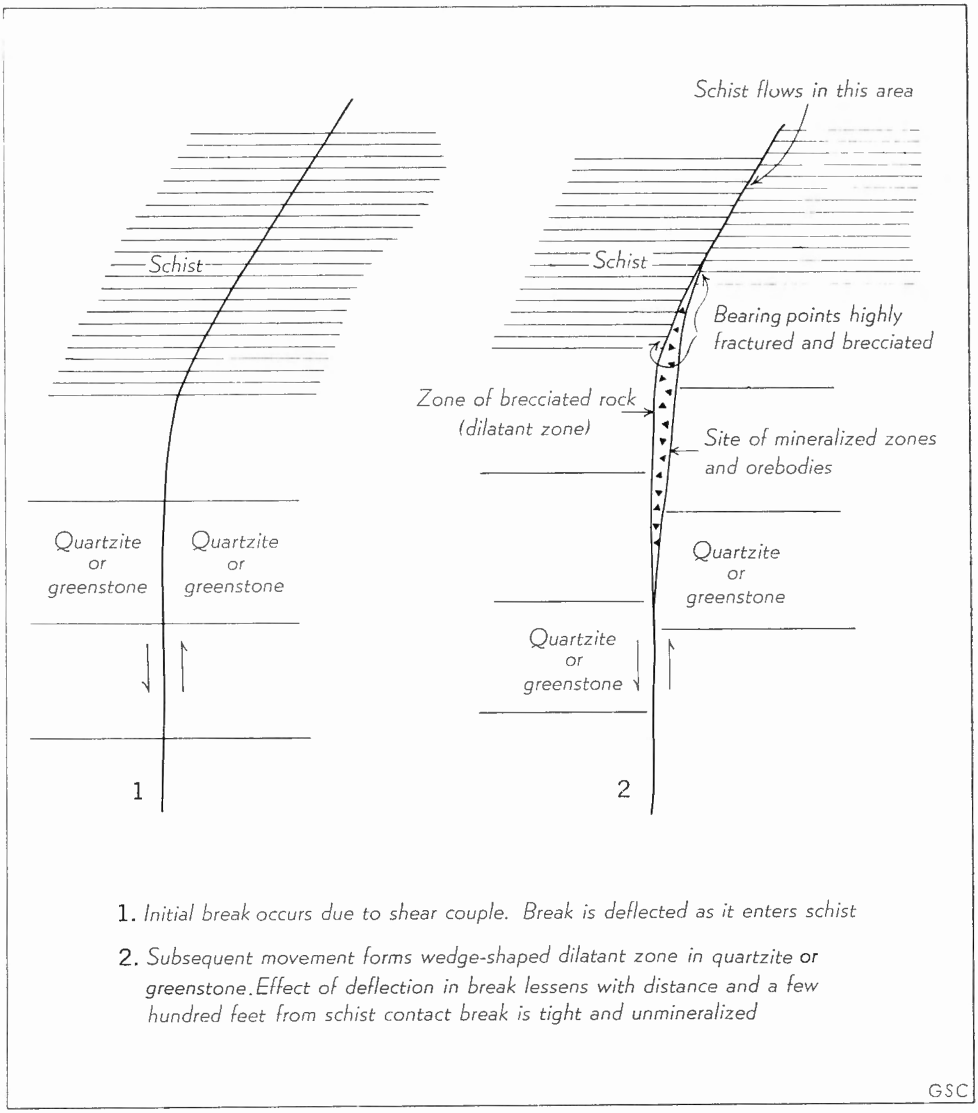


FIGURE 19. Sketches illustrating formation of a dilatant zone below schist capping.

Considering the influence of schist cappings, a detailed study carried out at the Bellekeno mine shows that as the fault enters the schists and phyllites it is deflected in strike slightly to the right. The dip likewise shows a deflection, but this is not uniform. The movement on the fault is left hand, and the foot-wall part of the fault immediately below the point where the fault enters the all-schist zone is highly brecciated and fractured. The extent of the brecciation and fracturing diminishes markedly in a perpendicular direction from the all-schist contact, and along a line paralleling and some 350 feet below this contact the fault is relatively tight. It will be noted (*see* Fig. 12) that the ore shoots are restricted to this favourable zone of brecciation and fracturing. A study of the longitudinal section of the No. 9 vein (*see* Fig. 9) indicates nearly identical phenomena.

Figure 19 illustrates in a diagrammatic manner how extreme brecciation occurs below schist cappings. Considered physicochemically, the main point is that the area below the schist capping is a dilatant zone where a marked increase in volume has taken place. This dilatant zone was a site of low pressure and low chemical potential towards which diffusion currents and/or migrating solutions moved and where they deposited their mineral content. The junctions of the vein faults are likewise dilatant and low-pressure zones due to brecciation and fracturing (a volume increase) caused by movement along the various fault planes.

From a practical viewpoint the formation of favourable dilatant zones does not appear to be restricted to any particular vein fault system. The so-called longitudinal vein faults appear to be as favourable to mineralization as the transverse type. The main and important fact seems to be the correct structural conditions, viz., a change in the rock type producing brecciated zones beneath schist cappings or vein fault junctions. Some of the favourable places have been pointed out in the description of the vein fault systems; others will suggest themselves to the interested investigator.

Chapter IV

GEOCHEMISTRY OF GLACIAL DEPOSITS, SOILS, AND COUNTRY ROCKS

Glacial Deposits

The glacial deposits of the area were laid down during the advance and retreat of at least two ice-sheets that spread over the area from the east. The evidence for the first glaciation is rather meagre and is restricted to the presence of erratics above an elevation of 4,000 feet on Keno and Galena Hills and to an old till in the upper part of Dublin Gulch. The most distinctive deposits are those of the last glaciation and these received most attention in this investigation.

These deposits, as shown on Figure 1, floor the principal valleys and form benches on the lower slopes of the hills. They vary in thickness from a few feet to 50 feet or more and are composed mainly of till, glacio-fluvial deposits, glacio-lacustrine gravel, sand and silt, and layers of peat.

The tills, rarely more than a few feet thick, are absent in places. They are grey or greenish buff and consist of a heterogeneous mixture of fine sand, clay, small particles of schist, quartzite, and greenstone, and variously sized stones and boulders. Carbonate, mostly in the cementing materials, is present in some tills.

The clay and sand fractions are composed principally of irregular grains and broken fragments of quartz, feldspar, mica minerals, and hornblende. Heavy mineral accessories as determined by X-ray are magnetite, ilmenite, rutile, sphene, leucoxene, zircon, staurolite, garnet, monazite, epidote, tourmaline, pyrite, and red and black jasper pebbles. The till minerals are generally angular and abraded, and look fresh with little visible evidence of chemical decomposition. Most tills give a neutral or slightly alkaline reaction (pH 7–7.5).

Most of the rock pebbles and fragments and the heavy minerals in the tills are probably derived locally. Some minerals such as garnet and staurolite and the jasper pebbles may, however, have travelled considerable distances, because these minerals are not plentiful in the rocks underlying Keno and Galena Hills.

Lenses of gravel and sand are common in some tills, and thin peat layers are present locally. The gravel and sand lenses generally contain the same mineral assemblage as the tills. The peat layers are composed essentially of brownish and brownish black decomposed plant remains and much brownish material (humus). A small amount of mineral matter, consisting of quartz, feldspar, mica flakes, and a suite of heavy accessory minerals similar to that in the tills, is present throughout the peat.

The glacio-fluvial deposits are as much as 50 feet or more thick and include poorly sorted gravels and sand deposits which occur in kames, eskers, and glacial benches. Most of the pebbles and stones are relatively well rounded to subangular and consist of quartzite, schist, greenstone, diorite, and granite, all mainly derived locally. The fine sandy fractions contain the same mineral assemblage as the tills.

The glacio-lacustrine deposits range from a few feet to tens of feet in thickness. In places they are stratified, in others they consist of unsorted, washed gravels containing sand lenses. The gravels contain well-rounded pebbles, stones, and subangular schist fragments of local derivation. The mineral constitution of the sand lenses and fine fractions of the gravels is similar to that of the other glacial deposits described above.

Soils, Muck, Peat, and Half-bog Soils

Leahey (1953) has discussed the nature of the soils in Yukon, and some of his generalizations apply to the Keno Hill-Galena Hill area. Soil development has been affected by four principal factors: the variability of parent materials, the marked relief of the country, the climatic and vegetative forces under which the soil developed, and the presence of permafrost.

In the Keno Hill-Galena Hill area both bedrocks and glacial materials have served as parents for soil. The marked relief has had the effect of producing deeper soils in the valleys and on the lower slopes of the hills. The difference in the exposure of the hillsides has been responsible for the occurrence of greatly different soils within short distances. South-facing slopes are generally less densely wooded and freer from permafrost than north-facing slopes. On the former the soils are somewhat better developed; the latter are covered in most places by deposits of muck, peat, and half-bog soils.

Except for a few localized areas, the soils are not strongly weathered or deeply leached. They also exhibit a poor profile development, particularly those underlain by permafrost.

The soils in the area can be conveniently classified into two general types: (1) residual, and (2) muck, peat, and half-bog.

The residual soils were formed principally from the weathering of the various types of bedrocks, or as is evident in some places, particularly in the vicinity of Dublin Gulch, from the decomposition of a till that predates the last glaciation.

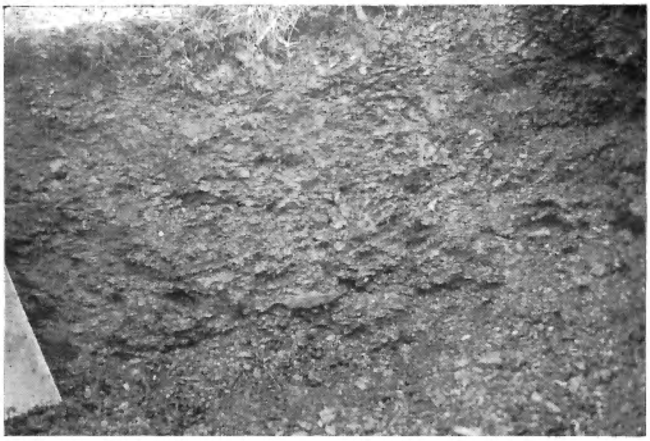


PLATE XIV
Residual soil developed on schist, south of Keno Summit. Note highly disturbed character of profile.

RWB, 1-8-55

The thickness of the residual soils varies, depending upon the slope of the hills. On the tops of the hills they are rarely more than 3 feet thick and in places are entirely absent; lower down on the slopes the soils, thickened by slope wash and land creep, may exceed 10 feet. In most areas they are highly disturbed by solifluction and frost-boiling, and their profile development is either immature or non-existent (Pl. XIV). In places the following generalized profile is present from the surface downward:

Horizon	Description
Surface A_{00}	Trees, shrubs, grass, moss, loose leaves, etc.
A_0	Undecomposed, partly matted organic layer consisting of roots, moss, woody fragments, humus, etc.—3 to 6 inches thick—unfrozen during summer.
A_1	Organic layer consisting of decomposed roots, moss, woody fragments, humus, clay, sand, etc.—3 to 6 inches thick—generally unfrozen during summer. This layer is thin or absent in places.
B + C	Residual soil—1 foot to 10 feet thick. Frozen except locally. The soil overlying quartzite and greenstone is light reddish and yellowish brown and contains much fine sand, clay, and small amounts of humus. Because of frost action angular blocks of quartzite and greenstone are generally admixed with the soil in all areas. The principal mineral constituents are quartz, feldspar, micas, clay minerals, hornblende, and limonite. The common heavy minerals are zircon, rutile, sphene, ilmenite, magnetite, epidote, monazite, tourmaline, and garnet. The soils overlying greenstones carry much sphene and leucoxene and small amounts of chromite. In the vicinity of the siderite-galena-sphalerite and pyrite-arsenopyrite lodes cerussite, beudantite, scorodite, native gold, oxidized galena cubes, goethite and limonite particles, and oxidized pyrite nodules appear in the heavy fractions. Over parts of the Dublin Gulch granodiorite mass and in the vicinity of some skarn zones the soils and weathered residuum carry scheelite. The soil overlying schists is grey or black, depending upon the type of schist. Over graphitic schists the soil is black and contains much graphitic material. Small fragments and plates of schist are universally present. The principal mineral constituents are quartz, feldspar, micas, clay minerals, graphite, and limonite. The common heavy minerals are similar to those overlying quartzite. Near the cassiterite veins north of Dublin Gulch the soils overlying schists and quartzites carry small amounts of cassiterite and tourmaline.
Bedrock D	Quartzite, phyllite, greenstone, and schist.

Most residual soils are moderately well drained on the lower slopes of the hills, but poorly drained on the tops of the hills, where the upper layers of the soil are water-saturated all summer. The pH of most residual soils varies from 5.2 to 6.5.

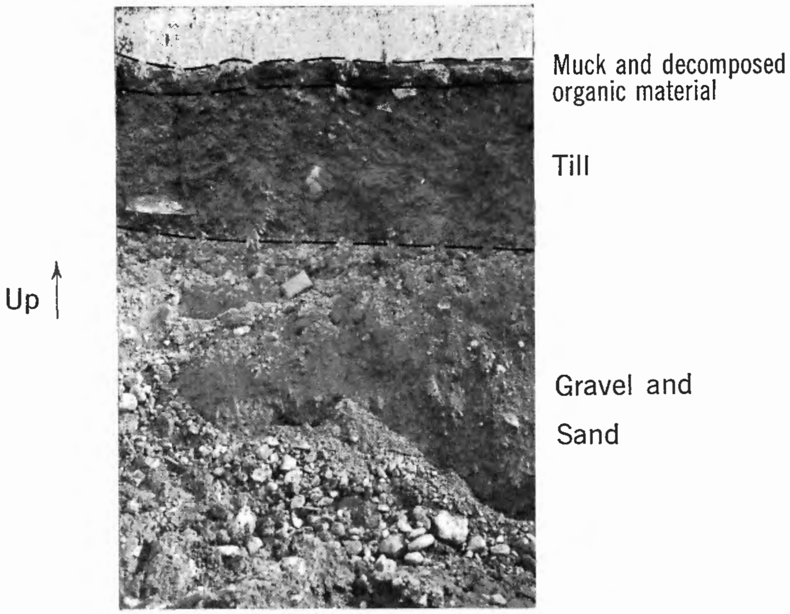


PLATE XV Organic soil developed on glacial deposits, bulldozer-cut east of Silver King mine.

The muck, peat, and half-bog soils are largely developed on the north slopes of the hills and on low-lying poorly drained ground. In most occurrences the profiles show the following sequence from the surface downwards (Pl. XV):

Horizon	Description
Surface A_{00}	Trees, grasses, low shrubs, mosses, loose leaves, etc.
A_0	Slightly compressed undecomposed organic matter consisting of woody fragments, roots, mosses, leaves, and minor amounts of mineral matter; 3 to 6 inches thick; unfrozen during summer.
A_1	Muck composed of dark brown to black decomposed organic matter and humus with a slight admixture of clay, sand, etc.; 6 to 10 inches thick; generally permanently frozen below top few inches.
B + C (Residual soils) D (Glacial materials)	Residual soil or till, gravel, and sand; generally frozen; thickness varies.
Bedrock D	Quartzite, phyllite, greenstone, and schist.

The muck, peat, and half-bog soils are very poorly drained and are water-saturated all summer. Their pH varies from 6.0 to 7.0.

Geochemistry of Soils and Glacial Deposits

Major Constituents, Base Exchange Capacities, etc.

Table 3 records chemical analyses of composite samples of residual soils, glacial tills, and muck together with the pH, organic content, and base exchange capacity of each type. The main points of interest in the analyses are the differences in content of SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, and MgO between the parent bedrocks, residual soils, and glacial tills, and the differences in the base exchange capacity and organic content of the soils, tills, and muck.

The residual soils contain less silica and more alumina and iron than either their parent bedrocks or the glacial tills. The chemical differences between the residual soils and tills are a measure of the difference in the degree of weathering, leaching, and hydrolytic activity that took place during the formation of each. The glacial tills are relatively fresh and show little evidence of weathering. The residual soils, on the other hand, exhibit the effects of weathering and mild laterization. During the latter process silica is generally leached out of the parent materials, and alumina and iron are concentrated as a result of certain hydrolytic processes involving the formation of clay minerals and the hydroxides of aluminum and iron. Compared with the residual soils, the high exchangeable calcium value and the relatively high lime, magnesia, and carbon dioxide contents recorded for the glacial till indicate that carbonates are present, a feature that further emphasizes the low degree of weathering of the tills.

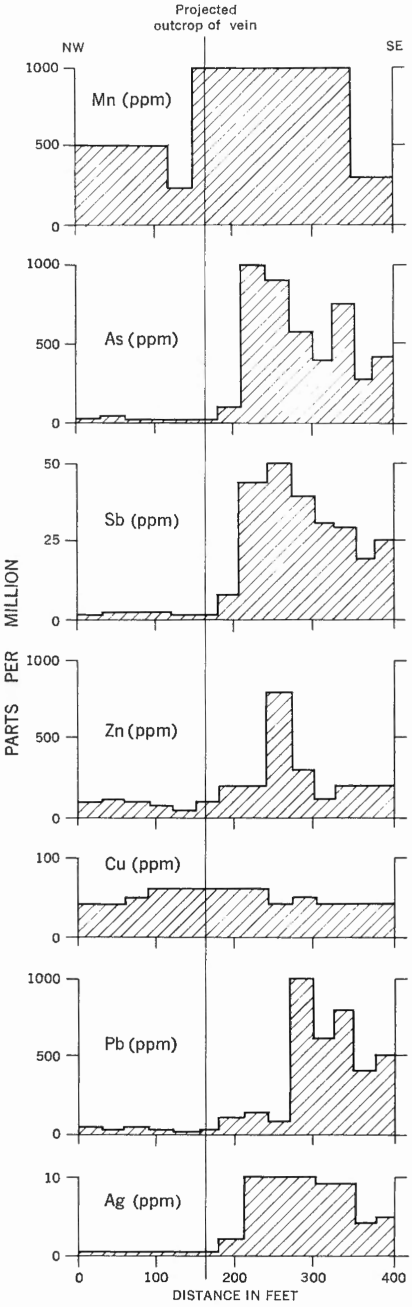
The residual soils and glacial tills are relatively low in organic matter compared with the composite sample of mucks and half-bogs. Likewise, the base exchange capacity of the residual soils and tills is several magnitudes lower than that recorded for the mucks. It is shown in Chapter V that mucks have a high adsorption capacity for zinc, copper, and other trace elements and hence have a marked effect on the dispersion of these elements from the lead-zinc-silver orebodies.

Minor and Trace Elements

Table 4 records the average content of certain trace elements in the various types of soils compared with the content in the material from which they were probably derived. All averages are from samples well removed from mineral deposits, and they should, therefore, represent background values.

With the exception of zinc and silver, the mucks and half-bogs contain smaller amounts of the trace elements than the underlying glacial till. In the muck and organic layers developed on residual soils, copper and zinc are enriched; all the other trace elements are present in smaller amounts.

Residual soils developed on quartzites and schists are generally enriched in Ag, Pb, Cu, Zn, Sb, and As. Except for copper the same is true of soils overlying greenstones, and even copper is enriched in places, amounts up to 150 ppm having been found. Zinc and especially arsenic, antimony, and tungsten are enriched in the highly aluminous soils and weathered debris overlying parts of the Dublin Gulch granodiorite. The high content of arsenic and tungsten reflects the presence of the pyrite-arsenopyrite-gold veins and scheelite concentrations known to occur around the borders and in parts of the granodiorite stock.

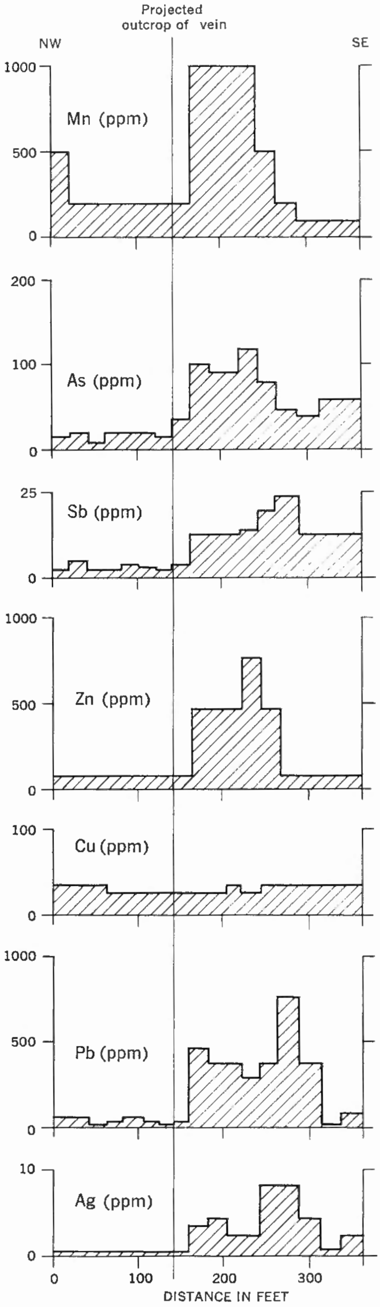


SAMPLING DETAILS

Depth of soil cover 1 to 3 feet
Depth of sampling 1 to 2 feet
Permafrost distribution is irregular

For location of traverse see Figure 20

FIGURE 21. Metal content of soil on traverse D, No. 6 vein, Keno Hill.



SAMPLING DETAILS

Country rock-graphitic schist
Depth of soil cover 2 feet
Underlain by permafrost

Samples taken 1 foot from surface
Dip of vein, southeast
Gentle slope to southeast

GSC

FIGURE 22. Metal content of soil on traverse across Kinman-Porcupine vein, Keno Hill.

Table 5 gives the metal content of localized composite samples of organic layers, peat, muck, and half-bog soils compared with their underlying soils and tills. In some places the organic soils are enriched in silver, lead, and zinc; in others the content of the organic soils and of the soils, etc., underlying them is about the same or the former may contain less. Arsenic and antimony are generally lower in the organic soils than in the underlying parent materials.

Samples Taken Across Vein Faults

The results of laboratory analyses on samples of residual soils and tills taken on traverses across several known vein faults are given in Tables 6 to 13, and graphs of some are given in Figures 20 to 25. Similar work based on field analyses has also been done (Boyle and Cragg, 1957).

Tables 6, 7, 8, and 9 and Figures 20, 21, and 22 show the distribution of Ag, Pb, Cu, Zn, As, Sb, and Mn in samples taken across the No. 6 and Kinman-Porcupine veins. The following summarizes the most interesting points.

There is general agreement between the field and laboratory analyses, that is, nearly all anomalies shown by the field analyses were confirmed by more precise analytical procedures. Marked anomalies in the content of silver, lead, zinc, arsenic, and antimony occur near the veins. The anomalies generally contrast well with the background, and most are broad, spanning a distance of 100 feet or more. Most anomalies are also offset down the slope a short distance and their upper edges are close to the projected outcrops of the veins. Lead and silver anomalies are the most consistent; zinc is more erratic.

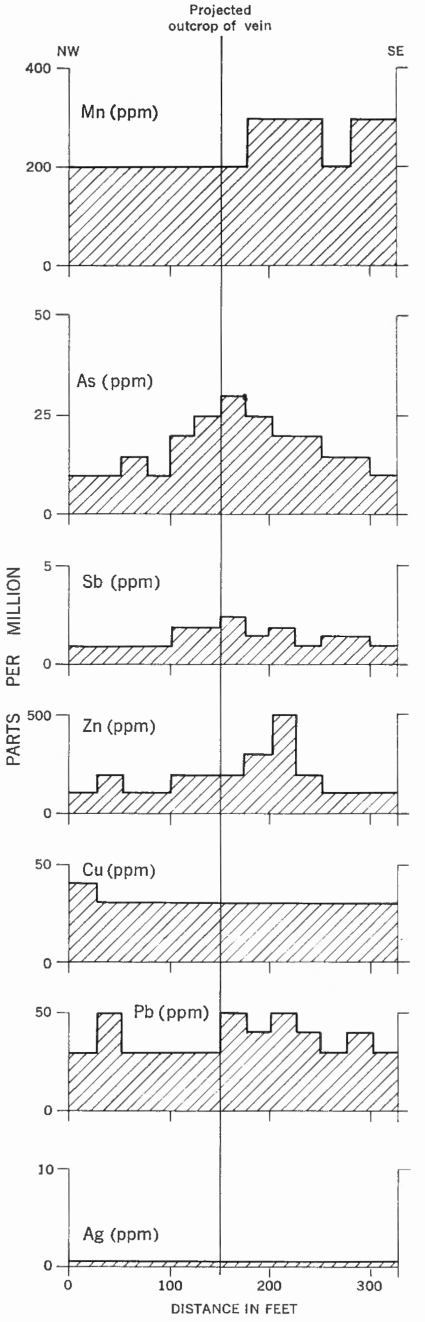
The copper content is fairly uniform and does not generally reflect the presence of the veins. It will be noted, however, that the copper content of the soil is generally higher over or near greenstones (*see* Tables 6 and 8).

Both the arsenic and antimony content in the soil reflects the presence of the veins. The anomalies obtained are broad, generally extending over a distance of 100 feet or more, and like the lead and zinc anomalies are offset a short distance down the slopes.

Manganese also shows anomalous values near some veins, and appears to follow silver, lead, zinc, arsenic, and antimony closely.

Table 10 and Figure 23 give the distribution of heavy metals, manganese, etc. in samples taken across the Bellekeno 48 vein. No silver anomaly appears in the soils along this traverse, but the content of lead, zinc, arsenic, and antimony reflects the presence of the vein. Zinc and arsenic appear from the data to be the best indicator elements over this particular vein. The results for manganese are indefinite, but there is a slight step up (from 200 to 300 ppm) in the soils to the southeast of the projected outcrop of the vein.

The results obtained on the traverses across the No. 6, Porcupine-Kinman and Bellekeno veins are representative of areas on Keno and Galena Hills where the residual soil cover is light (1 foot to 5 feet) and where slope wash and other modes of soil creep are limited. Where the soils are deep, and where slope wash and other effects are pronounced, the results obtained are somewhat indefinite, and the anomalies are



SAMPLING DETAILS

Country rock-quartzite

Depth of soil cover 3 to 5 feet

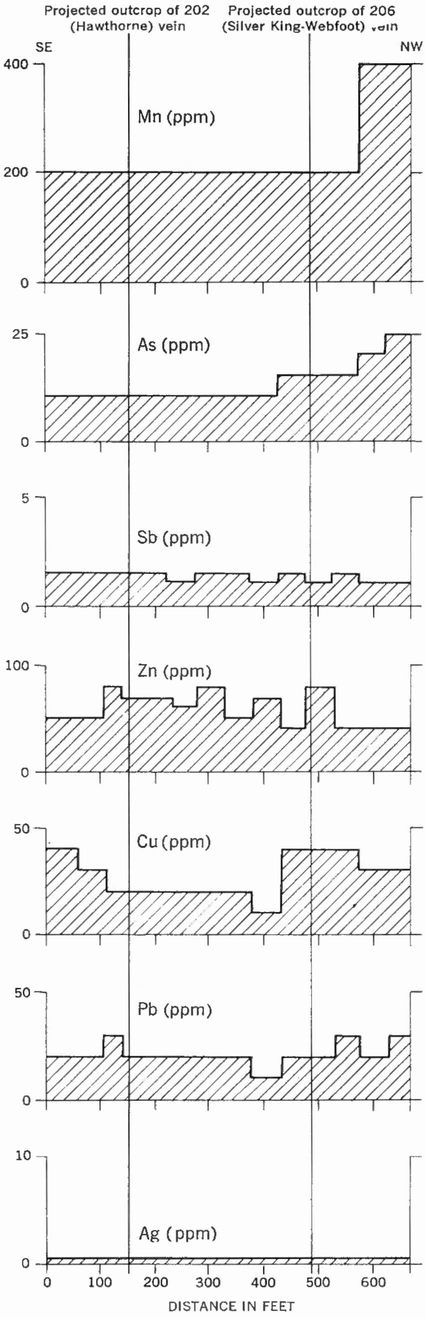
Underlain by permafrost

Samples taken 2 feet from surface

Dip of vein, steeply southeast

Moderate slope to northeast

FIGURE 23. Metal content of soil on traverse across Bellekeno 48 vein, Sourdough Hill.



SAMPLING DETAILS

Country rock-quartzite

Depth of soil, glacial till, and gravel 10 to 20 feet

Samples obtained 2½ feet from surface

Underlain by permafrost

Dip of veins, southeast

Gentle slope north

GSC

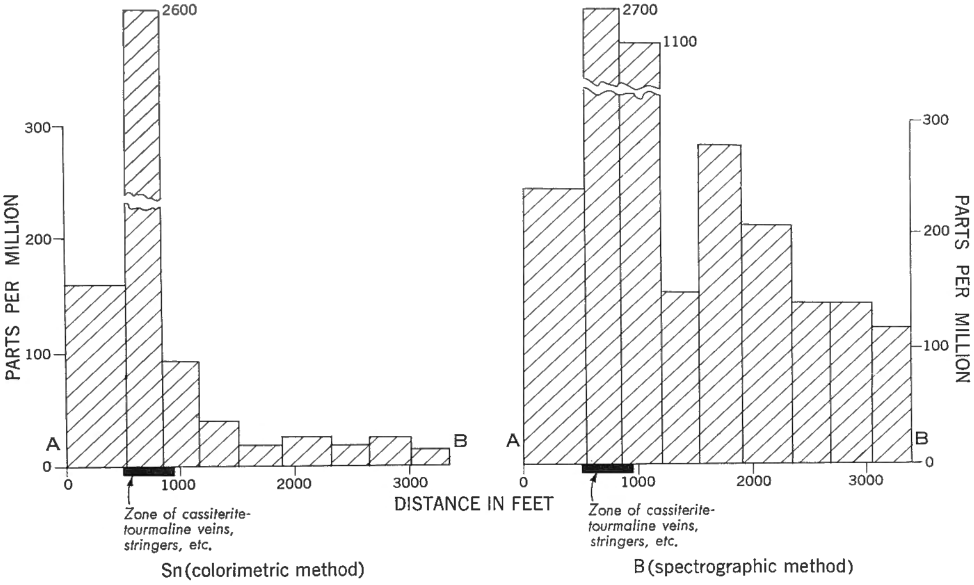
FIGURE 24. Metal content of soil on traverse across Silver King veins, Galena Hill.

generally much broader and less pronounced. In these cases successful prospecting requires more detailed sampling, and samples must be taken close to bedrock to establish the edges of the anomalies.

The analyses for silver, lead, zinc, arsenic, antimony, and other elements given in Table 11 illustrate the variation in metal content of soil, with depth over the Onek vein. As the vein is approached there is a consistent increase in all the elements except manganese.

The results of analyses over vein faults covered by deposits of glacial material 10 to 30 feet thick are typified by those obtained over the two veins at the Silver King mine (*see* Table 12 and Fig. 24). There the metal content of near-surface glacial material is relatively uniform and no anomalies indicate the presence of the veins beneath. Spot samples taken a foot or so above bedrock, however, contain high amounts of all metals in the vicinity of the veins, indicating that deep sampling of glacial till, etc., may effectively locate vein faults.

The results of tin and boron analyses of samples taken along a traverse over the cassiterite zones north of Dublin Gulch (Fig. 18, A-B) are given in Table 13 and plotted on Figure 25. The soils in the area are mainly residual and are developed on schists, phyllites, and quartzites. The vein zone is strongly reflected in the soils by the high content of tin and boron, but there is no apparent enrichment of the other elements. The excess tin and boron is held in cassiterite and tourmaline, both of which are plentiful in the heavy concentrates from panning. It should also be noted that the soils



Sn (colorimetric method)

B (spectrographic method)

SAMPLING DETAILS

Country rock-graphitic schist, phyllite, and quartzite
Depth of soil cover 2 to 10 feet
Underlain by permafrost

Samples taken 1 to 2 feet from surface
Moderate slope to south
For location of traverse line see Figure 18.

GSC

FIGURE 25. Tin and boron content of soil on traverse A-B, Dublin Gulch.

north of Dublin Gulch are enriched in arsenic and particularly in antimony, like those south of the Gulch (Table 4). Such enrichments probably reflect the presence of quartz-arsenopyrite-pyrite-boulangerite veins below the soil cover.

Ease of Extraction of Trace Elements

The ease with which zinc, copper, and lead can be extracted from the various soils in the Keno Hill-Galena Hill area is recorded in Table 14. The following features are apparent.

The hot nitric acid treatment and fusions with potassium bisulphate remove nearly all the three metals from the soils and organic material. More metal was generally extracted by fusions than by the hot nitric acid treatment, but in a few samples this was not so for lead and zinc. The discrepancies are, however, small, and one can conclude that for geochemical prospecting reliable results may be obtained by either method.

Metal-free water removes only infinitesimal amounts of lead and zinc and practically no copper from the samples. It is interesting to note, however, that of the various types of soil tested, the highest percentage of zinc was extracted from the organic materials. This suggests that some of the zinc is only lightly bound and exchangeable with H^+ in the organic soils. The amount of lead yielded to metal-free water by the organic soils is relatively large, but the per cent extraction is less than from some of the other soils and till.

The sodium acetate and ammonium citrate solutions remove small amounts of the three metals from all soil types. The per cent extraction of zinc is highest for the organic soils, confirming the conclusion that some of the zinc is loosely bound in exchangeable positions in these materials. The values for copper from organic samples show a somewhat similar trend, but the lead results are erratic.

A comparison of the results obtained by the two extractive solutions with those for HNO_3 and $KHSO_4$ indicates a general sympathetic agreement; that is the values obtained by the solutions in general vary directly with the amount of metal in the sample as obtained by the rigorous treatment. It is also evident that the sodium acetate solution is the more effective extractant for all three metals. These general observations suggest that mild leaching methods can be used with effect in reconnaissance geochemical prospecting or on a preliminary survey, but for more detailed surveys the strong attacks are desirable.

Binding of Minor and Trace Elements

Several investigations were carried out on the residual soils, tills, peat, muck, and half-bog soils to determine the manner of binding of lead, zinc, cadmium, copper, silver, manganese, arsenic, antimony, tin, and tungsten. These included various leaching experiments, X-ray determinations of heavy minerals, and spectrographic analyses of limonite, wad, organic matter, and heavy concentrates (*see* Table 15). The results of this work can only be summarized here.

The average content of *lead* in the organic soils is generally low; it is slightly higher in the tills, and variable in the residual soils, depending on the proximity of the samples to a lead deposit.

Most of the lead in the organic material is strongly bound as a constituent of the colloidal brown humic complexes and can only be removed by ashing. Small amounts are adsorbed to the surface of these humic complexes and to any clay minerals present. This lead is in exchangeable positions and can be partly removed by distilled water and mild acetate or citrate solutions. The remainder of the lead is probably present as a lattice constituent in feldspar grains, clay minerals, and magnetite, and as an interstitial constituent in zircon.

In the tills most of the lead is in clay minerals, carbonates, feldspar, and zircon with small amounts in organic matter. Traces are adsorbed to the surface of all the above-mentioned minerals and colloids.

In the normal residual soils lead is bound in or adsorbed on clay minerals, organic humic complexes, zircon and other heavy minerals, and iron and manganese colloids and oxides. Near a lead deposit, where the lead contents often exceed 500 ppm, cerussite and small particles of galena coated with anglesite appear in the heavy concentrates. In addition to these, small particles of beudantite, limonite, and manganese oxides (wad) contain appreciable amounts of lead.

Much of the *zinc* in the organic soils is bound in the humic complexes with the remainder adsorbed to the surface of these complexes or bound in clay minerals, magnetite, and any iron and manganese oxides and hydroxides in the samples. In the tills some of the zinc occurs as an adsorbed constituent in exchangeable positions, but most appears to be present in clay minerals, organic matter, carbonates, and in heavy constituents such as magnetite.

Most of the zinc content of the residual soils appears in the iron and manganese coatings on the various mineral grains, in the colloidal clay complex, in organic matter, in small particles of limonite and wad, and in heavy minerals such as magnetite. Small amounts are in exchangeable positions, adsorbed to all these constituents judging from leaching experiments (Table 14). Sphalerite and other zinc minerals rarely appear among the heavy concentrates in soils taken from near the veins.

The results of experiments on the binding of zinc in the soils of the Keno Hill area essentially confirm the conclusions drawn by Baughman (1956) and White (1957).

The *cadmium* content of all soils and glacial materials is low (<2 ppm) and is therefore difficult to determine accurately. The element follows zinc closely and is probably bound in a similar manner. No cadmium minerals were observed in any of the soil samples studied under the microscope.

Copper is generally present in low amounts (15 to 50 ppm) in all surficial materials with the exception of the residual soils overlying certain greenstone bodies. In the latter the element is present in significant amounts (up to 150 ppm) and occurs mainly in the limonite and manganese coatings on the mineral grains, in the colloidal organic and clay complexes, and in rare microscopic particles of malachite. In the normal residual soils, organic muck, and peat, most of the copper occurs in the iron and manganese mineral coatings, in the colloidal humic and mineral complexes, and in heavy minerals such as magnetite and hornblende.

Near some veins the residual soils contain higher than average amounts of copper. Much of the excess copper is present in small unweathered particles of freibergite and in microscopic particles of malachite. The remainder appears to be bound in the limonite and wad granules and dust in the soil.

Silver follows lead closely in the soils as shown by the results in Tables 6 to 13 and Figures 21 to 24. It is generally not possible to determine the position of silver in the various constituents of the soils where the values lie below 1 ppm. Near the veins, where the silver values rise to 10 ppm or more, most of the silver is contained in the heavy concentrates (Table 15) such as galena, cerussite, and anglesite. Some silver is also present in particles of beudantite and in wad and limonite.

Manganese is present in the residual soils mainly as coatings of manganese oxides on the constituent grains and also as a constituent of various silicate minerals and accessory minerals such as magnetite. In the tills the element is probably nearly wholly within the silicates and carbonates and in magnetite and garnet. In the organic muck and peat much manganese occurs in the colloidal humic complexes and in various silicates, etc. Some of the residual soils in the vicinity of the veins carry higher than average amounts of manganese. A microscopic and X-ray study of these soils indicates that the excess manganese is present mainly in wad, limonite, and highly weathered particles of siderite.

On Keno and Galena Hills *arsenic* and *antimony* follow each other closely in the soils and organic materials. In the latter the contents of both elements are generally low (5 to 22 ppm for As, and 1 to 3 ppm for Sb), the greatest amounts being bound in the humic complexes and iron hydroxides. In the residual soils remote from veins, most of the arsenic and antimony is present as a constituent of the iron and manganese hydroxides coating the mineral grains. Some may also be present as an adsorbed constituent on clay minerals and in the lattice of these colloidal minerals. Near the veins some arsenic and antimony occur in limonite and wad particles and in very finely divided iron and manganese hydroxides. The excess arsenic is present mainly in small particles of scorodite, beudantite, and pharmacosiderite. The excess antimony near the veins is present mainly in residual particles of freibergite in galena and sometimes in jamesonite, boulangerite, beudantite, and senarmontite; also in small amounts in the various arsenates mentioned above.

In the Dublin Gulch area many of the soil samples overlying both granitic bodies and sediments contain much arsenic and antimony (Tables 4 and 13). No detailed work was done in this area but the high values of both these elements in the soils probably reflect the presence of the quartz-arsenopyrite-pyrite-boulangerite-gold veins described in Chapter III. In the weathered residuum overlying the granodiorite stock most of the arsenic and antimony appears to be present in the iron hydroxides and colloidal clay complex. In the soils overlying the various schists and quartzites the two elements are similarly bound. Near the veins mentioned above the anomalous contents of the two elements are found in scorodite and less commonly in senarmontite. Directly over some veins the soil near bedrock is greenish due to an abundance of scorodite derived from the oxidation of arsenopyrite in the vein beneath.

The *tin* content of residual soils and organic muck and peat on Galena and Keno Hills is generally low, probably less than 20 ppm. Near some veins the content may rise to 100 ppm or more. Examination of the superpanner concentrates from these soils shows that most of the tin occurs in the lead minerals, particularly galena, anglesite, and cerussite. In the Dublin Gulch area high tin values occur in the soils near the tin-tourmaline veins (Table 13). Nearly all the tin in these soils is present in minute crystals of cassiterite and in nodules consisting of tourmaline and cassiterite.

The *tungsten* content of residual soils, tills, and organic muck and peat on Galena and Keno Hills is generally less than 4 ppm. In the Dublin Gulch area a much higher content is present in the soils and weathered residuum overlying or downhill from the granodiorite stock, its contact zone, and associated skarn lenses. Nearly all the tungsten in these soils occurs in grains of white scheelite, with smaller amounts in scattered wolframite crystals.

Trace Elements in Vegetation

The average content of lead, zinc, and copper in two species of shrub and one species of tree growing in glacial till is given in Table 16. These values should be compared with samples 1A, 2A, and 3A given in Table 5.

It will be noticed that the copper and lead contents in the shrubs and tree are relatively low and fairly uniform, the copper content exceeding the lead by a factor of 20. The zinc content differs with the species but is greater by a large factor than either the lead or the copper content. Compared with the muck and tills in which they grow, it is also evident that the accumulation of lead by the three species is low, that for copper relatively high, and for zinc very high.

Geochemistry of Country Rocks

The geochemistry and probable origin of the various types of sediments, greenstones, and granitic rocks are discussed briefly in the following sections. The geological occurrence and petrographic descriptions of the rocks are given in Chapter II.

Major Constituents

Graphitic Schists, Argillites, Slates, and Phyllites

Analyses of composite samples of these rocks are given in Table 17. In general the graphitic schists, argillites, and phyllites on the three hills have a fairly uniform composition and only minor variations are evident. Of particular interest are the large amounts of carbon, carbon dioxide, and sulphur that these rocks contain. Considering their great volume it is readily apparent from the analyses that they constitute a great reservoir of sulphur and carbon dioxide, two major components of the veins. In addition they contain, as is shown in a later section, enormous quantities of the sulphopile elements such as zinc, copper, silver, and lead.

The graphitic schists, argillites, and phyllites were probably once marine shales and as such can be classified geochemically as hydrolysates. They represent the accumulation of various clay minerals, colloidal silicates, silica, carbonates, silt, and other weathered debris. Hydrolytic processes, involving the precipitation of hydroxides, are partly responsible for the large amounts of alumina in these sediments and also for much of the iron, magnesium, titanium, and manganese. Adsorption and base exchange with clay minerals in the site of deposition are probably responsible for their high potash content.

The environment of deposition of the original shales must have been a reducing one as witnessed by the large amounts of free carbon and the presence of syngenetic pyrite and other sulphides. Primeval organisms probably also played a leading role in the accumulation of numerous constituents of which carbon, sulphur, phosphorus, silica, and carbon dioxide are the most significant.

Following deposition, the shales underwent various diagenetic changes which are now obliterated, and they were further subjected to low-grade regional metamorphism. This has resulted in numerous recombinations of their constituents and has left them in the quartz-sericite facies as argillites, phyllites, and schists.

Quartz-sericite Schists

An analysis of a composite sample of typical quartz-sericite schists is given in Table 18. The principal point of interest about these schists is their high silica and alumina content compared with other constituents. In addition they contain significant amounts of sulphur.

The origin of the quartz-sericite schists is uncertain. They are not clastic rocks and show little evidence of original bedding or other depositional features. Because of this one can conclude that either their original clastic features have been completely destroyed during regional metamorphism or they represent chemical and colloidal precipitates. The latter seems more probable, and it is suggested that the quartz-sericite schists represent the accumulation of silica, alumina, and other constituents largely precipitated as a result of hydrolytic activity, adsorption, and base exchange processes in a marine environment. In this respect they probably represent an intermediate stage between the argillaceous phyllites and schists and the cherty quartzites described below.

Quartzites

Analyses of composite samples of several types of quartzite from Keno and Galena Hills are given in Table 19. There is considerable variation in the silica, alumina, and calcareous components and also in the sulphur and carbon content. Some varieties, such as the white cherty quartzites, consist almost entirely of quartz, others are diluted with sericite and carbonate minerals. All except the highly calcareous varieties contain sulphur, bound principally in pyrite.

The origin of the quartzites presents many puzzling features. Some quartzites exhibit crossbedding and other original depositional features, and a few show faint overgrowths on their constituent quartz grains. These quartzites were undoubtedly originally fine-grained orthoquartzites. Other quartzites, especially the nearly pure white cherty varieties and some fine-grained grey varieties, exhibit no original depositional features and consist almost entirely of a schistose mosaic of fine-grained quartz grains with interstitial sericite flakes and carbonaceous material. Some of these quartzites also show a faint banding reminiscent of some types of chert. Such quartzites may represent material of both detrital and chemical origin. It is probable that waters in a basin where so much fine quartz silt was being deposited carried considerable amounts of silica in solution as hydrated monosilicic acid, $Si(OH)_4$. During deposition of the fine quartz silt much of the silica in solution was probably carried down by adsorption on the silt particles as suggested by Bien *et al.* (1959). Consolidation of this material, partly of detrital but largely of chemical origin, would in the writer's opinion give rise to many of the fine-grained quartzites in the Keno Hill-Galena Hill area.

The environment of deposition of most of the quartzites must have been a reducing one and various low forms of life were probably active, as witnessed by the presence of much free carbon in some quartzites and the occurrence of syngenetic pyrite in nearly all types.

Limestones

Analyses of two varieties of limestone are given in Table 20. The white to grey limestone lenses are composed mainly of calcite and contain much quartz that appears as silica in the analysis. The black limestones are dolomitic, judging from the quantity of magnesia present. Both types contain some sulphur, generally held as pyrite, and the black variety is particularly rich in free carbon.

No original depositional features are present in any of the limestone lenses seen by the writer. This suggests that the limestones probably represent consolidated calcareous oozes precipitated in a marine environment. Low-order organisms probably played a part in the precipitation of the lime and magnesia, judging from the presence of sulphur and free carbon in these rocks.

Skarn

Table 21 records analyses of four different types of skarn. These should be compared with the analyses of limestones (Table 20) from which most of the skarns were probably derived. The following features are evident.

There is a major increase in the content of silica, alumina, and total iron and a general decrease in carbon dioxide, lime, and manganese in the skarn as compared with the limestone. The trend of magnesia is uncertain; if the parent rocks were originally dolomitic a decrease in MgO is indicated, if not magnesia has increased. The latter seems more probable because most of the calcareous bodies in the district are non-magnesian. Some of the skarn bodies exhibit an increase in water, soda, and potash, and most are enriched in titanium and phosphorus compared with their parent calcareous bodies. Two of the bodies contain marked concentrations of sulphur, and three of the skarns are greatly enriched in tungsten. The latter element is present in scheelite, a mineral in sufficient quantity to provide an ore, if large enough bodies of skarn could be found.

The various elemental additions and subtractions are the result of equilibrium adjustments during regional metamorphism. The principal exchange reactions involve silica and carbon dioxide. As silica was added from diffusion currents, carbon dioxide was removed in accordance with the following generalized equation:

$$\text{Carbonate} + SiO_2 = \text{Silicate} + CO_2$$

Ideally, the silicates would be alumina free, such as scapolite and diopside. However, in most lenses the chemical system has been more complex involving the introduction of alumina, iron, some water, and various other elements and the abstraction of others. Under equilibrium conditions these exchanges have given rise to rocks consisting largely of diopside, amphibole, scapolite, quartz, plagioclase, and epidote.

In some lenses sulphur has been introduced together with iron, and these have crystallized mainly as pyrrhotite. Small amounts of gold also accompanied these elements as the sulphide type of skarn may contain up to 0.10 ounce Au/ton, and minor amounts of other chalcophile elements such as tin, copper, and zinc were also introduced.

Tungsten was probably introduced by diffusion as a hydrated alkali tungstate. On reaching a calcareous lens the tungstate radical was exchanged for the carbonate radical and the former was bound by calcium into scheelite. (*See* Origin of Deposits, Chapter VI.)

The compact nature of the skarn lenses and their enclosing rocks, their thorough metamorphic transformation, and the fact that they are not associated with fracture systems suggest that diffusion was the process responsible for their formation. The source of the introduced elements need not be sought in the granodiorite stocks; on the contrary all the elements including tungsten are available in the enclosing schists and quartzites. The granodiorite stocks probably provided the energy for mobilization of the elements in the country rocks but beyond this played only a passive role.

Greenstones

Table 22 records analyses of composite samples of greenstone bodies from Keno Hill and Galena Hill together with an analysis of an average gabbro, as given by Nockolds. With the exception of water and carbon dioxide (not given by Nockolds), the quantity of major components in the greenstones and average gabbro are in general agreement, and it can be concluded that most of the greenstones were originally gabbros.

Analyses of a relatively fresh greenstone and a metamorphosed part of the same body along strike are given in Table 23 and plotted in Figure 26. The main points of interest are the decreases in silica, alumina, lime, and total iron, and the increases in soda, potash, water, carbon dioxide, and sulphur. These changes can be attributed to the effects of regional metamorphism.

The origin of the greenstone bodies is discussed in Chapter II. They show none of the features of volcanic flows and are, therefore, thought to be sills of gabbro and diabase thrust into incompetent schists, phyllites, and thin-bedded quartzites. Some bodies have produced a cherty baked zone in the adjacent sediments substantiating the latter origin.

After intrusion, cooling, and consolidation the sills were involved in the folding and intense thrusting of the region. Being competent rocks enclosed in soft sediments

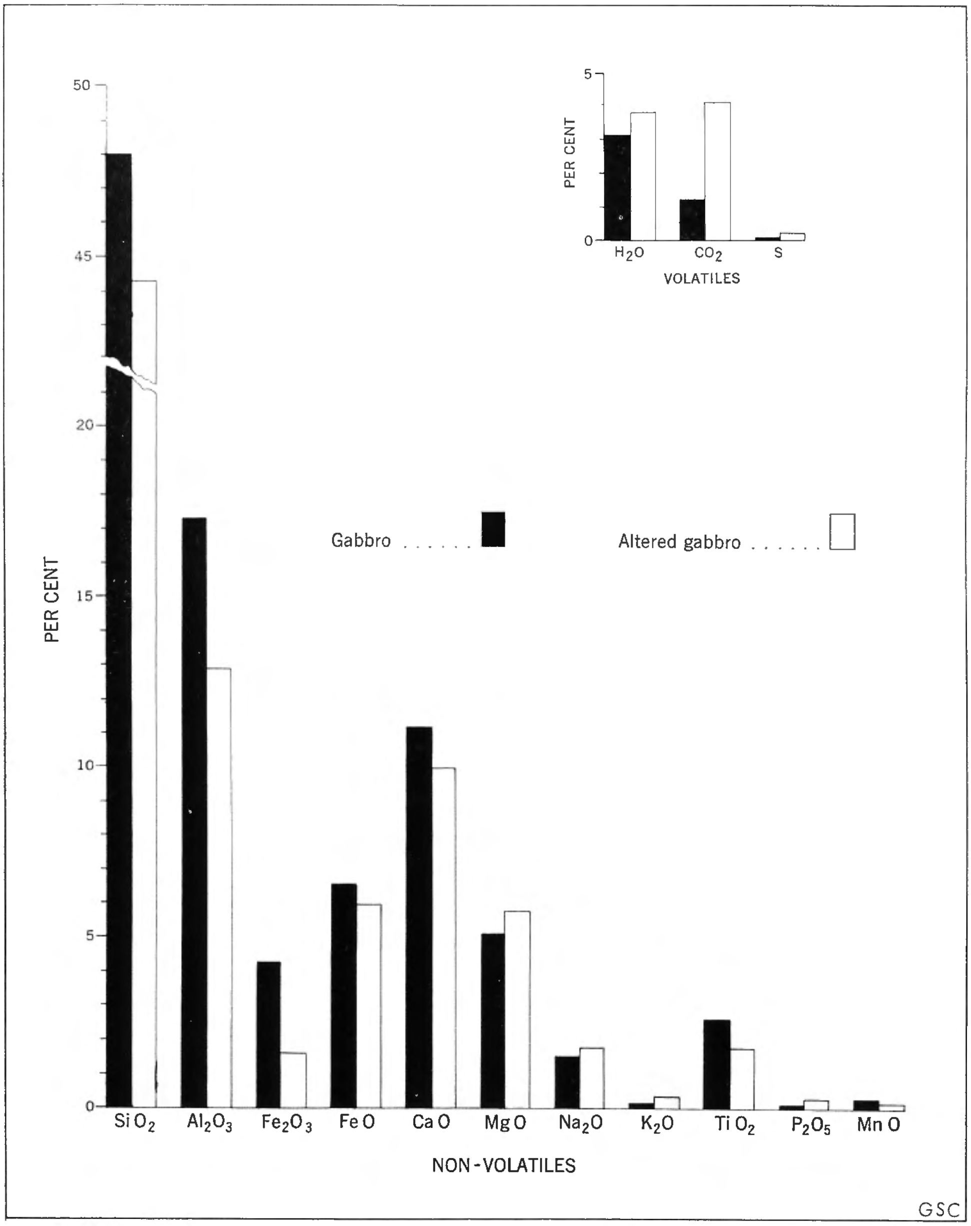


FIGURE 26. Chemical changes resulting from regional metamorphism of gabbro, Sourdough Hill.

they were sheared out into great strings of boudin-like lenses. During this shearing they probably dilated a little thus drawing in water, carbon dioxide, potash, soda, and some sulphur from the enclosing sediments. These constituents reacted with the original pyroxene, plagioclase, ilmenite, etc., to form chlorite, saussurite, carbonate minerals, leucoxene, some pyrite, and other secondary minerals. To establish equilibrium among the various components some silica, alumina, iron, and lime was mobilized and extracted. These components are now probably in the numerous quartz and quartz-carbonate-epidote-chlorite veinlets and masses that occur both within the greenstone body and in the adjacent sediments.

Granitic Rocks

Analyses of composite samples of all types of granitic rocks in the Keno Hill-Galena Hill area together with an analysis of average granodiorite are given in Table 24.

A comparison of the analyses suggests that most of the granitic rocks can be classified as granodiorites. The marginal facies of the batholith north of Mayo Lake is a little more basic than the inner facies and core of the body. The quartz-feldspar porphyries are unique in that they contain much water and carbon dioxide.

The geological details of the granitic masses and porphyry dykes suggest that they are intrusive into the sediments. Their ultimate origin, however, is uncertain. The analyses given for the granitic bodies in many respects, closely resemble those for the various schists and quartzites, and the granitic bodies may have formed from these rocks by granitization processes at great depth.

The vein faults cut and offset the quartz-feldspar porphyry dykes, and apophyses of the Dublin Gulch granitic mass are similarly affected. It is improbable, therefore, that any of the near-surface intrusive granitic rocks are responsible for the mineralization of the area. It is difficult to see how the porphyries or granodiorites could have given rise to hydrothermal metal-bearing solutions that found their way into vein faults, because the igneous bodies were completely crystallized, solid bodies before being cut by the vein faults.

Biotite Lamprophyres

An analysis of a biotite-lamprophyre is given in Table 25. The interesting features are the high content of water, carbon dioxide, and sulphur in this rock.

The origin of the lamprophyres is not clear, mainly because only a few are present in the area, and these are poorly exposed. They appear to be sills and are probably intrusive into the sediments. They are cut and altered by the vein faults and could not, therefore, have contributed material to these by magmatic differentiation.

Minor and Trace Elements

The distribution range and arithmetic average of a suite of minor elements is given in Table 26, and the averages plotted in part in Figure 27. Some averages have not been given in Table 26, simply because the range is so wide that an average value would be meaningless. Composite samples of the rock types as far removed from mineral deposits as possible were analyzed.

An attempt was made to determine the minerals carrying the trace elements in the various rock types. For some rocks this proved possible, especially for the trace elements in pyrite and other heavy constituents; in other rocks the mineral grains are so fine that separations were not possible. Certain assumptions are made, therefore, about the location of some of the trace elements in the following outline. These are based on the general geochemistry of the element in question and on qualitative spectrographic analyses where partial separations of the minerals could be made.

The *sulphur* content of the rocks varies widely, being greatest in the graphitic schists and argillites and least in the granitic rocks. The element is nearly all contained in pyrite in most rock types, but pyrrhotite binds sulphur in some skarns, in the biotite lamprophyres, and in some of the schists and quartzites. Chalcopyrite is rare in all rock types, but small amounts of the mineral may occur in some greenstone bodies. Only trace amounts of sulphur occur in the apatites of the various rock types.

In the sedimentary rocks most of the sulphur is probably derived by biogenic processes, involving the reducing action of low-order bacteria on dissolved sulphates. This is suggested by the fact that the sedimentary rocks containing the most sulphur are also those that are highest in free carbon, a biophile element. The sulphur in some of the skarns may in part be original but in most places it appears to have been introduced during metamorphism, probably from adjacent sulphur-rich sediments. The sulphides in the greenstones may be original in part, but it seems more probable that much of the sulphur was introduced during regional metamorphism, probably from adjacent sediments. The origin of the sulphur in the lamprophyre is uncertain. The sulphides in the granitic rocks appear to be original and probably crystallized from the parent magmas of these rocks.

Arsenic follows sulphur closely in all rocks with the exception of the quartz-feldspar porphyry and Dublin Gulch granodiorite. In the sediments, skarn, and greenstone the bulk of the arsenic is contained in pyrite and pyrrhotite in amounts up to 2,000 ppm as shown in Table 27. Small amounts may also be present in magnetite and ilmenite in which As^{3+} (0.58Å) can replace Fe^{3+} (0.64Å) or Ti^{4+} (0.68Å). Only trace amounts occur in apatite and in the silicate minerals. In the quartz-feldspar porphyry and Dublin Gulch granodiorite the bulk of the arsenic is probably in pyrite. However, most of the quartz-feldspar porphyry and granodiorite samples were obtained from surface outcrops and contain small amounts of limonite and other weathered constituents. It is probable that some arsenic is present in these weathered materials as large amounts were recorded in the limonitic clay material overlying the Dublin Gulch granodiorite (Table 4).

The *antimony* content of all rock types is low. The graphitic schists, argillites, and phyllites contain the largest concentrations with amounts up to 7 ppm; the other rocks generally contain less than 1 ppm. Most of the antimony is probably bound in the sulphide minerals with small amounts in magnetite, ilmenite, apatite, and silicate minerals (Tables 27 and 28).

The highest concentrations of *lead* are in the granitic rocks, graphitic schists, and argillites. In the sedimentary rocks lead appears to follow sulphur closely and is bound mainly in pyrite. Small amounts are present in the magnetite, ilmenite, zircon, micas, and other silicate minerals. In the granitic rocks lead follows potassium being largely present in the various feldspars. In these it probably substitutes as Pb^{2+} (1.28Å) for K^{+} (1.42Å). Zircon and allanite in the granitic rocks carry some lead.

Silver tends to follow sulphur and arsenic closely and the bulk of the element is contained in pyrite and other sulphides (Table 27). The sedimentary rocks and greenstones contain the largest amounts of silver.

Zinc is concentrated mainly in the graphitic schists and argillites, in the greenstones, and in the granitic rocks. In the sedimentary rocks zinc occurs largely in the sulphides and in the iron and titanium oxides. In the former, amounts up to 2,300 ppm are present, and in the latter, 2,000 ppm or more have been recorded. In the greenstones and granitic rocks the bulk of the zinc is in the iron and titanium oxides with smaller amounts in the dark silicates. In the latter and in the various iron oxides Zn^{2+} (0.74Å) probably substitutes for Fe^{2+} (0.74Å) or Fe^{3+} (0.64Å).

The highest contents of *copper* occur in the greenstones, with smaller amounts in the sedimentary and granitic rocks. In the greenstones the element is concentrated principally in the iron and titanium oxides and in the few sulphides in these rocks; the remainder is present in the dark silicates. In the sediments most of the copper is bound in the sulphides and in the iron oxides. Only small amounts occur in the silicates. The copper in the biotite lamprophyre, quartz-feldspar porphyry, and granitic rocks is mainly in the iron oxides, dark silicates such as biotite, and in the few sulphides. In the dark silicates and iron oxides in the various rocks it is probable that Cu^{2+} (0.72Å) substitutes for Fe^{2+} (0.74Å).

Gallium is concentrated in the graphitic schists, argillites, quartz-sericite schists, greenstones, and quartz-feldspar porphyry. The element is enriched in the skarns in amounts up to 70 ppm. In the various rock minerals gallium is probably present in the silicates, iron oxides, and sulphides. In the first it substitutes as Ga^{3+} (0.62Å) for Al^{3+} (0.51Å) and in the iron oxides it may substitute for Fe^{3+} (0.64Å). Its presence in the sulphides is a consequence of the sulphophile character of the element.

Molybdenum, *tin*, *indium*, *bismuth*, and *tungsten* are all present in very small amounts in the sediments, greenstones, and granitic rocks. The highest contents of molybdenum occur in the graphitic schists, argillites, and quartz-sericite schists, in which the element is present mainly in the sulphides. Tin exhibits a similar habit and appears to be bound mainly in the sulphides, although some is probably present in the micas. Some skarns are enriched in tin in amounts up to 73 ppm. In these the element appears to follow tungsten, bismuth, and gallium. Indium is generally present in amounts less than 0.5 ppm in most rocks but shows a slight enrichment in some samples of quartz-sericite schist. Bismuth is enriched only in some skarn samples, in which it may be present in amounts up to 120 ppm. Tungsten is present in the various schists and quartzites in amounts up to 4 ppm, but the general average of these rocks is less than 4 ppm. Some limestone samples contain up to 14 ppm W, but in general most of these rocks contain less than 4 ppm W. In the greenstones, quartz-feldspar porphyry, and granitic rocks the tungsten content is always less than 4 ppm. All the skarn rocks are enriched in tungsten, and in places some contain concentrations of scheelite.

Barium is present in the largest amounts in argillites, graphitic schists, phyllites, quartz-sericite schists, and in the various granitic rocks. The element follows potassium closely and generally substitutes as Ba^{2+} (1.43Å) for K^+ (1.42Å) in the mica and feldspar. Small amounts of barium are probably also present in carbonates, iron oxides, and various silicate minerals.

Strontium is concentrated principally in limestone, biotite-lamprophyre, quartz-feldspar porphyry, and granodiorite and is present in smaller amounts in skarn, greenstone, graphitic schist, and argillite. It appears to follow the calcium content of the rocks closely and is particularly enriched in those rocks containing carbonates. The relatively small amounts in the calcareous quartzites are, however, an exception to this generalization. Strontium (Sr^{2+}, 1.16Å) can substitute for calcium (Ca^{2+}, 1.03Å) in carbonates and feldspars, and it is probable that most of the strontium is in these minerals. It may also substitute for potassium (K^+, 1.42Å), and the micas may contain small amounts of the element.

Chromium is present in the largest amounts in the biotite lamprophyre, argillites, phyllites, and graphitic schists, and in the quartz-feldspar porphyry. The content of the element in all other rocks generally averages less than 100 ppm. The site of the chromium in the various rock minerals was not investigated, but it seems probable that the element is present mainly in the iron oxides and micas with small amounts in the various dark silicates. Chromite has been observed in some heavy concentrates from soils overlying greenstones and may occur in these rocks in small amounts. In the iron oxides and silicates Cr^{3+} (0.63Å) probably substitutes for Fe^{3+} (0.64Å); substitution for Al^{3+} (0.51Å), Ti^{3+} (0.76Å), Fe^{2+} (0.74Å), and Mg^{2+} (0.66Å) is also possible.

The greatest content of *titanium* is in the greenstones, argillites, graphitic schists, phyllites, quartz-sericite schists, and in the granitic rocks. These rocks also contain most of the aluminum and it is apparent that titanium follows this element closely. The bulk of the titanium in the various rocks is bound in rutile, ilmenite, leucoxene, magnetite, and sphene. In addition, some of the dark silicates in the greenstones, skarn, quartz-feldspar porphyry, biotite-lamprophyre, and granodiorite probably contain small amounts of the element. Most of the titanium in the sediments was probably concentrated by hydrolytic processes during sedimentation. This is substantiated by the facts that the soluble salts of the element are readily hydrolyzed, and that the hydroxides and oxides are precipitated in the same range as those of aluminum. The titanium minerals in the greenstone and granitic rocks were probably crystallized from magmas.

The bulk of the *manganese* in the sedimentary rocks is in the limestones and in the graphitic schists, graphitic argillites, and limy schists. The quartzites, even the calcareous ones, have rather small amounts of the element. The skarns appear to inherit much of the manganese from their parent limestones and limy schists. The greenstones average 750 ppm Mn, about the same as the biotite lamprophyres. The granitic rocks tend to be low in manganese, averaging around 400 ppm. The greater amount in the Dublin Gulch granodiorite is probably due to the presence of more biotite and some pyroxene.

Most of the manganese in the sedimentary rocks is extractable by hydrochloric acid solutions indicating that the element is present mainly in carbonates. Small amounts are also probably present in such minerals as biotite, chlorite, and ilmenite. In the skarns some of the manganese is bound in carbonates, but most is present in pyroxene, amphibole, scapolite, and epidote. What little manganese is present in the greenstones is mainly in hornblende, actinolite, epidote, chlorite, ilmenite, and carbonate minerals. In the granitic rocks the bulk of the manganese is probably in hornblende and biotite with smaller amounts in epidote, magnetite and the carbonate minerals. In the Dublin Gulch granodiorite much of the manganese appears to be bound in pyroxene, biotite, and scattered carbonates.

Summary

The geological and geochemical investigation of the soils, glacial deposits, and country rocks in the Galena Hill-Keno Hill area can be summarized briefly as follows:

1. Three types of surficial materials occur in the area: residual soils developed principally on schists, quartzites, and greenstones; glacial deposits consisting of till and glacio-fluvial and glacio-lacustrine gravel, sand, and silt; and muck, peat, and half-bog soils, mainly on the glacial deposits but also in places on the residual soils.

2. The residual soils exhibit poor profiles and are generally highly disturbed by solifluction and frost-boiling. Chemically the residual soils reflect the effects of mild laterization which has resulted in the leaching of silica and a general enrichment of alumina and iron compared with their parent bedrocks and the glacial tills. The glacial tills are relatively fresh and contain carbonates, indicating little weathering or leaching.

3. The residual soils and glacial tills are relatively low in organic matter (1–4 per cent), whereas the muck, peat, and half-bog soils may contain up to 44 per cent. The base exchange capacity of the latter is several magnitudes greater than that recorded for the residual soils and tills, and the adsorption capacity of the organic materials for zinc and various other trace elements is very high. The pH of residual soils is around 5.5; that for till and muck, 7.5 and 6 respectively.

4. The distribution of silver, lead, copper, zinc, cadmium, arsenic, antimony, manganese, tin, and tungsten was determined in the various soil types and is compared with their parent materials. The muck and half-bog soils developed on glacial tills show a slight enrichment of silver and zinc, and the organic layers overlying residual soils exhibit a general enrichment in copper and zinc. Other trace elements in the organic materials are either about equal to or lower in amount than in their parents. All residual soils show an enrichment in most of the metallic trace elements compared with schists, quartzites, and greenstones underlying them.The highly aluminous soils and weathered debris overlying parts of the Dublin Gulch granodiorite are greatly enriched in arsenic, antimony, tungsten, and zinc.

5. Average values for the lead, zinc, and copper contents of two species of shrub and one species of tree growing in muck developed on glacial till show that copper and lead are present in relatively low and uniform amounts and that the zinc varies with the species. The copper content exceeds the lead by a factor of about 20, and the zinc contents exceed the copper content by a factor of about 30. Compared with

the abundance of the three elements in the muck, muskeg, and till in which they grow, it is evident that the shrubs and trees take up zinc readily, copper less so, and lead in relatively small amounts.

6. A series of leaching experiments, heavy mineral separations, and other mineralogical investigations were employed to determine the mode of binding of lead, zinc, cadmium, copper, silver, manganese, arsenic, antimony, tin, and tungsten. In general the largest amounts of these elements are tightly bound up in coatings and films of iron and other oxides on the minerals, in colloids, clay minerals, various iron and manganese oxides, in organic constituents, and in the lattices of the mineral constituents of the soils. Only small amounts are adsorbed and lightly bound. Where much lead, silver, copper, arsenic, antimony, tin, and tungsten appears in the soils, the minerals cerussite, anglesite, galena, malachite, beudantite, wad, limonite, scorodite, cassiterite, scheelite, and wolframite are generally present.

7. Potassium bisulphate fusions and hot nitric acid remove practically all the zinc, copper, and lead from the soils. Sodium acetate and ammonium citrate solutions remove only small amounts of the three metals, but there is a general sympathetic agreement between the amounts determined by these mild chemical attacks and the actual content of metals in the samples, viz., high values obtained by the mild attacks reflect actual high values in the samples and vice versa. The strong chemical attacks are, however, recommended for detailed geochemical surveys.

8. The results of analyses of residual soil along a series of traverses across known mineralized vein faults indicate that, in the vicinity of these structures, the silver, lead, zinc, antimony, arsenic, and manganese contents of the soil rise several times above the background and give broad anomalies with strong contrast. Where lead deposits are present the anomalies are particularly marked and metal values tens, and in places hundreds, of times greater than background were obtained.

9. In depth the silver, lead, zinc, copper, arsenic, antimony, tin, and cadmium contents of residual soils increase consistently as the veins are approached.

10. Analyses of samples of near-surface glacial till, muck, and half-bog soils taken across known vein faults generally fail to detect the presence of the vein faults or deposits. Spot samples of glacial material taken close to bedrock, however, contain large amounts of all metals near the veins, indicating that deep sampling may effectively locate vein faults covered by glacial deposits.

11. Most of the rocks in the Galena Hill-Keno Hill area are sediments and include various schists, argillites, quartzites, and phyllites, and some limestone lenses. Some of the constituents of these rocks are of detrital origin, but most are the result of chemical precipitation by hydrolytic processes, adsorption, and the action of primitive organisms.

12. Greenstone lenses and boudins are abundant in some of the sedimentary members. Chemically these rocks are similar to gabbros, and it is thought that they represent gabbroic and diabasic sills intruded into the sediments. During regional folding they have been sheared into strings of boudins, and their primary minerals pyroxene, plagioclase, ilmenite, etc., have been altered to chlorite, saussurite, zoisite, albite, carbonate minerals, leucoxene, and other secondary minerals. During this process some silica, alumina, iron, and lime was lost, and some soda, potash, water,

carbon dioxide, and sulphur was gained. The last named constituents were probably drawn into the bodies from the enclosing sediments, and the silica, alumina, iron, and lime are probably now in quartz and quartz-carbonate-chlorite veinlets and masses that occur both in the greenstone body and in the adjacent sediments.

13. The bulk of the sediments and greenstones falls into the chlorite-sericite facies of regional metamorphism. Near the granodiorite stocks and batholiths, biotite, andalusite, garnet, and other higher-grade metamorphic minerals appear in the schists and quartzites, and skarn is developed from the limestone lenses and calcareous schists and quartzites. Chemically the formation of the skarn has involved the introduction of silica, alumina, iron, sulphur, tungsten, titanium, phosphorus, water and perhaps magnesia, and the abstraction of carbon dioxide, lime, and manganese. All the introduced elements, including the tungsten, are thought to have come from the enclosing schists and quartzites and to have arrived at their sites of deposition by diffusion.

14. The granitic rocks occur as stocks, small batholiths, and quartz-feldspar porphyry dykes and sills. Most bodies have a granodioritic composition, but the border phases of some batholiths and stocks are more basic and approach the composition of quartz diorites. The granodiorites and quartz-feldspar porphyries are probably intrusive into the sediments, but their ultimate origin is thought to be due to granitization processes at depth. The vein faults cut the granitic rocks and hence these rocks could not have supplied the ore elements by magmatic differentiation.

15. The distribution of a suite of trace elements has been determined in all rock types. The graphitic schists, phyllites, quartzites, and greenstones provide an enormous reservoir of sulphur, arsenic, silver, lead, zinc, cadmium, copper, manganese, iron, and carbon dioxide, the major constituents of the deposits of the area. These elements were undoubtedly concentrated by sedimentation processes in the schists, phyllites, and quartzites, and by magmatic processes in the greenstones. There was probably some rearrangement of the elements during regional metamorphism, but the overall composition of the sediments and greenstones has probably changed little since they were formed.

Chapter V

MINERALOGY AND GEOCHEMISTRY OF THE DEPOSITS

Mineralization History

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

1. Substage A—Formation of early quartz stringers and lenses containing some pyrite and carbonate minerals along bedding planes, fractures, drag-folds, and contorted zones in the various sedimentary rocks. In the greenstone bodies similar small lenses of quartz containing epidote, chlorite, and carbonate minerals were deposited in local shear zones and fractures.

Substage B—Development of quartz stringers and lenses containing wolframite and scheelite. These occur principally in quartzites, phyllites, schists, and granodiorite in the Dublin Gulch area. No cutting relationships are apparent between the quartz bodies of substage A and those of B; perhaps they were contemporaneous. The deposition of cassiterite and tourmaline in the tin lodes and the formation of the scheelite skarn lenses in the Dublin Gulch area probably took place during this substage or during the earliest part of stage 2 below.

2. Development of early faults with a general northeast strike. These constitute the longitudinal vein faults of Keno Hill and the principal vein faults of Galena Hill. Vein faults with a similar strike occur in the Dublin Gulch area and are probably present in the Mount Haldane area. All these faults have an associated system of transverse vein faults that are particularly well developed on Keno Hill. The exact age of the transverse faults is uncertain; some may be subsidiary to the longitudinal vein faults and hence formed at the same time, others may have been formed later during stage 3 below. Concomitant with or immediately following the formation of the longitudinal faults, deposition of quartz veins and lenses, containing pyrite, arsenopyrite, boulangerite, meneghinite, bournonite, and other sulphosalts took place in the N 45° E to N 70° E striking vein faults. On Keno Hill and in the Dublin Gulch area arsenopyrite is a typical mineral of this stage but is absent or present in only small amounts on Galena Hill. In a few vein faults small amounts of galena and sphalerite accompanied the quartz. The veins of this stage contain a little gold and silver.

3. Continued movement along the faults formed in stage 2 with consequent formation or reopening of transverse vein faults. During this period the quartz-pyrite-arsenopyrite veins deposited during stage 2 were brecciated. This was followed by the deposition in the longitudinal and transverse veins, of siderite, galena, sphalerite, pyrite, freibergite, chalcopyrite, meneghinite, boulangerite, dolomite, quartz, and

minor amounts of barite in dilatant zones at or near the junctions of vein faults, in subsidiary fractures striking off the main faults, in the brecciated quartz veins of stage 2, and at sites in the vein faults where they cut thick-bedded quartzites and/or greenstones and pass upward into schists and thin-bedded quartzites.

4. Local brecciation of the lodes formed in stages 2 and 3, resulting in the crushing of the siderite and pyrite and the local formation 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 late primary reworking and leaching of the minerals formed during stages 2 and 3, but most are probably supergene (*see* stage 7).

5. Formation of late faults with northeast, north, and northwest strikes. The principal trunk faults appear to be the McLeod fault and a fault that passes through the Wernecke area and the Christal Creek valley. All other faults appear to splay off these faults in northwest and northeast directions. Movement has taken place at several periods along some of the late faults; thus some movement along the Hector fault appears to be 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, arsenopyrite, sulphosalts, sphalerite, siderite, galena, and freibergite. This resulted in the formation of limonite, manganese oxides, anglesite, hawleyite, cerussite, calcite, quartz, azurite, malachite, brochantite, beudantite, plumbojarosite, silver-bearing jarosites, native silver, and numerous other secondary minerals. During this period many soluble salts of iron, manganese, zinc, silver, lead, and other elements were formed and migrated downward into the lodes. Most of the oxidation of the lodes probably took place in late Tertiary time, but in vein faults not sealed by permafrost oxidation processes are active at present.

(b) Precipitation of supergene quartz, calcite, smithsonite, native silver, pyrargyrite, sphalerite, galena, and other minerals, in brecciated lodes, late faults, and fractures in the zone of reduction at or 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 is of economic importance.

(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 forming.

8. Formation of placer deposits of gold, scheelite, and wolframite in the vicinity of the hypogene deposits and in the valleys of certain streams. These formed concurrently with stages 7 (a) and 7 (b), i.e., mainly during late Tertiary time.

Mineralogy

In the following description the minerals are classified into two categories, hypogene and supergene. The common minerals were determined in thin and polished sections and by visual examination; the complex were determined by X-ray and spectrographic methods.

The mineralogy of some of the deposits has been described by Thompson (1945), Wright (1951), Grove (1953), Zajac (1957), and Jambor (1957).

Hypogene Minerals

The principal hypogene minerals in the deposits are quartz, siderite, pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, and freibergite. Less common are barite, pyrrhotite, stibnite, boulangerite, jamesonite, meneghinite, bournonite, stephanite, polybasite, scheelite, wolframite, cassiterite, and tourmaline.

Quartz, SiO_2

Quartz is an ubiquitous mineral in all sedimentary rocks, skarn, quartz porphyries, and granitic rocks, and in some greenstones. In the sediments it occurs as discrete grains intergrown with other minerals, in small segregations, and in seams and veinlets. In some of the quartzites, phyllites, and schists the quartz grains are probably of detrital origin, in others the grains probably developed by recrystallization from colloidal silica deposited during sedimentation. The segregations, seams, and veinlets probably originated by the local solution, transportation, and deposition of silica during diagenesis and metamorphism. In the greenstones the mineral was probably a result of alteration. In the skarn some of the quartz was introduced during metamorphism, and the remainder is probably the result of recrystallization. The quartz in the quartz-feldspar porphyry and granitic rocks probably crystallized from magmas.

At least three generations of epigenetic quartz are present in the various types of deposits. The first appears in quartz stringers, irregular lenses, and boudins in the schists, phyllites, quartzites, and greenstones (Pl. VIII). In the sedimentary rocks most of these bodies are a few inches wide and less than a foot long. Others are larger and tend to form bulbous and irregular masses or occur along bedding planes and in contorted zones. All are in sharp contact with their enclosing rocks and have no discernible feeder channels.

The quartz is white, massive, coarsely crystallized in some bodies and mylonitized in others, and may contain diffuse ribbons of sericite, graphitic material, and other minerals. Small vugs lined with delicate quartz-crystal prisms occur in some lenses and stringers, and a few scattered pyrite crystals and carbonate minerals are present in places.

In the greenstones, lenses of quartz, commonly less than 20 feet long and 2 feet wide, occur in discontinuous shear zones and fractures. This quartz is generally massive and relatively coarsely crystallized, white, and commonly contains irregular masses of coarse-grained calcite and epidote. Rarely were ore minerals, such as pyrite and sphalerite, observed.

The second generation of quartz occurs in the longitudinal veins on Keno Hill, in the principal northeast-striking veins of Galena Hill, in the series of northeast-striking veins in the Dublin Gulch area, and only in small amounts in the transverse veins associated with the above. Quartz of this age is particularly well developed in the No. 6 system, the Comstock-Porcupine system, in places in the McLeod and Hector-Calumet systems, and in abundance in the veins in the Dublin Gulch area. In the transverse veins the best example of quartz of this age seen by the writer was in the Sugiyama vein of the Galkeno system.

In some lenses the quartz of this age is massive and relatively coarse grained; in others it is brecciated and mylonitized. Vugs, lined with prismatic crystals, occur in a few lenses, and some of these contain galena and sphalerite, as in the Klondyke-Keno east-west vein and in the veins on the Helen Fraction. In some lodes the massive quartz contains only a few metallic minerals, but in others, as in the No. 6 system and in the Dublin Gulch area, the quartz is intimately intergrown with abundant arsenopyrite and pyrite and is commonly seamed with various sulphosalts.

Quartz lenses of the second generation vary from a few feet to several tens of feet in length and are as much as 3 feet wide. In some places their contacts with the wall-rocks are irregular, showing replacement features; in others the contacts are sharp (Pl. X).

A third generation of quartz was deposited contemporaneously with the bulk of the siderite, galena, sphalerite, and pyrite. In most lodes quartz of this generation is not abundant, but it is characteristically developed in lodes cutting greenstones. Where found it appears as white anhedral to euhedral grains and crystals lining fractures and surrounding fragments of quartz, greenstone, and sedimentary rock in the sheeted and brecciated zones. It is mostly an early mineral (Pl. XVI), overgrown by siderite, galena, and sphalerite, but in some lodes a crude rhythmical banding of siderite and quartz, or galena and quartz may be present.

Several generations of quartz were deposited after the brecciation of the siderite-galena-sphalerite-pyrite lodes. In places, especially in the Bellekeno system, one age of quartz occurs as clear euhedral prisms encrusting brecciated oxidized fragments of ore. This quartz probably owes its origin to supergene processes. Similar quartz in the Silver King and other veins encrusts fragments of primary ore and is probably also of supergene origin. In other lodes, as in the Ladue-Sadie-Friendship system, a fine-grained, grey, massive quartz fills fractures and cavities in hypogene ore and gangue. The origin of this quartz is uncertain; it may be supergene, but its nature and occurrence at considerable depth suggest that it represents either introduced hypogene silica or silica deposited from reworking of the lodes.

Carbonates

Carbonates, including dolomite, magnesite, and calcite, are relatively abundant in the schists, phyllites, and quartzites, and make up the bulk of the limestone and dolomite lenses. In the greenstones the carbonate is mainly dolomite (ankerite) but calcite is present in places. The granitic rocks, with the exception of some quartz-

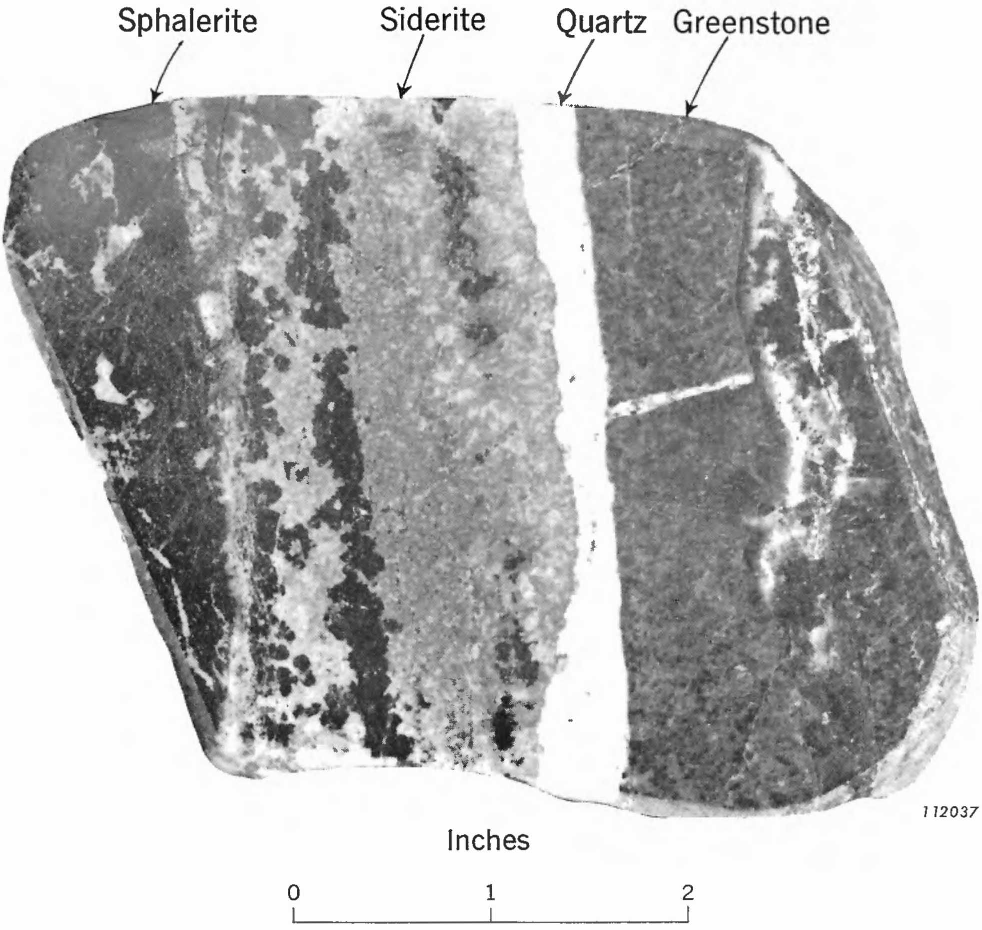


PLATE XVI. Early white quartz lining fractures in greenstone. Quartz is overgrown by siderite and sphalerite. Sadie-Friendship mine, Keno Hill.

feldspar porphyries, contain only a little calcite and dolomite. The biotite lamprophyres generally contain an abundance of calcite and minor amounts of dolomite. Coarse-grained carbonates, generally calcite, are present in most of the skarn lenses in the Dublin Gulch area and elsewhere.

Siderite, $FeCO_3$, and ankerite, $Ca(Fe, Mg, Mn)(CO_3)_2$, are the principal hypogene carbonates in the deposits; calcite, $CaCO_3$, is present in the early quartz lenses and in some of the deposits.

An early generation of hypogene calcite occurs in the small quartz lenses, stringers, and boudins throughout the sedimentary rocks and in some of the early fractures in the greenstones. In the sediments it is present as white, coarsely crystallized masses intergrown with the quartz; in the greenstones the carbonate is of a similar nature and is intergrown with quartz and epidote or chlorite. An analysis of the early calcite is given in Table 29. The mineral contains relatively small percentages of iron, magnesium, and manganese.

Small amounts of calcite occur in most vein faults. Although the bulk of this mineral appears to be supergene, there are occurrences, such as in the lodes of the Ladue-Sadie-Friendship and Cream veins, where it may be hypogene.

Siderite is the principal gangue mineral in the lead-zinc-silver lodes of the longitudinal and transverse vein faults. In nearly all occurrences the siderite is intimately intergrown with galena, sphalerite, pyrite, and freibergite and all were probably deposited contemporaneously.

Below the oxidized zones most of the siderite is cream to light brown, and in the oxidized zones the mineral is brown to black, due to the oxidation of its contained iron and manganese. In some places the intergrowths of galena, freibergite, sphalerite, and other sulphides are so pervasive and fine grained that the siderite is rendered an ash-grey or reddish brown.

In the lodes, the siderite cements the breccia of the vein faults, fills fractures in the earlier quartz-pyrite-arsenopyrite lenses, sheeted zones, and wall-rocks, and occupies all available cavities in the lodes. Much of the siderite occurs as drusy masses, and the remainder is largely coarse grained and massive. The siderite lining the numerous vugs and cavities exists as rhombohedral crystals with curved and composite faces. In some lodes fine- to medium-grained compact siderite commonly alternates with galena, sphalerite, and pyrite, forming crudely banded vein-like masses. In other places the fine-grained siderite and sulphides are intimately intergrown, forming dense compact masses. Stalactitic, globular, and botryoidal masses of siderite have been observed in a few lodes, but these are generally rare. Parts of the lodes in some vein faults are sliced by late faults and slips, and in these zones the siderite is severely crushed and in places reduced to a loosely coherent rubble.

Analyses of fresh and oxidized samples of siderite are given in Table 30. From these it is evident that the siderite is manganiferous and contains relatively large percentages of magnesium. During the oxidation most of the ferrous iron is oxidized to the ferric state. Water is considerably increased as a result of hydration, and magnesia, manganous oxide, and carbon dioxide are leached out. For more detailed discussion of these oxidation processes *see* pp. 182-188.

The minor and trace element content of characteristic samples of siderite and calcite is given in Table 31. Gold values in siderite are presented in Table 57. The following features are evident.

Strontium follows calcium closely and is most abundant in the early and late varieties of calcite. This may be attributed to the closer similarity of Sr^{2+}(1.16Å) to Ca^{2+}(1.03Å) than to Fe^{2+}(0.74Å).

The calcites in the early quartz lenses tend to be enriched in scandium and the rare earths, whereas the siderites and the late calcites derived from them by supergene processes are relatively low in these elements. The reasons for this are not clear. It may be that the early diffusion currents and/or migrating solutions were enriched in these elements whereas later when the siderite was deposited, they were depleted. On the other hand the type of mineral structure formed may have exerted an influence on the capture of these elements. Thus, the calcite structure is probably more favourable for the incorporation of Y, Yb, La, and Sc than is siderite because of several energetic considerations such as ionic radii, bond orbital configurations, etc.

Barium is present in all the carbonates in small amounts. With increasing oxidation of siderite and the formation of wad the barium content seems to increase. This is probably due to the marked adsorption capacity of manganese hydroxide sols for barium. Where relatively large amounts of barium were present in the supergene solutions, psilomelane, the basic oxide of barium and manganese, may appear in the wad.

The small amounts of nickel and cobalt probably substitute for Fe^{2+} (0.74Å) as Ni^{2+} (0.69Å) and Co^{2+}(0.72Å) in the siderite lattice. The relatively large amounts of nickel, cobalt, and zinc in the late porous supergene calcite from the Bellekeno mine are probably present in smithsonite ($ZnCO_3$), small amounts of which cannot be physically removed from samples of calcite of this age (see *Smithsonite*).

A little zinc, copper, lead, tin, arsenic, and antimony may substitute in the carbonate lattice, but the amounts cannot be accurately ascertained, as microscopic crystals of their sulphides are common in all carbonates. The content of these elements together with silver and sulphur increases markedly as siderite is oxidized. This is probably due to three processes: adsorption by the negative sols of manganese; coprecipitation with the manganese and iron hydroxides; and coprecipitation of the elements as their respective sulphates, arsenates, etc.

The gold content of siderite is low (0.1 ppm). The element is probably present in small amounts of admixed sulphides.

Barite, $BaSO_4$

Barite occurs in some of the lodes of the Bellekeno system, in the Porcupine vein, and in small amounts in several other lodes on Keno and Galena Hills. It is not an important gangue mineral in any of the lodes.

In some occurrences the mineral is present as crystal aggregates or stout individual tabular crystals in secondary (supergene?) dolomite in vugs and cavities (Pl. XVII). In other places the mineral forms crystallized aggregates cementing masses of fine-grained colloform-like dolomite enclosing angular fragments of galena (Pl. XVIII). Many of the crystals exhibit growth zones, with white central zones and colourless outer zones. The massive crystalline barite tends to be white throughout. The closest associates of barite are colourless coarse-grained calcite and brownish, fine-grained siderite and dolomite.

The paragenesis of barite is not entirely clear. It is, however, always a late mineral and was definitely deposited after the primary siderite, galena, and sphalerite in the vugs of several lodes. This barite may be of late hypogene origin. On the other hand some barite was deposited after the brecciation of the lodes and is associated with dolomite, siderite, and calcite thought to be of supergene origin.

Spectrographic and chemical analyses of barite from two characteristic occurrences are given in Table 32. The following features are of interest.

The small amounts of iron, calcium, magnesium, manganese, cobalt, zinc, copper, and lead may substitute for barium and the arsenic and antimony for sulphur in the lattice of barite. The relatively high content of strontium is normal as barite and celestite, $SrSO_4$, are isostructural and probably form a complete solid-solution series.

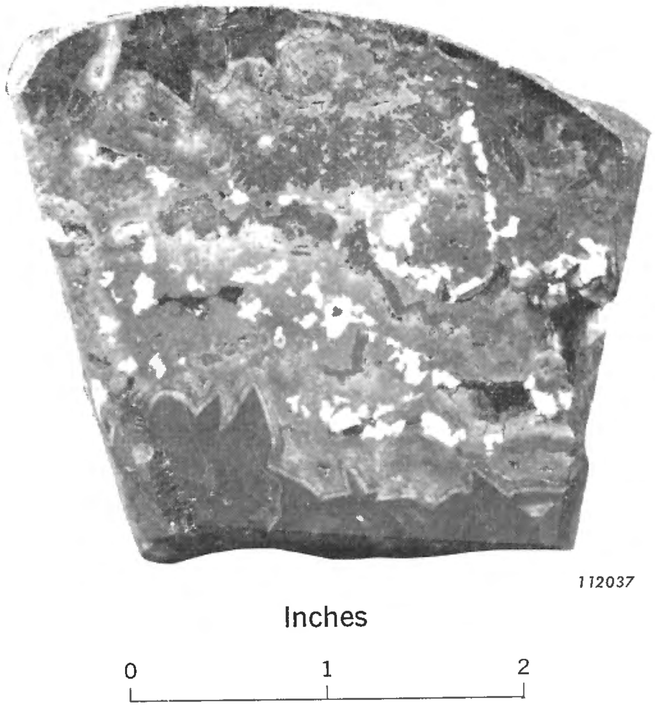


PLATE XVII

Barite (white) in secondary (supergene?) siderite and dolomite (light grey) in vug lined with primary euhedral siderite (dark grey), Porcupine mine, Keno Hill.

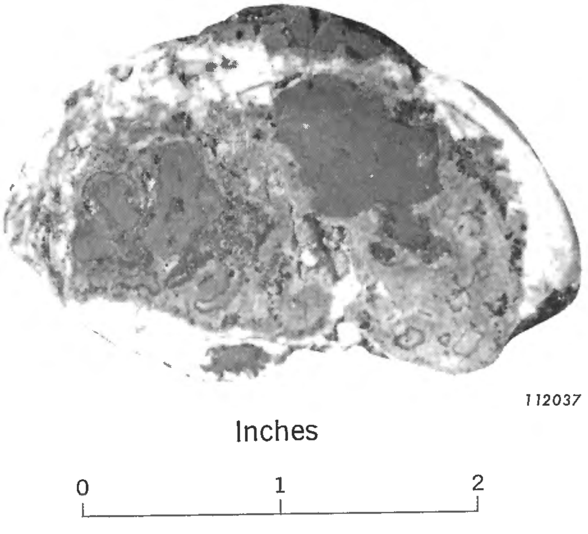


PLATE XVIII

Barite (white) encrusting galena fragments (dark grey) in a matrix of secondary siderite and dolomite (light grey), Bellekeno system, Sourdough Hill.

The small amount of lead in the barite samples is rather unusual if the mineral crystallized contemporaneously and in the same milieu as galena. If such were so a relatively high degree of capture of lead ions by the barite structure would be expected because of their similar ionic radii, Ba^{2+} (1.43Å), Pb^{2+} (1.28Å) and the fact that barite and anglesite are isostructural. The low lead content, therefore, suggests either that the barite formed late in the primary mineralization stage after the precipitation of lead or that it is of supergene origin. The latter seems more probable as most of the supergene waters contain very little lead, generally less than 0.001 ppm Pb.

Pyrite and Marcasite, FeS_2

Pyrite occurs as cubes, pyritohedrons, and irregular masses in the schists, quartzites, phyllites, and porphyries, and in small amounts in the greenstones and granitic rocks. It is particularly abundant in the black schists, phyllites, and grey quartzites and is an original constituent of these rocks. The pyrite in the porphyries may be an original mineral, or its components may have been absorbed from the sediments. The sulphur component of the pyrite in the greenstones was probably drawn into these bodies from the sediments during regional metamorphism as suggested in Chapter IV. The small amounts of pyrite in the granitic rocks may have originally crystallized from the magmatic parent of these bodies.

Pyrite is present in all stages of hypogene mineralization and occurs in small amounts as a supergene mineral in the zone of reduction of some lodes. At least three generations of hypogene pyrite can be clearly distinguished.

Many of the early quartz stringers and blows in the sedimentary rocks and greenstones contain pyrite cubes and crystallized masses. In these occurrences the pyrite is intimately intergrown with quartz and calcite, and occasionally with epidote, and was probably deposited contemporaneously with these minerals.

In the early hypogene mineralization of all longitudinal and transverse vein faults pyrite is a particularly abundant mineral. It occurs massive or as cubes, pyritohedrons, and irregular crystal groups in the quartz lenses, and as disseminated crystals and small irregular masses in their wall-rock alteration zones. Its closest associates are arsenopyrite, boulangerite, bournonite, and rarely pyrrhotite. The pyrite is fractured in most occurrences and seamed with quartz, siderite, galena, sphalerite, and other late minerals.

Two generations of pyrite are generally present in the siderite lodes. The first, which is probably of the same age as the generation noted in the preceding paragraph, occurs as individual crystals, crystal groups, and masses, commonly in quartz but also in the breccia and wall-rocks. It is generally fractured and seamed with quartz, siderite, galena, and sphalerite. The second generation is related to the galena-sphalerite stage of deposition. It occurs as euhedral cubes and pyritohedrons, as reniform and radiating crystallized masses, as irregular masses in the siderite veins, and also intergrown with sphalerite and galena. In many of the lodes this generation of pyrite rims wall-rock fragments and small masses of galena and sphalerite, fills small fractures, and is disseminated throughout the lodes and wall-rocks. The second generation of pyrite is particularly common on the borders, ends, and near the bottom of the siderite lodes.

In most lodes the quantity of pyrite varies with depth. In the oxidized parts it is present in small amounts as highly altered disintegrated masses in a limonitic boxwork or in the oxidized rubble of the veins. Downward, as the oxidation effects decrease, more residual pyrite is present, and in the hypogene zones it is an ubiquitous primary mineral. The chemistry of the oxidation of pyrite is discussed on page 183.

In polished sections the pyrite is seen to be coarse to fine grained, the diameters of the grains and crystals ranging from 0.005 mm to 3 cm with an average of about 0.2 mm.

Most of the first generation pyrite is fractured, crushed, and cemented or seamed with quartz, siderite, galena, sphalerite, and other minerals. Its closest associates are arsenopyrite, boulangerite, meneghinite, bournonite, and rarely pyrrhotite; with these minerals it generally exhibits mutual boundaries although in some places the sulphosalts may occur in fractures in the pyrite.

The second generation occurs in euhedral crystals and crystal groups that generally exhibit little fracturing except where late slips and faults slice through the lodes. It is present largely in siderite and is commonly associated with galena, sphalerite, freibergite, and chalcopyrite. With these minerals it generally exhibits mutual boundaries, but in some sections pyrite rims sphalerite and galena and may be cut by these two minerals. This suggests some overlapping in the deposition of pyrite and the other sulphides.

Most of the evidence, both from field studies and polished sections, suggests at least two clear-cut generations of pyrite in the lodes. The first was precipitated contemporaneously with quartz and arsenopyrite, the second with siderite, sphalerite, galena, and freibergite.

Only small amounts of marcasite occur in the country rocks and lodes. The mineral has been detected by X-ray in the sulphides from outcrops of some porphyry bodies and may also be present near the surface in other rocks. In some lodes a little marcasite is commonly associated with pyrite in the oxidized zones and in the zones of reduction. Its occurrence in these sites suggests that it is of supergene origin.

Chemical and spectrographic analyses of pyrite and marcasite from several characteristic lode occurrences and from the country rocks are given in Tables 27 and 33. Gold assays of pyrite are presented in Table 57. All the samples were ground to a fine powder, leached with concentrated hydrochloric acid to remove extraneous galena, sphalerite, etc., and were then repeatedly washed with distilled water.

The pyrite from all occurrences tends to collect numerous chalcophile elements, among which nickel, cobalt, zinc, lead, copper, silver, gold, tin, antimony, and arsenic are the most common. The large amounts of zinc, lead, and silver in some samples suggest that microscopic amounts of galena and sphalerite remain despite efforts to remove them by leaching. Because of this possibility little can be said about substitution of these elements in the lattice of the pyrite from the deposits. In the samples from the country rocks, however, the amount of the chalcophile elements is lower, and few minerals like galena and sphalerite can be observed in polished sections of the pyrite. In these samples it can be assumed, therefore, that the recorded quantities of zinc, lead, copper, silver, gold, antimony, and arsenic represent the range of substitution of elements in the lattice of the pyrite.

Most pyrite samples contain large quantities of arsenic. In some, as in the sample from the No. 6 vein, the arsenic may be bound in small particles of arsenopyrite, in the others, however, arsenopyrite is rarely visible in polished sections, and it can be concluded that most of the arsenic substitutes for sulphur in the pyrite lattice.

There are no clear-cut correlations between the minor element content of pyrite and its position in the lodes, nor are there any marked differences between the pyrite from different vein systems or of different ages. There is, however, a difference between the minor element content of marcasite and that of pyrite; the former mineral generally contains only small amounts of zinc, lead, copper, silver, tin, antimony, and arsenic. These differences are probably due to the temperature of formation. Pyrite, which formed at relatively high temperatures, would accept a much greater quantity of extraneous elements because of its expanded lattice condition compared with marcasite, which formed at low temperatures, probably from groundwaters.

All pyrite samples contain some gold in amounts ranging from 0.005 to 0.46 ounce a ton. The higher contents are in samples from the early quartz-pyrite-arsenopyrite veins and the lower in those from the siderite lodes and country rocks. Further details on gold in pyrite are discussed in the section on gold (*see* p. 179).

Pyrrhotite, $Fe_{(1-x)}S$

In a few places pyrrhotite accompanies pyrite as an original constituent of the sedimentary rocks, but in general it is rare in the country rocks.

Pyrrhotite is also uncommon in most of the lodes of the area, but does occur in considerable quantity in the Duncan Creek vein where it is associated with pyrite, galena, sphalerite, and siderite.

Some of the skarn lenses carrying scheelite contain small amounts of disseminated pyrrhotite.

Sphalerite $(Zn,Fe,Cd)S$

Sphalerite is an abundant ore mineral in the lodes of both longitudinal and transverse vein faults on Mount Haldane, Galena Hill, Keno Hill and Sourdough Hill. It belongs principally to the second stage of mineralization of the vein faults and appears in only a few places, accompanied by galena, in the early unbrecciated quartz-pyrite-arsenopyrite lodes. The mineral was not observed in the quartz-pyrite-arsenopyrite veins in the Dublin Gulch area, but may be present in siderite veins as indicated by the sporadic occurrence of nodules of siderite in the placers. Most of the sphalerite is of hypogene origin, but in the zones of reduction of many vein faults small quantities of supergene sphalerite are present in porous zones and along fractures and slips.

In unbrecciated lodes the hypogene sphalerite is amber to dark brown or black and occurs as large crystallized masses, as veins and stringers, and in individual crystals and crystal groups in the drusy parts of the lodes. Perfect tetrahedrons are present in places and dodecahedrons are common. Complex and distorted crystals as well as crystal intergrowths are locally abundant.

In nearly all occurrences the sphalerite is associated with siderite, galena, freibergite, pyrite, and quartz, and in places with dolomite and calcite. Frequently these minerals are highly intergrown or arranged in crude bands suggesting nearly contemporaneous deposition.

In some lodes sphalerite follows quartz and siderite during deposition, but in places the siderite has grown on sphalerite, and both siderite and quartz may fill fractures in masses of sphalerite, suggesting much overlapping in the depositional sequence.

In the brecciated parts of lodes the sphalerite is sheared and highly crushed and in places is recemented by veinlets of siderite, dolomite, calcite, and quartz.

In most lodes sphalerite varies in abundance with depth. In the oxidized parts it is present in small amounts as highly altered crystallized masses in a limonitic boxwork. Downward, as the oxidation lessens, more sphalerite is present, and in the hypogene zones it is an ubiquitous mineral. The details of the oxidation of sphalerite are described on page 194.

As seen in polished sections the sphalerite is coarse to fine grained, the diameters of the grains and crystals ranging from 0.01 mm to 3 cm with an average of about 5 mm. The normal sphalerite possesses perfect cleavage, is isotropic, and exhibits little birefringence due to strain. Its most persistent associates are galena, freibergite, chalcopyrite, and pyrite; less frequently arsenopyrite, boulangerite, meneghinite, and pyrargyrite.

In most sections sphalerite appears to be later than pyrite and arsenopyrite, but in places a generation of fine-grained pyrite post-dates the sphalerite. In some fine-grained galena specimens sphalerite occurs as blebs and patches, but more generally the sphalerite has mutual boundaries with galena and freibergite, suggesting nearly contemporaneous deposition of these minerals. In some sections, however, freibergite rims crystals of sphalerite, and both freibergite and galena penetrate and cut sphalerite. In other sections galena is penetrated along cleavage planes by sphalerite. Most specimens of sphalerite contain oriented blebs of chalcopyrite, indicating exsolution of the latter. In a few lodes sphalerite veins chalcopyrite.

All the above relationships are somewhat difficult to interpret but, combined with field studies, there appear to be at least three generations of hypogene sphalerite—a minor generation associated with, but slightly later than, the quartz-pyrite-arsenopyrite phase of mineralization; a major period of deposition associated with the siderite-galena-freibergite-pyrite phase; and a minor generation associated with late chalcopyrite. The last two generations are probably nearly contemporaneous.

The sphalerite in parts of the brecciated lodes is severely comminuted and mylonitized. It commonly shows the effects of strain and shearing and is intricately mixed with fragments and recrystallized patches of galena, siderite, chalcopyrite, and freibergite. Quartz, siderite, dolomite, and calcite in places vein and cement the mylonitized sphalerite.

In the near surface parts of most lodes, sphalerite has been almost completely removed leaving only limonitic and siliceous boxworks. In places highly altered residuals of sphalerite remain, and these are commonly coated with native sulphur, gypsum, and various other secondary minerals.

Chemical and spectrographic analyses of sphalerite from several characteristic occurrences, are given in Tables 34 and 35. Gold assays are presented in Table 57.

Zinc sulphide can exist in three polymorphs—sphalerite (βZnS) with a cubic face-centred lattice, wurtzite (αZnS) with a hexagonal close packed structure, and a γZnS modification with a threefold rhombohedral structure. It has been shown by Buck and Strock (1955) that, as the temperature increases, the inter-atomic forces become more directional and the symmetry of the ZnS structure reduces from the fourfold cubic structure of sphalerite to the threefold rhombohedral structure of γZnS, and finally to the threefold hexagonal structure of wurtzite. These authors also found that γZnS is stable at temperatures ranging from 600° to 1020°C.

Ideally sphalerite has a face-centred cubic-stacking arrangement of ZnS layers. In these each Zn atom is coordinated with four sulphur atoms and each sulphur in turn with four zinc atoms. The bonding is largely of a covalent nature with some ionic character. The metallic character of the crystals is very weak. Sphalerite is isostructural with βCdS (hawleyite), β-MnS, InAs, InSb, SnSb, and numerous other cadmium, zinc, mercury, and copper selenides, tellurides, etc. Voltzite, Zn (S,As), yields a similar X-ray powder pattern to that of sphalerite and may have an analogous structure.

Natural sphalerites, according to Smith (1955), contain ZnS layers with both cubic and hexagonal packing, a feature that introduces some complexity in the interpretation of lattice substitutions. Because of the possible presence of hexagonal packing in sphalerite it seems desirable to point out that the hexagonal modification of ZnS, wurtzite, is isomorphous with γMnS, αCdS (greenockite), stannite-1, and several other manganese, cadmium, and indium compounds.

The sphalerite lattice is remarkably tolerant to substitution of iron, cadmium, and manganese, and nearly all natural sphalerites are diodochic compounds of ZnS with FeS (up to 42 per cent), CdS (up to 2 per cent), and MnS (up to 9 per cent). These substitutions can be explained on energetic grounds as all these sulphides, with the exception of FeS, are isostructural in one of their modifications, and the various radii of the substituting metals are similar. Thus the tetrahedral covalent radii of Cd (1.48Å), Fe (1.24Å), and Mn (1.26Å) are similar to Zn (1.31Å) and fall within the generally accepted 15 per cent range of substitution. The ionic radii are likewise similar—Zn^{2+}(0.71Å), Cd^{2+}(0.97Å), Fe^{2+}(0.74Å), Mn^{2+}(0.80Å)—for all except cadmium. The normalized radii of Zn, Cd, Fe, and Mn in AX type sulphides are close—Zn (1.19Å), Cd(1.35Å), Fe(1.10Å), Mn(1.13Å)—and the lattice energy coefficients of the four metals fall within relatively narrow limits—Zn(610), Fe(580), Mn(560), Cd(550).

All the Keno Hill sphalerites contain iron, cadmium, and manganese (Table 34), elements that were undoubtedly incorporated in the lattice sites of the sphalerite during crystallization as a result of the energetic considerations discussed in the foregoing. The iron content ranges between 0.63 and 11.54 per cent, with the lowest content in the late, probably low temperature sample. The manganese content is relatively low (0.005 to 0.82 per cent) despite the fact that manganiferous siderite appears in most places to have crystallized simultaneously with the zinc sulphide. This probably means that the carbonate lattice has a greater affinity for Mn than the sphalerite lattice in a crystallizing milieu where manganese is abundant. The cadmium content of the sphalerites varies over a narrow range (0.71 to 1.16 per cent). There is no linear or logarithmic correlation between the cadmium content and that of either zinc or iron, nor is there any particular relationship between early (high temperature?) and late (low temperature?) sphalerites. This suggests that neither the presence of these major elements nor the temperature affects the incorporation of cadmium. It follows, therefore, that the availability of the element in the solutions or the diffusion front is the main consideration in the incorporation of Cd in sphalerite during crystallization.

All the sphalerite samples contain some silver, gold, copper, lead, arsenic, and antimony. Most of these elements are probably present in microcrystalline particles and blebs of chalcopyrite, freibergite, and galena, minerals commonly visible in polished sections of the sphalerite. This is also confirmed in a general way by the apparently sympathetic variations in the Ag, Cu, As, and Sb contents of some samples. Consideration should be given, however, to the possibility that small amounts of these elements may occupy lattice sites in the sphalerite. The covalent radius of copper (1.24Å) and the ionic radius, Cu^{2+}(0.72Å), are close to those of zinc (1.33Å), Zn^{2+} (0.71Å) and some substitution should be possible. The large size of the lead atom and ion (1.69Å), Pb^{2+}(1.28Å), however, precludes much substitution of this element. Substitution of much silver also seems unlikely because of the difference in its charge. It seems most probable that As, and perhaps also Sb, would occupy some of the sulphur sites. The data on voltzite, Zn(S, As), suggest that such substitutions are possible.

Most of the sphalerite samples contain tin in amounts up to 800 ppm. These amounts exceed by a wide margin those to be expected in the small particles of admixed galena and other sulphides, and, as no cassiterite or stannite were observed in polished sections of the sphalerite, it is concluded that the tin is most probably present in lattice sites. The covalent radius of tin (1.40Å), and the ionic radius, Sn^{4+} (0.71Å), are close to those of zinc (1.33Å), Zn^{2+} (0.71Å) but the charge is double. A limited multiple substitution of 1Sn for 2Zn may, however, be possible, thus equalizing the charge distribution. In addition a certain degree of substitution of Sn^{2+} (0.93Å) may take place in the zinc sites despite the large size of the stannous ion. Alternatively it is to be noted that the compound SnSb is isostructural with sphalerite, and it seems likely that as Sn is substituted for Zn, Sb may simultaneously substitute for S.

Indium is commonly found in sphalerites but in general those at Keno Hill appear to contain little of the element. It is generally stated, following the work by Erämetsä (1938), that indium is captured in the sphalerite structure as In^{3+} (0.81Å). This ion is similar to Zn^{2+} (0.74Å) in radius but not in charge, and hence for crystal stability some other univalent element, probably Cu^{+} (0.96Å) must be taken into the sphalerite structure. Alternatively, as InSb is isostructural with sphalerite, substitution of In for Zn and Sb for S also seems acceptable.

The germanium content of the samples was not determined precisely but is below 50 ppm. This is in general agreement with the findings of Stoiber (1940), Goldschmidt (1954, p. 387), and others for deposits of the Keno Hill type which, according to these authors, supposedly formed at intermediate to high temperatures.

An investigation using sphalerite as a geothermometer was carried out and is described elsewhere (Boyle and Jambor, 1962). Briefly, the results indicate that the cell edges of the sphalerite samples in Table 34 vary in a linear manner with the FeS contents, but the values obtained for the crystallization temperatures of sphalerite according to the recent data of Sims and Barton (1961) cannot be interpreted in a geological sense. On this account it was concluded that the sphalerite geothermometer is not applicable to the Keno Hill deposits at our present state of knowledge.

Galena, PbS

Galena is one of the principal ore minerals. In most deposits it is a hypogene mineral, but in places some supergene galena is present. Galena figures largely in the second stage of mineralization of the vein faults, occurring in quantity in both the longitudinal and transverse types. In a few veins, as at the Klondyke-Keno mine and Helen Fraction, galena occurs in vugs and fractures in early quartz lenses and may have been precipitated during the early stage of mineralization of the longitudinal vein faults (Pl. XIX).

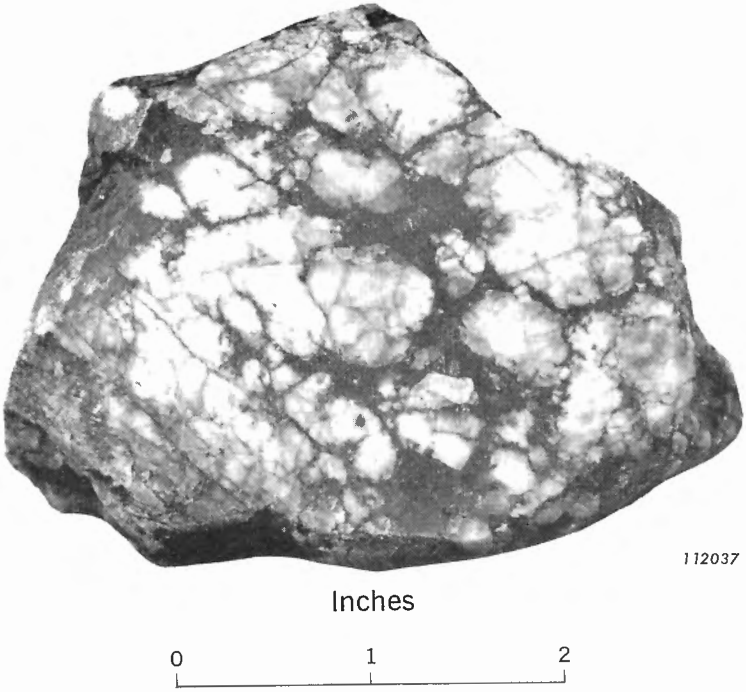


PLATE XIX. Galena (dark grey) in vugs and fractures in early white quartz, Helen Fraction, Keno Hill.

The hypogene galena occurs in large crystallized masses in veins and stringers and as individual crystals and crystal groups in vugs and cavities in the lodes. In most occurrences the galena is associated with siderite, calcite in places (Cream vein), freibergite, sphalerite, quartz, and pyrite, commonly in intimate intergrowths suggesting nearly contemporaneous deposition for all of the sulphides and gangue minerals. In other occurrences galena is a late mineral encrusting siderite and quartz and filling the spaces between quartz combs and siderite bands lining fractures. In still other occurrences galena is interbanded with siderite, quartz, sphalerite, and pyrite, and several stages of deposition of galena, other sulphide minerals, and gangue are evident (Pl. XX).

In lodes that have not been severely disrupted by brecciation, slips, or faults, the galena occurs in coarsely crystalline cleavable masses forming irregular tabular bodies, vein-like masses, and lenses. In places beautiful crystal groups, individual cubo-octahedral crystals, and twins are present, particularly in the drusy parts of the lodes. Where brecciation has occurred and where slips and faults slice through the lodes, the galena is crushed, sheared, plumose, gneissic, or schistose in appearance (steel galena).

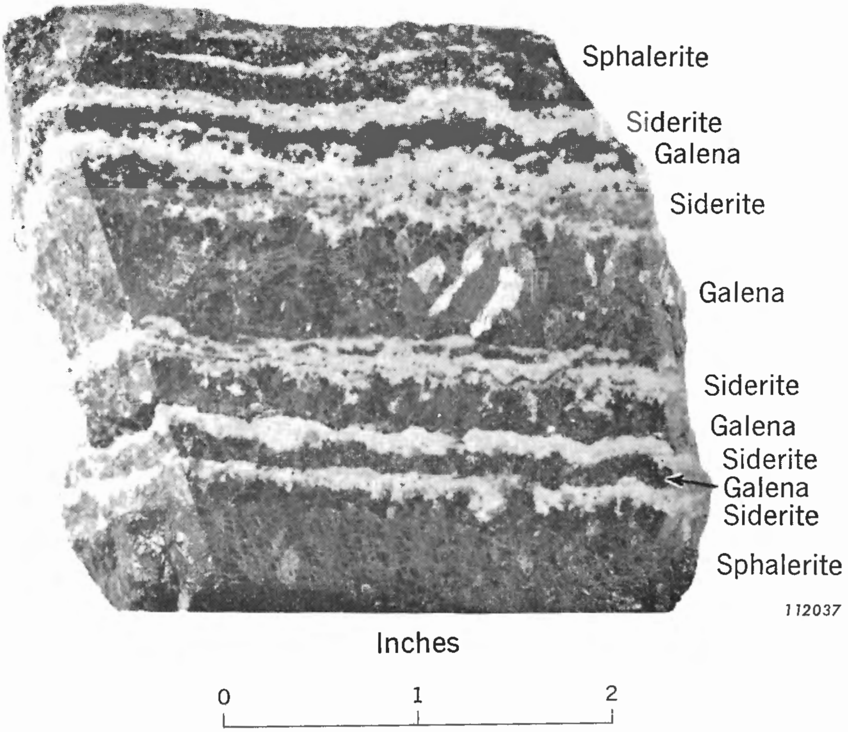


PLATE XX. Interbanded galena, siderite, and sphalerite, Hector mine, Galena Hill.

Seen in polished sections, the galena is coarse to fine grained, the diameter of the grains ranging from 3.0 cm to 0.005 mm with an average of about 1 cm. The normal galena exhibits good cubic cleavage and some varieties have a poorly developed octahedral parting; the plumose galena has the characteristic curved and elongated crystals, and the steel galena is marked by the bands and curved cleavage surfaces peculiar to this variety. A very dense, hard, fine-grained galena with abundant specks of sphalerite and freibergite and showing relatively little distortion, is present in small amounts in some lodes. This may be completely recrystallized or may have been originally deposited in a fine-grained form. The former seems the more likely as the fine-grained galena contains streaked-out gangue minerals, grades imperceptibly into a coarser schistose galena in some places, and is generally present near slips and small faults.

As seen in polished sections the galena is closely associated with pyrite, arsenopyrite, sphalerite, chalcopyrite, freibergite, and locally with pyrargyrite, meneghinite, and bournonite. Generally it cuts pyrite and arsenopyrite and was thus deposited later than these minerals. Galena also penetrates sphalerite in many sections, but is itself often pervaded by the latter mineral along cleavage planes or cracks. Small rounded isolated blebs of sphalerite also occur in places in the galena. These relationships suggest overlapping depositional features best interpreted as nearly contemporaneous. Meneghinite and bournonite are generally closely associated with galena and have mutual boundary relationships, again suggesting nearly contemporaneous deposition. Freibergite is very closely associated with galena and occurs as small euhedral tetrahedrons and as isolated rounded patches in the body of the galena, as elongated blebs along the 111 parting planes, as penetrating veinlets along the cubic cleavage planes, and in cracks. In most of these occurrences the freibergite is accompanied by chalcopyrite. Some of the blebs along the various oriented planes suggest exsolution phenomena; many of the other relationships, however, point to nearly contemporaneous deposition of galena and freibergite. Some galena specimens contain specks, blebs, and rods of pyrargyrite (ruby silver) oriented mainly along the parting and cleavage planes. This pyrargyrite gives the appearance of being a primary exsolution phenomenon, but its occurrence largely in galena that exhibits some oxidation suggests a secondary origin.

Oxidation of the galena to anglesite and cerussite is a common phenomenon in the oxidized zones of the deposits. The process begins by a general darkening of the splendent lustre of the galena and is followed by the development of tongues and seams of anglesite along the cleavage planes (Pl. XXI). Gradually the anglesite front advances into the galena along a series of scalloped surfaces until the original mineral is wholly enveloped or until only a small irregular core of galena remains. In some specimens cerussite appears to form from the anglesite and penetrates or encrusts this mineral. In other specimens the cerussite develops directly on the cleavage surfaces of galena as an earthy rind or as a drusy intergrowth of minute crystals.

Galena, with an oxidized rind of anglesite, is relatively stable in the residual soils and has been found in some of the placers of the area as rolled, water-worn nodules. Small cubes and cubo-octahedral crystals were found in many of the heavy concentrates from the residual soils in the vicinity of the veins.

Spectrographic and chemical analyses of various types of hypogene and supergene galena are given in Table 36, and gold assays of the mineral are presented in Table 57. The presence of significant amounts of Ag, Au, Sn, Cu, Zn, Sb, Bi, and Fe in the mineral is of interest.

At the outset it should be pointed out that none of the galena samples consists of one homogeneous phase, PbS. On the contrary, under high magnification most polished sections of all types reveal the presence of intergrown minerals, but because of the extremely small size of most of these, in the form of lamellae, rod-shaped, and rounded inclusions and blebs, their precise identification is often difficult, if not impossible. Some inclusions can be definitely identified as freibergite and pyrargyrite. In places acanthite and miargyrite, $AgSbS_2$, appear to be present, and in the high bismuth-bearing galena matildite, $AgBiS_2$, and aramayoite, $Ag(Bi, Sb)S_2$, may occur, but their identification is uncertain.

The amount of silver in the galena varies considerably. With some exceptions, there is generally less silver in the crystals than in the massive varieties. Schistose and microcrystalline varieties tend to be enriched in silver, and this is generally borne out by the higher silver assays of those parts of the veins that contain significant amounts of these varieties of galena. All the supergene galena samples contain much silver and in addition are enriched in copper, zinc, cadmium, and iron. This age of galena is generally pulverulent and is highly contaminated with much finely divided supergene sphalerite, pyrite, and pyrargyrite, accounting for most of the large amounts of zinc, etc.

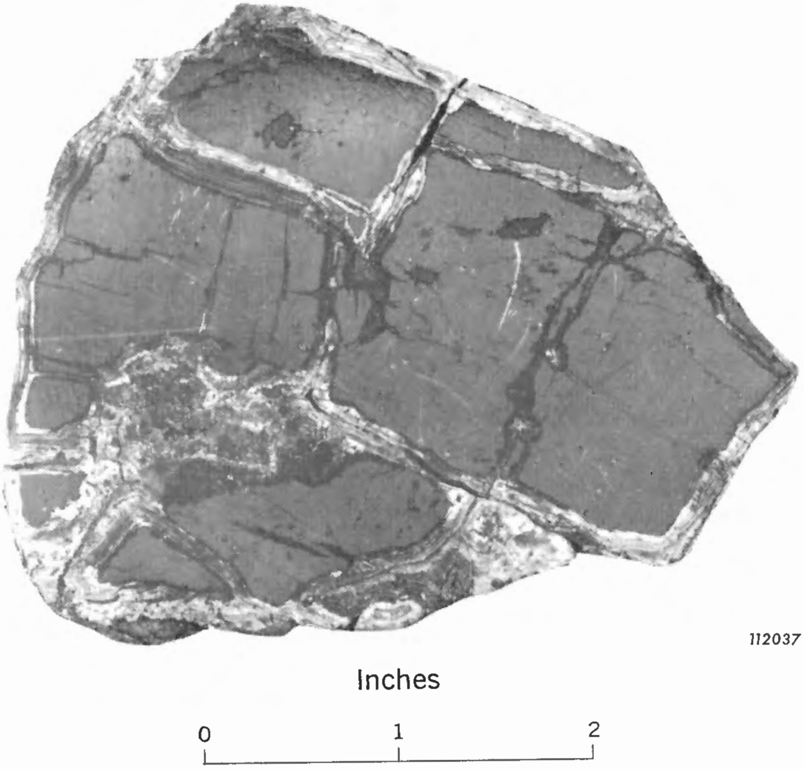


PLATE XXI. Galena (medium grey) pervaded by tongues and seams of anglesite (light and dark grey), Comstock Keno mine, Keno Hill.

Tin varies in amount in the different types and ages of galena but no definite statement can be made regarding its distribution. About equal amounts appear to be present in both the hypogene and supergene varieties. Bismuth, however, tends to be enriched in the first generation of galena in the early deposited quartz-arsenopyrite-pyrite veins, viz., Helen Fraction. Some investigators have suggested that high bismuth galena is indicative of higher temperatures, an assumption that appears to hold at Keno Hill.

Gold may occupy two sites in the galena samples: it may replace lead in the galena lattice, or copper in the included crystals and blebs of freibergite. Because of the relatively large amounts of gold in freibergite (Table 57), the latter seems more likely.

The silver, antimony, and bismuth in galena have received much investigation and comment, most of which is aptly summarized by Edwards (1954), and more recently by Van Hook (1960) and Ontoiev, *et al.* (1960). Only the significant features of the investigations are mentioned here.

Galena is face-centred cubic with a sodium chloride lattice and contains 8 atoms per unit cell. Each Pb atom is bonded to 6 S atoms and each S atom in turn to 6 Pb atoms. The bonding is largely of a semi-metallic character as evidenced by the high metallic lustre, specific conductivity, diode, and thermoelectric properties of the mineral. Because of the semi-metallic nature of galena diffusion of metallic and semi-metallic substances within the crystals should be relatively rapid.

The high temperature forms of several silver, antimony, and bismuth minerals are isostructural with galena and may enter into solid solution with the lead sulphide at elevated temperatures (above 200°C). Among these the most common are miargyrite, $AgSbS_2$, matildite, $AgBiS_2$, and aramayoite, $Ag(BiSb)S_2$. It is also possible that certain forms of argentite, Ag_2S, smithite, $AgAsS_2$, chalcostibite, $CuSbS_2$, emplectite, $CuBiS_2$, and other lead, tin[1], and zinc sulphosalts have somewhat similar relationships, although no data are yet available. The limits of solid solution of the common silver minerals in PbS are relatively well known from experimental data. The three sulphides Ag_2S, Bi_2S_3, and PbS melt congruently at the pressure of the system, and the following features have been observed by Van Hook.

The miscibility of Ag_2S in PbS is limited to 0.4 mol per cent Ag_2S in the binary system PbS—Ag_2S, whereas much higher amounts of Bi_2S_3(9 mol per cent at 800° C) are soluble in galena in the system PbS—Bi_2S_3. A series of solid solutions appears in the ternary system PbS—Bi_2S_3—Ag_2S at relatively high temperatures, and although considerable amounts of $AgBiS_2$ unmix at 195°C (the $\alpha \rightleftharpoons \beta$ inversion point of matildite), much of this component remains dissolved in galena at low temperatures (10 mol per cent $AgBiS_2$ at 170°C in the presence of excess $AgBiS_2$). These observations have led Van Hook to conclude that the solubility of Ag in PbS may be extensive, even at low temperatures, when Bi is present, and that similar relationships probably prevail when Sb is present in the system.

It thus seems to be well established that at elevated temperatures Ag, Bi, and Sb partake of the galena structure, and this is probably also true to a lesser degree of Sn, Cu, Fe, Zn, and Cd. Such substitutions probably take place without any marked distortion of the galena lattice or any great increase in the free energy of the crystal. From energetic considerations it seems probable that at relatively high temperatures Ag, Sn, Cu, Bi, and Fe would occupy some of the lead positions in the expanded PbS lattice and that the charge distribution would be equalized where necessary by multiple substitutions of the type ($Ag^+ + Bi^{3+} = 2Pb^{2+}$), ($Ag^+ + Sb^{3+} = 2Pb^{2+}$), or by substitution of Sb in interstitial positions, or perhaps even in the S positions. In considering the later type it should be remembered that Sb, and also Bi, may be electron acceptors, taking up three electrons (-3 oxidation state) in their valency orbitals to attain the noble gas configuration. Arrangements such as those suggested above appear to be a feature of some semi-metallic lattices and in this respect they simulate certain alloys.

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[1] According to Goldschmidt, V. M. (Geochemistry, Oxford, 1954, p. 406) SnSb is isomorphous with PbS.

At lower temperatures, however, the presence of foreign constituents with marked size differences and charge distributions (eg. Ag^+ – 1.31Å, Pb^{2+} – 1.24Å; Ag° – 1.44Å, Pb° – 1.74Å) distort the galena lattice with a consequent rise in the free energy of the crystal. In order to reduce the free energy of the system to a minimum, components such as Ag, Sb, Bi, Cu, Fe, Zn, etc., migrate by diffusion to 111 or 100 planes or other suitable low chemical potential sites where they crystallize as freibergite, argentite (acanthite), matildite, etc. In the Keno Hill galenas, as perhaps in other natural galenas, the diffusion process is greatly enhanced by the large numbers of crystal imperfections found by Greig (1960) by thermoelectric methods.

Although these speculations on the presence of silver in galena may answer the problems of solid solution and exsolution of various silver minerals, they do not provide an adequate explanation for the observation that certain galena deposits carry large amounts of silver whereas others carry relatively little. The answer must be sought beyond the deposits.

Two types of lead deposits may be recognized—silver-rich lodes or veins in shales, black shales or schists, quartzites, limy shales, argillaceous limestones, tuffs, porphyries, and volcanic rocks; and silver-poor deposits, often referred to as 'Mississippi Valley type', in carbonate rocks and limy shales. In the former type galena is generally associated with large amounts of silver minerals and may contain appreciable amounts of Sb, Bi, As, Sn, and other chalcophile elements; in the latter type the galena, and the deposits as a whole, tend to be low in silver as well as in other closely associated chalcophile elements.

Some investigators have sought an explanation of these differences in the temperature of formation of the deposits. Thus, the high-grade silver deposits are assumed to have formed at higher temperatures than the low-grade ones. This appears unlikely as there is no great difference in the metamorphic facies in which both types of deposits are formed (generally in the low-grade quartz-sericite-carbonate facies), and furthermore pyrite, chalcopyrite, enargite, and locally small amounts of tetrahedrite may occur in the so-called low-temperature types. These latter minerals are precisely the ones most often associated with the presumed higher temperature silver sulphosalts.

The writer believes that the answer to silver-rich and silver-poor galena deposits lies in part in the availability, abundance, and mode of binding of the elements, Ag, Bi, Sb, etc., in rocks in which the deposits occur.

It is well established that shales, particularly organic black shales, contain appreciable amounts of all chalcophile elements such as silver. This is a consequence of organic activity, precipitation by H_2S, and other factors operating during sedimentation. Certain volcanic rocks, tuffs, and porphyries are also enriched in silver and other chalcophile elements as a result of original processes of formation. Most carbonate rocks, however, generally contain relatively small amounts of silver, bismuth, arsenic, etc. These features are shown even in a local sense by the rocks in the Keno Hill area (Table 26). There is thus an inadequate source of Ag, Bi, etc., in carbonate rocks for concentration in the lead deposits.

One other notable difference between the two types of silver deposits must be taken into consideration. The high grade silver-lead deposits occur in rocks that have undergone extensive folding and contortion and in which both high- and low-grade metamorphic processes have been active. Such processes have undoubtedly provided the energy for the mobilization and migration of considerable quantities of Ag, Bi, As, etc. In the carbonate rocks tectonic and metamorphic activity have generally not been severe if present at all, and little concentration of silver and other associated elements has taken place.

These two considerations, the abundance of the elements in the host rocks and the necessary energy to mobilize and concentrate them, appear to be the most important factors in the formation of silver-bearing lead deposits. Others, such as the differential diffusion rates of Pb, Ag, Bi, As, etc., and their precipitation ranges require more research before the problem can be further elucidated.

Chalcopyrite, $CuFeS_2$

Chalcopyrite has been observed in small segregations and along seams in greenstones where it is generally associated with calcite. In the lodes it is one of the less abundant sulphides, occurring only in the siderite lodes of Sourdough, Keno, and Galena Hills. It is closely associated with sphalerite and freibergite in most occurrences and with galena in a few places.

In hand specimens the chalcopyrite appears as small grains, generally intergrown with the sphalerite and galena. Another characteristic habit is as rims around freibergite or as small irregular seams and patches in this mineral. In a few lodes, as at the Cream prospect, relatively large crystalline masses of chalcopyrite occur intergrown with black sphalerite and some galena.

In polished sections the chalcopyrite is seen to be closely associated with sphalerite, galena, and freibergite. The diameters of the chalcopyrite grains vary between 0.005 mm and 1 mm, but in some lodes the grains are coarser.

Where sphalerite is present, chalcopyrite occurs in two characteristic habits—as intergrown grains that have mutual boundaries—a feature suggesting simultaneous deposition of the two minerals; and as microscopic blebs, some exhibiting a preferred orientation along the (111) directions of the sphalerite. This latter mode of occurrence suggests exsolution and indicates that the maximum upper limit of exsolution for the two phases (sphalerite-chalcopyrite) was 350 to 400°C (Buerger, 1934).

Where chalcopyrite and galena are in contact the two are generally intergrown and mutual boundaries prevail, indicating simultaneous deposition. In some sections, however, small veinlets of chalcopyrite with associated freibergite and sphalerite penetrate and lie along the cleavage planes of the galena. This indicates that in some places the chalcopyrite is younger than the galena.

Most sections of freibergite contain some chalcopyrite either as rims around the silver sulphosalt or as intimate granular intergrowths and irregular patches. The relationships between the two minerals in polished sections are such as to suggest simultaneous deposition in most cases. Edwards (1954) believed that chalcopyrite and tetrahedrite are capable of solid solution at temperatures of about 500°C, but that exsolution textures of the two minerals are rather rare. Some of the blebs and patches of chalcopyrite in tetrahedrite may indicate exsolution phenomena of these two phases in the Keno Hill lodes, but the mineralogical relationships in polished sections are too obscure to be certain of this.

The field occurrence of chalcopyrite and the polished section data strongly suggest that the bulk of this mineral was deposited nearly simultaneously with the galena, sphalerite, and freibergite of the siderite lodes. There is some indication of a late generation of chalcopyrite, but this is relatively minor and in any event probably represents the final stages of the sulphide mineralization of the siderite lodes.

In most of the siderite lodes chalcopyrite varies in abundance with depth. In the oxidized parts it is present in only small amounts as highly altered grains and small masses in a limonitic boxwork or in the oxidized rubble of the veins. Deeper down, as the oxidation decreases, larger amounts of chalcopyrite make their appearance. The principal alteration products of chalcopyrite are malachite and azurite. In a few places small amounts of covellite were observed on highly oxidized grains of chalcopyrite.

A spectrographic and chemical analysis of massive granular chalcopyrite from the Cream vein is given in Table 37, and the gold content is presented in Table 57.

The mineral collects small amounts of Pb, Ag, Au, Zn, Sn, Co, and Ni. These elements probably substitute in the copper and iron positions in the lattice. The small amounts of As and Sb present in the mineral are probably in interstitial positions or substitute for S. A small proportion of all of the trace elements may also be present in small wisps and blebs of sphalerite, galena, and freibergite, all of which can rarely be excluded from the samples despite painstaking preparation.

Arsenopyrite, FeAsS

Arsenopyrite is present mainly in the early quartz-pyrite lodes in the longitudinal vein faults on Keno Hill and in the Dublin Gulch area. The quartz-pyrite lodes on Galena Hill contain only small amounts of arsenopyrite, and the mineral is rare in most siderite-galena-sphalerite lodes and absent in all late faults and fractures anywhere in the area.

In the quartz-pyrite lodes the arsenopyrite occurs as intergrown crystal groups, individual stubby and elongated prismatic crystals, and as granular aggregates and veinlets both in the quartz veins and in their wall-rock alteration zones. The closest mineral associate is pyrite, and in many places the two minerals are intimately intergrown, suggesting simultaneous deposition. In places arsenopyrite is also associated with boulangerite, jamesonite, and meneghinite.

As seen in polished sections the arsenopyrite is coarse to fine grained, the sizes of the grains and crystals ranging from 0.002 mm to 1 cm with an average of about 0.2 mm. Most of the arsenopyrite appears to be early and is intimately intergrown with pyrite, with which it generally exhibits mutual boundaries. In some sections there is a suggestion that two generations, both early, may be present. Fractured and shattered grains and crystals of arsenopyrite are common in some lodes, and these are cemented by quartz that often contains minute crystals of sulphosalts.

In some lodes arsenopyrite varies in quantity with depth in a manner similar to that of pyrite. The near surface parts of the lodes contain only small amounts of the mineral, generally present as disintegrated masses and nodules altered to scorodite and limonite. Deeper down, as the oxidation effects decrease, the arsenopyrite is relatively fresh. In the Dublin Gulch area the alteration to scorodite and limonite is intense. There, many of the near surface exposures now consist mainly of greenish stained quartz with streaks, bunches, and irregular pockets of scorodite.

Arsenopyrite nodules, generally with an oxidized rind of limonite and commonly with some scorodite, occur in the residual soils in the vicinity of the quartz-pyrite-arsenopyrite lodes. Similar rolled nodules and masses are present in the placers of the area, particularly in the Dublin Gulch area.

Spectrographic and chemical analyses of characteristic samples of arsenopyrite are given in Table 38, and the gold content is presented in Table 57.

Assays of most arsenopyrite samples from the early quartz-pyrite veins indicate gold in amounts ranging from 0.1 to 0.5 ounce a ton. In polished sections, however, free gold was not observed, indicating either that the gold particles are submicroscopic or that the element is present as a lattice constituent. The latter view is favoured by the writer because of certain energetic and crystallochemical considerations discussed in an earlier memoir (Boyle, 1960) and also under *Gold* (p. 179).

In general the arsenopyrite lattice appears to tolerate very little lead. The large content in two of the samples is probably due to minute amounts of admixed galena which can be seen in polished sections. The small quantities of copper, zinc, silver, nickel, and titanium are probably lattice constituents, substituting for iron. Excessive amounts of these elements, as in the arsenopyrite from the Comstock vein, are probably in impurities such as freibergite and chalcopyrite. Antimony is consistently present in all the arsenopyrite samples. Some may be present in minute amounts of freibergite, but it seems more probable that the element is a lattice constituent substituting for arsenic. In this respect it is worth noting that gudmundite, FeSbS, is isostructural with arsenopyrite, FeAsS, and considerable substitution of Sb for As would be expected if the former element were relatively abundant in the crystallizing medium.

Stibnite, Sb_2S_3

Visel reported stibnite from the Betty claim, and Stockwell (1926) found the mineral in the Coral and Wigwam veins. In other veins the mineral is rare.

Tetradymite, Bi_2Te_2S

This mineral was found by Thompson (1949) at Dublin Gulch, as a small placer pebble with an embedded subhedral crystal of gold.

Sulphosalts

The following sulphosalts were identified by X-ray and spectrographic methods:

Tetrahedrite (variety freibergite)—	$(Cu, Fe, Zn, Ag)_{12}(Sb, As)_4 S_{13}$
Pyrargyrite	Ag_3SbS_3
Stephanite	Ag_5SbS_4
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$
Boulangerite	$Pb_5Sb_4S_{11}$
Jamesonite	$Pb_4FeSb_6S_{14}$
Meneghinite	$Pb_{13}Sb_7S_{23}$
Bournonite	$PbCuSbS_3$

Freibergite and pyrargyrite are the most abundant sulphosalts and carry the largest proportion of silver in the lodes. The other sulphosalts are present in small amounts and are not of economic importance. Pyrargyrite is principally a supergene mineral in most occurrences and is described in a later section. The other sulphosalts are hypogene.

Freibergite

Freibergite occurs in the lodes of both longitudinal and transverse vein faults on Mount Haldane, Galena Hill, Keno Hill, and Sourdough Hill. It belongs principally to the second stage of mineralization of the vein faults and appears in only a few places, accompanied by galena, in the early unbrecciated quartz-pyrite-arsenopyrite lodes. The mineral was not observed in the quartz-pyrite-arsenopyrite veins in the Dublin Gulch area. In all occurrences observed by the writer, freibergite is a hypogene mineral. It may carry up to 18 per cent silver, and is the most important silver mineral in the lodes.

The freibergite is iron black to metallic grey and generally occurs disseminated all through the galena-sphalerite lodes. In some lodes it occurs between quartz-combs (Klondyke-Keno east-west vein) and in small irregular masses and intergrown tetrahedral crystals in the drusy parts of the lodes. The mineral is commonly concentrated in small siderite stringers and veins that cross from one vein fault to another or that form spurs.

In polished sections the freibergite is seen to be coarse to fine grained, the diameters of the grains ranging from 0.003 mm to 2 cm with an average of about 2 mm. Its most persistent associates are galena, sphalerite, chalcopyrite, and pyrargyrite.

In most sections the freibergite occurs in galena or sphalerite. In the former it is present both as small elongate blebs, averaging 20 microns in length, along the cleavage and 111 parting planes and as small tetrahedral crystals embedded within the galena crystals. The elongated blebs suggest exsolution from the galena. In the sphalerite the freibergite occurs mainly as small rounded blebs and irregular patches without any preferred orientation. In addition to the above modes of occurrence, many freibergite crystals and masses exhibit mutual boundary relationships with both galena and sphalerite suggesting contemporaneous deposition. In some sections veinlets of freibergite and associated chalcopyrite were seen to penetrate galena along cleavage planes, and occasionally galena was seen to cut across masses of freibergite. Again, all these relationships suggest overlapping and nearly contemporaneous deposition.

In numerous occurrences freibergite is closely associated with chalcopyrite. The latter rims the former in places but both minerals are more often intimately intergrown with each other suggesting contemporaneous deposition. Pyrargyrite is in places also closely associated with freibergite, and the two may show mutual boundary relationships. In other places the pyrargyrite forms an 'island-and-sea' texture with the freibergite suggesting replacement of the latter by the former. In some sections bournonite is present as minute inclusions in freibergite, but the relationships of the two minerals are rarely clear-cut.

The polished section and field relationships suggest two generations of freibergite—an early and relatively minor generation in quartz, formed soon after the deposition of pyrite and arsenopyrite, and a later and important generation deposited with galena, sphalerite, chalcopyrite, and siderite. Both are probably almost contemporaneous as no definite cutting relationships by either were observed in any of the lodes.

In the oxidized parts of the lodes freibergite is altered to limonite, malachite, azurite, and bindheimite.

Spectrographic and chemical analyses of three characteristic occurrences of well crystallized freibergite are given in Table 39, and gold assays of the mineral in Table 57. All samples were hand picked for purity.

The elements of principal interest are lead, silver, gold, zinc, cadmium, iron, tin, and arsenic. Of these Pb, Ag, Au, Zn, Cd, Fe, and Sn undoubtedly substitute in the copper positions in the lattice. Arsenic substitutes for antimony, there being a complete isomorphous series from freibergite (tetrahedrite), the antimonian member, to tennantite the arsenian member.

With the exception of sphalerite, freibergite is the only mineral in the hypogene sequence that carries considerable amounts of cadmium.

Boulangerite, Jamesonite, Bournonite, and Meneghinite

Boulangerite and jamesonite are the most common of this group of sulphosalts, the others being relatively rare. All are found principally in the early quartz-pyrite-arsenopyrite lodes on Keno Hill, Galena Hill, and in the Dublin Gulch area. Boulangerite, jamesonite, and bournonite are also present in small amounts in some of the siderite-galena-sphalerite lodes.

In the early quartz lodes these sulphosalts are generally present in the parts where arsenopyrite and pyrite are abundant. They are, however, paragenetically later than these two minerals and are more closely associated with galena and freibergite. In some of the siderite lodes fine acicular crystals of boulangerite are intimately intergrown with siderite giving a metallic grey aggregate. In addition some boulangerite is common as inclusions in freibergite.

Polished sections from the quartz lodes show that boulangerite and jamesonite occur with fibrous and massive habits and also as felted masses of acicular crystals. Both minerals are associated with galena, sphalerite, meneghinite, and bournonite, and together these minerals form irregular discontinuous lenses, small nests, and crosscutting seams in the quartz gangue. Bournonite is generally massive and commonly finely twinned. It is generally accompanied by meneghinite, but the latter is common alone. Seen in some sections, bournonite veinlets cut sphalerite, galena, and even boulangerite; in others these minerals are intimately intergrown with one another. Where galena is reasonably abundant in the quartz gangue, bournonite may be present as discontinuous veinlets and lenses along the cleavage planes. In addition small blebs of bournonite are common in the felted masses of boulangerite. Meneghinite is commonly intergrown with the galena in the quartz lodes. The mutual boundaries of the two minerals are generally smooth, indicating nearly contemporaneous deposition.

As seen in polished sections from the siderite lodes, boulangerite is the most common of this group of sulphosalts, but locally some bournonite may be present. In a few lodes isolated felted masses of boulangerite are present in places, but more commonly this sulphosalt occurs as fine acicular crystals and small fibrous masses intimately intergrown with siderite. Many of the acicular crystals penetrate the siderite grains and others are wholly enclosed within the grains, features suggesting contemporaneous deposition of the two minerals. Bournonite, as noted above, is rather rare in the siderite lodes, occurring sporadically as irregular inclusions in freibergite.

The paragenetic relationships of boulangerite, jamesonite, bournonite, and meneghinite with respect to the more abundant sulphide minerals is not entirely clear-cut. Their common association with arsenopyrite in the early quartz lodes, and their presence as intimate intergrowths with siderite suggest two periods of deposition. However, all sulphosalts are definitely later than the early arsenopyrite, and in most occurrences they vein the quartz. Furthermore, most show a definite association with galena and freibergite, a feature suggesting that perhaps the sulphosalts were largely introduced during the formation of the siderite-galena-sphalerite-freibergite lodes. This postulate seems to be in better accord with the fact that this was the period of mineralization marked by a major introduction of lead, copper, antimony, and sulphur, the principal constituents of this group of sulphosalts.

In the zone of oxidation boulangerite, jamesonite, bournonite, and meneghinite alter principally to bindheimite, cerussite, and anglesite. Beudantite may also coat these minerals where arsenopyrite is present. Locally bournonite is altered to azurite and malachite, and senarmontite is a common alteration product of jamesonite in some of the Dublin Gulch veins.

Nodules and irregular masses of boulangerite and jamesonite coated with cerussite, anglesite, and beudantite are common constituents in the heavy concentrates separated from soils in the vicinity of the lodes. These nodules and irregular masses also appear in the heavy concentrates from the placers of Dublin Gulch and Haggart Creek.

Spectrographic and chemical analyses of characteristic occurrences of boulangerite and jamesonite are given in Table 40, and gold assays are in Table 57. All samples were hand picked for purity.

Both minerals appear to tolerate small amounts of Zn, Cu, Ag, Au, Sn, and Bi in their structures. These probably substitute in the lead sites of the boulangerite and in both the lead and iron sites in jamesonite. Some may, however, be in impurities such as sphalerite and galena. The arsenic probably proxies for antimony.

Stephanite and Polybasite

These two silver sulphosalts were identified only in the siderite lodes of Keno and Galena Hills. They are present in only small amounts and are generally associated with the other sulphosalts, particularly freibergite and pyrargyrite. They appear to be of hypogene origin although their occurrence with pyrargyrite may indicate that in some places they are supergene.

Cassiterite, SnO_2

Cassiterite occurs in two types of deposits in the Dublin Gulch area—in small tourmaline-cassiterite-quartz impregnations along faults and fractures in quartzites, phyllites, and graphitic schists, and as greenish brown sugary tourmaline-cassiterite nodules in the placers of Dublin Gulch and Haggart Creek.

In the impregnation zones the cassiterite occurs in a dense greenish brown, highly brecciated rock composed essentially of microscopic green tourmaline, quartz, and chlorite. Small amounts of pyrite and a few grains and small masses of chalcopyrite are present, and the rock as a whole is stained and seamed with limonite. Locally cellular limonite is abundant in parts of the zones.

Thin sections of the impregnated zones contain essentially tourmaline, cassiterite, quartz, chlorite, graphitic material, and limonite. These minerals are intimately intergrown with one another, producing a relatively uniform granular texture.

The cassiterite is yellow to yellowish brown with a pronounced colour banding. The grain size is remarkably uniform, most grains averaging about a millimetre across. Geniculated, contact, and penetration twins are common in some sections. Many cassiterite crystals contain small needles of tourmaline and others contain rutile. The tourmaline crystals occur in random orientation and in rosettes and fibrous aggregates. They are greenish to brownish, and average a few tenths of a millimetre in diameter. The quartz is colourless and clear, occurring as anhedral grains in seams, veinlets, and elongated aggregates. Both the veinlets and small lenses of quartz contain tourmaline needles and small crystals of cassiterite. Pyrite tends to occur within the quartz veinlets, but some is found in the cassiterite-tourmaline matrix. Chlorite is present mainly in seams and irregular patches. Limonite is a late supergene mineral; it stains most of the primary minerals and cements brecciated parts of the impregnated zones.

The intimate intergrowths of cassiterite and tourmaline and the general coexistence of these two minerals in quartz veinlets and segregations suggest that boron and tin were introduced simultaneously.

Near the tin zones cassiterite is fairly abundant in the soils. Cassiterite-tourmaline nodules can also be panned from the soils all the way from the tin zones down to Dublin Gulch (*see* Fig. 18). In the placers of this gulch and in Haggart Creek the nodules vary from pea size to irregular rounded lumps several inches in diameter. A thin section examination shows that the mineralogical and textural characteristics of the nodules are identical with those of the material in the tin lodes.

Semiquantitative spectrographic analyses of cassiterite from the tin lode and from the nodules in Dublin Gulch are given in Table 41.

The relatively large number of trace elements in the cassiterite is due to the intimate intergrowth of minerals such as rutile and tourmaline, which cannot be physically separated from the cassiterite.

Much of the iron, calcium, manganese, magnesium, and gallium, and practically all the boron, is bound in tourmaline. Rutile accounts for much of the titanium and some of the iron, aluminum, vanadium, zirconium, niobium, and tungsten. Relatively pure cassiterite contains some manganese, tungsten, iron, titanium, niobium, zirconium, gallium, lead, vanadium, and scandium. All these elements probably substitute for Sn^{4+} in the cassiterite lattice because of similar radii and the isostructural relationships of some of their oxides. Thus, rutile, TiO_2, pyrolusite, MnO_2, and plattnerite, PbO_2, are isostructural with cassiterite, and W^{4+} (0.70Å), Nb^{4+} (0.74Å), Zr^{4+} (0.79Å), Ga^{3+} (0.62Å), Fe^{3+} (0.64Å), and Sc^{3+} (0.81Å) are close to Sn^{4+} (0.71Å).

The presence of bismuth, arsenic, and antimony in the cassiterite concentrate suggests that small quantities of native bismuth, arsenopyrite, and sulphosalts occur in the lode. These minerals were not seen in thin and polished sections of the tin ore, but they accompany the cassiterite in the soils and placer gravels.

Scheelite, $CaWO_4$, and Wolframite, $(Mn,Fe)WO_4$

Scheelite and wolframite occur in primary deposits, residual deposits, and placers in the Dublin Gulch area. The primary scheelite deposits include small quartz vein stockworks, quartz pegmatites, and skarn bodies; the secondary concentrations occur in the soils and residuum overlying highly disintegrated granodiorites and skarn rocks, and in the placers of Dublin Gulch and its tributary streams, in Lynx Creek and its tributaries, and in Haggart Creek. Primary wolframite occurs mainly in quartz veinlets and small pegmatites; the secondary concentrations are similar to those noted above for scheelite.

In all occurrences the scheelite is white with a slight yellowish brown tinge in places. Most of it occurs as anhedral grains, but good octahedral crystals have been observed, both in the primary and secondary deposits. The wolframite is iron black to brownish black. In the quartz veins it tends to occur in short, well-developed, prismatic crystals; in the residual deposits and placers the crystals and grains are rounded and pitted.

The scheelite and wolframite in the small quartz vein stockworks and pegmatites occur principally as individual crystals, crystal aggregates or irregular grains in the quartz gangue. Some grains of scheelite are also present in the adjacent granitic rock, skarn, or quartz-mica schist. In the quartz veinlets the minerals most commonly associated with the scheelite and wolframite are minor quantities of pyrite and calcite. In the quartz pegmatites, muscovite and feldspar are common associates.

The scheelite in the skarn rocks is present as subhedral to anhedral crystals and crystal aggregates disseminated in a groundmass composed of diopside, fibrous amphibole, scapolite, quartz, calcite, plagioclase, epidote, sphene, and apatite. In some thin sections the scheelite tends to be concentrated in the carbonate or quartz-rich parts of the skarn.

Semiquantitative spectrographic analyses of scheelite and wolframite crystals from the vein and placer deposits are given in Table 41. The analysis of the wolframite sample indicates that the mineral is a true wolframite, lying between the manganese variety huebnerite and the iron variety ferberite.

The presence of small amounts of calcium, magnesium, barium, and rare earths is normal for wolframites. These elements probably substitute for either iron or manganese in the structure. Titanium, as Ti^{4+} (0.68Å), probably substitutes for W^{4+} (0.70Å), and the small amounts of tin as Sn^{4+} (0.71Å) do likewise. The relatively large amount of aluminum is notable. It does not seem to be present in extraneous silicates; possibly the element occupies some of the tungsten sites in the lattice as Al^{3+} (0.51Å).

Scandium is present in most wolframites and may be fairly abundant. According to Goldschmidt and Peters (1931) this is the result of the isomorphism between Fe^{2+} Mn^{2+} WO_4 and $ScNbO_4$ and $ScTaO_4$. Trivalent scandium replaces Fe^{2+} and Mn^{2+} and substitution of WO_4^{2-} by NbO_4^{3-} or TaO_4^{3-} maintains the electroneutrality of the structure. Such electronic stability demands may be responsible for the low content of scandium in the Dublin Gulch samples, because niobium and tantalum may not have been available during crystallization of the wolframite.

In the scheelite samples the small amounts of iron, magnesium, manganese, barium, strontium, and rare earths probably occupy some of the calcium sites in the lattice. Titanium, as Ti^{4+} (0.68Å), and Sn^{4+} (0.71Å) probably substitute for W^{4+} (0.70Å). Again the relatively large amounts of aluminum are notable in the pure crystalline scheelite. Some may be bound in extraneous wisps of silicates, but in clear, nearly pure scheelite Al^{3+} (0.51Å) may occupy some of the tungsten sites in the lattice.

The presence of molybdenum in the scheelite is normal. The radii of Mo^{4+} (0.70Å) and W^{4+} (0.70Å) are identical and scheelite, $CaWO_4$, and powellite, $CaMoO_4$, are isostructural and probably isomorphous.

Tourmaline

This mineral occurs in small amounts in the lead-zinc lodes of Keno and Galena Hills and as a major constituent of the cassiterite zones in the Dublin Gulch area. In the lead-zinc lodes it is present mainly in greenish grey seams in some of the early quartz lenses. In addition needles and microscopic fibrous aggregates are present in some of the siderite particularly in the Sugiyama and Sadie-Friendship veins.

Its occurrence in the cassiterite veins has already been described. Briefly, it is present as fibrous aggregates and needles intimately intergrown with cassiterite, chlorite, and a little quartz. Needles and small crystals are widely distributed in the soils of the Keno Hill-Dublin Gulch area, being particularly concentrated in the vicinity of the tin lodes. Tourmaline-cassiterite nodules are also common in the placers of Dublin Gulch and Haggart Creek.

Supergene Minerals

The principal supergene minerals are limonite, wad, quartz, calcite, cerussite, smithsonite, anglesite, gypsum, beudantite, scorodite, bindheimite, malachite, azurite, native silver, pyrargyrite, and ice. Less abundant are pharmacosiderite, brochantite, aurichalcite, dundasite, jarosite, rozenite, gunningite, senarmontite, minium, various clay minerals, serpentine, sulphur, native zinc, acanthite, covellite, galena, sphalerite, hawleyite, marcasite, and pyrite.

Limonite ($HFeO_2.nH_2O$) and other Hydrous Iron Oxides

The term 'limonite' as used in this report includes all the supergene iron oxides. X-ray investigations indicate that much of the so-called limonite is goethite with small amounts of lepidocrocite and hematite. Furthermore, much of the limonite in the vein faults is intimately mixed with small amounts of other supergene minerals, including cerussite, anglesite, beudantite, plumbojarosite, bindheimite, sulphur, scorodite, quartz, clay minerals, secondary calcite, rozenite, and manganese oxides.

Limonite is the most abundant of the oxides in the oxidized parts of the vein faults and is widespread all through the rocks, fault zones, and fractures near the surface. Its most common associate in the vein faults is wad. In the vein faults it is derived principally from siderite, pyrite, and sphalerite. It is brown to orange-yellow depending upon its derivation, the brown material having been derived largely from siderite and pyrite and the orange-yellow variety from sphalerite.

This mineral occurs in many forms, ranging from ocherous and earthy material coating ore and gangue minerals and rock fragments, to clinker-like, botryoidal, and hard compact masses cementing the vein breccia and nodules of ore minerals. Characteristic cellular boxworks derived from siderite and sphalerite are also common in some veins, and pseudomorphs of limonite after pyrite were observed in some ore shoots. In places the oxidized zones contain a loose, deep brown earthy variety of limonite derived from the oxidation of freibergite, galena, and sphalerite. This material is generally high in silver-bearing beudantite, bindheimite, plumbojarosite, anglesite, and cerussite and in some veins is a good indicator of ore.

The amount of limonite in vein faults is not entirely dependent upon the presence of nearby mineralized zones. The oxidized lodes are, by their very nature, high in limonite, but other sections of the vein faults also contain large amounts of the mineral, suggesting that surface waters have pervaded all parts of the vein faults, depositing limonite in all available open or porous parts near the surface.

Chemical and spectrographic analyses of limonite are given in Table 42, and gold assays in Table 57. Care was taken to select material that was relatively free of other supergene minerals.

The large quantities of manganese, silicon, aluminum, titanium, calcium, and magnesium in the limonite are most probably present in microcrystalline or amorphous wad, quartz, hydrated silica, rutile, and calcite. These cannot be effectively separated from the limonite, and appear to be an integral part of the mineral complex. All were probably coprecipitated with the hydrous iron oxides as a result of various hydrolytic processes.

Relatively large amounts of zinc, cadmium, copper, lead, tin, silver, gold, arsenic, and antimony are present. In the vein limonite the bulk of these elements is probably bound in microcrystalline and amorphous secondary minerals such as anglesite, jarosite, beudantite, scorodite, bindheimite, and cerussite, so intimately mixed with limonite that they appear to be coprecipitates. Some of these elements, however, especially those in the precipitates from springs, appear to be bound within the hydrous iron oxide complex. Some are probably adsorbed, others may be bound in indefinite hydrous oxides and arsenates that were coprecipitated with the hydrous iron oxides. Part of the gold is free and can be panned as dust, small nuggets, and wires from the limonite-scorodite mixtures developed from the early quartz-pyrite-arsenopyrite veins.

Wad (hydrous manganese oxides)

Next to limonite the hydrous manganese oxides are the most abundant supergene minerals in the vein faults and in fractures and faults in the rocks near the surface. X-ray determinations indicate that pyrolusite, psilomelane, and manganite are present in some samples, but generally the manganese oxides are so intimately intergrown that they cannot be separated and determined. The term 'wad' best describes these mixtures and is used in this report. Most of the wad has resulted from the oxidation of manganiferous siderite. Small amounts may also have come from the alteration of sphalerite that contains up to 0.82 per cent Mn.

Wad is characteristic of the surface outcrops of some of the lode deposits, and manganese stain on float is a common indicator of a vein fault not far distant. Residual soils in the vicinity of some vein faults also carry greater than average amounts of manganese, held mainly in small particles of wad and weathered siderite. This observation suggests that manganese may be used as a tracer in locating siderite-galena-sphalerite lodes (*see also* Chapter IV).

Wad occurs in various forms. Incipient oxidation of siderite develops thin films and specks of black manganese oxides along cleavages and throughout the mineral, imparting a black colour to the siderite. With increasing oxidation the siderite is obliterated and only irregular compact and earthy masses of limonite and wad remain. Migration of the manganese results in the development of wad as dendrites, stains, pulverulent masses, earthy films, and crusts on vein minerals and along fractures in the wall-rocks and also as botryoidal forms and banded aggregates rimming and cementing breccia, nodules of ore minerals, gangue, and secondary minerals. In a few places small, well-developed crystals of manganite and pyrolusite are developed on and in a wad matrix.

Chemical and spectrographic analyses of relatively pure wad are given in Table 42.

Practically the same elements are enriched in the wads as in the limonites and for nearly the same reasons. The effect of the negative character of the colloidal manganese sols in concentrating cations such as zinc, cadmium, and lead permits a greater concentration of metals in most wads than in the coexisting limonite.

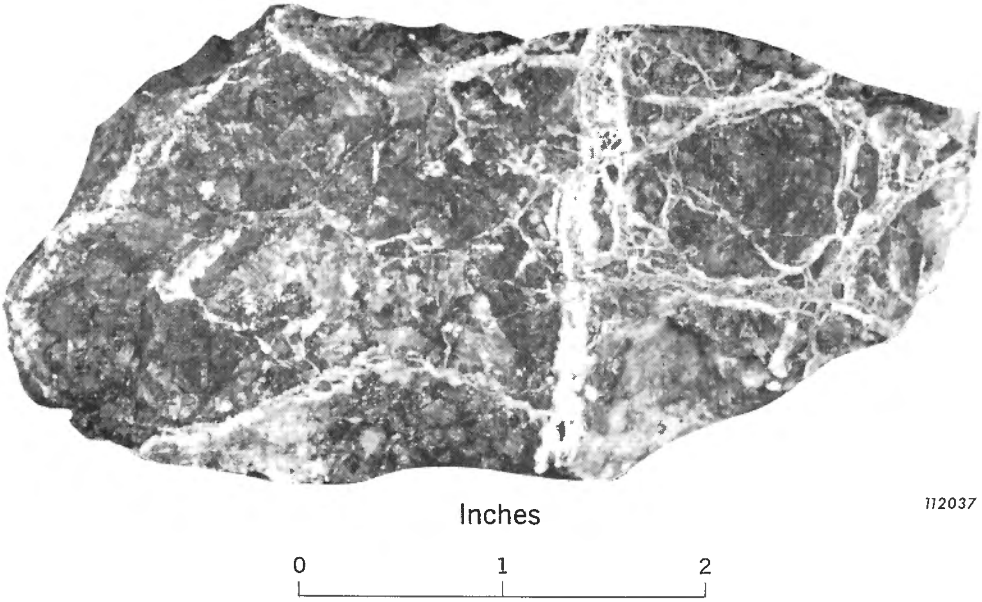

PLATE XXII. Brecciated sphalerite (dark grey) cemented by supergene quartz (white), Bellekeno mine, Sourdough Hill.

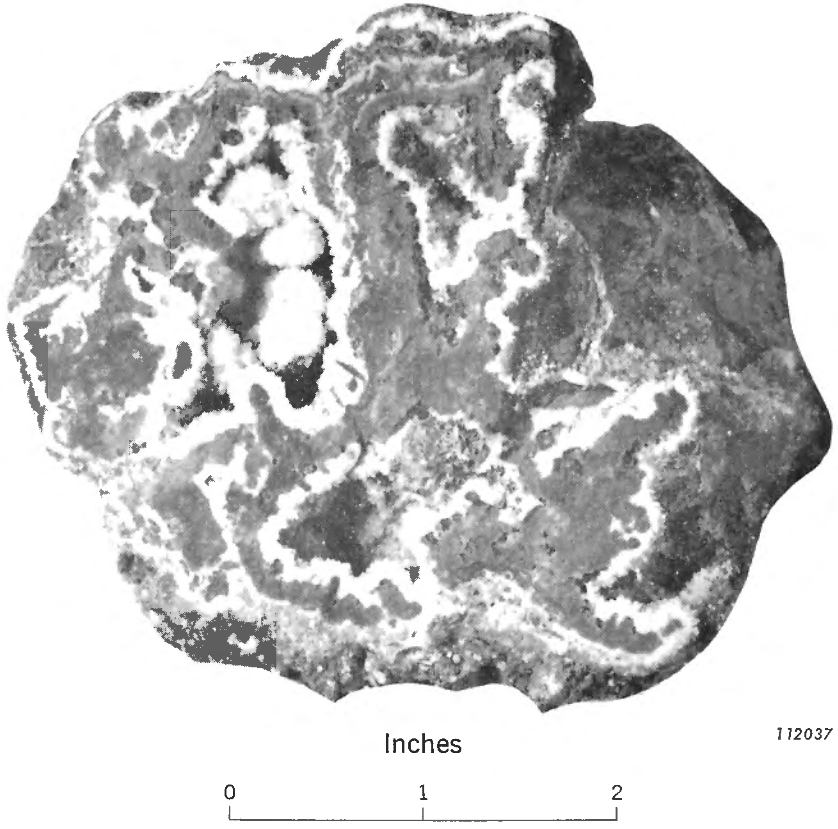

PLATE XXIII. Supergene quartz (white) in vugs and seams in oxidized siderite (dark grey), 203 stope, 48 vein, Bellekeno mine.

Quartz, SiO_2

Supergene quartz is common in some oxidized parts of the vein faults. It generally occurs as small clear prisms arranged in aggregates in the earthy oxidized material of the vein faults or as small prisms lining druses and cavities in oxidized siderite, sphalerite, and other minerals. Limonite boxworks, likewise, commonly contain much finely crystallized quartz.

In the lower parts of the oxidized zones and in the primary zones immediately below, supergene quartz is commonly present as aggregates of small milky and clear prisms. These encrust and fill vugs in both primary and incipiently oxidized minerals and may also occur in fractures and seams in these minerals (Pl. XXII). A characteristic occurrence of supergene quartz is in one of the ore shoots of the Bellekeno system (203 stope, 48 vein) where, at a depth of 300 feet, laminated crusts and aggregates of quartz crystals are developed on layers of limonite, anglesite, gypsum, smithsonite, and calcite, which in turn encrust nodules of slightly oxidized siderite, galena, and sphalerite (Pls. XXIII, XXIV, and XXV).

There can be little doubt that much of the finely crystalline prismatic quartz in the veins is of supergene origin. First, nearly all this type of quartz is associated with a definite group of supergene minerals and in places actually encrusts these minerals. Secondly, meteoric waters migrating downward in the vein faults contain up to 9 ppm silica, and precipitates from these waters contain much silica (Tables 58 and 60).

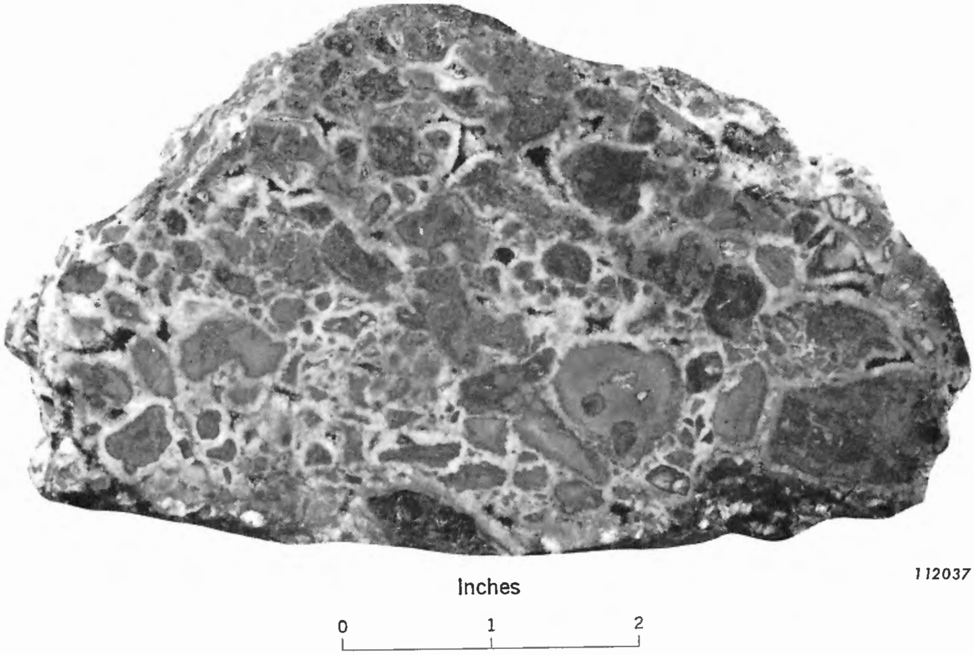

PLATE XXIV. Brecciated galena (light grey) and siderite (dark grey) cemented by supergene quartz (white), 203 stope, 48 vein, Bellekeno mine, Sourdough Hill.

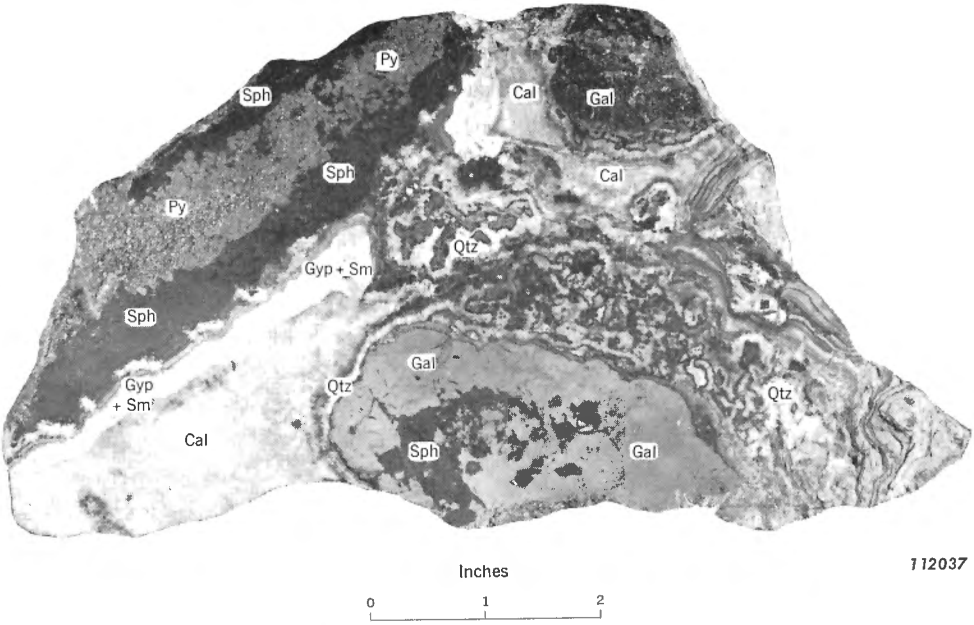

PLATE XXV. Brecciated galena (gal), sphalerite (sph), and pyrite (py) cemented by supergene gypsum and smithsonite (gyp + sm), calcite (cal), and quartz (qtz), 203 stope, 48 vein, Bellekeno mine, Sourdough Hill.

Calcite, $CaCO_3$, Aragonite, $CaCO_3$, Dolomite, $CaMg(CO_3)_2$, and Siderite, $FeCO_3$

Supergene calcite is present in nearly all oxidized parts of the vein faults and appears in places in the zones of reduction. Small amounts of crystalline supergene dolomite and siderite have also been observed with the secondary calcite in some of the ore shoots, and small aragonite crystals in vugs associated with gypsum were noted in the near surface parts of the Comstock vein.

The supergene calcite occurs principally as earthy masses, but fine- and coarse-grained crystal aggregates surrounding breccia fragments and lining fractures and vugs in both primary and oxidized minerals were observed in places. In one of the ore shoots of the Bellekeno system (203 stope, 48 vein), coarse-grained white to grey calcite fills some of the interstices between quartz encrusted fragments of oxidized ore minerals and gangue (Pls. XXV and XXVI). Other spaces are filled by a vuggy fawn-coloured dolomite containing gypsum crystals. In addition, cryptocrystalline calcite, intimately intergrown and interbanded with quartz, smithsonite, gypsum, and limonite, forms characteristic banded coatings and crusts on oxidized nodules and brecciated pieces of siderite, sphalerite, galena, and pyrite in some parts of this ore shoot. Colloform supergene siderite also forms rims and crusts on fragments of oxidized siderite. Similar features have been noted in other vein faults of the area, but they are seldom as well developed.

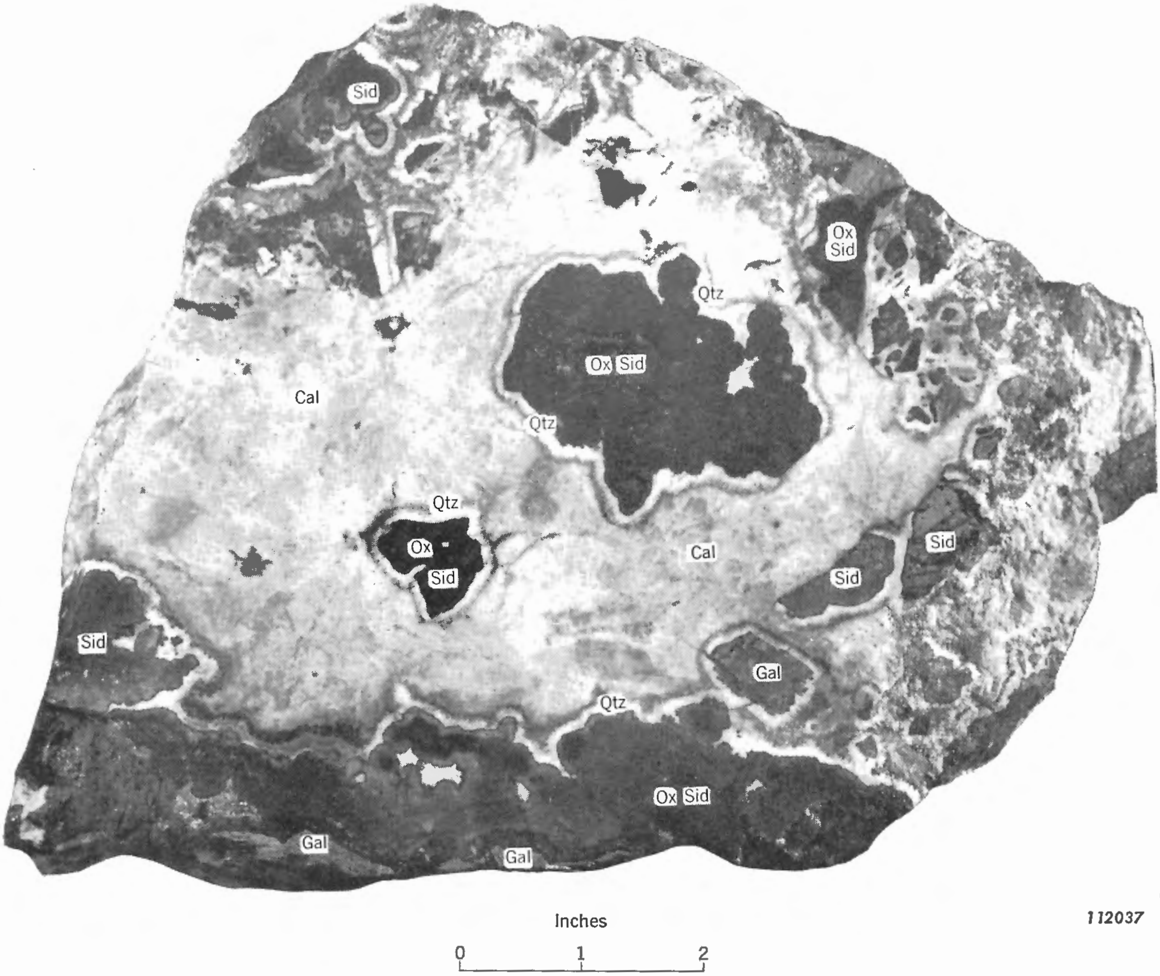

PLATE XXVI. Supergene calcite (cal), quartz (qtz), and siderite (sid) cementing fragments of galena (gal) and oxidized siderite (ox sid), 203 stope, 48 vein, Bellekeno mine, Sourdough Hill.

Complete chemical analyses of two characteristic samples of supergene calcite are given in Table 29 and spectrographic and other trace element analyses of similar carbonates are listed in Table 31.

For a discussion of the trace elements in the late carbonates *see* the section on the hypogene carbonates, page 116.

Cerussite, $PbCO_3$

This mineral is widely diffused in the oxidized parts of the lodes where it is generally intimately associated with limonite, wad, anglesite, bindheimite, and the other supergene minerals. It is generally colourless to white to grey or smoky, and its habit is extremely varied. In some occurrences it is present as earthy coatings, pulverulent disseminations, crusts, and ramifying networks of small microcrystalline masses in the oxidized rubble of the lodes. In other occurrences it forms rosettes, clusters, and irregular aggregates of small well-developed tabular and elongated crystals, particularly in druses in oxidized siderite and galena and in limonitic boxworks. Cyclic twins are common, and a variety of forms are usually present.

Cerussite is characteristically associated with anglesite in most veins and commonly encrusts, seams, or is intimately interbanded with it. In some specimens the detailed relationships make it rather obvious that the cerussite developed directly from the anglesite; in others some migration of the components of cerussite over short distances has taken place.

Of the secondary lead minerals, cerussite appears to be the most stable during weathering because it is plentiful as individual crystals and crystal groups in the heavy concentrates of most of the soils in the vicinity of the lodes. Cerussite and some anglesite are also present on weathered nodules of galena, boulangerite, and jamesonite in the soils and placers of the area.

A spectrographic and chemical analysis of cerussite crystals from a characteristic occurrence in the Hector-Calumet vein system is given in Table 43. The cerussite is relatively pure, containing only small amounts of Al, Fe, Si, Cu, Zn, Ag, Ba, Ca, Mg, and Mn. Of these Fe, Cu, Zn, Ag, Ba, Ca, Mg, and Mn probably occupy some of the lead sites in the lattice.

Malachite, $Cu_2(OH)_2(CO_3)$, and Azurite, $Cu_3(OH)_2(CO_3)_2$

These two basic carbonates of copper are widely distributed in the oxidized parts of the lodes, and are frequently observed in seams and joint planes in greenstones and occasionally in small amounts along the bedding planes of some schists[1]. The two minerals generally occur together and are commonly found near freibergite or chalcopyrite, the primary minerals from which they are mainly derived.

In the lodes the two minerals occur as smears and crusts on freibergite and chalcopyrite and may seam these minerals. Masses and radiating clusters of microcrystals are common in places, and tufts of crystals, small concentrically banded aggregates, and small botryoidal masses in vugs and porous vein material may be seen in some lodes. The common associated supergene minerals are wad, limonite, anglesite, calcite, and cerussite.

Spectrographic analyses of pure malachite are given in Table 44. The mineral tends to incorporate some iron, zinc, lead, antimony, tin, silver, manganese, nickel, titanium, magnesium, barium, silicon, and aluminum. Probably all these substitute for copper, with the exception perhaps of silicon, aluminum, and titanium. Some varieties of malachite have been found to be highly zinciferous. These have a variable cell size indicating substitution of the zinc in the copper sites.

Brochantite, $Cu_4(SO_4)(OH)_6$ and Antlerite, $Cu_3(SO_4)(OH)_4$

These basic sulphates of copper are present in small amounts in several veins. Good specimens were obtained from the Comstock Keno vein on Keno, and from

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[1] Small amounts of malachite were noted in a sericite schist in Thunder Gulch north of the Bellekeno mine.

the Elsa vein on Galena Hill. The usual associated minerals are malachite, azurite, anglesite, cerussite, aurichalcite, limonite, etc. Brochantite and antlerite are derived mainly from freibergite and probably formed in a mildly acid environment.

Smithsonite, $ZnCO_3$

Smithsonite is present in small amounts in most of the oxidized lodes and in some of the zones of reduction.

The mineral is greyish white to brownish and tends to occur as encrustations, earthy and porous masses, and as small botryoidal forms. In the 48 vein of the Bellekeno mine, smithsonite is intergrown and interbanded with fine-grained crystals of gypsum, calcite, limonite, and supergene quartz, the whole forming concentric bands about nodules of gangue and primary ore minerals (Pl. XXV). The most common supergene associates of smithsonite are gypsum, limonite, calcite, and anglesite.

A spectrographic analysis of relatively pure smithsonite is given in Table 43. The principal point of interest is the presence of small amounts of Cd, Sn, Ni, Co, Pb, and Ag. These probably substitute for zinc in the smithsonite lattice because of similar energetic properties such as ionic radii and the isostructural relationships of their carbonates. Thus Sn^{4+}(0.71Å), Ni^{2+}(0.69Å), and Co^{2+}(0.72Å) are close to Zn^{2+} (0.74Å). However, Pb^{2+}(1.24Å), Ag^{+}(1.31Å) and Cd(0.97Å) are somewhat larger than Zn^{2+}(0.74Å) and lie outside of the general prescribed limits of substitution. Their groupings with oxygen are, however, somewhat similar to those of zinc, and because of this a certain degree of substitution in the smithsonite lattice seems possible. Otavite, $CdCO_3$, and cobaltocalcite, $CoCO_3$, are isostructural with smithsonite, as are also calcite, magnesite, siderite, and rhodochrosite. Solid solution series are known amongst most of these carbonates, and this explains the presence of Co, Cd, Ca, Fe, Mn, and Mg in nearly pure samples of smithsonite.

Aurichalcite, $(Zn,Cu)_5\ OH_6(CO_3)_2$

This mineral is rather rare but good specimens of encrusted material were obtained from the Highlander claim on Keno Hill. The common associated minerals are malachite, azurite, brochantite, smithsonite, anglesite, cerussite, and limonite.

Anglesite, $PbSO_4$

Anglesite is the most abundant of the secondary lead minerals and is widely distributed in all oxidized parts of the lodes. It is generally associated with limonite, wad, cerussite, bindheimite, beudantite, smithsonite, malachite, and azurite.

The anglesite is light to dark grey and generally occurs as earthy coatings or concentric cryptocrystalline bands around nodules of galena, boulangerite, and other primary lead minerals.

The oxidation of galena to anglesite was studied in some detail in polished sections that showed all stages of oxidation of galena. In many specimens the process began with a general darkening of the splendent lustre of the galena and was followed by the development of tongues and seams of dark grey anglesite along the cleavage planes and fractures (Pl. XXI). Gradually the anglesite front advanced into the galena along a series of scalloped surfaces until the original mineral was wholly enveloped or until a small irregular core of galena remained. This process yielded concentric bands of light to dark grey pure anglesite in some specimens and alternating banded arrangements of anglesite, cerussite, beudantite, and bindheimite in others in which freibergite was present. In other specimens of galena at various stages of oxidation an irregular pervasive front of anglesite appears to have begun along the cubic cleavage directions of the galena, advanced inward, and finally converted it to a pseudomorphous mass of anglesite after galena in which the cleavage is beautifully preserved.

The oxidation of galena to anglesite is usually attended by some expansion along the cleavage planes and by the migration of the constituents of anglesite into the spaces between these planes. This effect tends to accentuate the original cleavage planes and also provides sites for the development of several of the oxidation products of galena and freibergite, including cerussite, beudantite, and bindheimite.

In some of the ore shoots migration of the components of anglesite appears to have taken place over distances measuring several feet. This is proved by the presence of earthy anglesite along secondary fractures in siderite, limonite, and other minerals and by its presence as banded concretionary masses lining fractures and cavities. In these occurrences the anglesite is mostly associated with supergene quartz and calcite, some of which may encrust the bands.

Anglesite is widely distributed in the soils near the lodes as earthy coatings and rinds on small and large pieces of galena, boulangerite, and jamesonite. The mineral is also present on rolled nodules of the primary lead minerals in the placers of the area.

Spectrographic and chemical analyses of hand picked anglesite coatings and concretionary bands are given in Table 45 and gold assays in Table 57.

The relatively large amounts of iron, calcium, aluminum, silicon, antimony, and arsenic in the samples attest to the impurity of nearly all anglesites, regardless of the care taken to separate pure material. The impurities most often seen in polished and thin sections are quartz, clay minerals, cerussite, calcite, and limonite. These undoubtedly account for much of the Fe, Mn, Ca, Mg, Ba, Sr, Al, and Si in the analyses.

Further difficulties due to impurities present themselves when the attempt is made to allocate elements such as zinc, cadmium, copper, silver, gold, tin, bismuth, arsenic, and antimony. Most anglesite samples contain small residuals of primary galena and, in places, pulverulent supergene galena. In addition to these there is always more or less jarosite, bindheimite, beudantite, malachite, and azurite, all of which contain the above metallic elements.

The purest specimens of anglesite all contain appreciable quantities of silver, cadmium, tin, and bismuth. These probably substitute in the anglesite lattice because of similar energetic properties such as their radii. Thus Ag^+ (1.31Å), Cd^{2+} (1.01Å), and Bi^{3+} (1.00Å) are close to Pb^{2+} (1.24Å). Of all the trace elements in anglesite, cadmium, bismuth, and perhaps tin show a marked enrichment compared with the galena from which the anglesite was derived.

Gypsum, $CaSO_4.2H_2O$

Gypsum is one of the commonest of the sulphate minerals in the oxidized lodes and in the zones of reduction. It is also occasionally seen in some of the soils near the veins.

In most occurrences the gypsum is colourless to white, occurring as aggregates of small crystals, as microcrystalline masses, fibrous seams, and as earthy coatings. The common associated supergene minerals are calcite, smithsonite, limonite, anglesite, and cerussite. The gypsum is either intimately mixed or intergrown with these minerals, or it may encrust one or all of them. In the zones of reduction the gypsum occurs in seams and vugs in primary pyrite, siderite, and sphalerite. In one of the shoots of the 48 vein of the Bellekeno system a beautiful display of gypsum in its many forms was present. There the gypsum occurred mainly as small irregular crystals intergrown with and also interbanded with calcite, smithsonite, limonite, and supergene quartz. In addition, selenite crystals and crystal aggregates were present in vugs and as overgrowths on calcite (Pl. XXVII). The crystals were transparent, long prismatic in habit, commonly bent or twisted, and were up to 3 inches long.

Chemical and spectrographic analyses of selenite crystals are given in Table 46. All are relatively pure with only traces of iron, magnesium, manganese, barium, strontium, zinc, and lead. These probably occupy some of the calcium sites in the gypsum lattice.

Beudantite, $PbFe_3(AsO_4)(SO_4)(OH)_6$

This mineral is widely distributed in the oxidized parts of the lodes, where it has developed from freibergite and galena, the lead sulphosalts, and less commonly from aggregates of arsenopyrite and galena. Its common supergene mineral associates are anglesite, cerussite, limonite, wad, bindheimite, scorodite, and pharmacosiderite.

The beudantite is greenish to yellowish brown and generally occurs as crusts, coatings of drusy crystals, and small cryptocrystalline aggregates on galena, freibergite, and the lead sulphosalts. It also occurs in cavities in these minerals and in oxidized siderite, limonite, and wad, and commonly with anglesite, cerussite, and bindheimite as banded seams ramifying through freibergite, galena, and the lead sulphosalts.

The mineral occurs in some of the soils near the lodes, but only in small amounts and generally with residual oxidized nodules of galena and freibergite. In the Dublin Gulch placers it is common as an alteration product on the nodules of jamesonite and boulangerite.

Spectrographic analyses of selected crusts of beudantite are given in Table 43.

Beudantite is one of a group of basic salts that tend to incorporate a large number of available cations and anions in their structure. Among this group phosphate and aluminum members are known as well as those containing strontium (hinsdalite and svanbergite) and calcium (woodhouseite). The beudantite group is isostructural with the plumbogummite group which includes various hydrated basic phosphates and arsenates of lead, barium, strontium, calcium, cerium, iron, and aluminum, and also with the alunite group which comprises various basic sulphates of the alkalies, ammonium, iron, silver, lead, and copper. The jarosites, including argentojarosite and plumbojarosite, are members of the last-named group.

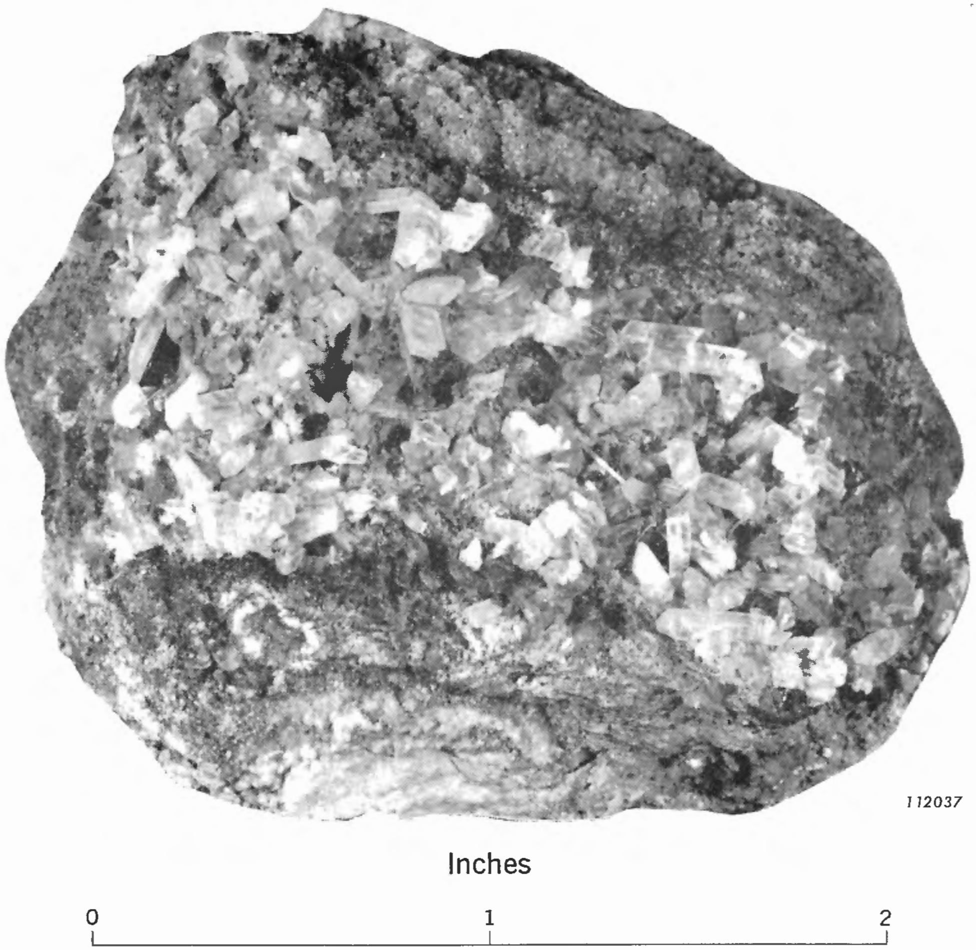


PLATE XXVII. Gypsum crystals (light grey) in vug in supergene siderite (dark grey), 203 stope, 48 vein, Bellekeno mine, Sourdough Hill.

The cationic positions in all these groups are very tolerant with respect to ionic size and permit considerable substitution of Zn, Cu, Ag, Cd, Mn, Ba, Ca, Mg, Sn, Ni, and other cations, as shown by the analysis of the pure beudantite sample. Al, Ti, B, and even Si seem to be accommodated in the beudantite structure, and there is probably also considerable substitution of Sb for As. Beudantite can be considered as one of the 'chemical sinks' among the secondary minerals.

Bindheimite, $Pb_2Sb_2O_6(O,OH)$

Bindheimite is widespread in the oxidized parts of the lodes. It is generally closely associated with freibergite, jamesonite, and boulangerite from which it derives its antimony content. Of the supergene minerals, anglesite and cerussite are its closest associates.

Most of the bindheimite is yellow, greenish yellow, or brownish. It is present as small cryptocrystalline masses in druses in galena, oxidized siderite, and limonite, as encrustations and earthy coatings on the primary sulphosalts, and as banded seams along cleavage planes in galena and ramifying through freibergite and the other sulphosalts. In the last habit it is commonly interbanded or otherwise intimately intergrown with anglesite. Pseudomorphs of bindheimite after freibergite were observed in the Bellekeno and other lodes.

Bindheimite is apparently unstable in the soils as it was not observed in the heavy concentrates therefrom, nor has it been found coating nodules of sulphosalts in the placers.

Spectrographic and chemical analyses of characteristic bindheimite samples are given in Table 43, and a gold assay of one of the purer samples is presented in Table 57.

Most of the bindheimite samples are impure, containing much limonite, cerussite, anglesite, secondary silicates, and quartz. The purer specimens, however, tend to accommodate a large number of elements in their structure, particularly Zn, Cu, Ag, Au, Cd, Ba, Ca, As, Bi, and Sn. Of these Cd and Sn and perhaps Bi appear to be in greatly enriched amounts.

Pyromorphite and Mimetite, $Pb_5(PO_4,AsO_4)_3Cl$

These two minerals, in which there is a mutual replacement of P and As, were found in the oxidized zones of the Shamrock, No. 9, and Hector-Calumet systems. The minerals are rare in other veins.

The pyromorphite and mimetite are green to greyish green to yellowish brown. They occur principally as clinker-like masses of globular and botryoidal form surrounding galena nodules coated with anglesite and cerussite and in wad and limonite. They also occur in cavities near galena and rarely in small seams and fractures. In a few places acicular crystals and small euhedral hexagonal prisms with cavernous basal terminations were observed.

Mimetite was determined in the heavy concentrates from the Dublin Gulch placers, but only in small amounts.

A spectrographic analysis of crystalline pyromorphite is given in Table 43. The principal points of interest are the presence of Cr, Mo, V, Ti, and the rare earths Y and Yb. The Cr, Mo, V, and Ti probably substitute in the AsO_4 and PO_4 sites as CrO_4, MoO_4, VO_4 and TiO_4. There may also be substitution of SiO_4 for AsO_4 and PO_4, although this is difficult to confirm as the samples contain some secondary quartz. The rare earths, iron, silver, and magnesium probably occupy some of the lead sites in the lattice.

Dundasite, $Pb\,Al_2(CO_3)_2(OH)_4.2H_2O$

This hydrated basic carbonate is present in small amounts as white to faintly yellowish felted crusts and small radiating crystal aggregates in several deposits on Keno and Galena Hills. Good specimens were also found in the Bellekeno veins on Sourdough Hill. Characteristically the mineral is associated with cerussite, kaolinite, and serpentine, and generally occurs on highly oxidized siderite or in vuggy parts of this carbonate. Being a basic salt, its precipitation probably took place during the neutralization of acidic lead- and aluminum-bearing solutions by siderite and other carbonates.

Minium, Pb_3O_4, and Massicot, PbO

Minium was reported by Visel as fairly abundant in the oxidation products of the No. 9 vein system. Unfortunately the writer could not obtain samples of this mineral because all the workings in the system were inaccessible.

Some specimens of cerussite are coated and pervaded by a yellowish powder, which is generally amorphous to X-rays. This powder may be massicot, although the identification is uncertain.

Scorodite, $(Fe,Al)(AsO_4).2H_2O$

Scorodite is common in some of the oxidized parts of the lodes, particularly in those carrying an abundance of arsenopyrite.

The mineral is yellowish green to greyish green to greenish brown, and occurs as crusts, sinter-like masses, irregular microcrystalline groups, and earthy masses in the rubble and gossans of the lodes. It is generally associated with primary arsenopyrite and pyrite and with supergene pharmacosiderite, beudantite, limonite, gypsum, quartz, and wad.

Scorodite is particularly abundant in the deeply oxidized quartz-pyrite-arsenopyrite gold veins of the Dublin Gulch area. There the mineral occurs with limonite, sulphur, etc., as streaks and earthy bunches in highly stained quartz, containing residual altered arsenopyrite, pyrite, and frequently jamesonite and boulangerite. Free gold as fine dust, minute flakes, and occasionally as wires can be panned from the scoroditic vein material.

Scorodite occurs in some of the soils and weathered residuum in the Dublin Gulch and Keno Hill areas, mainly in the vicinity of the deeply weathered early pyrite-arsenopyrite-quartz lodes. Where scorodite is fairly abundant the weathered debris has a slight greenish tinge.

A spectrographic and chemical analysis of pure scorodite is given in Table 43, and gold assays of the mineral are presented in Table 57. Small amounts of lead, silver, manganese, and calcium are probably accommodated in the lattice, where they probably substitute for iron. There is only a minor replacement of arsenic by antimony. Transported scorodite contains no gold, whereas the residual variety may contain up to 10 ppm, where it is probably all present in the free state.

Pharmacosiderite, $Fe_3(AsO_4)_2(OH)_3.5H_2O$

This hydrated basic ferric arsenate is widely diffused in small amounts in the oxidized parts of the veins containing arsenopyrite from which it is derived.

The mineral is yellowish green to yellowish brown. It occurs principally as microcrystalline aggregates and earthy coatings on arsenopyrite and also as crusts and seams in the primary quartz-pyrite-arsenopyrite aggregate. The most common supergene mineral associates are scorodite, beudantite, gypsum, and limonite.

Senarmontite, Sb_2O_3

In some of the near surface oxidized zones, greyish white to colourless senarmontite heavily stained with earthy yellowish native sulphur occurs as earthy coatings and crusts on jamesonite intergrown with massive pyrite.

A spectrographic analysis of senarmontite and admixed sulphur is given in Table 43. Of interest is the relatively large content of bismuth, cadmium, and tin in the mineral.

Jarosites

Lead- and silver-bearing jarosites occur in small amounts in some of the oxidized zones as small crusts and earthy coatings on oxidized galena and as small pulverulent masses composed of microscopic hexagonal plates in the oxidized rubble of the lodes. The colour of the jarosites ranges from light yellow to orange to golden brown. They are invariably associated with limonite, anglesite, and cerussite.

Jambor (1957) investigated the nature of the jarosites in one of the oxidized zones of the Hector-Calumet system (Calumet mine), and concluded from X-ray and other analyses that the jarositic material is essentially plumbojarosite, $PbFe_6(SO_4)_4(OH)_{12}$. A partial chemical analysis of the material showed the following:

Constituent	*Per Cent*
PbO	20.74
Fe_2O_3	39.03
Ag	0.63

A spectrographic analysis of the type jarositic material is given in Table 47.

Rozenite, $FeSO_4.4H_2O$

Rozenite, the tetrahydrate of ferrous sulphate, recently described and named by Kubisz (1960), has been identified in several of the oxidized zones at Keno Hill.

The mineral is colourless to white and generally occurs as microcrystalline coatings on pyrite or as small earthy coatings in the rubble of the oxidized lodes. Several fine specimens consisting of earthy and microcrystalline masses were found seaming a pyritized quartz breccia in the Comstock vein.

Rozenite is formed principally by the weathering of pyrite. In some places the heptahydrate, melanterite, probably formed first and this dehydrated to yield rozenite. Elsewhere rozenite probably precipitated directly from ferrous sulphate solutions containing some sulphuric acid.

A spectrographic analysis of pure rozenite is given in Table 43. It is evident that the mineral is reasonably tolerant of cationic and anionic substitution. There is considerable substitution of Zn, Mn, Ca, Mg as well as minor substitution of Pb, Cu, Ni, and Co for Fe. Limited amounts of As and Sb also appear to replace S in the mineral lattice.

Gunningite, $ZnSO_4.H_2O$

Gunningite is a new mineral recently described by Jambor and Boyle (1962). It is monoclinic and isostructural with the members of the kieserite group. Synthetic gunningite has cell dimensions of $a_0=7.566$, $b_0=7.586$, $c_0=6.954$Å, $\beta=115°56'$; space group $C_{2h}^{6}-A2/a$. The unit cell contains four formula weights. The specific gravity is 3.195 (pycnometer); 3.321 (calculated). Refractive indices are $\alpha'=1.570$, $\gamma'=1.630$. The natural material is very fine grained, white, and has a hardness of about $2\frac{1}{2}$.

The gunningite is generally closely associated with incipiently oxidized sphalerite and has been found in several oxidized lodes and on old mine dumps. The mineral is present in the relatively dry parts of the deposits, and appears on the oxidizing sphalerite of the dumps after long periods of hot dry weather. In all occurrences it appears as delicate efflorescences directly on the surface of sphalerite, or as efflorescences on limonite, scorodite, gypsum, and other supergene minerals closely associated with the zinc sulphide.

A spectrographic analysis of pure gunningite is given in Table 48. It is apparent that some Cd, Fe, and Mn substitute for Zn in the lattice of the mineral.

Gunningite is derived directly from the oxidation of sphalerite. Surface and underground waters carrying dissolved oxygen attack the sphalerite, yielding soluble sulphates of zinc, manganese, iron, and cadmium. In the presence of abundant water all the soluble salts are removed. If, however, the conditions are such that the supply of water is restricted or evaporation takes place, the metal-bearing solutions become supersaturated with the consequent precipitation of several hydrates of zinc, manganese, and iron of which gunningite is one.

Other Sulphates

Small amounts of other sulphates were identified in the oxidized zones of various lodes and from old mine dumps. Chief among these are szomolnokite, $FeSO_4.H_2O$, szmikite, $MnSO_4.H_2O$, and ilesite (Mn, Fe, Zn) $SO_4.4H_2O$.

Szomolnokite and szmikite are present mainly in the oxidized lodes of the Hector-Calumet mine.

Several grams of white and flesh-coloured efflorescences collected from the dumps of the Silver King mine proved to be szmikite free of iron and unusually rich in zinc. Ilesite was also found in this sample.

Clay Minerals and Serpentine

The supergene clay minerals identified in the oxidized zones and in the primary zones immediately below include montmorillonite and kaolinite. These appear to be rather locally distributed and are nowhere abundant. In most places they occur in small seams and vugs in both the supergene and primary minerals. Elsewhere they form small earthy masses in vugs in limonite, oxidized siderite, and sphalerite.

Serpentine has been identified by X-ray in a number of places mainly in the primary zones just below the lower limits of oxidation. Only microscopic amounts occur in any one place, and these are generally along late slips and fractures. The serpentine is generally associated with supergene calcite, dolomite, gypsum, and quartz.

Sulphur, S

Sulphur has been observed in the oxidized zones of most vein faults. It occurs as thin crusts and powdery coatings on sphalerite, pyrite, and other sulphides and as microcrystals in seams and vugs in the rubble of the oxidized zones. Commonly it is associated with limonite, gypsum, anglesite, and cerussite.

Native Silver, Ag

Native silver occurs in three forms in the lodes: as splendent foil (leaf silver); as arborescent, filiform, and wire silver, commonly in tangled masses resembling ordinary steel wool; and as small scales, spangles, distorted crystals, and microscopic spongy masses. The first type is rare; the other two are present in small amounts in many lodes.

The splendent leaf silver is the most spectacular, especially as it occurs mainly in clear ice lenses in the oxidized zones. In these sites it appears to have grown by the coalescence of numerous separate flattened arborescent forms and may be perched on limonite, wad, and rock fragments in the ice or ramify through clear ice in an intricate manner. One particularly good specimen from the Elsa mine is shown in Plate XXIX.

In the ice lenses the common associates of the leaf silver are pulverulent and botryoidal limonite, sooty manganese oxides, wad, beudantite, earthy calcite, and a few greyish white plates of native zinc. Oxidized nodules and masses of freibergite and galena, in places fairly plentiful, are generally present near the ice lenses containing the native silver.

The leaf silver shows no evidence of tarnish, indicating a virtual absence of hydrogen sulphide or sulphide ion either during or after its deposition. It is also of high purity, containing only copper, iron, and manganese in amounts less than 10 ppm.

Arborescent masses, filaments, and tangled wires of native silver occur in small amounts, mainly in the zones of oxidation and reduction and to a limited extent in the primary zones. In the oxidized zones most of this type of silver occurs in small voids attached to oxidation products, but some is present in small cavities in oxidized galena and siderite nodules or in cellular boxworks near freibergite residuals. In a few ice lenses wire silver was observed on oxidized minerals lining the cavities containing the ice. In all these varied occurrences oxidized siderite nodules and cerussite appear to be the closest mineral associates of the native silver.

In the primary zones and zones of reduction, wires and filaments of native silver occur in small fractures, perched on secondary quartz crystals, and in cavities, mainly in siderite but also in galena and in places in sphalerite and freibergite. In these occurrences the silver is generally, though not everywhere, associated with pyrargyrite, acanthite, and small amounts of secondary galena and sphalerite.

Most specimens of arborescent, filiform, and wire silver are bright and show little evidence of tarnish. The silver is also of high purity, containing only traces of the metals noted in the leaf variety.

Native silver, in small scales, spangles, distorted crystals, and microscopic spongy masses, is found in minor quantities in the three zones of several lodes. Its mineral associates and the details of its occurrence are similar to those described for the other types of native silver.

In most lodes native silver occurs in minor amounts and its presence does not affect the average grade of the ore. In some lodes it is so rare that it is a mineral curiosity. In the No. 9 and Lucky Queen, however, it was present in quantities sufficient to enrich parts of the oxidized zones and zones of reduction.

Native Zinc, Zn

Very small amounts of native zinc occur in some of the highly oxidized lodes, particularly in the Elsa mine (Boyle, 1961a).

It occurs mainly as small irregular greyish metallic plates and scales on oxidized siderite and in pulverulent limonite and manganese oxides. In one occurrence a few native zinc scales accompanied native silver in an ice vein in one of the Elsa lodes. Some of the plates exhibit striations, commonly in more than one direction, resembling cross-hatching. This feature, according to some authors, represents incipient crystal formation. Other plates have a lumpy or microbotryoidal development on their surface.

The closest mineral associate of the native zinc is native silver; other closely associated minerals are limonite, various manganese oxides, and highly oxidized sphalerite, freibergite, and galena.

Spectrographic analyses of the native zinc show it to contain a few per cent each of tin, lead, and cadmium, and traces of iron, manganese, boron, silicon, copper, silver, calcium, and barium.

Pyrargyrite (Ruby Silver), Ag_3SbS_3

Pyrargyrite is widely diffused in small amounts in most lodes, and in a few of the zones of reduction it can be considered an economic mineral. According to the early reports of Wernecke and Cockfield the mineral was abundant on and below the 200-foot level of the Lucky Queen mine, in the near surface stopes of the Silver King, and in some of the less oxidized veins of the Elsa. Isolated bunches of pyrargyrite in siderite were also observed in parts of the Ladue, Sadie, and Hector-Calumet mines.

The best field occurrences could not be examined in detail because the workings of the mines where the mineral was abundant are largely worked out and inaccessible. The specimens in the writer's possession, some from Mr. Wernecke's original collection, however, show that much of the pyrargyrite occurs along small fractures that cut across primary minerals such as siderite. Some also occurs along late cracks and small fissures in the quartzite walls of the lodes. In a few specimens taken from depths well below the zones of reduction, massive pyrargyrite is present in siderite and is associated with galena and sphalerite. This pyrargyrite may be of primary origin.

In numerous places the pyrargyrite is found as a crust on shattered freibergite or in seams intersecting this sulphosalt. Elsewhere, particularly in the Silver King mine, it is associated with fine-grained supergene quartz, being deposited on the quartz crystal faces that line the cavities and small fissures in the lode. The associated minerals in most of these occurrences are acanthite, native silver, dolomite, calcite, and rarely fine-grained supergene galena and sphalerite.

In polished sections much of the pyrargyrite appears as a late mineral intersecting primary siderite, sphalerite, and freibergite. Some pyrargyrite penetrates along the cleavage planes of galena, and the mineral is commonly found along the boundary between galena and its oxidized product, anglesite. Most of the pyrargyrite is very fine grained, the grains ranging from 5 to 100 microns, but in some samples from the Silver King and Lucky Queen mines it is relatively coarse grained and crystalline, the crystals being as much as one quarter of an inch long.

In many of the lodes, some of the pyrargyrite occurs as specks, blebs, and rods oriented mainly along the 111 parting planes of galena, and gives the appearance of being a primary exsolution phenomenon. Its occurrence, however, principally in galena that has been more or less oxidized, suggests, although it does not prove, that the pyrargyrite is secondary.

Wernecke speculated that most of pyrargyrite is of supergene origin. Certainly most of the available facts, such as its late occurrence in very late fractures cutting primary minerals and its concentration in the zone of reduction, strongly support his contention. Only the origin of some pyrargyrite in massive siderite and that in exsolution blebs in galena remains in doubt; some of this may be hypogene.

Spectrographic analyses of a pure sample of pyrargyrite are given in Table 49.

The mineral appears to tolerate relatively large amounts of lead, zinc, copper, cadmium, iron, and manganese in its lattice. These elements probably occupy some of the silver sites. The As present substitutes for Sb.

Acanthite, Ag_2S

Acanthite accompanies pyrargyrite and native silver in many of their occurrences. The mineral is not abundant and cannot be considered as an economic silver mineral in the deposits.

Small fibrous crystalline masses, film-like coatings, and groups of whiskers are most common. These tend to occur in small cavities in siderite, galena, and sphalerite and have also been observed in crevices in quartzite. The acanthite is commonly associated with primary freibergite.

Covellite, CuS, and Chalcocite, Cu_2S

These two secondary copper sulphides are rarely observed in the veins. In some places, however, both may occur as an alteration product of chalcopyrite.

Galena, PbS, and Sphalerite, ZnS

Both these minerals have been observed in the zones of oxidation and reduction in several vein faults. The amounts are small and of no economic consequence.

Supergene galena occurs in a microcrystalline state associated with anglesite and smithsonite in the 48 vein of the Bellekeno mine, and with anglesite in the Nabob vein. In other veins on Keno and Galena Hills it has been observed in late fractures and slips and in vuggy parts of the lodes, generally in the zone of reduction but also in places in the oxidized zone. Most of this galena is pulverulent, but some is well crystallized in small cubo-octohedrons that grow on supergene calcite or crusts of quartz. In some places a small amount of supergene pyrite may accompany the supergene galena.

Supergene sphalerite seems to be more widespread than supergene galena. It generally occurs in the zone of reduction, but small amounts have been observed in the oxidized zones of some vein faults. The sphalerite occurs in cavities and along late fractures as small amber or ruby coloured crystals. Associated minerals include calcite, supergene quartz, and dolomite.

Hawleyite, βCdS

This is a new mineral that crystallizes in the isometric system (Traill and Boyle, 1955). It has a sphalerite-type structure with space group $F\bar{4}3\,m$. The lattice constant, $a = 5.818 \pm 0.005$Å, and the calculated specific gravity is 4.87. Hawleyite is bright yellow and is chemically identical with greenockite, the α modification of CdS.

Hawleyite is rare and has been observed in only a few veins, but good specimens were obtained from the Hector-Calumet and Onek mines. It forms earthy coatings on sphalerite, pyrite, and siderite, generally in the zones of reduction or in the lowermost parts of the zones of oxidation.

Marcasite, FeS_2, and Pyrite, FeS_2

Small amounts of marcasite occur in the country rocks and lodes. The mineral has been detected by X-ray in the sulphides obtained from the surface outcrops of some porphyry bodies, and it occasionally occurs near the surface in other rocks. In some lodes a little marcasite may be associated with pyrite in the oxidized zones and in the zones of reduction. Good specimens of radiating marcasite were obtained from some of the pyrite-jamesonite veins in the Dublin Gulch area and from the Silver King mine.

Supergene pyrite is not abundant in any of the lodes. Small globular and granular masses were observed in a few of the zones of reduction and in the lower parts of some oxidized zones. In these sites the mineral occurs mainly in vugs and along late fractures and seams and is associated with supergene galena, sphalerite, marcasite, calcite, and quartz. In the zones of reduction of the Silver King veins a generation of pyrite, probably of supergene origin, is widely distributed along late fractures, in vugs, and in small solution cavities. This pyrite is well crystallized with small interpenetrating cubic crystals predominating; also common are radiating arrangements of crystals that line late fractures and surround nodules of quartzite, early quartz, and the ore and gangue minerals. A late generation of marcasite and drusy quartz generally accompanies the pyrite; in some occurrences the pyrite is intergrown with the quartz, in others it encrusts euhedral quartz crystals. The marcasite generally encrusts the pyrite, forming characteristic botryoidal masses.

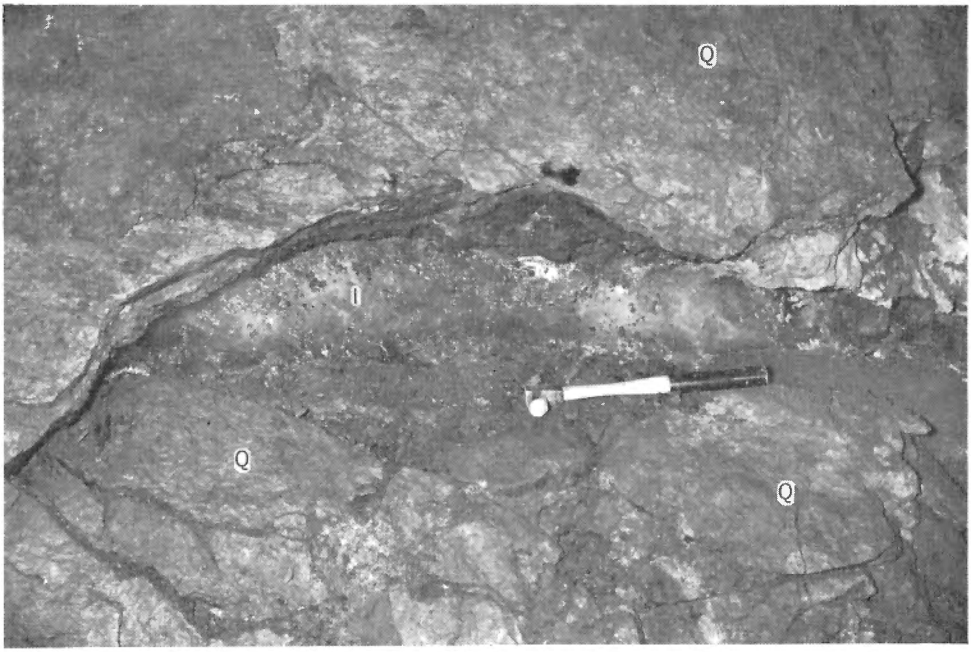
Spectrographic and chemical analyses of marcasite from the Silver King lode and the Dublin Gulch area are given in Table 49.

The principal point of interest is the relatively low content of minor elements in the marcasite as compared with pyrite. It has been suggested (p. 123) that this feature is the result of different formation temperatures for the two minerals.

Ice, H_2O

In the permafrost zone ice occurs as long narrow veins, stringers, bunches, and small irregular pods in the vein faults, late faults, and fractures, and in delicate skeletal and stellate forms as hoar frost on the walls of the mine openings. Most of the veins and pods are concentrated in the porous oxidized parts of the lodes where they fill solution cavities (Pl. XXVIII) or form small stockworks cementing slabs and brecciated pieces of quartzite, greenstone, and lode material.

Two varieties of ice occur in the veins and pods—a clear and a milky variety (Pl. XXIX). Under the microscope the clear ice exhibits numerous rod-shaped and round gas bubbles, some randomly distributed, others in short trains along a reticulating network of planes. Most of the bubbles are less than a tenth of a millimetre in diameter and contain essentially nitrogen with small amounts of carbon dioxide. The milky variety of ice is composed of intergrown loosely connected dendritic ice crystals



RWB, 5-2-53

PLATE XXVIII. Ice lens in solution cavity in oxidized zone, Bellekeno mine, Sourdough Hill. Q—quartzite; I—ice containing limonite, wad, and rock fragments.

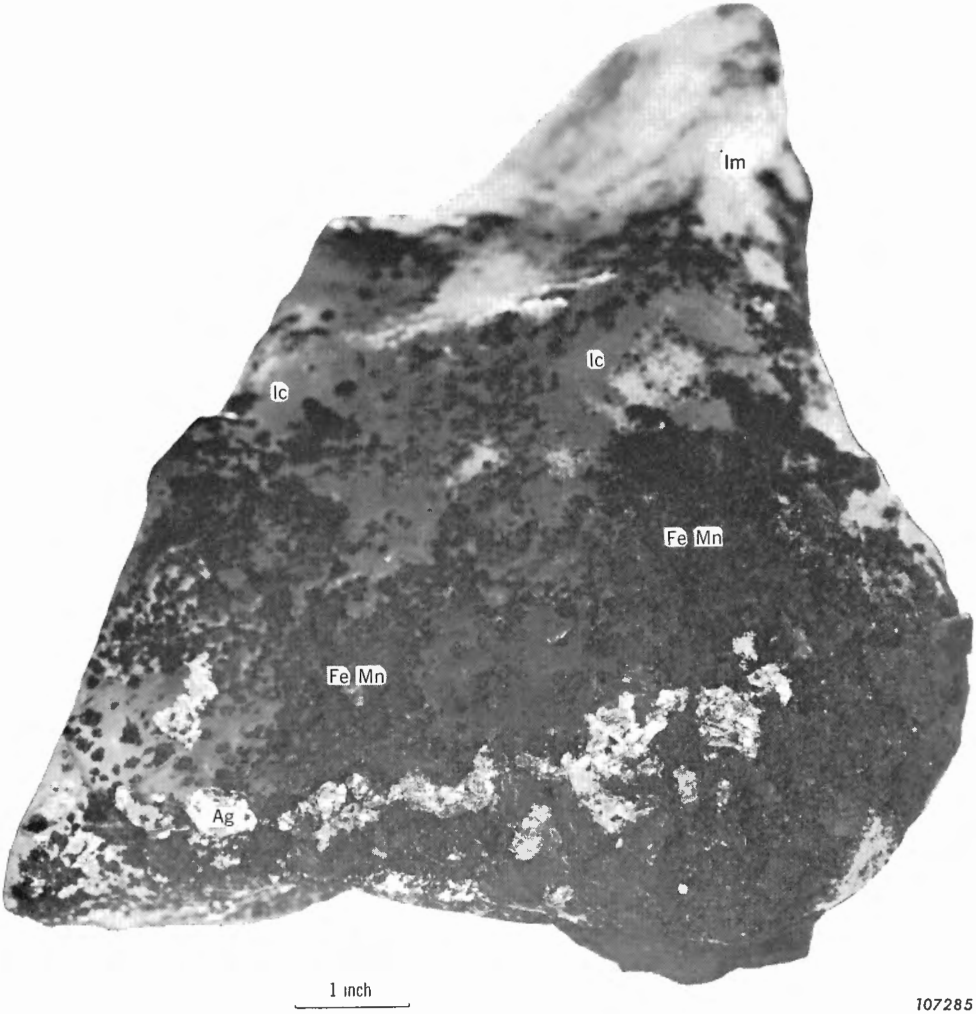


PLATE XXIX. Ice containing native silver, Elsa mine, Galena Hill. Ag—leaf silver; Fe, Mn—limonite and wad; Im—milky ice composed of loosely connected dendritic ice crystals; Ic—clear ice.

and resembles masses of compact snow. Most lenses and stringers are composed of clear ice, a few contain only the milky, and some have both varieties.

In the oxidized parts of the lodes the common mineral constituents in the ice are pulverulent and botryoidal limonite and black manganese oxides, earthy calcite, gypsum, anglesite, and numerous other oxidation products. Wire and leaf silver and small plates of native zinc are present locally. The limonite and other oxidation products coat the walls of the fractures or cavities confining the ice and also occur within the ice as coatings on suspended rock fragments, as small irregular nodules, as a fine dust, and in discontinuous seams and films.

Details of the origin of the water from which the ice veins and pods crystallized are far from simple. Wernecke (1932) suggested that the water probably came from below because, at the time of formation of the ice veins, i.e., during the Glacial

Period, the surface was frozen, thus sealing the veins and preventing the downward movement of any surface water. He suggested that the water was meteoric water migrating along fault and fracture zones, and that it rose into the permafrost zone where it congealed into ice. This mechanism is probably valid for some ice veins.

On the other hand, evidence suggests that some ice veins were formed from water vapour, diffusing through the porous zones. Visible today are veins that are obviously forming in this manner. The first stages in their development are represented by loosely connected clusters of ice crystals, which in turn grow together, thus forming a coherent milky variety of ice that by gradual expulsion of the trapped gas bubbles yields a mass of crystal clear ice. The water vapour to form such ice veins may have come from below the permafrost zone, from the general surrounding permafrost, or from the surface. In most occurrences the surface seems the most likely source.

Eluvial and Placer Minerals

The following minerals were identified in the eluvial and placer deposits of the Keno Hill-Dublin Gulch area:

Native metals
- Gold
- Bismuth

Sulphides
- Pyrite
- Arsenopyrite
- Galena

Sulphosalts
- Boulangerite
- Jamesonite

Oxides
- Cassiterite
- Rutile
- Magnetite
- Hematite
- Limonite
- Chromite
- Ilmenite

Tungstates
- Scheelite
- Wolframite

Carbonates
- Cerussite

Sulphates and arsenates
- Anglesite
- Beudantite
- Mimetite

Phosphates
- Monazite

Silicates
- Quartz
- Feldspar
- Amphibole
- Pyroxene
- Epidote
- Garnet
- Zircon
- Tourmaline
- Allanite

Of these minerals only gold, scheelite, and wolframite are present in economic amounts. The primary source of minerals such as cassiterite, scheelite, and tourmaline is discussed on preceding pages. The occurrences of gold and native bismuth are described below.

Gold, Au

Assays of primary lode material show that most of the gold is present in the early quartz-pyrite-arsenopyrite veins, and, more specifically, largely within arsenopyrite and pyrite (Table 57). Only small amounts occur in the later siderite-galena-sphalerite lodes. In these the bulk of the element is mainly in freibergite with small amounts in galena, sphalerite, and pyrite. Native gold is rarely seen in any of the sulphides, suggesting that the element is a lattice constituent of these minerals. This feature is discussed further on page 179.

Native gold can be panned from the residual soils of the area, particularly from those near the quartz-pyrite-arsenopyrite lodes. This gold occurs as small flattened grains, scales, small rounded nuggets, and fine dust. In the Dublin Gulch area the weathered rubble of the quartz-arsenopyrite veins always yields native gold to the pan. This gold is mostly in the form of a fine dust or as minute wires and flakes and is concentrated in the greenish streaks, bunches, and irregular masses of green scorodite and limonitic material derived from arsenopyrite and pyrite.

The gold placer deposits of Duncan Creek, Haggart Creek, Dublin Gulch, and other creeks in the area (Fig. 18) have been adequately described in other reports and the details need not be repeated (Keele, 1905; Bostock, *in* Little, 1959).

The gold in Duncan Creek occurs in glacial sands and gravels that clog the whole of the Duncan Creek valley (Fig. 1). In and below the canyon on the creek the gold occurred mainly on the bedrock and was present as flattened and rolled particles without quartz. Above the canyon the gold was found embedded in a blue clay just above bedrock, where it was very coarse, nuggets about the size of lima beans being common. The nuggets were worn smooth and contained no quartz.

According to Bostock, the area immediately around Dublin Gulch is beyond the limit of the last well-marked Pleistocene glaciation, but evidence of an earlier glaciation is present. The streams in Dublin Gulch and Haggart Creek have entrenched parts of their courses in deep overburden forming terraces with old modified profiles. The gold, accompanied by scheelite and wolframite, occurs near the bedrock in gravels and weathered debris in Dublin Gulch and mainly in sand and gravel in Haggart Creek. Most of the gold is present as fine dust, flakes, and small nuggets. Larger nuggets about the size of hickory nuts have been found, but are rare. Most of the nuggets are worn and pitted. One that contained vein quartz was seen by the writer.

Spectrographic analyses of acid-washed nuggets of native gold are presented in Table 50. Silver is a universal constituent, and small amounts of Fe, Cu, Pb, and Ni are probably lattice constituents. Mercury is probably a contaminant as it is used to extract the dust and fine gold from the heavy concentrates of the placers.

Native Bismuth, Bi

Small grains and cleavage pieces of native bismuth were identified in many of the heavy concentrates from the placers of Dublin Gulch and Haggart Creek. Some of the grains have an alteration crust consisting essentially of bismutite, $(BiO)_2(CO_3)$.

The source of the native bismuth is uncertain, but its presence in concentrates containing much cassiterite and wolframite suggests that it came from veins containing these minerals. The marked enrichment of bismuth in the cassiterite samples from the tin lode (*see* Table 41) lends support to this idea. Furthermore, the association of native bismuth with cassiterite and wolframite is common in other parts of the world.

Nature of the Mineralization

Hypogene Mineralization

Vein Textures

In the longitudinal vein faults the early unbrecciated quartz-pyrite-arsenopyrite lenses exhibit a coarsely crystalline massive texture in which the pyrite and arsenopyrite are intimately intergrown with the quartz. Where sulphosalts are present in these early lenses, they tend to occur in fibrous bunches and along seams and small fractures in the quartz. In most places the contact between the quartz lenses and wall-rock is sharp, but some lenses grade through a narrow silicified and pyritized zone into relatively unaltered wall-rocks. Most fragments of wall-rock in the quartz lenses are highly altered, and some early quartz veins show a crude ribbon structure. In a few longitudinal vein faults, as at the Klondyke-Keno mine and in the vein on the Helen Fraction, comb quartz is present, and vugs filled with massive crystallized galena and sphalerite are common.

The cassiterite, scheelite, and wolframite veins in the Dublin Gulch area exhibit various textures. The cassiterite veins are more in the nature of impregnation zones, consisting of brecciated rock pervasively impregnated with cassiterite, quartz, chlorite, and microcrystalline tourmaline. Vugs and openings, although present in places, are not common. The quartz-scheelite and quartz-wolframite veins and stringers are generally coarse-grained, clean-cut bodies in granodiorite, schists, and quartzites. The scheelite skarns have the typical coarse-grained texture of these particular metamorphic rocks.

The siderite lodes in the transverse vein faults and fractured parts of the longitudinal vein faults present various characteristics, depending upon the amount of late brecciation they have undergone. In the relatively unbrecciated lodes the most striking feature is the crustified and drusy texture and the excellent crystal development of both gangue and ore minerals. Siderite, galena, pyrite, and quartz have a strong tendency to euhedral crystal development, whereas sphalerite, freibergite, and chalcopyrite are much less commonly well crystallized. Some veins are notable for their rhythmical banding of siderite, galena, and sphalerite (Pl. XX), or of galena, sulphosalts, and sphalerite. Other veins contain sections of fine-grained dense intergrowths of siderite and sphalerite, and siderite, sulphosalts, and galena.

The relatively unbrecciated siderite lodes have the features of a stock-work in places and consist of a multitude of stringers and veinlets of siderite containing galena, sphalerite, and freibergite. These stringers, seams, and veinlets ramify through the vein fault zone and may extend out into the walls for 20 feet or more. In other places the lodes consist of tabular bodies of ore minerals, siderite, and quartz all of which cement and encrust breccia fragments. Alternate banding of gangue and ore minerals may be present, and cavities containing crystals of gangue and sulphides are generally abundant. In most lodes the siderite-galena-sphalerite veins and stringers have knife-sharp contacts with the wall-rock, and the hypogene minerals break cleanly from the fracture walls.

In many of the brecciated siderite-galena lodes it is difficult to determine whether or not the minerals deposited after brecciation are of hypogene or supergene origin. In a few lodes, as at the Ladue-Sadie-Friendship mine, some of the minerals deposited after brecciation may have been derived by reworking of early vein materials. These late minerals, mainly grey quartz and dolomite, in places cement a rubble of angular and rounded fragments of early siderite, quartz, galena, and sphalerite into a hard compact mass. In other places, crude banded structures and vugs lined with euhedral crystals are common.

The coarse-grained compact texture of the early lodes and their mineral assemblage, viz., cassiterite, scheelite, tourmaline, and arsenopyrite, suggest that these bodies were formed at considerable depth and under conditions of relatively high temperature and pressure. Replacement processes have played a part in their formation, but the bulk of the minerals was deposited in dilatant zones in the fault systems. The siderite-galena-sphalerite lodes differ from the early lodes in that they are characterized by numerous vugs, crustified banding, and a widespread development of euhedral crystal clusters. These features suggest development in open dilatant zones under conditions of relatively low temperature and pressure. Replacement processes have played practically no part in their formation.

Wall-rock Alteration

The wall-rock alteration effects induced by the hypogene quartz-pyrite-arsenopyrite and siderite-galena-sphalerite mineralization are slight in all sediments, but marked where the lodes cut greenstones. The effects are practically the same in both longitudinal and transverse vein faults, and the following descriptions cover the principal features of both types.

Lodes in the greenstones are marked by distinctive alteration zones extending out from individual veins and stringers to distances generally measured in inches, rarely in feet. The greenstone wall-rocks may, however, contain stringers of quartz, siderite, galena, sphalerite, and other ore minerals at distances of 25 feet or more from the main veins and lodes.

The greenstones were originally diorites or gabbros containing hornblende, plagioclase, magnetite, ilmenite, and sphene. Adjacent to the veins and stringers these minerals are completely destroyed and replaced by a soft, confused, slightly schistose mass of fine-grained carbonate, sericite, leucoxene, and quartz. In places pyrite occurs in the highly altered zones, particularly those adjacent to the early quartz-arsenopyrite-pyrite lenses. The contact of the main siderite and quartz veins and stringers with the altered greenstone is generally sharp, but small amounts of galena, sphalerite, and other ore minerals are common in tiny seams and stringers in the altered zones.

The highly altered carbonate-sericite and carbonate-chlorite zones grade imperceptibly into a chlorite-carbonate zone distinguished mainly by the large amount of chlorite. This zone in turn grades into relatively unaltered greenstone.

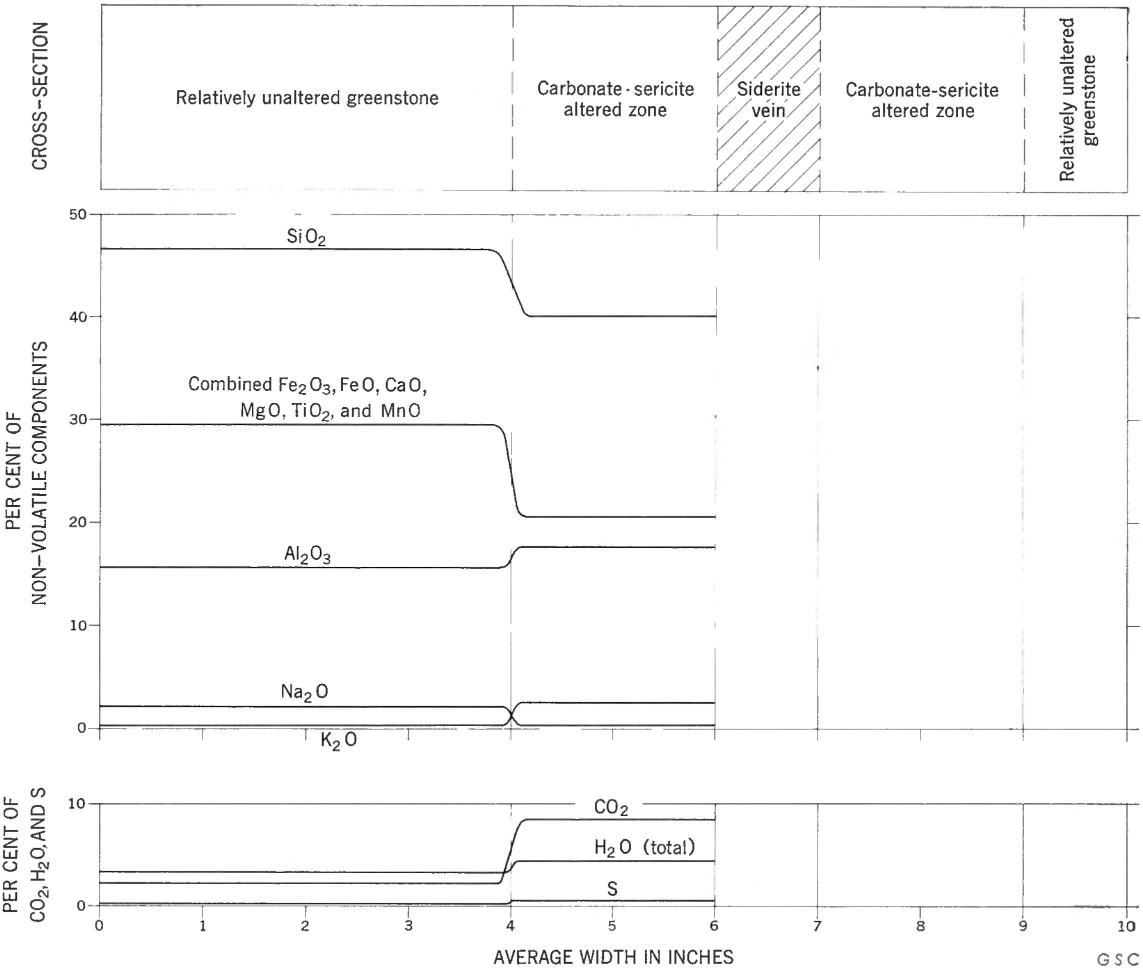


FIGURE 28. Chemical changes produced by alteration of greenstone, composite samples, Sadie-Friendship mine.

The chemical changes attendant upon the alteration of greenstone are given in Tables 51 and 52 and plotted in Figures 28 and 29. The following features are of note:

Adjacent to siderite-galena-sphalerite veins the chemical changes in the greenstone wall-rock show some marked variations. Silica is generally reduced in the chlorite-carbonate zones and may be added in part to the more highly altered carbonate-chlorite zones or transferred to the veins where it probably crystallized as quartz. Small quantities of alumina are abstracted from some of the altered zones but added in others. The same is true for the iron, calcium, and magnesium oxides. Titanium and phosphorus show a general depletion, and manganese a general increase in all the altered zones. Soda is extracted in some zones and added in small quantities in others; potash shows a marked increase in all zones. Water is depleted in the Hector-Calumet zones, but shows a slight increase in the Sadie-Friendship

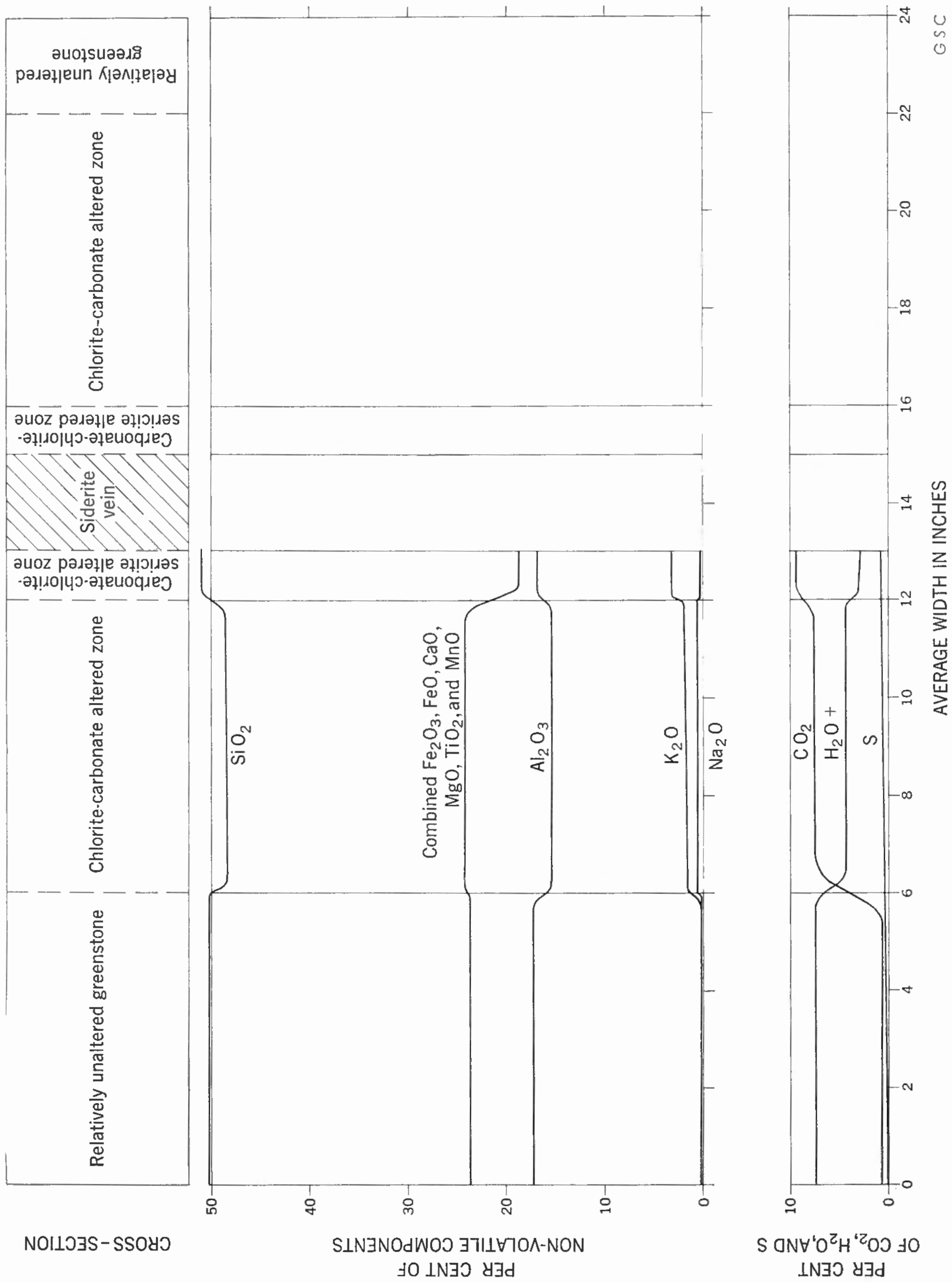


FIGURE 29. Chemical changes produced by alteration of greenstone, composite samples, Hector-Calumet mine, Galena Hill.

zones. In all zones carbon dioxide, sulphur, lead, and zinc exhibit a marked increase as the veins are approached.

These relationships represent the end results of equilibrium reactions in the chemical system that prevailed when the veins were formed in the greenstones. The system was evidently controlled by the concentration of carbon dioxide and to a less extent by water and sulphur.

As carbon dioxide was introduced, some of the ferromagnesian silicates reacted with this component, with the consequent binding of much of their iron, calcium, magnesium, and manganese in carbonates. Silica, alumina, titania, soda, potash, and water, all components not accommodated in the carbonates, were released. Some silica, alumina, soda, and potash recombined as sericite; the remainder, in consort with some iron, magnesia, and calcium, probably migrated to the more strongly dilated zones or to the vein sites where they were precipitated as quartz, carbonates, pyrite, and other sulphides.

Lodes cutting quartzites and schists have effected little alteration of the wall-rocks. Small stringers and veinlets of siderite carrying galena, sphalerite, and other ore minerals are, however, common at distances up to 25 feet from the main lodes.

In thin sections about the only mineralogical changes visible in quartzite or schist are the introduction of some carbonate, generally siderite, some pyrite, and the formation or recrystallization of some sericite in certain places. Generally, no textural changes are visible where the veins are frozen to the walls. Where extensive brecciation and comminution of the quartzite and schist have taken place the rock cannot be effectively studied in thin sections, as the material in hand specimens is an incoherent mass of finely ground, mainly powdery, quartzite and schist partly cemented by carbonates and quartz.

Difficulties in assessing the chemical changes in the wall-rock alteration of the sedimentary rocks are numerous. These stem mainly from the varied nature of the sedimentary rocks through which the veins pass and also from the fact that representative samples are not easily obtained. An attempt was made to trace the chemical changes in one of the veins in the Hector-Calumet mine. A composite sample of altered quartzite was chosen and compared with a composite sample of thick- and thin-bedded quartzites. The results, given in Table 53, indicate the following trends.

There is a small decrease of silica, alumina, lime, soda, potash, water, titania, and phosphorus in the altered quartzite. The main additions are in iron, magnesium, manganese, and carbon dioxide, the principal components of siderite. Sulphur, lead, and zinc, the components of pyrite, galena, and sphalerite, likewise, are greater in the altered zones.

In the tin lodes of the Dublin Gulch area replacement processes have played a large part, producing marked effects in the quartzites and schists. In thin sections these are manifest by the development of intimately intergrown masses of cassiterite, tourmaline, some chlorite, and quartz.

Compared with the normal quartzites and schists (Table 54), the tin impregnation zones show a marked enrichment in tin, boron, iron, and perhaps in magnesium. The latter three elements are bound principally in tourmaline. Silica, calcium, and carbon dioxide are reduced in the impregnation zones. These elements probably now reside in quartz and calcite in fractures, fissures, and brecciated parts of the tin lodes.

Hypogene Distribution of Trace Elements in the Wall-rocks of Deposits

Several investigations were carried out of the hypogene distribution of a suite of ten trace elements in the wall-rocks of the various deposits, the results of two are given in Table 55. The magnitude of the differences in the trace element contents makes true graphical presentation somewhat difficult, but ideally the profiles for some elements such as lead and arsenic may be represented as shown in Figure 30. Inspection of the values given in the table reveals the following additional features.

The amount of lead, zinc, cadmium, silver, tin, arsenic, and antimony increases in a relatively regular manner as the veins are approached. Copper, indium, and gallium behave in some cases in a similar manner, but in general the profiles are erratic. Cadmium follows zinc closely, increasing in amount concomitantly. Silver and tin appear to follow lead rather closely as does also antimony and perhaps arsenic.

One significant feature has emerged from the studies of the distribution of the trace elements in the wall-rocks of the deposits, namely, that there is little indication of the presence of veins at any great lateral distance. As a rule it can be said that 50

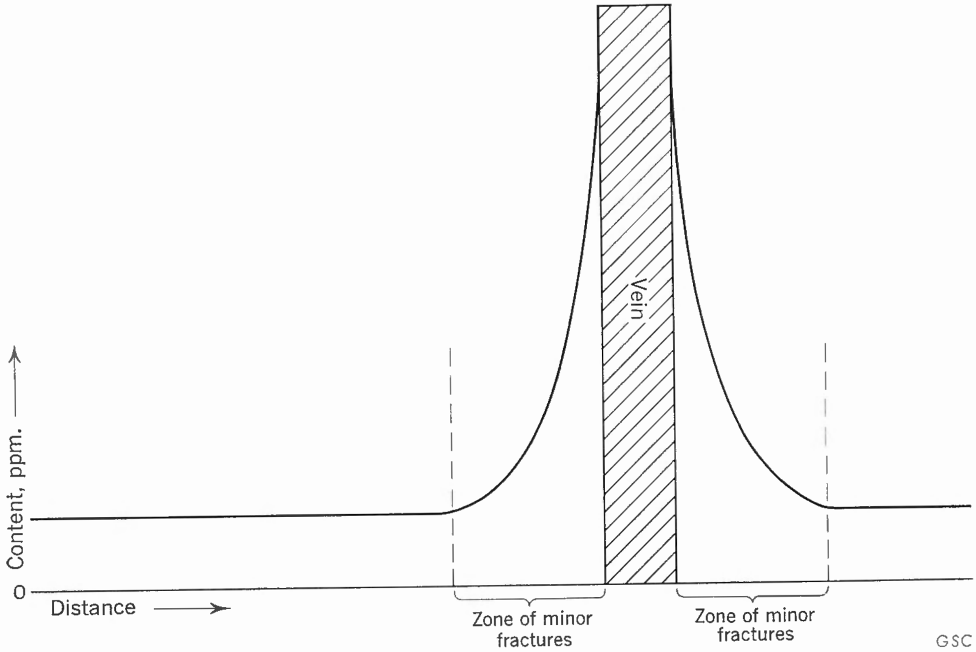


FIGURE 30. Idealized profile showing distribution of trace elements in wall-rocks.

feet is the farthest from a vein that the trace element content of the enclosing rocks may reflect its presence. As shown by geological studies and thin section investigations this distance depends entirely upon the degree of fracturing (dilatancy) in the wall-rocks. If the rock is unfractured the trace element content is generally normal to within a short distance, commonly measured in inches, from the vein. If the rock is fractured outward from the vein a general anomalous trace element content prevails, and this can be related to the presence of small amounts of galena, sphalerite, and other ore minerals in the fractures.

Supergene Mineralization

Vein Textures

All vein faults and their lodes are oxidized to a depth of from a few tens of feet to 500 feet. Two zones are generally developed in the lodes—a zone of oxidation and a zone of reduction or cementation. The textural features developed in these two zones are different.

In the zone of oxidation the most important feature is the breakdown of hypogene minerals such as siderite, sphalerite, galena, pyrite, arsenopyrite, and freibergite, and the formation of various oxides, sulphates, and carbonates, among which limonite, wad, quartz, anglesite, cerussite, beudantite, scorodite, bindheimite, and malachite are the most characteristic. The general breakdown of the hypogene minerals renders the lodes and mineralized parts of the vein faults porous and cavernous, with some irregular open spaces large enough for a man to crawl into. These cavernous openings are the result of extensive solution and removal of lode material, principally siderite, pyrite, and sphalerite. The openings, as well as the other porous parts of the vein faults, are marked by an abundance of pulverulent limonite and wad, and the presence of coatings or crusts of various sulphates, wad, limonite, calcite, and malachite. Nodules and tabular masses of galena are rimmed with banded anglesite, and crusts of small quartz crystals on fragments of ore and gangue minerals are common. The characteristic boxworks, resulting from the solution of pyrite, sphalerite, and siderite are widespread in all parts of the oxidized zones. Ice veins, with features described in a previous section, occupy solution cavities and other open spaces in the permafrost zone.

The deeper parts of some oxidized zones exhibit interesting textures and structures. In the 48 vein fault of the Bellekeno mine one of the ore shoots presented a remarkable development of cockade structures, banding, and cementation by quartz and other minerals (Pls. XXII to XXVII). This ore shoot was severely brecciated after the deposition of siderite, galena, pyrite, and sphalerite, resulting in rounded aggregates of both gangue and ore minerals. Subsequent deep oxidation produced limonite and wad, and darkened the siderite. The sphalerite and pyrite were highly oxidized in some places leaving boxworks, and anglesite developed in concentric bands around cores of galena. This brecciated mass has been cemented with quartz, calcite, gypsum, smithsonite, and anglesite. The quartz occurs as short prismatic crystals encrusting the ore and gangue fragments and is overgrown by calcite, which fills the spaces between the quartz-encrusted fragments. In other parts of the ore shoot alternating bands of gypsum, smithsonite, and limonite occur about fragments of ore and gangue, and seams of anglesite overgrown by quartz are present. These textures and the presence of sulphates and oxides suggest deposition from downward percolating waters that derived their mineral load from the upper oxidized parts of the ore shoot. The fact that this particular vein fault is sealed by permafrost and that circulating waters are not now leaching the ore shoot suggests that the oxidation and cementation took place prior to the formation of the present permafrost.

All the features of the oxidized zones indicate extensive solution and removal of material from the zones. Siderite, pyrite, and sphalerite are the minerals most affected and galena the least. The lead and silver contents of the oxidized parts are enriched in some vein faults; the reason for this enrichment is discussed in sections that follow.

In the zones of reduction supergene quartz, calcite, and dolomite cement brecciated fragments of ore and gangue minerals in some lodes, forming compact masses. These minerals may also fill cavities and line late fractures. In many of the vein faults supergene sphalerite, marcasite, pyrite, and galena occur as small crystals and pulverulent masses in late fractures in the lodes and wall-rocks, and in a few veins, as at the Lucky Queen and Silver King mines, pyrargyrite and native silver were abundant in late fractures and cavities. Botryoidal pyrite and marcasite were common in the Silver King lodes.

Wall-rock Alteration

In nearly all vein faults meteoric waters migrating downward have altered some of the wall-rock minerals and leached out some of the soluble compounds leaving the rocks soft and porous. In the sediments where hypogene alteration zones are absent or poorly developed, supergene effects are not marked. For a few inches outward from the lodes the few hypogene carbonates in the wall-rocks have been attacked and oxidized to limonite and hydrous manganese oxides. In some quartzites adjacent to vein faults the carbonate cement has been leached, and in schists silica and alumina have been removed leaving the rock porous or the remaining grains incoherent and resulting in the breakdown of the rock to a sand or mud. This effect is mostly localized and rarely extends more than a foot outward from the veins.

The hypogene alteration zones in the greenstones are the most severely affected. These are highly oxidized and softened owing to the breadkown of the hypogene carbonates and pyrite to limonite, wad, and soluble salts.

In the zone of oxidation the fractures in and about all hypogene lodes in both sediments and greenstones are stained with limonite or manganese oxides as a result of the migration of meteoric solutions into them and consequent precipitation of the oxides along them. This staining may extend outward from the lodes for distances of 50 feet or more, and it is often possible to locate mineralized parts of vein faults by tracing this supergene dispersion halo.

Geochemistry of the Deposists

Composition of the Ores

The ores in the Keno Hill area are of three main types—gold-quartz, lead-zinc-silver-cadmium, and cassiterite. To these may be added a fourth variety, the scheelite ore in skarn. Comprehensive analyses of the first three types are given in Table 56, and analyses of the fourth variety in Table 21.

The analyses given in Table 56 cover both the oxidized and unoxidized ores. Unfortunately the two analyses given for the quartz-arsenopyrite-pyrite-gold ore are not directly comparable because the sampling was done in two different places, a procedure necessitated by the absence in the places examined of a good sequence from oxidized to fresh ore. The Bellekeno ores are all highly oxidized and hence no comparison can be made with the primary material. The extensive workings in the Hector-Calumet mine facilitated the detailed sampling of the No. 3 vein from the surface to the 900-foot level[1]. The results obtained are, therefore, comparable in most respects and provide a fairly accurate idea of the elemental variation with depth resulting from the marked effects of oxidation (Figs. 14 and 31).

The elemental fluctuations in the siderite-galena-sphalerite-pyrite lodes are pointed out in the following discussion, and some brief comments are made; in general the chemical reasons for these are reserved for later sections. The comments are based not only on chemical analyses but also upon extensive field and mineralogical investigations.

There is a general increase in the *silica* content of the highly oxidized near surface parts of the siderite lodes compared with the primary ore. This is largely due to residual concentration of the siliceous component of the ores as a result of the leaching of minerals such as siderite, pyrite, and sphalerite.

Alumina tends to decrease in the oxidized zones. Probably it is removed as soluble aluminum sulphate.

The *iron* content of oxidized and unoxidized ore remains within relatively constant limits. There is, however, a slight decrease in most of the highly oxidized parts of the lodes.

Calcium and *magnesium* display a close coherence and remain relatively constant within certain limits in both oxidized and fresh vein material. In some lodes there is a decrease in both elements in the more highly oxidized zones.

Sodium and *potassium* exhibit little difference in the primary and oxidized zones in the Hector-Calumet No. 3 vein.

Titanium and *phosphorus* are present in relatively constant amounts in both the oxidized and fresh ores. There is a suggestion, however, that both elements are slightly enriched in the more highly oxidized parts of some veins.

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[1] Both chip and channel samples were used to make up the composites. Care was taken to exclude wall-rock material. Some bias may have been introduced because in places only remnants of the vein and pillars were available for sampling.

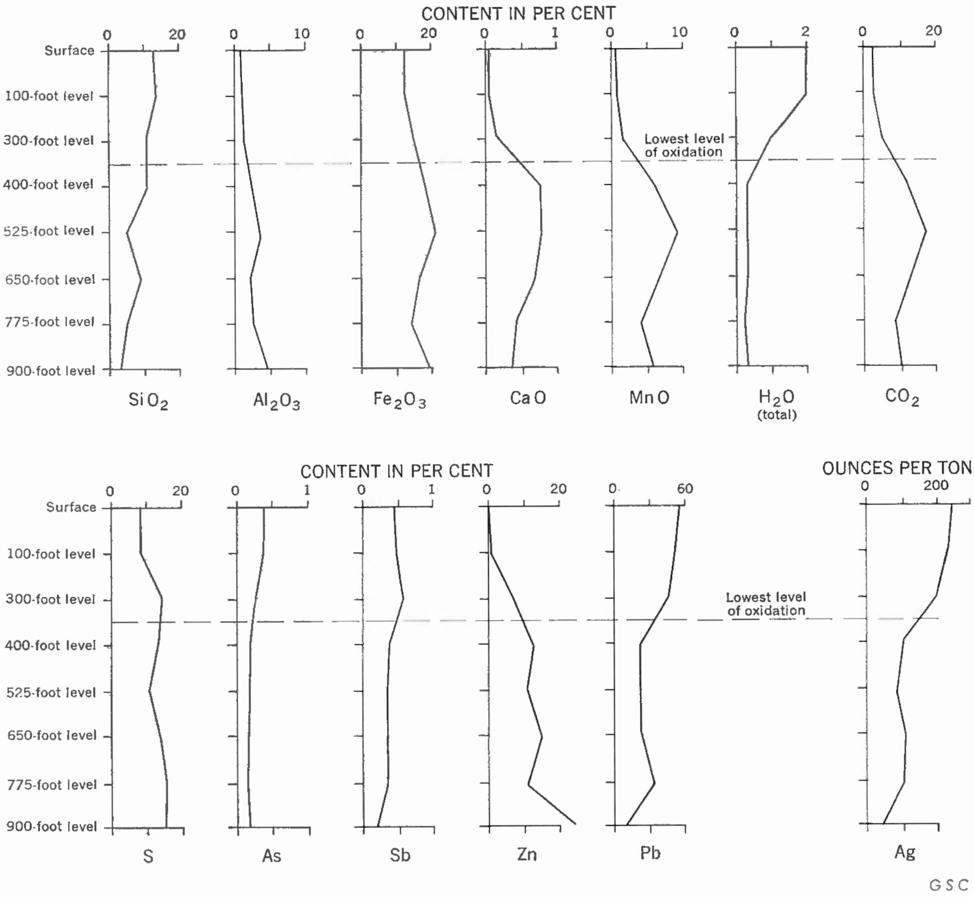

FIGURE 31. Variation of elemental content with depth, No. 3 vein, Hector-Calumet mine, Galena Hill.

Manganese displays a somewhat varied habit. In some vein systems the oxidized zones are slightly enriched in manganese, whereas in others the element is leached. In the Hector-Calumet No. 3 vein, manganese is strongly leached, a feature that is probably true for most lodes.

Water is markedly enriched in all oxidized zones, and the content of this component increases with increasing oxidation. The reverse is true for *carbon dioxide* and *sulphur*. Both these components show a marked decrease with increasing oxidation.

The *arsenic* and *antimony* contents of the oxidized and primary siderite lodes exhibit only small differences. In the Hector-Calumet No. 3 vein and Onek mine both elements are slightly enriched in the oxidized zones, but this habit does not seem to hold in the Bellekeno mine. Both arsenic and antimony appear to have been leached in the oxidized parts of the quartz-arsenopyrite lodes on Keno Hill, judging from the two analyses in Table 56. This is surprising as the oxidized parts of these veins in the Dublin Gulch area are characterized by abundant scorodite, and the soils in their vicinity are greatly enriched in both As and Sb (*see* Table 4).

No definite statement can be made about the habit of *gold* in the oxidized and primary ores from the analyses presented in Table 56. In the siderite lodes the content is relatively uniform in both zones. The analyses of the quartz-arsenopyrite ores seem to suggest that gold is leached from the oxidized zones, but the non-sequential nature of the samples may introduce a bias. The results of panning of weathered residuum overlying the gold veins suggest that gold is somewhat enriched in the oxidized zones. Assays quoted by MacLean (1914) for the Dublin Gulch area support this conclusion.

Both *silver* and *lead* show a marked enrichment in nearly all oxidized zones as shown by the analyses in Table 56 and from numerous mine records. On the other hand, *zinc* and *cadmium* are generally strongly leached from the highly oxidized zones. No general statement can be made about *copper*, although there appears to be a slight enrichment of the element in some oxidized zones. *Tin* appears to remain relatively constant in both oxidized and primary siderite ores, as does also *nickel* where found in detectable amounts.

Geochemistry of Hypogene Mineralization

The sequence of hypogene mineralization has been outlined in detail in the first part of this chapter. The principal stages may be briefly recapitulated to provide a background for a discussion of their geochemistry.

The earliest stage is marked by small quartz and carbonate stringers and lenses in both the sediments and greenstones and by quartz-carbonate-epidote stringers and lenses in greenstones. Development of cassiterite-tourmaline impregnation zones, quartz-wolframite, quartz-scheelite, and scheelite skarn zones near granodiorite stocks probably also took place during this stage or slightly later. The second stage of mineralization is represented by quartz-pyrite-arsenopyrite lenses in vein faults throughout the area. The third stage of mineralization took place in an extensive series of vein faults and included the development of siderite-pyrite-sphalerite-galena-freibergite lodes, generally with only small amounts of quartz. A late stage of mineralization, resulting in the precipitation of some dolomite, calcite, quartz, and small amounts of galena and sphalerite, took place in local brecciated zones in some vein faults. Some or all of the minerals formed at this stage may be supergene.

The elements and compounds precipitated during the main mineralization stages, their abundance, and their partition into the numerous mineral phases is discussed below. Chemical analyses of the various types of ores are given in Tables 21 and 56, and spectrographic analyses of the principal minerals are recorded in Tables 31 to 50. Figure 32 illustrates diagrammatically the relative amount of each element deposited at each stage of the hypogene mineralization.

Silica is bound principally in quartz in all types of deposits, with smaller amounts in epidote in the first stage quartz lenses and in tourmaline and other silicates in later stages. The maximum precipitation of silica took place during the formation of the early quartz stringers, lenses, and boudins. The second stage of mineralization was also characterized by an abundant precipitation of silica, but later stages were marked by a great decrease in the amounts of silica deposited as quartz.

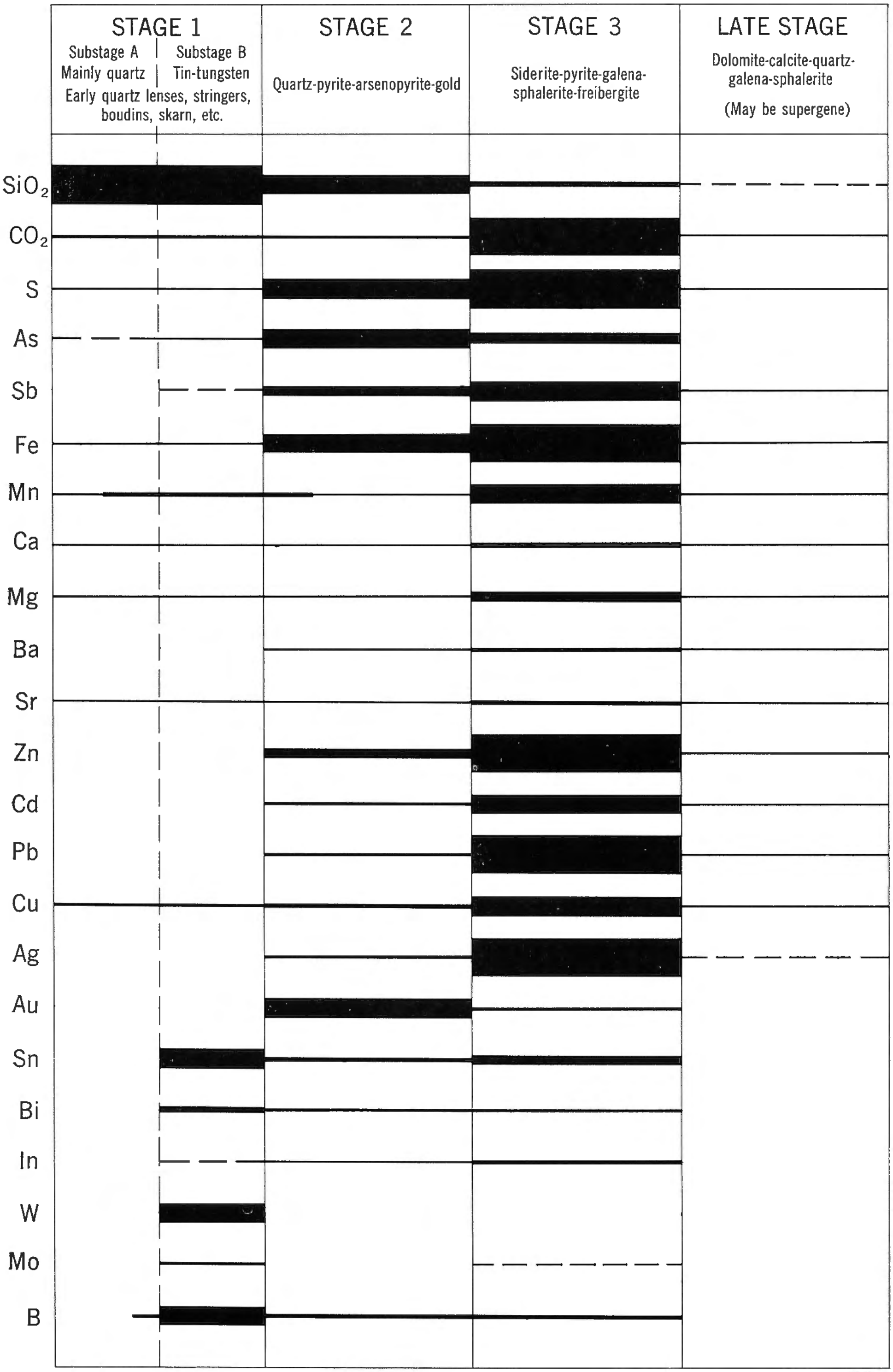

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FIGURE 32. Hypogene depositional sequence of elements in Keno Hill-Galena Hill area.

The bulk of the *carbon dioxide* is bound in siderite, dolomite, and calcite of the third stage. Only small amounts of calcite and other carbonates occur in the first and second stages of mineralization.

Sulphur is moderately abundant in the second stage of mineralization and reaches its maximum abundance in the third. The element is bound in the minor amounts of pyrite in the early quartz stringers and lenses of the first stage. In the second stage sulphur is partitioned between pyrite,arsenopyrite, sulphosalts, and minor amounts of galena and sphalerite. In the third stage the element shows great diversity; it is bound principally in galena, sphalerite, and pyrite with smaller amounts in chalcopyrite, freibergite, jamesonite, boulangerite, and other sulphosalts.

Arsenic is particularly abundant in the second stage of mineralization and forms a separate mineral phase, arsenopyrite, in the quartz lenses. In addition to this mineral the element is also a minor constituent of the various sulphosalts and is present in significant amounts in the pyrite of this stage. In the third stage of mineralization the bulk of the arsenic is camouflaged in the pyrite (Table 33) and freibergite (Table 39). Small amounts are also bound in the various sulphosalts and in galena, sphalerite, and chalcopyrite.

Most of the *antimony* is bound in the various sulphosalts of the second and third stages of mineralization. Small amounts are also camouflaged in the arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite of these stages.

Iron shows its greatest concentration in the third stage of mineralization. The element in this stage is partitioned into several phases, the most important being siderite and other carbonates, pyrite, and sphalerite. Small amounts are also bound in chalcopyrite, and the various sulphosalts. In the second stage most of the iron is present in pyrite and arsenopyrite with the remainder in the small amounts of carbonates and sulphosalts. Carbonates, pyrite, and epidote bind the iron in the early quartz lenses, and in the tin lodes and tungsten veins the bulk of the element is held in cassiterite, tourmaline, and wolframite, with small amounts in pyrite and chalcopyrite.

Manganese is markedly enriched in the siderite of the third stage of mineralization. Small amounts are also present in the sphalerite of this stage, and traces are found in pyrite and various other minerals. Some manganese is concentrated in the wolframite of the earliest stage of mineralization.

Calcium, *magnesium*, *barium*, and *strontium* tend to be enriched together, principally in the carbonates of the third stage. Some barium and strontium are bound in barite in the siderite lodes. Some or all of this barite may be of supergene origin.

Zinc reaches its maximum abundance in the third stage and is bound principally in sphalerite. Smaller amounts are partitioned into the sulphosalts, particularly freibergite. Traces of zinc occur in practically all the sulphide minerals and in the carbonates. *Cadmium* follows zinc closely, being bound mainly in sphalerite, with smaller amounts in freibergite. *Indium*, likewise, follows zinc and is enriched in some sphalerites.

Lead is concentrated largely as the sulphide galena in the third stage of mineralization. In addition to this mineral smaller quantities of the element are present in the lead sulphosalts, jamesonite, boulangerite, meneghinite, and bournonite. Traces of lead are found in nearly all sulphides and carbonates in the siderite lodes. The bulk of the lead in the quartz-arsenopyrite-pyrite lenses is bound as galena and lead sulphosalts.

Copper exhibits its greatest enrichment in the third stage of mineralization. The element is bound largely in freibergite and chalcopyrite with much smaller amounts in bournonite. Traces of the metal may be present in practically all the sulphides and carbonates of all stages of mineralization. Copper is also concentrated in chalcopyrite in some early thin seams in greenstone bodies and is present mainly in chalcopyrite in the tin lodes.

Silver follows lead, copper, and antimony closely and is strongly enriched in the third stage siderite lodes. In these the element is partitioned into several sulphide phases in which it is largely camouflaged. The richest silver mineral is freibergite with up to 18 per cent Ag, but the bulk of the element is present in galena. In this sulphide the silver is largely present in exsolved silver minerals such as freibergite, acanthite, and pyrargyrite. Some also appears to be present within the lattice of galena. Numerous other sulphides, including pyrite, arsenopyrite, lead sulphosalts, and sphalerite contain traces of silver either as a lattice constituent or in microscopic silver minerals. Only small amounts of silver occur in the second stage quartz-pyrite-arsenopyrite lenses. In these the element is mainly present in the small amounts of galena, sulphosalts, and other sulphides. Freibergite from the second stage quartz veins generally contains less silver than that from the third stage siderite veins (Table 39).

Tin is most abundant in the early and third stages of mineralization. In the former the element is bound principally as the oxide, in cassiterite-tourmaline impregnation zones. In the latter most of the tin is camouflaged, probably as a lattice constituent, mainly in sphalerite but also in galena.

Bismuth may occur as the native element in the cassiterite impregnation zones and in the quartz-wolframite veins but only in small amounts in both deposits. The bulk of the element is concentrated in the siderite lodes where it is present in galena probably in part as a lattice constituent and perhaps also as a separate exsolved bismuth sulphosalt.

Tungsten is concentrated in the early quartz-wolframite and quartz-scheelite veins and in the scheelite skarns near the granodiorite stocks. The element does not appear in any of the other stages of mineralization. *Molybdenum* follows tungsten and is present in traces in some scheelite samples. Traces of molybdenum are also found in some of the composite samples of oxidized ores from the Bellekeno mine, but the minerals carrying the element could not be determined.

Boron is enriched in the cassiterite impregnation zones and small amounts are concentrated in the deposits of both the second and third stages of mineralization. In these the element is bound principally in tourmaline. The presence of large amounts of boron in the cassiterite zones suggests that the tin may have been transported as a volatile tin-boron complex.

Gold is concentrated in the quartz-arsenopyrite-pyrite veins of the second stage of mineralization (Table 56). Among the minerals of this stage the element is concentrated in arsenopyrite, pyrite, and an early generation of freibergite (Table 57). The siderite lodes contain only small amounts of gold. In these the element is mainly in freibergite with smaller amounts in pyrite and sphalerite. In the latter mineral it seems likely that the gold is largely in freibergite inclusions.

All the sulphides in the second stage quartz-pyrite-arsenopyrite veins contain more gold than those in the siderite lodes. This can be readily seen by comparing the gold contents of the pyrite, galena, and freibergite from the No. 6, Cream, Helen Fraction, and Klondyke-Keno east-west vein with those from the Hector-Calumet and other siderite veins.

The field and chemical evidence indicates a close affinity between gold and arsenic. Veins rich in arsenic report the highest gold assays. This relationship is also shown by the minerals in Table 57. Arsenopyrite is rich in gold as are also those varieties of pyrite carrying relatively large amounts of arsenic. The evidence provided by the two ages of freibergite is particularly significant in this matter—the early varieties with a high arsenic content (Klondyke-Keno vein) carry more gold than the later varieties with a low arsenic content.

There is no clear relationship between gold and antimony in the deposits or their constituent minerals, except that freibergite, a high antimony-bearing mineral, carries much gold.

Native gold can rarely be seen in thin sections of the high-grade auriferous sulphides, suggesting that the bulk of the element is present in the minerals either as lattice constituents or submicroscopic particles. This is an old problem previously reviewed by the writer (Boyle, 1961). The evidence from crystallochemical considerations suggests that lattice substitution is probable, and this hypothesis is preferred by the writer over that of the submicroscopic particle.

In the covalent mineral freibergite silver with a tetrahedral covalent radius of 1.52Å substitutes for copper (1.35Å), not especially because of the similarity in radii but more probably as a result of the particularly favourable and similar bond orbital configurations with S, As, and Sb. Gold (1.50Å) is very similar in this latter respect to silver and it seems nearly certain that it substitutes in the copper sites in freibergite. The amounts of the noble metals incorporated in the sulphosalt would seem to depend, therefore, only on the availability of each element in the crystallizing medium.

The probability of some substitution of gold in pyrite and arsenopyrite can be substantiated on certain energetic grounds.

In pyrite (and the closely related arsenopyrite) each iron atom is covalently bonded to six sulphur atoms at the corners of a nearly regular octahedron. In addition there is also a moderate degree of metallic bonding (Fe-Fe) indicated by the metallic lustre, especially of arsenopyrite. The octahedral covalent radius of ferrous iron in pyrite is 1.23Å, and for gold in aurostibite, $AuSb_2$, a mineral isostructural with pyrite, the octahedral radius is 1.40Å. Gold will form two rather unstable artificial sulphides, AuS and Au_2S_3, indicating that the bond to sulphur although weak is nonetheless possible.

These considerations suggest that some gold may substitute in the iron sites of pyrite and arsenopyrite mainly because of similar octahedral radii, a certain affinity for sulphur, and the isostructural relationships of the two minerals pyrite and aurostibite[1]. In addition the metallic binding in the sulphides, especially arsenopyrite, confers certain alloying properties on them, permitting other metals such as gold and silver to reside in the lattices without excessive distortion.

Geochemistry of the Supergene Mineralization

Three zones can be recognized in most of the lodes of the area—an upper oxidized zone, an intermediate zone of reduction, and a lower primary zone. The oxidized and primary zones are present in all lodes and are generally well developed and demarcated. The depth of the oxidized zones varies. In some mines, as at the Silver King and Ladue-Sadie-Friendship, oxidation terminated at a depth of 20 feet; in others, as at the Elsa, Galkeno, Hector-Calumet, and Bellekeno, the oxidized zones extend to depths ranging from 250 to 500 feet. Many zones of reduction are diffuse and irregular and tend to overlap the lower parts of the oxidized zones and upper parts of the primary zones. This is presumably the result of fluctuations in the level of former water-tables. In some lodes the zones of reduction are poorly developed and are of minor economic importance; in others, as at the Silver King and Lucky Queen mines, marked zones of reduction carrying abundant secondary silver minerals were developed 25 to 50 feet vertically.

In attempting to trace and outline the chemistry of supergene processes the geochemist can follow two lines of evidence—first, he can study the various mineral species in the primary, oxidized, and reduced zones, and second he may observe the oxidizing and reducing reactions taking place within the lodes, mainly through the medium of circulating ground and surface waters. Both these lines have been followed in this study where the veins are not sealed by permafrost. It should perhaps be remarked that seldom is it possible to define all the parameters in oxidation processes (particularly those of the past) because of the extreme complexity of supergene solutions, their multicomponent nature, and their rather erratic behaviour, resulting from both climatic and geological changes.

Most of the oxidation of the lodes probably took place during Tertiary time, under somewhat different climatic conditions than those now prevailing in Yukon. It is generally agreed that the Tertiary was characterized by a warm, rather humid climate in the northern latitudes. These conditions would facilitate the rate of various chemical reactions but would probably have little effect on the direction of the oxidation processes. One can assume, therefore, that the present oxidation processes are similar to those that prevailed during past geological periods.

Chemistry of Underground and Surface Waters

A detailed study of the surface and underground waters of the Keno Hill-Galena Hill area was carried out, to aid in the interpretation of the oxidation processes of the

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[1] Note that pyrite generally contains antimony—sufficient it would seem to bind the gold in the pyrite lattice, thus neutralizing any charge differences.

lodes and to determine the suitability of hydrogeochemical prospecting in the area. The results have been published in two reports (Boyle, *et al.*, 1955, 1956).

Table 58 records complete chemical analyses of two characteristic samples of water, one from a spring on Keno Hill and the other from drill-holes and fissures in the vicinity of the Hector-Calumet deposit. Table 59 summarizes the range of soluble cations and anions in the underground waters, and Table 60 contains analyses of several characteristic natural precipitates at spring orifices. The relationship of pH, temperature, and heavy metal content of several underground springs are recorded in Table 61. The following points of interest are shown by the data in the tables and the investigations published in the reports referred to above.

In the waters percolating through the lodes the principal anions are sulphate, bicarbonate, and silica with minute amounts of chloride, fluoride, and nitrate; the main cations are calcium, magnesium, aluminum, manganese, and iron. Small amounts of zinc, copper, arsenic, antimony, silver, and numerous other elements are also present. From the analyses it is evident that many of the cations are carried largely as sulphates and in smaller amounts as bicarbonates. Several field investigations indicate that the sulphate content commonly reflects the heavy metal (Zn, Pb, Cu) content, and hence the presence of mineralized zones and orebodies. This circumstance is however, not invariable, and large amounts of sulphate are commonly found in waters with a relatively low heavy metal content. This sulphate was probably derived from the oxidation of pyritiferous schists, phyllites, and quartzites.

The pH of the surface and underground waters varies between 4.4 and 7.8. The lower pH's are generally recorded in underground waters where active oxidation of sulphides is taking place, but the pH of these increases rapidly as soon as the waters come in contact with siderite. Acid waters (pH about 5) were also observed in some bog areas. There is no apparent relationship between the pH and the heavy metal (mainly Zn) content of the waters, nor is the pH of the waters an effective indicator of mineralized zones and orebodies.

The oxidation-reduction potential (Eh) of the waters was not examined in detail, principally because of the difficulty in obtaining significant readings. The oxidation-reduction potentials tend to be high (about 0.5v) near the surface but decrease rapidly (to values about 0.1v) as the waters pass downward and are depleted in atmospheric oxygen.

The temperature of the underground waters varies between 2° and 5° C; that of surface waters cover a wide range, from 0° for meltwaters to 15° C for stagnant pools in bogs and streams.

Chemistry of Individual Elements

The supergene processes in the vein faults are due to the action of meteoric waters containing dissolved oxygen and carbon dioxide of atmospheric origin. During these processes the mobility of the various elements is a function of the solubility of their salts, generally their sulphates or hydrogen carbonates, the pH of the migrating solutions, and the Eh of the environment, manifested principally by the presence of free oxygen.

The supergene waters near the surface effect a widespread oxidation of the hypogene lode minerals and remove various soluble components. As the waters pass downward from oxidizing to reducing conditions some of the dissolved components are precipitated as new minerals that cement brecciated parts of the lodes and fill late fractures, vugs, and cavities. The remainder of the dissolved components are dispersed into the groundwater system and finally through springs into the stream systems.

The meteoric solutions in the vein faults are multicomponent systems that do not readily admit of simple interpretation because their phase relationships are complex, and they undergo constant change due to reaction with gangue or ore minerals. Because of these complexities it seems best to discuss the various minerals and their constituents individually and attempt an integration of the chemical factors from the analyses of the waters and the final mineral products, as observed in the field.

In preparing parts of the following discussion on the chemistry of the oxidation processes the writer has drawn on the works of many investigators, especially those by Emmons (1901, 1917), Weed (1902), Van Hise (1904), Stokes (1906), Wells (1910, 1911, 1915), Buehler and Gottschalk (1910, 1912), Cooke (1913), Palmer and Bastin (1913), Lehner (1914), Nishihara (1914), Ravicz (1915), Lindgren (1933), Smirnov (1951), Bateman (1954), and Shcherbina (1955).

Iron, Manganese, Calcium, and Magnesium

In the hypogene lodes these elements are concentrated principally in siderite, pyrite, arsenopyrite, and sphalerite with smaller amounts in the sulphosalts and chalcopyrite. In the zones of oxidation and reduction they are bound mainly in limonite, wad, beudantite, jarosites, scorodite, and gypsum.

Siderite, pyrite, and sphalerite, being the most abundant minerals in the lodes, influence many of the reactions in the zones of oxidation and reduction. The dissolved oxygen and carbon dioxide in the meteoric waters attack these minerals and release the iron, manganese, calcium, and magnesium as soluble hydrogen carbonates and sulphates. Thereafter the oxidation-reduction potential (Eh)[1] of the environment, as manifested principally by the presence of free oxygen, modifies the course of the chemical reactions and results in some cases in a differential separation of the four elements. Thus much of the iron and manganese may be fixed as insoluble hydrous oxides whereas the calcium and magnesium may migrate downward in the solutions. The various reactions, although complex in detail, can be discussed simply as follows.

Siderite, when attacked by water containing CO_2 yields soluble hydrogen carbonates thus:

$$FeCO_3 \text{ (iron component)} + H_2O + CO_2 = Fe(HCO_3)_2$$
$$MnCO_3 \text{ (manganese component)} + H_2O + CO_2 = Mn(HCO_3)_2$$

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[1] For the theory of oxidation-reduction potentials the reader should consult Latimer (1952). The geochemical importance of oxidation-reduction potentials is discussed by Mason (1949), Shcherbina (1955), Garrels (1960), and Sato (1960).

Strictly speaking, oxidation potential values refer only to equilibrium systems and perhaps in most oxidizing zones such conditions do not exist. Potential data may however be useful in predicting possible reactions, but must be employed judiciously in geochemistry as they measure only energy differences and have no bearing on reaction kinetics or processes. These can only be understood by a study of the geochemical environment, the reactants, and the products of the reactions.

$$MgCO_3 \text{ (magnesium component)} + H_2O + CO_2 = Mg(HCO_3)_2$$
$$CaCO_3 \text{ (calcium component)} + H_2O + CO_2 = Ca(HCO_3)_2$$

Pyrite and arsenopyrite when oxidized yield soluble ferrous sulphate, ferric arsenate, and sulphuric acid:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$$
$$2FeAsS + 7O_2 + 2H_2O = 2FeAsO_4 + 2H_2SO_4$$

The FeS and MnS components of sphalerite (Zn,Fe,Mn,Cd)S oxidize to soluble ferrous and manganous sulphates

$$FeS + 2O_2 = FeSO_4$$
$$MnS + 2O_2 = MnSO_4$$

and chalcopyrite yields copper sulphate and ferrous sulphate

$$CuFeS_2 + 4O_2 = CuSO_4 + FeSO_4$$

The sulphuric acid derived from the oxidation of pyrite and arsenopyrite would react immediately with any available siderite or other carbonates, thus reducing the acidity and producing soluble iron, manganese, calcium, and magnesium sulphates. The reaction for the iron component of the siderite may be written:

$$FeCO_3 + H_2SO_4 = FeSO_4 + H_2CO_3$$

In solution the Fe and Mn are markedly affected by the oxidation-reduction potential (Eh) and pH of the environment because these elements have two possible valence states. Calcium and magnesium are not affected by the Eh because of their single oxidation state in nature (oxidation state 2). Their mobility is essentially dependent on the pH of the solution (H^+ concentration), the concentration of H_2CO_3, CO_3^{2-}, and HCO_3^-, or the concentration of SO_4^{2-}.

With respect to the migration and precipitation of iron and manganese the following couples[1] in acid and alkaline solutions are of interest:

Alkaline Solutions

$$Fe(OH)_2 + OH^- = Fe(OH)_3 + e^- \qquad E^o = 0.56$$
$$Mn(OH)_2 + 2OH^- = MnO_2 + 2H_2O + 2e^- \qquad E^o = 0.05$$
$$Mn(OH)_2 + OH^- = Mn(OH)_3 + e^- \qquad E^o = -0.1$$
$$4OH^- = O_2 + 2H_2O + 4e^- \qquad E^o = -0.401$$

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[1] These couples and those in the following sections are taken from Latimer (1952) and are referred to the standard hydrogen gas-hydrogen ion couple $H_2 = 2H^+ + 2e-$, with $E^o = 0.00$ volt. The potentials given are for unit activity (or concentration assuming complete ionic dissociation), pressure 1 atmosphere, and T=25°C. The oxidation potentials change with varying concentration, pressure, temperature, and pH. A positive value for E^o indicates that the reduced form of the couple is a better reducing agent than H_2 and similarly a negative E^o indicates that the oxidized form of the couple is a better oxidizing agent than H^+. The couples are given in order of decreasing oxidizing power or increasing reducing power, the reduced form of any couple having sufficient potential to reduce the oxidized form of any couple of lower potential. For example, O_2 oxidizes Fe $(OH)_2$ and Mn $(OH)_2$ in alkaline solutions and Fe^{++} in acid solutions. Similarly Fe^{++} reduces Ag^+ to Ag in acid solutions. The potentials of the oxygen couples approximate those of natural solutions in contact with air at atmospheric pressure. At the pH of the Keno Hill waters (pH 6.5 to 7.5) the potential for the oxygen couple is about −0.86. The couples for hydrogen peroxide are given since Sato (1960) considers that H_2O_2 is formed as an intermediate product of oxygen reduction in aqueous solutions under weathering conditions and that the $H_2O_2 - O_2$ couple controls the oxidation potential of the weathering environment. This concept, however, requires confirmation from extensive field data.

Acid Solutions

$H_2O_2 = O_2 + 2H^+ + 2e^-$ $E^o = -0.682$

$Fe^{++} = Fe^{+++} + e^-$ $E^o = -0.771$

$2H_2O = O_2 + 4H^+ + 4e^-$ $E^o = -1.229$

$Mn^{++} + 2H_2O = MnO_2 + 4H^+ + 2e^-$ $E^o = -1.23$

$2H_2O = H_2O_2 + 2H^+ + 2e^-$ $E^o = -1.77$

A study of these potentials indicates that ferrous iron will be oxidized to the ferric state by atmospheric oxygen in both an acid and alkaline environment; the reaction will, however, proceed with greatest facility in alkaline solutions. As regards manganese, however, the potential developed by the oxygen couple is not sufficiently powerful to oxidize Mn^{++} to MnO_2 in acid solutions but is adequate in an alkaline environment.

In the oxidized zones a separation of manganese and iron may take place in some vein faults because of the difference in the oxidation potentials of the two elements. Thus in some places limonite derived from manganiferous siderite is not accompanied by wad, the reason being that at the lower pH's (about 5) the manganese is more mobile because it remains largely in the soluble Mn^{+2} state whereas the ferrous iron is nearly all oxidized and precipitated as ferric iron in limonite. The fact that manganese is more mobile than iron is also substantiated by the analyses of the spring waters (Table 58) which mostly contain from 2 to 20 times as much manganese as iron.

During the oxidation of the lodes, the iron, once it is released as ferrous salts from the various hypogene minerals, may follow several courses, as follows:

1. In relatively dry parts of the oxidized zones small amounts of iron are precipitated as rozenite and other hydrated sulphates. These probably result largely from evaporation and supersaturation, and most are temporal, redissolving during the influx of further increments of meteoric water.

2. Most of the iron is bound in limonite. The reactions to produce this mineral aggregate are complex but simplified probably run as follows. As released initially at a relatively high acidity the iron in solution would be in the ferrous state. As the acidic solutions are neutralized by reaction with siderite and other gangue minerals much of the ferrous iron is oxidized to ferric iron which undergoes extensive hydrolysis with the precipitation of either basic salts (*see* 3) or insoluble ferric hydroxide. Water may then be split out from the colloidal ferric hydroxide with the consequent formation of limonite.

Beginning with ferrous sulphate, the most abundant iron salt in the initial oxidizing solutions, the reactions may be described as follows: At a pH of about 2.5, ferrous sulphate in the presence of abundant oxygen begins to oxidize to ferric sulphate and some insoluble ferric hydroxide

$$12FeSO_4 + 3O_2 + 6H_2O = 4Fe_2(SO_4)_3 + 4Fe(OH)_3$$

Hydrolysis of the ferric sulphate will then take place with the formation of basic salts under certain conditions and finally insoluble ferric hydroxide and sulphuric acid thus—

$$Fe_2\,(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4$$

Splitting out of water from the colloidal-like ferric hydroxide yields goethite (limonite)

$$Fe(OH)_3 = \underset{\text{goethite}}{\underline{HFeO_2 + H_2O}}$$

Some of the water may be physically adsorbed to the goethite yielding the familiar limonite, $HFeO_2.nH_2O$.

The reactions leading to the precipitation of insoluble hydroxides of iron from soluble iron hydrogen carbonate are likewise those of oxidation and hydrolysis. They may be condensed and represented as

$$4Fe(HCO_3)_2 + O_2 + 10H_2O = 4Fe\ (OH)_3 + 8H_2CO_3$$

By splitting out of water goethite is formed

$$Fe(OH)_3 = \underset{\text{goethite}}{\underline{HFeO_2 + H_2O}}$$

Much of the limonite in the vein faults contains some hydrous manganese oxides (wad). This is probably because at the pH of the oxidizing waters (4-7.5) some of the manganous ion in solution is oxidized to MnO_2 and coprecipitated with the hydrous ferric oxides. Colloidal phenomena may also play a part. The colloidal manganese hydroxide always carries a negative charge whereas colloidal iron hydroxide is positively or negatively charged depending on the conditions of precipitation. When positively charged the iron hydroxide tends to coprecipitate the negatively charged manganese hydroxide; when negatively charged the manganese hydroxide is repelled and dispersed to precipitate in other sites.

Natural colloidal iron precipitates, in general, tend to have low adsorption capacities for cations as compared with those of manganese. This suggests that in most cases the former are positively charged. Substantiation of this supposition is also found in the fact that arsenic and antimony, which probably migrate as negatively charged anionic complexes (arsenates, antimonates) are strongly adsorbed and coprecipitated by natural iron hydroxides.

3. Some iron is precipitated in the basic sulphates, arsenates, and sulphate-arsenates such as beudantite, $PbFe_3(AsO_4)(SO_4)(OH)_6$, jarosites, $(K,Na,Ag)\ Fe_3\ (SO_4)_2\ (OH)_6$, and pharmacosiderite, $Fe_3(AsO_4)_2(OH)_3\ .5H_2O$. These minerals are precipitated from mildly acid solutions (pH 4-6) as intermediate products in the hydrolysis of ferric sulphate. Most are unstable minerals and tend to decompose in mildly acid and alkaline oxidizing solutions to soluble sulphates, sulphuric acid, and insoluble ferric hydroxide which precipitates ultimately as limonite.

4. Where arsenopyrite is abundant in the lodes much of the iron is bound in scorodite, $(Fe,Al)(AsO_4)\ .2H_2O$. With prolonged leaching by meteoric water the arsenate component may be removed to lower levels probably as soluble alkali arsenates leaving the iron bound mainly as limonite.

5. In the lower parts of the oxidized zone small amounts of iron are precipitated in secondary carbonates. In the zones of reduction and in local sites where reducing conditions prevailed a little ferrous iron is precipitated in secondary sulphides, principally pyrite, by the action of H_2S or by reaction with primary sulphides.

6. Very small amounts of iron are coprecipitated with several secondary minerals such as calcite, anglesite, smithsonite, malachite, etc.

7. The remainder of the iron (about 1-5ppm) migrates in the groundwater and is dispersed through springs into the streams of the area. There the waters again absorb oxygen and some of the iron is thrown down as ferric hydroxide, ultimately to accumulate as limonite.

Iron springs as described in 7 are widespread throughout the Keno Hill area. These springs are marked by an abundance of iron and manganese precipitates at their orifices and on rocks and gravel in the stream bottoms. In some streams characteristic limonitic conglomerates are developed. Iron springs found in an area should be regarded by prospectors as favourable indicators of lodes. It need hardly be pointed out that in many parts of the world iron springs carrying copper, zinc, and other metals have drawn attention to an area in which deposits were later found.

If the geochemical prospector finds iron springs in an area he should carefully consider the topographic location of the springs and the possible sources of the contained metals. In some places iron springs are closely related to lodes and are, therefore, good indicators; in other places the springs may lie some distance, generally downhill, from the lodes. In the latter, the water carrying the metal has entered mineralized zones and lodes at higher elevations and has migrated downhill along underground fractures and faults. Furthermore, the fractures and faults from which the springs issue may not be the ones containing the lodes but may be subsidiary faults or fractures or post-ore faults. There may be two sources for the zinc and other metals in the springs. The metal is derived either from oxidation of lodes or from the oxidation of sulphides scattered in the country rock or along sparsely mineralized faults and fractures. There is no way of determining which source is the main contributor. From the research carried out on the iron springs in the Keno Hill-Galena Hill area it would appear that those carrying a high manganese content and a concentration of zinc in excess of 0.05 ppm derive their zinc and manganese mainly from siderite-galena-sphalerite lodes or mineralized zones. This may not always be so, and areas around all iron springs or conglomerates should be carefully prospected, especially if the water or the material precipitated contains detectable amounts of zinc, copper, or other metals.

The chemistry of manganese in the oxidized zones is similar in many respects to that of iron and many of the details can be omitted. Once the element is released from siderite and sphalerite as either manganous sulphate or hydrogen carbonate, it may follow the following courses.

1. The bulk of the manganese is bound in wad, an indefinite mineral aggregate composed of pyrolusite, manganite, and psilomelane. This aggregate is the final product of the oxidation and hydrolysis of manganous sulphate and manganous hydrogen carbonate. The simplified reactions giving pyrolusite (MnO_2) can be stated as follows:

$$2MnSO_4 + 2H_2O + O_2 = 2MnO_2 + 2H_2SO_4$$
$$2Mn\ (HCO_3)_2 + 2H_2O + O_2 = 2MnO_2 + 4H_2CO_3$$

Unlike iron, the oxidation and hydrolysis of manganous salts is suppressed at low pH's, as predicted by the potentials given on page 183, and the two elements may be separated—limonite precipitating in one part of the oxidized zone and wad in another. More generally, however, both are found in close proximity to or intergrown with each other. This is probably because the initial acidic solutions are quickly neutralized by siderite, causing nearly simultaneous deposition of both iron and manganese. The negatively charged colloidal manganese oxides and hydroxides also tend to precipitate the positively charged iron hydroxides as already discussed under the formation of limonite. In addition they also tend to carry down relatively large amounts of cations such as zinc, silver, etc. (Table 60).

2. Small amounts of manganese are captured in the lattices of various secondary minerals, particularly in the basic sulphates, in scorodite, and in anglesite, smithsonite, etc. The secondary carbonates may also contain small amounts of the element.

3. The remainder of the manganese migrates in the groundwater and is ultimately dispersed through springs into the streams of the area. Some may be precipitated in the limonitic deposits and conglomerates. In general the mobility of manganese in the oxidizing solutions and groundwater is greater than iron. This is substantiated by the analyses given in Tables 58 and 59 which indicate that the content of dissolved manganese generally exceeds that of iron by a factor greater than 2.

Calcium and magnesium are not affected by the Eh of the environment and are in general relatively mobile under oxidizing conditions, especially in solutions containing dissolved CO_2. The contents in the spring and mine waters range from 50 to 200 ppm for Ca and 10 to 120 ppm for Mg, several times those for iron and manganese.

In the oxidized zones, the calcium and magnesium are released from siderite and other carbonates in the form of sulphates and hydrogen carbonates; they may follow one or more of the following suggested courses.

1. Small amounts of calcium and magnesium are precipitated in the upper parts of the oxidized zones as calcite and/or dolomite.

2. A very small amount of magnesium is bound in serpentine which occurs in small vugs and late fractures in various parts of the oxidized zones and immediately below in the hypogene parts of the lodes.

3. Some calcium is precipitated as microcrystalline gypsum, $CaSO_4.2H_2O$, in the upper parts of the oxidized zones and as selenite in the deeper parts of certain lodes. In the former the gypsum is intimately associated with anglesite and limonite and has probably been precipitated from a supersaturated calcium sulphate solution under mildly acidic, neutral, or mildly alkaline conditions. Direct action by H_2SO_4 on the calcium component of siderite or other carbonates may also be partly responsible for some of the gypsum in the limonitic boxworks and masses derived from siderite, thus:

$$CaCO_3 \text{ (calcium component)} + H_2SO_4 + 2H_2O = CaSO_4.2H_2O + H_2CO_3.$$

The selenite in the deep parts of some oxidized zones occurs in intimate association with calcite and transported limonite, indicating precipitation under near neutral conditions. Supersaturation with respect to $CaSO_4$, partly as a result of the decrease in acidity of the descending meteoric solutions, is probably responsible for the precipitation of selenite and gypsum in the lower parts of the oxidized zones.

4. Small amounts of calcium and magnesium are precipitated in well-crystallized calcite and dolomite in the deeper parts of some oxidized zones. Supersaturation with

respect to $CaCO_3$ and $MgCO_3$, resulting from a decrease in acidity as the meteoric solutions migrate downward, is probably the main reason for the formation of these secondary carbonates.

5. Relatively large amounts of both calcium and magnesium migrate in the groundwater and are ultimately dispersed through springs into the stream systems of the area. Some of this calcium and magnesium is precipitated with the limonitic masses on the stream bottoms (Table 60), as microcrystalline carbonates, or as indefinite hydroxides. The rest moves on.

In the light of the above discussion and with reference to the data in Table 56, the chemistry of Fe, Mn, Mg, and Ca during the oxidation of the lodes can be summarized as follows:

The iron content of the oxidized and unoxidized lodes remains constant within relatively narrow limits. This is because iron is strongly influenced by the Eh and pH of the environment. Most of the ferrous iron released by oxidation of carbonates and sulphides is quickly precipitated as limonite and basic sulphates as a result of oxidation and hydrolysis in the mildly acidic solutions. Only relatively small amounts migrate out of the deposits into the groundwater.

Manganese is not as markedly affected as iron by free oxygen in mildly acid solutions, but tends to be precipitated in larger amounts in neutral or slightly alkaline solutions. This endows manganese with a somewhat higher mobility, and the element tends to be leached in certain vein faults. The amounts migrating out of the deposits into the groundwater system are generally much greater than those for iron.

Calcium and magnesium are not affected by the Eh of the environment but are pH dependent. There is a general decrease of these elements in the more highly oxidized parts of the lodes, and a relatively large amount of both is dispersed into the groundwater system and ultimately through springs into the stream systems.

Alkalies, Silica, and Alumina

The chemistry of sodium and potassium is not affected by the Eh of the environment, nor to any marked degree by the pH. Consequently each is highly mobile under both oxidizing and reducing conditions. According to the most recent data the equilibrium solubility of silica is essentially independent of the pH between the range 2 to 8. Above pH 8 the solubility increases rapidly with alkalinity because of the formation of soluble silicate anions. Aluminum, an amphoteric element, however, shows a marked pH dependence. Below pH 4 and above pH 10 Al_2O_3 is readily soluble; between pH's 6 to 8 Al_2O_3 is relatively insoluble.

In the lodes the alkalies and alumina are mainly in the wall-rock minerals, but small amounts occur in siderite and various other gangue minerals. Silica is bound in the wall-rock silicates and in the quartz of the lodes. During oxidation of the lodes the carbonated meteoric water and H_2SO_4 released during oxidation of pyrite and other sulphides attack the silicates and quartz releasing the alkalies as soluble carbonates, hydrogen carbonates, and sulphates. Silica may be released either as soluble alkali silicates or as dissolved silica probably in the form of monosilicic acid, $Si(OH)_4$. Alumina probably enters solution as the soluble sulphate or as the alkali sulphates.

Sodium and potassium can be traced as follows:

1. Small amounts of sodium and potassium are bound in the jarosites and in numerous other secondary minerals, especially limonite and wad. In the jarosites, the alkalies are lattice constituents. In the other minerals a small part of the alkali content may be adsorbed; the form in which the remainder is present is unknown.

2. Small amounts of sodium and potassium (0.5 to 3 ppm) are dispersed through springs into the streams of the area.

The lead-zinc ores (Table 56) contain relatively little sodium and potassium, and there is little indication of any marked change in their content between the oxidized and primary parts of the lodes.

Alumina follows one of the following courses during the oxidation of the lodes:

1. Much alumina is bound in limonite, wad, scorodite and the basic sulphates and sulphate-arsenates (Tables 42, 43, and 60). This alumina is coprecipitated with ferric hydroxide between pH's 5-7.5 largely as $Al(OH)_3$ as a result of the hydrolysis of the aluminum sulphate either by dilution or by neutralization of the acidic solutions:

$$Al_2(SO_4)_3 + 6H_2O = 2Al(OH)_3 + 3H_2SO_4$$

Colloidal aluminum hydroxide carries a positive charge and may also be coprecipitated by the negatively charged manganese hydrosols.

2. Small amounts of alumina are bound in the secondary clay minerals that occur in parts of the oxidized zones and upper parts of primary zones. These minerals likewise probably result by hydrolysis of aluminum salts due to changes in acidity.

3. Some alumina (1-15 ppm) is dispersed into the groundwater and finally through springs into the stream system of the area. A little alumina is coprecipitated with ferric hydroxide (limonite) on the stream bottoms near the springs.

In the lodes some alumina remains behind in the oxidation products but as a general rule the alumina tends to be leached from the more highly oxidized parts (Table 56).

Silica probably enters solution as soluble alkali silicates, complex aluminosilicates, or as monosilicic acid, $Si(OH)_4$. The reaction representing the solubility of the latter molecule may be represented thus:

$$(SiO_2)_n + 2n(H_2O) = nSi(OH)_4$$

This is a hydration and depolymerization reaction (Iler, 1955).

The precipitation of silica is actually a most complicated process, not readily treated in detail here. For the purposes of discussion it is sufficient to say that the precipitation is a polymerization process represented by the reverse equilibrium given above:

$$nSi(OH)_4 = (SiO_2)_n + 2n(H_2O)$$

The precipitate is often of a colloidal nature, the colloid carrying a negative charge in alkaline, neutral, and weakly acid solutions and a positive charge in strongly acid solutions.

The solubility of silica is lowered by the presence of $Ca(HCO_3)_2$, $Mg(HCO_3)_2$, Na_2SO_4, and other similar compounds in solution. Positively charged cations tend to precipitate colloidal silica at slightly acid or near neutral pH's by neutralizing the negative charge on the colloids. Al^{3+} precipitates silica from a sol with the formation of insoluble aluminum silicates, and other cations capable of forming insoluble silicates probably behave in a similar manner. Ferric hydroxide causes rapid coagulation of excess silica from supersaturated solutions.

During the oxidation of the lodes at Keno Hill silica may follow one of the following courses:

1. Much silica is bound in microcrystalline quartz in the limonitic and manganiferous debris of the oxidized zones. This quartz probably resulted by supersaturation of the solutions with respect to silica as a result of changes in acidity and the presence of abundant ferric hydroxide, $Ca(HCO_3)_2$, and other components.

2. Some silica is bound in limonite, wad, basic sulphates, and other products of oxidation (Tables 42, 43, and 60). The precise nature of much of this silica is unknown. Some is probably present as microcrystalline quartz; the remainder may be present as hydrated silica, $SiO_2.nH_2O$. Much of this silica was probably coprecipitated as a colloid with ferric hydroxide and manganese hydroxide as a result of neutralization of the negative charges of the silica sols mainly by $Fe\ (OH)_3$.

3. Some silica is precipitated as secondary fine-grained quartz in the deep parts of some oxidized zones, and in the zones of reduction; also in some places in the vuggy parts of the primary lodes. In these sites the quartz is generally accompanied by secondary calcite, gypsum, transported limonite, and smithsonite. Precipitation of the silica was probably induced by the high concentrations of $Ca(HCO_3)_2$ and $Mg(HCO_3)$ in the solutions in these sites.

4. Small amounts of silica are bound in the hydrated aluminosilicates such as montmorillonite and kaolinite that occur in some parts of the oxidized zones and primary zones.

5. A little silica (5-10 ppm) is dispersed into the groundwater and ultimately through springs into the stream systems. A small amount of this silica may be coprecipitated in the iron and manganese precipitates near the orifices of the springs and on nearby stream bottoms.

There is a general enrichment in silica in the highly oxidized parts of the siderite-galena-sphalerite lodes over that in the primary ore (Table 56). Probably all of this silica was in solution at one time and was precipitated before migrating far by the processes discussed above.

Sulphur

In the primary lodes sulphur is bound in the various sulphides and sulphosalts. There is relatively little sulphur in the form of primary sulphate, although some barite may be of hypogene origin.

During the oxidation of the various sulphides, sulphur is generally oxidized directly to SO_4^{2-} but in some places native sulphur encrusts sphalerite, pyrite, and the lead sulphosalts and may in addition occur as coatings and microcrystals in the limonitic rubble of the oxidized zones.

During oxidation of the lodes sulphur behaves as follows:

1. Some of the sulphur oxidized to sulphate is precipitated as rozenite, $FeSO_4.4H_2O$, gunningite, $ZnSO_4.H_2O$, and similar sulphates as a result of supersaturation, most probably due to evaporation. These minerals seem to form in dry environments and are temporal, dissolving again in fresh increments of meteoric waters.

2. Some of the sulphate is bound in basic sulphates such as beudantite and the jarosites. These minerals are largely precipitated during the hydrolysis of ferric sulphate and are described under iron (*see* p. 185).

3. Much sulphate is bound in anglesite and some in gypsum. The chemistry of these secondary minerals is discussed under lead and calcium.

4. Small amounts of sulphur are precipitated in the native state on pyrite, sphalerite, and the lead sulphosalts. The reactions producing sulphur from pyrite are probably very complicated but may be represented as follows:

$$FeS_2 + 2O_2 = FeSO_4 + S$$

Such a reaction is only possible when both the oxidation potential and pH are low.

Garrels and Thompson (1960) suggest that the oxidation of pyrite by ferric iron under equilibrium conditions yields molecular sulphur, but that any excess of ferric iron will rapidly oxidize this sulphur through intermediate species to sulphate. This seems to hold for most of the oxidation of the pyrite in the Keno Hill lodes.

The action of H_2SO_4 on sphalerite yields some H_2S thus:

$$ZnS + H_2SO_4 = ZnSO_4 + H_2S$$

In accordance with the potentials given on page 205 the hydrogen sulphide and any sulphide ion are oxidized rapidly and quantitatively to sulphur by oxygen and Fe^{3+} ion in acidic solutions. In most cases it is probable that the ferric ion is the responsible agent for the production of molecular sulphur, and the reaction may be written as:

$$H_2S + 2Fe^{+++} = S + 2Fe^{++} + 2H^+$$

5. A little sulphur is bound in secondary sulphides, such as pyrite, marcasite, sphalerite, galena, and pyrargyrite, in the zones of reduction and in local sites where reducing conditions prevailed.

6. Relatively large quantities of sulphur are dispersed as sulphate (200-1200 ppm) into the groundwater and are ultimately delivered through springs into the stream system of the area. Some sulphate is temporarily precipitated as jarosites in some of the limonitic deposits near the springs, but these minerals tend to be unstable and break down to give limonite and soluble sulphate. This sulphate then joins that in solution in the streams and moves on.

During the oxidation of the lodes sulphur as sulphate is strongly leached (Table 56). In most veins more than half the sulphur of the hypogene ores is lost as a result of oxidation.

From these considerations it follows that springs having a high soluble sulphate content may indicate the presence of oxidizing sulphides.

Arsenic

The most abundant primary arsenical mineral in the lodes is arsenopyrite. Small amounts of arsenic are also bound in freibergite and pyrite.

The reactions involved in the oxidation of arsenopyrite are probably complex but in a simplified way it would seem that the products consist essentially of ferric arsenate and some sulphuric acid as follows:

$$2FeAsS + 7O_2 + 2H_2O = 2FeAsO_4 + 2H_2SO_4$$

The arsenic component of freibergite and pyrite are probably also taken into solution as ferric arsenate, arsenites, and arsenic sulphate. In addition other arsenates may be formed during the oxidation of the arsenical minerals, but these would probably only be intermediate products in the reactions.

Ferric arsenate is a relatively insoluble compound, but in solutions containing H_2SO_4 it exhibits some mobility. The relative insolubility of ferric arsenate is reflected in the fact that the oxidation products of the arsenical minerals are generally found in close association with those from which they were derived.

During the oxidation of the lodes arsenic behaves as follows:

1. In the lodes carrying abundant arsenopyrite most of the arsenic is bound in scorodite, $(Fe, Al)(AsO_4).2H_2O$, with smaller amounts in pharmacosiderite, $Fe_3(AsO_4)_2(OH)_3.5H_2O$. The former mineral is the result of direct precipitation of hydrated ferric arsenate during the oxidation of arsenopyrite as discussed above. Pharmacosiderite is a basic salt and is precipitated as one of the products of the hydrolysis of ferric and arsenic sulphates during neutralization of the oxidizing solutions. Coprecipitation phenomena as outlined in 4 may also play a part in the formation of both minerals.

2. In lodes rich in lead minerals beudantite, $PbFe_3(AsO_4)(SO_4)(OH)_6$, is the stable secondary sulphate-arsenate. This basic salt is formed in mildly acid solutions as one of the products of the hydrolysis of ferric and arsenic sulphates.

3. Small amounts of arsenic are bound in pyromorphite and mimetite, $Pb_5(PO_4, AsO_4)_3Cl$. In these two minerals P and As substitute mutually, and a complete series extends between the essentially pure end-members. They were precipitated in zones where the chloride ion concentration was high.

4. Some arsenic is coprecipitated by $Fe(OH)_3$ and is bound in limonite and other secondary iron, manganese, and lead minerals. The amounts coprecipitated by ferric hydroxide are high compared with those in the manganese hydrosols (Tables 42 and 60). The reason for this is probably due to the fact that colloidal $Fe(OH)_3$ generally carries a positive charge which tends to neutralize and precipitate the arsenate ion, $(AsO_4)^{3-}$. The manganese sols, on the other hand carry a negative charge and hence repel the arsenate ions.

5. Small amounts of arsenic are bound in bindheimite, anglesite, rozenite, etc., and in the secondary sulphides, pyrite, marcasite, and pyrargyrite.

6. Only very small amounts ($<.002$ ppm) of arsenic are dispersed into the groundwater system and through springs into the streams of the area. This arsenic may be in the form of soluble alkali or alkaline earth arsenates.

During oxidation of the lead-zinc-silver lodes there is relatively little migration of arsenic as indicated by the composite analyses of these ores in Table 56. In some veins there appears to be a slight enrichment of the element in the oxidized parts. The analyses of the oxidized and primary quartz-pyrite-arsenopyrite ores indicate some migration of arsenic. This is, however, not general as the near surface parts of many of these veins, especially in the Dublin Gulch area, contain an abundance of scorodite.

Antimony

The bulk of the antimony in the hypogene lodes is bound in freibergite, jamesonite, boulangerite, and other sulphosalts. Small amounts are present in arsenopyrite, pyrite, galena, and other sulphides.

During the oxidation of the lodes antimony behaves somewhat like arsenic although chemically it is more basic. The sulphosalts probably initially yield antimony sulphate and some antimony trioxide to the oxidizing solutions. The reactions for jamesonite and tetrahedrite, although probably very complex, can be written simply as:

$$\frac{Pb_4FeSb_6S_{14}}{\text{jamesonite}} + 28O_2 = 4PbSO_4 + FeSO_4 + 3Sb_2(SO_4)_3$$

$$\frac{6Cu_{12}Sb_4S_{13}}{\text{tetrahedrite}} + 171O_2 = 72CuSO_4 + 10Sb_2O_3 + 2Sb_2(SO_4)_3$$

Antimony trioxide is slightly soluble in sulphuric acid solutions with the formation of the sulphate. On dilution or neutralization, solutions of antimony sulphate undergo rapid hydrolysis with the precipitation of the trioxide at high acidities and basic salts at low acidities. Oxidizing agents such as ferric iron tend to precipitate Sb_2O_3 from solutions of antimony salts.

During the oxidation of the lodes antimony may follow one of the following courses:

1. Some of the antimony is bound in bindheimite, $Pb_2Sb_2O_6(O,OH)$. This mineral is formed where a high lead content prevails in the ores. It is characteristically developed on or near galena, jamesonite, boulangerite, etc. Bindheimite is essentially a pyroantimonate of lead and is probably precipitated by the action of a lead salt on antimony trioxide in mildly acid and neutral oxidizing solutions.

2. A small amount of antimony is bound in senarmontite, Sb_2O_3. This mineral is nearly always found encrusting jamesonite or other lead sulphosalts intimately associated with pyrite. It is probably formed as one of the reaction products of the hydrolysis of acid antimony sulphate solutions, or alternatively it may have been precipitated from antimony solutions by ferric hydroxide.

3. Some antimony is coprecipitated by ferric hydroxide (limonite), wad, and various basic salts such as beudantite and jarosites. The indigenous limonites contain much greater amounts of the element than the transported hydroxides (limonites) (Table 42). The limonites also tend to be enriched in antimony compared with the

wads. This is probably because the negative antimonate ion is neutralized and precipitated by the positively charged colloidal ferric hydroxide, whereas it is repelled by the negatively charged manganese sols.

4. Small amounts of antimony are captured in the structures of scorodite, malachite, azurite, and anglesite.

5. In the zones of reduction and in sites where local reduction processes have been active in the lower parts of the oxidized zones, some antimony is precipitated as pyrargyrite, Ag_3SbS_3, and as traces in other secondary sulphides. The origin of pyrargyrite is discussed under silver. In some veins the quantity of pyrargyrite is of economic importance.

6. Very small amounts of antimony (<0.001 ppm) are dispersed into the groundwater system and ultimately through springs into the streams. A small amount of this antimony may be precipitated with limonite, wad, and other compounds on the stream bottoms and in conglomeratic masses (Table 60).

During the oxidation of the ores there is no marked migration of antimony. In most lodes (Table 56) the more highly oxidized parts are enriched in antimony, and in this respect the element tends to follow lead and silver closely in its geochemistry. In a few lodes antimony is leached to a moderate degree.

Zinc

Among the hypogene minerals zinc is principally in sphalerite with minor amounts in freibergite. Traces are also present in the other common sulphides and sulphosalts.

During oxidation of the sphalerite and tetrahedrite zinc is delivered to the oxidizing solutions as the soluble sulphate. The reactions for ZnS may be written simply as follows:

$$ZnS + 2O_2 = ZnSO_4$$

Sphalerite is also attacked by sulphuric acid thus:

$$ZnS + H_2SO_4 = ZnSO_4 + H_2S$$

This reaction is hastened by ferric sulphate and other oxidizing compounds.

According to Wang (1915), ferric sulphate in aqueous solution attacks sphalerite, forming ferrous sulphate, zinc sulphate, and sulphur. He gives the following equation for the reaction:

$$ZnS + Fe_2(SO_4)_3 = 2FeSO_4 + ZnSO_4 + S.$$

The crusts of sulphur on sphalerite in some places may be due to this reaction. Some sulphur may also be derived by oxidation of H_2S as described in the section on the element.

In all its salts and compounds zinc is bivalent, hence the element is not directly influenced by changes in the Eh of the environment. The element possesses amphoteric properties, forming the zinc ion $Zn(H_2O)_4^{2+}$ in acid solutions and the zincate ion, $Zn(OH)_4^{2-}$ in strongly basic solutions. Under the conditions of oxidation of the lodes at Keno Hill where the pH's of the waters range from 4 to 7.5 most of the zinc would probably be present as the zinc ion with only small amounts of zincate ion at the higher pH's.

Zinc salts undergo hydrolysis, but not as readily as ferric salts. The products of hydrolysis include basic salts, the hydroxide $Zn(OH)_2$, and in some cases soluble complexes. The sulphate displays much less tendency to hydrolyze than the chlorides and other salts.

During oxidation zinc may follow one of the following courses:

1. Minor amounts of zinc are bound in hydrated zinc and ferrous salts such as gunningite and rozenite. These salts are formed by supersaturation due to evaporation and are temporal, redissolving as fresh increments of meteoric water percolate through the lodes.

2. Small amounts of zinc are adsorbed and/or coprecipitated by iron hydroxide (limonite) and wad. Both these mineral aggregates tend to carry zinc, the manganese precipitates generally containing the greatest amounts (Tables 42 and 60). The nature of the zinc in these compounds is unknown. Some seem to contain sufficient to form separate mineral phases. Perhaps some of these are complex hydrous zinc manganites or ferrites. The precipitation of cationic zinc in limonite and wad is partly due to strong adsorption of the positively charged zinc ion on the negatively charged manganese hydrosols; the zincate ion may be adsorbed to the positively charged colloidal $Fe(OH)_3$ in an alkaline environment. In addition all limonites and wads carry considerable silica, alumina, calcium, and magnesium, all probably precipitated originally in a colloidal form either as hydroxides, hydrous oxides, or hydrous silicates. These would also tend to precipitate cationic zinc or zincate ion. Some zinc may also be precipitated with ferric hydroxide and other hydroxides as $Zn(OH)_2$.

3. Some zinc is captured in secondary minerals such as the jarosites, beudantite, malachite, anglesite, and senarmontite. Small amounts of zinc are precipitated locally in aurichalcite, the carbonate-hydroxide of copper and zinc.

4. In some of the deeper parts of the oxidized zones and in parts of the zones of reduction, a little zinc is precipitated from solution as smithsonite. This mineral generally occurs intimately associated with secondary calcite, gypsum, and transported limonite. The reactions to produce these minerals from solutions of their various dissolved ions and anions cannot readily be set down. The metathesis involved in the concomitant precipitation of smithsonite and gypsum may however be represented as follows:

$$ZnSO_4 + Ca(HCO_3)_2 + 2H_2O = ZnCO_3 + CaSO_4.2H_2O + H_2CO_3$$

This reaction is favoured under near neutral or slightly alkaline conditions.

5. Very small amounts of zinc are bound in tiny plates and scales of the native metal in intensely oxidized parts of a few veins (Boyle, 1961a). In these sites the native zinc is closely associated with native silver, pulverulent limonite, and manganese oxides. In most occurrences the mineral is obviously derived from sphalerite by oxidation, but the chemistry leading to its formation is not entirely clear.

Because of the relatively high position of zinc in the electrochemical series ($Zn = Zn^{2+} + 2e^-$, $E^o = 0.763v$), it seems unlikely that any of the metals or ions, normally present in the oxidizing environment at Keno Hill (viz., Ag, Fe^{2+}, Fe^{3+}, Mn^{2+}, Mn^{4+}, all lower in the series) would effect the reduction of zinc from sphalerite or its soluble salts. Both carbon and methane will reduce zinc from its compounds at high temperatures, but such a mechanism is hardly applicable to the situation in the veins at Keno Hill. However, the reducing power of various organic compounds is well known, and these may be responsible for the reduction of zinc from its salts in the veins.

Alternatively, an auto-oxidation process can be imagined for sphalerite whereby the sulphide (ion) is oxidized directly to sulphur in a neutral or slightly alkaline environment ($S^{2-} = S + 2e^-$) and the zinc is reduced to the metal ($Zn^{2+} + 2e^- = Zn$). Although such a direct mechanism seems unsatisfactory on purely energetic grounds, it does represent the overall reactions that have taken place. Moreover, it seems to fit the facts best at Keno Hill, where native sulphur is common in the oxidized zones, especially near residual nodules of sphalerite, and where the present oxidizing solutions are nearly neutral or slightly alkaline, a condition that favours the formation and preservation of the native zinc.

6. In the zones of reduction some zinc is bound in secondary sphalerite, and traces are captured in other secondary sulphides. The formation of secondary sphalerite appears to depend on a local concentration of sulphide ion or H_2S, both of which are probably derived by the action of sulphuric acid on galena, sphalerite, and other sulphides under a low oxidation potential. The acid reaction for sphalerite may be written

$$ZnS + H_2SO_4 \rightleftharpoons ZnSO_4 + H_2S$$

As the meteoric solutions pass downward and the acidity decreases, the reverse equilibrium will come into play, with the precipitation of some secondary sphalerite. In general, however, during transit, most of the liberated H_2S is oxidized on to sulphate ion leaving little to react with the soluble zinc in the zones of reduction. This circumstance is reflected in the general low contents of secondary sphalerite in all veins.

In some veins secondary sphalerite occurs in close proximity to graphitic argillites and schists. In such sites carbonaceous material may have had a reducing effect on $ZnSO_4$, precipitating secondary sphalerite under suitable conditions.

In other situations secondary microcrystalline sphalerite is intimately associated with fine-grained marcasite and secondary pyrite or with finely comminuted primary pyrite and galena. Such relationships suggest that pyrite and marcasite have a precipitating effect on zinc. In the scheme of the solubilities of the metal sulphides (Schürmann's series) zinc sulphide (sphalerite) ($Ksp = 7 \times 10^{-26}$) is much less soluble than ferrous sulphide (marcasite and pyrite) ($Ksp = 4 \times 10^{-19}$), and zinc should replace iron in a sulphide milieu. Simplified equations involving the precipitation of sphalerite by the reaction of $ZnSO_4$ with pyrite and marcasite may be written as follows:

$$7ZnSO_4 + 4FeS_2 + 4H_2O = 7ZnS + 4FeSO_4 + 4H_2SO_4$$

These reactions and probably others of a much more complex nature would seem to be responsible for the small amounts of secondary sphalerite found in association with iron sulphides in a few of the zones of reduction.

7. Much zinc (up to 80 ppm) is dispersed into the groundwater system and ultimately through springs into the streams of the area. A little of this zinc is temporarily precipitated in the iron hydroxides near the orifices of the springs. On the transformation and consolidation of these hydroxides into limonite most of this zinc tends

to be leached out and delivered again to the stream waters. If the precipitates contain much manganese, however, relatively large amounts of zinc may be retained.

Streams and springs that dissipate their water into bogs have their zinc (as well as other metals) largely removed as a result of adsorption on decaying vegetation, humic compounds, and other organic colloidal substances. Initially this zinc is loosely bound and can be removed by acid or citrate solutions. With aging, however, the zinc partakes of the organic colloidal complexes and is then relatively tightly bound and unavailable to most extractants. All bog and organic materials have a high base exchange capacity (Table 3), a feature which undoubtedly contributes to their great facility for extracting zinc and other metals from surface waters. Numerous bogs that extract the zinc from surface waters were observed in the Keno Hill area. One of these into which the mine water from the Hector-Calumet mine flows, effectively removes all of the zinc (40 ppm) in less than 2,000 feet.

A comparison of the zinc content of the oxidized and unoxidized ores (Table 56) shows that large tonnages of zinc have been removed in solution from the oxidized zones of most vein faults. This process is continuing and numerous springs carrying zinc occur throughout the main mineralized belt in the Keno Hill-Galena Hill-Mount Haldane area (Boyle, *et al.*, 1955, 1956).

Prospectors finding such springs, and attempting to relate them to hidden lead-zinc-silver deposits, should be guided by the principles set out under the section on iron springs.

Cadmium

Cadmium resembles zinc in its chemistry and behaves in much the same way during the oxidation of the lodes. Like zinc, cadmium is bivalent in its compounds and salts. The hydroxide is considerably more basic than zinc hydroxide, and there is no appreciable formation of cadmate ion in dilute hydroxide solutions. Cadmium salts do not dissociate readily and hence have less tendency to hydrolyze than do those of zinc. In nature the common salts of cadmium are the sulphate and the carbonate. The sulphate is very soluble in water; the carbonate is relatively insoluble in pure water, but the solubility increases with increase in the CO_2 content of water. The solubility of cadmium sulphide ($Ksp = 1.0 \times 10^{-28}$) in water is lower than sphalerite ($Ksp = 7.0 \times 10^{-26}$) and wurtzite ($Ksp = 1.6 \times 10^{-23}$). In the scheme of precipitation of the sulphides, CdS is precipitated by H_2S at acid pH's whereas ZnS precipitates at near neutral or alkaline pH's. Furthermore, since cadmium sulphide is less soluble than the sulphides of iron (pyrite, $Ksp = 4 \times 10^{-19}$), lead, and zinc, cadmium should replace these elements in their sulphide combinations.

Among the hypogene minerals of the lodes, cadmium is concentrated in sphalerite (maximum content 1.16 per cent) and in freibergite (up to 2,000 ppm). Galena may contain 200 ppm, but this is exceptional and most samples contain less than 10 ppm. All other sulphides and sulphosalts contain only traces of the element (< 10 ppm).

During the oxidation of sphalerite and freibergite, cadmium is delivered to the meteoric solutions as soluble cadmium sulphate or as soluble hydrogen carbonate:

$$CdS \text{ (in sphalerite)} + 2O_2 = CdSO_4$$
$$Cd^{2+} \text{ (in sphalerite)} + 2(HCO_3)^- = Cd(HCO_3)_2$$

From this point the cadmium may follow one of the following courses:

1. Small amounts of cadmium are bound in the vein limonites and wad (Table 42). The transported limonites are low in the element; the transported manganese oxide precipitates tend to be enriched (Table 60). The reasons for the precipitation of cadmium in limonites and wad are similar to those given above for zinc.

2. Several secondary minerals, particularly beudantite, jarosites, bindheimite, anglesite, and senarmontite tend to concentrate cadmium. Other oxidation products such as cerussite, scorodite, and pyromorphite generally do not contain cadmium. The presence of cadmium in beudantite, plumbojarosite, bindheimite, senarmontite, and anglesite suggests a close affinity between cadmium and lead and also between cadmium and antimony, especially since anglesites and beudantites that have high Sb contents also contain relatively high amounts of cadmium.

3. Small amounts of cadmium are bound in native zinc in intensely oxidized zones.

4. Some cadmium is bound in smithsonite in the lower parts of the oxidized zones or upper parts of zones of reduction. The formation of smithsonite is discussed in the section on zinc.

5. Some cadmium is precipitated as hawleyite (β CdS) on sphalerite or pyrite or in their near vicinity in the lower parts of the oxidized zones and in the zones of reduction. The formation of hawleyite may be due to two processes: one, the reaction of $CdSO_4$ (or $Cd(HCO_3)_2$) with sphalerite, and two, the precipitation of CdS by the action of H_2S on dissolved cadmium sulphate (or cadmium hydrogen carbonate) in a moderately acid environment.

In the first case the precipitation of cadmium is due to the differential solubilities of CdS and ZnS mentioned previously. The reaction can be written as follows:

$$ZnS + CdSO_4 = CdS + ZnSO_4$$

In the second case the process leading to the precipitation of hawleyite probably runs as follows: sulphuric acid, derived from the oxidation of pyrite or by the hydrolysis of ferric and other sulphates attacks the ZnS and CdS components of sphalerite yielding H_2S and soluble sulphates thus:

$$ZnS + H_2SO_4 = ZnSO_4 + H_2S$$
$$CdS + H_2SO_4 = CdSO_4 + H_2S$$

As the acidity decreases the second reaction is reversed and CdS is precipitated. ZnS, on the other hand, remains in solution because its solubility is high under acid conditions. The formation of CdS in the β form appears to be conditioned by the type of salt solution from which it is precipitated and also by the absence of chloride ion (Sato, 1959.) Thus β CdS tends to be precipitated from cadmium sulphate (or nitrate) solutions and α CdS (greenockite) from cadmium chloride solutions. Furthermore, Sato found that small amounts of chloride added to cadmium sulphate (or nitrate) caused the precipitation of α CdS. Since chloride ion is essentially absent in the underground waters at Keno Hill (0.5 to 1.0 ppm) and the cadmium is present mainly as sulphate, the precipitation of β CdS or hawleyite is readily understood.

6. Small amounts of cadmium are precipitated in secondary sphalerite and some is captured in pyrargyrite. This latter association again emphasizes the affinity of cadmium for certain types of antimony minerals.

7. Some cadmium (0.001-1.0 ppm) is dispersed into the groundwater system and ultimately finds its way through springs into the streams of the area. This cadmium essentially follows the same course as zinc from this point onward.

During the oxidation of the lodes cadmium is strongly leached from the more highly oxidized parts of the lodes (Table 56). In this respect the element is closely akin to zinc.

Lead

Lead forms two compounds in which the valences are +2 (plumbous) and +4 (plumbic). The plumbous compounds are prevailingly basic and their salts ionize in solution. The plumbic compounds are few, are largely covalent, and tend to be unstable. Only the plumbous compounds are of importance in nature.

Plumbous salts have a slight tendency to hydrolyze. The hydroxide, $Pb(OH)_2$, is amphoteric, reacting with acids to form plumbous salts and with hydroxyl ion to form plumbites. Several oxides are stable in nature and the carbonate and sulphate are frequently found.

Lead sulphate (anglesite) has a low solubility in water (0.0425 gms per litre at 25°C), and the solubility is decreased by high concentrations of H_2SO_4, which hinder the hydrolysis of the salt. In solutions containing CO_2 the salt may pass by stages to the relatively soluble lead hydrogen carbonate. In nature, therefore, anglesite may be leached out of deposits through which large volumes of meteoric water carrying CO_2 have passed.

Lead carbonate (cerussite) is slightly soluble in water containing CO_2 (10.9 milligrams dissolve in 1 litre of water containing 43.5 milligrams of CO_2 at 18°C). Some lead as carbonate will, therefore, be removed from deposits by meteoric waters carrying CO_2.

Certain organic compounds of lead, particularly the acetates, are very soluble. As organic compounds are common in soils and may also gain access to the oxidizing parts of veins, transfer of lead as an acetate or some other soluble organic complex may take place under certain conditions.

In the veins at Keno Hill most of the lead is bound as the sulphide, galena, and smaller amounts are present in several lead sulphosalts. Traces or minor amounts of lead occur in practically all the vein minerals.

During the oxidation of the lodes lead behaves as follows:

1. Large amounts of lead remain in nodules and lumps of galena and sulphosalts coated with anglesite and cerussite. During weathering these may pass into the nearby soils.

2. Relatively large amounts of lead are bound in anglesite, $PbSO_4$. This mineral is developed largely on galena and sulphosalts, but some is present in seams and porous zones and represents transported material. The formation of anglesite from galena and

sulphosalts may proceed by various mechanisms—direct oxidation, the action of H_2SO_4, and the action of ferric sulphate solutions. For galena the reactions may be written:

$$PbS + 2O_2 = PbSO_4$$

$$PbS + H_2SO_4 = PbSO_4 + H_2S$$

$$PbS + Fe_2(SO_4)_3 = 2\,FeSO_4 + PbSO_4 + S$$

Some of the $PbSO_4$ may migrate in solution into local fractures and porous zones where it is precipitated. More generally, however, because of its low solubility, the greater part remains in situ on the galena and sulphosalts.

3. Large amounts of lead are bound in cerussite, $PbCO_3$. From mineralogical evidence this appears to be the most stable of the lead minerals in soils and in the highly oxidized zones. Paragenetic relationships suggest that much of the cerussite is developed from anglesite, probably by the direct action of carbonic acid (H_2O+CO_2) as follows:

$$PbSO_4 + H_2CO_3 = PbCO_3 + H_2SO_4$$

Other mechanisms may also be effective, such as the action of solutions carrying alkaline earth bicarbonates on anglesite and the co-mingling of solutions bearing $PbSO_4$ and alkaline earth bicarbonates. Both these reactions are essentially similar and may be written:

$$2PbSO_4 + Ca(HCO_3)_2 = 2PbCO_3 + CaSO_4 + H_2SO_4$$

Some cerussite develops directly on galena and is probably due to the action of carbonic acid on the sulphide, thus:

$$PbS + H_2CO_3 + 2O_2 = PbCO_3 + H_2SO_4$$

All reactions to form cerussite must take place under neutral or alkaline conditions because of the relatively high solubility of the carbonate in acid solutions.

4. Much lead is bound in the vein limonites and wads (Table 42). Some of this lead occurs in extremely finely divided anglesite, cerussite, and other secondary lead minerals that cannot readily be separated from the iron and manganese oxides; the remainder is probably adsorbed or forms an integral part of the mineral aggregates. It is apparent from the data of the natural precipitates (Table 60) that lead is more strongly adsorbed or coprecipitated by the manganese oxides than by ferric hydroxide. The reasons for this are the same as those given for zinc and other metals. The high charge on the lead ion should permit the same degree of adsorption as zinc, but the very low solubility of the lead salts hinders any marked degree of enrichment in the precipitates from the natural waters.

5. Some lead is bound in beudantite, jarosites, and bindheimite. The formation of the first two minerals was discussed under iron and the last-named under antimony. Small amounts of lead are bound in dundasite, the hydrated basic carbonate of lead and aluminum. This mineral appears to have formed during the neutralization of acidic lead- and aluminum-bearing solutions by siderite and other carbonates.

6. Small amounts of lead are bound in pyromorphite and mimetite, $Pb_5(PO_4, AsO_4)_3\,Cl$. In most occurrences these minerals appear to have been precipitated from

solutions of their respective constituents. They probably reflect local conditions where phosphate and chloride were abundant in the meteoric waters. The waters from which pyromorphite and mimetite were deposited must have had pH's close to the neutral point as both minerals are soluble in acid and alkaline solutions.

7. Very small amounts of lead occur as the oxides. These minerals tend to form in intensely oxidized zones where few if any sulphides remain. Most appear to develop from anglesite and cerussite. The oxides are decomposed by H_2SO_4 with precipitation of $PbSO_4$. Hence they must have been formed during the last stages of oxidation when all the sulphuric acid from oxidizing sulphides had been dissipated or neutralized.

8. Small amounts of lead are bound in secondary galena in the zones of reduction and in local sites where reducing conditions prevailed. Traces of lead are also present in secondary sulphides such as pyrargyrite and marcasite.

The formation of secondary galena appears to depend on a local concentration of sulphide ion or H_2S, both of which are probably formed by the action of sulphuric acid on sphalerite, galena, and other sulphides under a low oxidation potential. The acid reaction for galena may be written:

$$PbS + H_2SO_4 \rightleftharpoons PbSO_4 + H_2S$$

As the meteoric solutions pass downward and the acidity decreases, the reverse equilibrium will take effect, with the precipitation of some secondary galena. In general however, during transit most of the liberated H_2S is oxidized on to sulphate ion, leaving little for reaction. This, combined with the very low solubility of the common lead salts, is the reason for the general low contents of secondary galena in all zones of reduction.

In some veins a little secondary galena occurs in close proximity to graphitic sediments or intimately associated with fine-grained marcasite and secondary pyrite. The reasons for precipitation in these sites are similar to those for zinc sulphide as given on page 196.

9. Very little lead (<0.005 ppm in nearly all waters) is dispersed into the groundwater system and through springs into the streams of the area. The reason for this is the very low solubility of both $PbSO_4$ and $PbCO_3$ and the strong binding of most available lead in basic salts and other complexes during the hydrolytic reactions that precipitate beudantite, jarosites, and closely similar minerals. The nature of the soluble lead cannot be determined with certainty. Anglesite and cerussite are slightly soluble and transport may be either as the sulphate or as lead hydrogen carbonate. Alternatively, the transport of the small quantities of lead may involve unusual complexing agents such as organic compounds, particularly acetates and probably the humic acids, some of which may well be present in the oxidizing zone.

These factors have led to a marked enrichment of lead in all the oxidized zones compared with that in the hypogene ores (Table 56). The general low mobility of lead and its narrow dispersion make the element an excellent indicator for geochemical prospecting by soil analyses (Boyle and Cragg, 1957). If consistent anomalies with a good contrast are found in soils the investigator may be certain that a vein fault or lode lies close by. By the same token the low solubility of lead makes the element unsuitable as an indicator in hydrogeochemical prospecting.

Copper

The normal valence states of copper are +1 (cuprous) and +2 (cupric). Cuprous compounds are generally stable only so long as they do not ionize. Most are oxidized to cupric compounds in water. Two common cuprous compounds Cu_2O, cuprite, and Cu_2S, chalcocite, are found in nature; both are very insoluble in water.

The divalent or cupric compounds are the most stable in nature. In solutions cupric ion has a strong tendency to form complexes. The hydroxide is to some extent amphoteric.

The most common natural cupric salt is $CuSO_4$. It is very soluble in water and has a weak tendency to hydrolyze with the formation of basic sulphates. Free H_2SO_4 in solution tends to depress the solubility of cupric sulphate as do also other sulphates.

Among the hypogene minerals in the lodes at Keno Hill copper is bound mainly in chalcopyrite, freibergite, and bournonite. Minor amounts and traces occur in sphalerite and numerous other sulphides.

During oxidation of the lodes copper is released from its minerals mainly as soluble copper sulphate. The reactions for chalcopyrite and freibergite (tetrahedrite) may be written:

$$\frac{CuFeS_2}{\text{chalcopyrite}} + 4O_2 = CuSO_4 + FeSO_4$$

$$\frac{6Cu_{12}\,Sb_4S_{13}}{\text{tetrahedrite}} + 1710_2 = 72CuSO_4 + 10Sb_2O_3 + 2Sb_2\,(SO_4)_3$$

From this point the copper behaves as follows:

1. Much copper is precipitated in malachite, $Cu_2(OH)_2CO_3$, and azurite, $Cu_3\,(OH)_2\,(CO_3)_2$. Both these minerals tend to develop directly on or near the chalcopyrite and freibergite, commonly on residuals of siderite. In some cases malachite appears to form by direct action of carbonated waters on the copper minerals, perhaps through an intermediate copper sulphate phase—

$$2CuSO_4 + 3H_2O + CO_2 = \frac{Cu_2(OH)_2CO_3}{\text{malachite}} + 2H_2SO_4$$

$$3CuSO_4 + 4H_2O + 2CO_2 = \frac{Cu_3(OH)_2(CO_3)_2}{\text{azurite}} + 3H_2SO_4$$

or alternatively a solution of copper sulphate may react with one of ferrous, manganous, magnesium, or calcium hydrogen carbonate to precipitate either malachite or azurite:

$$2CuSO_4 + 2Fe\,(HCO_3)_2 = \frac{Cu_2(OH)_2CO_3}{\text{malachite}} + 2FeSO_4 + 3CO_2 + H_2O$$

$$3CuSO_4 + 3Fe\,(HCO_3)_2 = \frac{Cu_3(OH)_2(CO_3)_2}{\text{azurite}} + 3FeSO_4 + 4CO_2 + 2H_2O$$

Copper sulphate may also react directly with siderite forming both carbonates

$$2CuSO_4 + 2FeCO_3 + H_2O = \frac{Cu_2(OH)_2CO_3}{\text{malachite}} + 2FeSO_4 + CO_2$$

$$3CuSO_4 + 3FeCO_3 + H_2O = \frac{Cu_3\,(OH)_2\,(CO_3)_2}{\text{azurite}} + 3FeSO_4 + CO_2$$

In some localities azurite encrusts malachite and may form from it by absorbing CO_2 from solutions

$$\frac{3Cu_2(OH)_2CO_3}{\text{malachite}} + H_2O + CO_2 = \frac{2Cu_3(OH)_2(CO_3)_2}{\text{azurite}} + 2H_2O$$

Both basic copper carbonates are soluble in sulphuric acid solutions, and more so in the presence of ferric sulphates. It follows, therefore, that in the oxidized zones they must have formed under neutral or slightly alkaline conditions—that is, during the more advanced stages of oxidation after the neutralization of H_2SO_4 and the nearly complete hydrolysis of ferric and other salts.

2. Locally some copper is precipitated in brochantite and antlerite, the basic sulphates of copper. Being basic salts these minerals would form in a mildly acid or neutral environment.

3. Small amounts of copper are adsorbed and /or coprecipitated as the hydroxide by the vein limonites and wads. Only very small amounts are present in the precipitates from the natural waters. Of these the high manganese varieties contain the most.

4. Minor amounts and traces of copper are captured in a great variety of secondary minerals, particularly the basic salts such as jarosite and beudantite.

5. Covellite, CuS, and chalcocite, Cu_2S, are developed in very small amounts on chalcopyrite. These two secondary sulphides are rarely observed in the zones of reduction, indicating that relatively little copper migrates downward for any distance in the veins.

6. Very little copper is dispersed into the groundwater system and through springs into the streams of the area. Only rarely is copper detected by dithizone in the waters and rarely in quantities greater than 0.5 ppm.

During the oxidation of the lodes copper is relatively immobile. From the data in Table 56 there is a suggestion that the element is slightly enriched in most oxidized zones, and in this respect behaves like silver.

Copper is not suitable as an indicator element in geochemical prospecting for the Keno Hill lodes because of two factors: First, the element is present in low quantities in the lodes (average content 0.34%), a feature that limits the amounts dispersed into the soils and waters; and secondly it has a low mobility in the groundwater system because the waters are largely neutral or slightly alkaline, and the copper is thrown down as the basic carbonates or sulphates.

Silver

Silver is a typical noble metal and has a relatively simple chemistry. It forms only one stable series of salts in which the element has oxidation state +1.

Weed, Stokes, Cooke, Palmer and Bastin, Ravicz, and W. H. Emmons have dealt with the factors leading to the enrichment of silver ores, and some of their findings bear on the geochemistry of silver as discussed here.

Under oxidizing conditions silver forms a soluble sulphate, Ag_2SO_4, and a slightly soluble carbonate, Ag_2CO_3. In solutions saturated with CO_2 the solubility of the carbonate is increased. Ferrous sulphate readily precipitates metallic silver from solutions containing Ag_2SO_4 and Ag_2CO_3, but due to the formationof ferric sulphate during the reactions the precipitation is not complete. The reactions may be expressed as follows:

$$Ag_2SO_4 + 2\ FeSO_4 \rightleftharpoons 2\ Ag + Fe_2(SO_4)_3$$
$$Ag_2CO_3 + 3\ FeSO_4 \rightleftharpoons 2\ Ag + FeCO_3 + Fe_2(SO_4)_3$$

It should be particularly noted that the presence of large amounts of ferric sulphate will reverse the equilibrium and inhibit the precipitation of silver. This point should be kept in mind in the discussion to follow.

Other factors that may lead to the precipitation of native silver are a decrease in acidity, a decrease in the oxidation-reduction potential, and the presence of various reactive sulphides and gangue minerals. Freibergite, chalcopyrite, and arsenopyrite cause nearly complete precipitation of either metallic silver or argentite from solutions of silver carbonate or sulphate. Galena will also precipitate some silver, but pyrite and sphalerite have little effect. According to Ravicz siderite alone will not precipitate native silver unless sulphides are present. Other effective precipitants are carbonaceous matter, kaolin, and other silicates.

Hydrogen sulphide and alkaline sulphides precipitate silver as sulphide from solutions of the sulphate and carbonate:

$$Ag_2SO_4 + H_2S = Ag_2S + H_2SO_4$$
$$Ag_2CO_3 + H_2S = Ag_2S + H_2CO_3$$

Solutions carrying soluble arsenates, antimony sulphate, and hydrogen sulphide react with freibergite to form pyrargyrite or proustite. Alternatively these solutions on mingling with those carrying silver sulphate or carbonate will precipitate the silver as pyrargyrite or proustite in a neutral or alkaline environment.

In the scheme of precipitation of the sulphides (Schürmann's series) silver sulphide, Ag_2S, with Ksp — 1.6×10^{-49} is much less soluble than the sulphides of copper, zinc, and iron (pyrite, Ksp $= 4 \times 10^{-19}$) in that order. Hence silver should replace these elements in their sulphide combinations.

In the hypogene parts of the Keno Hill lodes silver is present mainly in freibergite $(Cu,Fe,Zn,Ag)_{12}\ (Sb,As)_4,\ S_{13}$, in amounts varying between 5 and 18 per cent. Galena carries some silver (up to 6,300 ppm) both as intergrown silver minerals and as a lattice constituent. Sphalerite contains small amounts of the element, generally in minute blebs of freibergite. Chalcopyrite, boulangerite, and other suphosalts contain some silver, probably as a lattice constituent. Pyrite, arsenopyrite, siderite, and the other gangue minerals contain traces of the metal. Pyrargyrite, a rich silver-bearing mineral, may be primary in some of the hypogene zones.

In the oxidized zones much silver is isolated from the oxidation processes by retention in nodules and lumps of galena coated with anglesite and cerussite. Some silver is also present in the oxidized zones in unoxidized particles of freibergite.

During the oxidation of the lodes freibergite is broken down, and silver is released either as the sulphate or as carbonate. Galena, likewise, on its conversion to anglesite and cerussite yields some silver sulphate and/or carbonate.

Once released from its primary minerals the silver may follow six courses depending on the circumstances:

1. Some silver is bound in the basic sulphates of iron, lead, and arsenic such as beudantite and plumbojarosite. These basic salts are formed in a mildly acid environment and represent intermediate products in the hydrolysis of ferric sulphate. They are discussed in more detail in the section on iron.

2. Some silver is bound in the vein limonites and wads and a little occurs in the natural iron and manganese precipitates from the circulating waters. In the latter the high manganese material tends to concentrate more of the element than the iron hydroxides. Most of the silver in limonites and wads results from adsorption and/or coprecipitation processes involving the Ag^+ ion according to the principles outlined in the sections on iron, manganese, and zinc.

3. Small amounts of silver are captured in various secondary minerals, particularly in bindheimite, malachite, azurite, and anglesite. In these minerals silver probably substitutes for lead or copper.

4. Some silver is present as the native metal in the near surface and central parts of the oxidized zones. In some veins the native silver occurs in ice lenses in the permafrost zone, a unique habitat for the metal. The geochemistry and origin of the native silver has been discussed previously (Boyle, 1960).

In the zones of oxidation and reduction the precipitation of native silver is controlled in large measure by the oxidation-reduction potential and the pH of the environment. In this respect the following couples in alkaline and acid solutions are of interest:

Alkaline Solutions

$Fe(OH)_2 + OH^- = Fe(OH)_3 + e^-$ .... $E^o = 0.56$
$S^{--} = S + 2e^-$ .... $E^o = 0.48$
$Mn(OH)_2 + 2OH^- = MnO_2 + 2H_2O + 2e^-$ .... $E^o = 0.05$
$Mn(OH)_2 + OH^- = Mn(OH)_3 + e^-$ .... $E^o = -0.1$
$2Ag + 2OH^- = Ag_2O + H_2O + 2e^-$ .... $E^o = -0.344$
$4OH^- = O_2 + 2H_2O + 4e^-$ .... $E^o = -0.401$

Acid Solutions

$H_2S = S + 2H^+ + 2e^-$ .... $E^o = -0.141$
$Fe^{++} = Fe^{+++} + e^-$ .... $E^o = -0.771$
$Ag = Ag^+ + e^-$ .... $E^o = -0.799$
$2H_2O = O_2 + 4H^+ + 4e^-$ .... $E^o = -1.229$
$Mn^{++} + 2H_2O = MnO_2 + 4H^+ + 2e^-$ .... $E^o = -1.23$

From a study of the above potentials one can see that ferrous iron will be oxidized to the ferric state by atmospheric oxygen in both an acid and alkaline environment; the reaction will, however, proceed with greatest facility in alkaline solutions. As regards manganese, the potential developed by the oxygen couple is not sufficiently powerful to oxidize Mn^{++} to MnO_2 in acid solutions but is adequate in an alkaline environment. Hydrogen sulphide and any sulphide ion are oxidized rapidly and quantitatively to sulphur by atmospheric oxygen in an alkaline environment and by both atmospheric oxygen and ferric ion in an acid medium. In accordance with the potentials Ag^+ is reduced to the metal by Fe^{++} in acid solutions and particularly by $Fe(OH)_2$ in basic solutions because $Fe(OH)_2$ is a much better reducing agent than ferrous ion. $Mn(OH)_2$ has a similar effect in a basic medium. High concentrations of Fe^{+++} in solution will, however, as noted previously, inhibit the precipitation of silver.

By applying these concepts to the various reactions in the lodes, the origin of native silver can be traced rather precisely. In the oxidized parts of the lodes hydrogen sulphide, if formed by the action of free sulphuric acid on sulphides such as sphalerite, is largely eliminated from the reactions because it is oxidized rapidly to sulphur by atmospheric oxygen and ferric iron. This inhibits the formation of any silver sulphide and explains the absence of tarnish on most specimens of native silver, the general paucity of acanthite and other silver sulphides, and the omnipresence of small quantities of native sulphur in the oxidized zones. With depth, however, as the oxidation potential decreases, some hydrogen sulphide may escape oxidation, pass downward, and be available for binding silver as sulphide in the zone of reduction.

The near surface oxidation of the primary lode minerals yields ferrous and manganous ions and the argentous ion to slightly acid solutions. Incipient precipitation of silver may take place by the reduction of Ag^+ by Fe^{++} but this will be limited and generally suppressed by two factors—the formation of large amounts of ferric ion in solution because of the high oxidation potential and the oxidizing effect on both the ferrous ions and silver of any manganese dioxide present in the feebly acid to neutral solutions. Silver is, therefore, relatively mobile in the near surface parts of the lodes, and only small amounts of native silver are formed, a fact substantiated by observation.

As the waters pass downward, however, atmospheric oxygen is consumed, the oxidation potential decreases, the pH increases due mainly to neutralization of the solutions by siderite, and the concentration of ferric ion in solution decreases. These conditions promote the precipitation of native silver according to the following ionic equations:

$$Ag^+ + Fe^{++} = Ag + Fe^{+++}$$
$$2\,Ag^+ + Mn^{++} = 2\,Ag + Mn^{4+}$$

During these reactions the Fe^{+++} and Mn^{4+} are removed and fixed as insoluble ferric hydroxide and manganese dioxide (limonite and wad).

With further downward migration the silver passes into the zone of reduction. Here Ag^+ comes into contact with sulphides such as freibergite, or reacts with solutions carrying H_2S, antimony sulphate, and soluble arsenates, resulting in the precipitation of pyrargyrite or acanthite. Some of the residual Ag^+ may undergo reduction to the metal by ferrous ion, by carbonaceous material in the sediments, or by reaction with galena, chalcopyrite, and other sulphides.

The occurrences of native silver in the ice lenses are phenomena not readily explained. In some places there is evidence suggesting that the ice and silver crystallized nearly contemporaneously. In other places the ice appears to have crystallized around leaf and wire silver after its precipitation in solution channels and vugs. Elsewhere, the silver appears to have precipitated on the ice and within fractures in the ice. Whatever their origin, these occurrences of native silver are certainly unique and are similar in most respects to occurrences of native gold in ice lenses described by the writer (Boyle, 1951) from Yellowknife, Northwest Territories.

5. Some silver is bound in pyrargyrite and acanthite. These minerals, especially the former, occur in abundance in well demarcated zones near the bottom of the oxidized zones or in the topmost parts of the primary zones. Acanthite is rather rare. It is formed in local sites where a high H_2S potential developed, precipitating the sulphide:

$$Ag_2SO_4 + H_2S = Ag_2S + H_2SO_4$$

The reactions leading to the formation of secondary pyrargyrite are complex and not readily stated. As already noted they involve either the reaction of silver bearing solutions with a mineral like freibergite or the co-mingling of silver solutions with those carrying antimony and sulphur. For the latter the following equation may be written:

$$3Ag_2SO_4 + Sb_2(SO_4)_3 + 6H_2S = 2Ag_3SbS_3 + 6H_2SO_4$$

6. Only minute amounts of silver are dispersed into the groundwater system and through springs into the streams of the area. The amounts in the water cannot be measured directly but can be computed from the contents present in evaporated residues from a large volume of water. The content of silver in the water as determined by this method may approximate 0.001 ppm, or it may be much lower.

As shown by the data in Table 56, most of the oxidized zones are highly enriched in silver. Some of the zones of reduction, viz., Lucky Queen, No. 9, and Silver King, were also enriched in native silver and pyrargyrite.

Higher than average amounts of silver are retained in the soils near the lodes, either in unoxidized nodules of galena or in numerous secondary minerals such as beudantite, limonite, anglesite, and cerussite. As shown in Chapter IV, the element can be used effectively as an indicator element for the location of veins by soil sampling methods. The very low mobility of silver in the waters, indicated by the infinitesimally low contents therein, makes the element unsuitable as an indicator in hydrogeochemical methods.

Gold

Gold has a relatively simple chemistry and is found in nature principally as the native metal. The metal forms salts with oxidation state +1 (aurous) and +3 (auric). The auric salts are largely covalent compounds and do not ionize appreciably in solution. Auric ion is relatively unstable in solutions except in the form of soluble complexes such as the chloraurates, $AuCl_4^-$. The aurous ion is likewise unstable in solution but may form a number of stable complex ions such as $AuCl_2^-$.

Much has been written on the transport of gold in the exogene cycle, but there is no general agreement on the agents that effectively dissolve and permit transport of the element. Emmons (1917) maintained that manganese plays a major part in the transport of gold by the production of nascent chlorine resulting from the reaction of manganese dioxide and hydrochloric acid derived from the intermingling of sodium chloride solutions with those carrying free sulphuric acid. In this scheme the chlorine binds the gold as a soluble chloraurate ion. Other investigators believe that gold migrates as a colloidal complex, and still others call upon humic acids as effective solvents for the noble metal. These latter modes of transport have not been investigated in detail and require further research.

In the quartz-arsenopyrite lodes of the area the gold is held mainly in lattice sites in arsenopyrite and pyrite. Some may be present as extremely divided particles either in the sulphides or in gangue. The small amounts of gold in the siderite lodes are held in lattice sites in pyrite, freibergite, and various other sulphides.

During the oxidation of the quartz-arsenopyrite lodes the gold in the free state is released from its gangue minerals and collects as small particles in the oxidized residuum. The gold chemically bound in the sulphides is probably liberated in an ionic form either as Au^+ or as Au^{3+}. This gold would be quickly immobilized in the oxidizing zones because of two factors—the general low content of good solvents such as chloride and the high content of ferrous and/or manganous ion.

With regard to the latter ions and their effect on dissolved gold the following potentials in acid solutions are of interest.

$$
\begin{array}{ll}
Fe^{++} = Fe^{+++} + e^- & E^o = -0.771 \\
2H_2O = O_2 + 4H^+ + 4e^- & E^o = -1.229 \\
Mn^{++} + 2H_2O = MnO_2 + 4H^+ + 2e^- & E^o = -1.23 \\
Au = Au^{+++} + 3e^- & E^o = -1.50 \\
Au = Au^+ + e^- & E^o = -1.68
\end{array}
$$

It is evident from a study of these that both ferrous and manganous ion will reduce gold from its ionic state to the metal. It follows, therefore, that there can be little migration of the element during the initial phases of oxidation of pyrite and arsenopyrite when an abundance of ferrous sulphate is present. The liberated gold simply collects as extremely finely divided dust in scorodite and limonite.

With complete oxidation of sulphides, ferrous salts are largely eliminated from the chemical systems. It is then that carbonate solutions, soil solutions, and humic complexes come into play, dissolving the finely divided gold locally and precipitating it again on larger particles and as wires in the weathered residuum of the veins.

The geochemistry of gold during the oxidation of the siderite lodes is probably similar to that already discussed. From the data given in Table 56 it can be concluded that there is little enrichment or depletion of gold during the oxidation processes in most siderite veins. This attests to the general low mobility of the element where abundant ferrous and manganous salts are present in the chemical system and where chloride ion[1] is essentially absent.

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[1] The chloride content of the oxidizing waters is generally less than 1 ppm (Tables 58 and 59).

The origin of nuggets and flakes of gold in soils and placers has received much attention down through the years. Two processes are generally advanced: a straight mechanical concentration as the result of weathering of free gold from veins, and an accretion of gold into small nodules by chemical action both in the soils and in the placers. Probably both have operated in the Keno Hill area.

It has been shown that relatively little free gold is present in any of the veins of the area. This rules out, in the writer's opinion, a straight mechanical concentration of particles of gold from the veins. On the other hand, it is clear that relatively large particles of gold are forming in and near the weathered rubble of the veins as a result of the chemical accretion of the gold liberated during oxidation of arsenopyrite and other gold-bearing minerals. As the veins weather down these particles pass into the eluvium where they gather more gold from the soil solutions. This process probably continues as the particles are moved mechanically down the slopes and into the stream bottoms until finally small nuggets are formed that come to rest in riffles and other sites in the streams. Even in these locations the nuggets may continue to accrete gold from the stream waters that wash them continuously. The formation of gold nuggets should be viewed in a dynamic sense, the agents forming them being both chemical and mechanical and their action being concomitant.

Tin

Tin cannot be traced with any degree of accuracy through the oxidation stages of the tin veins in the Dublin Gulch area because of poor exposures and the impossibility of obtaining samples at depth. Cassiterite is dispersed into the soils and ultimately finds its way into the placers where it occurs in rolled nodules and small lumps. A petrographic and trace element study of these indicates little difference from the vein material, and it may be concluded that oxidation has little effect on the cassiterite.

In the siderite veins the small amounts of tin are bound mainly in galena, sphalerite, chalcopyrite, and sulphosalts. During the oxidation of these minerals the tin is liberated and appears to follow lead and zinc closely, as it is bound largely in the secondary minerals of these two elements, viz., beudantite, bindheimite, anglesite, jarosite, and smithsonite. Small amounts of tin are also adsorbed and/or coprecipitated by iron and manganese hydroxides and are bound in the vein limonites and wad.

The values for tin given in Table 56 suggest that the element is relatively immobile during the oxidation of the siderite lodes. In this respect the element behaves like lead and silver.

Summary

Three main stages of hypogene mineralization, and a supergene stage that is still in progress, are represented in the Keno Hill-Galena Hill area.

The first hypogene stage was marked principally by the introduction of silica which resulted in the development of quartz veins and lenses in local dilatant zones throughout the area. Near the granitic stocks these may carry some cassiterite and wolframite and a little native bismuth. In skarn, scheelite is present locally. The chief mobile elements and constituents during this period were, therefore, silica, tin, tungsten, and bismuth.

The second stage was characterized by an extensive introduction of silica which was precipitated as quartz lenses in dilatant zones in a series of northeast-trending vein faults. The quartz lenses carry moderate amounts of pyrite, arsenopyrite, boulangerite, and other sulphosalts. A little gold accompanies the sulphides, especially the arsenopyrite. Silver is present in early freibergite and galena, but the element is not abundant. The principal mobile constituents during this period were silica, sulphur, arsenic, iron, gold, and to a less extent antimony, lead, copper, and silver.

The third and major stage of mineralization culminated in an extensive introduction of carbon dioxide, iron, manganese, sulphur, antimony, lead, zinc, silver, cadmium, and a little arsenic, gold, and silica. These mobile elements and constituents were partitioned into siderite which forms the main gangue, pyrite, chalcopyrite, galena, sphalerite, freibergite, boulangerite, and a few other sulphosalts. These minerals constitute the principal economic deposits of the mineral belt, yielding lead, zinc, silver, and cadmium.

The siderite lodes show evidence of a rude primary zoning both laterally and vertically. The flanks and ends of the lodes are marked by numerous veinlets and stringers of siderite containing mainly pyrite. Inward, the pyrite decreases and the main parts of the lodes contain essentially siderite, galena, sphalerite, freibergite, and other sulphosalts. Sphalerite increases and galena decreases fairly uniformly with depth in most lodes. Siderite and pyrite generally increase erratically with depth and are the main minerals at the bottoms of most lodes. Freibergite decreases with depth, but its vertical range is greater than that of galena. It appears to decrease in quantity as sphalerite increases, and it decreases rapidly where siderite and pyrite become abundant near the bottoms of the lodes.

Most of the siderite lodes have been brecciated or crushed and locally recemented by a third generation of minerals. These include dolomite, calcite, crusts of clear quartz crystals, massive grey quartz, and small amounts of reddish brown, resinous sphalerite, pyrargyrite, native silver, acanthite, and fine pulverulent galena. Some or all of these minerals may be secondary (supergene) in origin.

The main period of supergene alteration probably took place in Tertiary time and has continued since then in those areas not sealed by permafrost. The magnitude of the supergene processes has been conditioned by several factors, the most important being an abundance of meteoric water and the presence of numerous fractures to allow ingress and downward migration of the oxidizing solutions. In ideal situations two supergene zones were formed in the veins—a zone of oxidation and a zone of reduction. The oxidized zones are generally well developed and demarcated. The zones of reduction are, however, diffuse and tend to telescope both the oxidized and primary zones. The depths of the oxidized zones vary. In some mines, as at the Silver King and Ladue-Sadie-Friendship, oxidation terminated at 20 feet. In others, as at the Elsa, Galkeno, Hector-Calumet, and Bellekeno, the oxidized zones may extend to depths ranging from 200 to 500 feet.

The oxidized zones contain a veritable host of minerals. Limonite (goethite, lepidocrocite, hematite), wad (pyrolusite, manganite, psilomelane), anglesite, cerussite, bindheimite, and silver-bearing beudantite are the most characteristic. In addition to these the following are present, often in considerable amount: gypsum, native sulphur, malachite, azurite, smithsonite, pharmacosiderite, pyromorphite, mimetite, jarosites, scorodite, rozenite, calcite, aragonite, montmorillonite, serpentine, quartz, covellite, pyrargyrite, acanthite, ice, native silver, and an occasional speck of native gold and native zinc.

In the zones of reduction the principal secondary minerals are pyrargyrite, acanthite, native silver, calcite, quartz, and gypsum. Secondary pyrite, galena, sphalerite, marcasite, and hawleyite occur in some veins.

The limonite, jarosites, beudantite, and other secondary iron minerals were derived mainly from siderite, pyrite, and sphalerite. The secondary manganese minerals were formed from manganiferous siderite, the lead oxygen salts from galena, smithsonite from sphalerite, the basic copper carbonates from freibergite and chalcopyrite, and the secondary antimony and arsenic minerals from arsenopyrite, freibergite, and other sulphosalts. The supergene silver minerals were derived from freibergite and silver-bearing galena.

The chemical factors that influence the mobility of the elements during oxidation are the Eh as manifested by the presence of free oxygen, the pH, and the solubility of the various elemental salts. Hydrolytic, colloidal, and adsorption phenomena also play their part. These factors have been dealt with in detail as they have affected the various elements during the supergene processes. Only the more important elements are considered in this summary.

Iron and manganese are markedly affected by the Eh and pH of the environment and by hydrolytic reactions. Both these elements are released from their primary minerals in their lowest oxidation state under acid conditions. With increasing oxidation and a decrease in the pH of the solutions their soluble salts underwent hydrolysis, with the precipitation of basic salts in the case of iron, and finally the precipitation of hydroxides and hydrated oxides (limonite and wad). During the formation of these mineral aggregates, small quantities of arsenic, antimony, lead, zinc, silver, cadmium, and other elements were coprecipitated with them or adsorbed to their surfaces and ultimately bound within their structures.

The mobility of calcium and magnesium is controlled in large measure by the carbon dioxide content and pH of the solutions and the solubility of their sulphates. The high solubility of the sulphates of zinc and cadmium endow these elements with a marked mobility whereas the reverse is true for lead. The mobility of silver and gold is influenced by the pH and Eh of the environment and especially by the relative concentration of ferrous and ferric ions in the oxidizing solutions. The migration of arsenic and antimony depends essentially upon the solubility of their oxygen salts and upon various hydrolytic processes.

The formation of supergene minerals in the zone of reduction is determined by many special structural and chemical conditions. Brecciated hypogene lodes and a network of fractures are the necessary structural features. Escape of H_2S into the deeper parts of the veins must be fairly rapid to prevent its oxidation, and thus make it available for binding elements such as Zn, Pb, Cd, Ag, Sb, and As into secondary pyrargyrite, galena, sphalerite, pyrite, and marcasite. In some veins reactions with hypogene sulphides by downward migrating metal-bearing solutions have led to the precipitation of some pyrargyrite, native silver, and a little supergene galena and sphalerite.

The oxidized zones are enriched in lead and silver and depleted in zinc and cadmium, compared with the hypogene ores. This feature has an economic significance, as has also the development of native silver and pyrargyrite in some of the deeper parts of the oxidized zones and in the zones of reduction of a few veins.

Chapter VI

ORIGIN OF THE HYPOGENE DEPOSITS

Three essential factors must be considered in discussing the origin of ore deposits: the geological and structural setting of the deposits, the source of the elements in the deposits, and the geochemical processes leading to their concentration. The reader will be aware that the first is a matter of observation, the second admits of some interpretation if it is assumed that the elements were derived from rocks on the plane of observation, the third is largely a matter of inductive reasoning and speculation as only the products of the processes remain as objects of study.

The origin of five types of hypogene deposits in the Keno Hill-Galena Hill area is discussed in the following sections. These include the early quartz lenses and boudins, the scheelite skarn deposits, the tin lodes, the quartz-arsenopyrite-pyrite-gold lenses, and the siderite-galena-sphalerite-freibergite lodes. A historical synthesis of the mineralization processes by which these were formed is given at the end of the chapter.

Geological Setting of the Deposits

The regional geological setting is shown on Map 1147A and Figure 33. The principal features may be briefly summarized as follows:

1. The early quartz lenses and boudins occur in all types of sedimentary rocks and in some of the greenstone bodies. They do not occur to any extent in the granitic rocks, nor do they exhibit any direct relationship to them either in quantity or spatial distribution. All are isolated entities and most are structurally controlled by fractures, small faults, shear zones, disrupted bedding planes, drag-folds, and crushed zones—structures that were developed during the early thrusting and folding of the region.

2. The tin lodes and most of the quartz-scheelite-wolframite stringers occur in sedimentary rocks near granitic stocks and plugs. A few quartz-scheelite-wolframite veinlets cut the granitic masses and their apophyses. These were precipitated in fractures after the consolidation of the granitic bodies, and hence could not have been derived by any differentiation process in a magmatic sense.

3. The scheelite skarns are developed in interbedded limestone lenses, calcareous schists and phyllites, and calcareous quartzites near the granitic stocks and plugs. Limestones and other calcareous rocks at a distance from the granitic bodies carry no scheelite nor are they enriched in tungsten.

4. The early quartz-pyrite-arsenopyrite-gold lenses occur in dilatant zones in northeast-striking vein faults throughout the area. Most of the lenses are localized in thick-bedded quartzites or in greenstone bodies, the most competent rocks in the region. The quartz-pyrite-arsenopyrite lenses exhibit no direct spatial or genetic relationship to the granitic stocks and plugs. Some cut apophyses of the granitic bodies in the Dublin Gulch area, and it may be assumed from these observations that they were formed after the consolidation of the granodiorite and its satellites.

5. The siderite-galena-sphalerite-freibergite lodes are developed principally in extensive systems of northeast-striking vein faults and their subsidiaries. Most lodes occur in greenstones and thick-bedded quartzites that lie above a thick series of graphitic schists, phyllites, and thin-bedded quartzites. The siderite lodes are younger than the quartz-pyrite-arsenopyrite lodes.

6. The main siderite lodes lie in a belt about midway between the two principal granitic masses of the area. This spatial relationship is probably in part a structural one—the two granitic masses acted as buttresses, the rocks between them failing by extensive faulting and fracturing. Alternatively, the vein faults and fractures may have been caused by stresses set up during injection of the granitic masses.

7. On a regional scale the siderite lodes exhibit no close spatial relationship to the numerous greenstone masses. Locally, however, vein faults may contain lodes where they cut the competent greenstones.

8. The main siderite lodes and the quartz-feldspar porphyry sills and dykes have a similar distribution (Map 1147A and Figure 33). The reasons for this are not clear, but probably structural conditions (i.e., faulting and fracturing) were the responsible factors. The lodes cut the porphyries and were definitely formed later, a fact suggesting that there is no close genetic relationship by magmatic differentiation between the siderite-galena-sphalerite mineralization and the porphyries.

9. There is a relatively well defined mineral zonation in the area. Near the granitic rocks, scheelite, wolframite, cassiterite, and native bismuth are characteristic. Farther out siderite, sphalerite, galena, chalcopyrite, and freibergite are abundantly developed. Minerals such as quartz, pyrite, arsenopyrite, jamesonite, boulangerite, and gold are randomly distributed and show no spatial relationship to the granitic bodies.

10. A crude elemental zonation is present in the area. Near the granitic stocks and plugs tungsten and perhaps bismuth are concentrated. Farther out manganese, lead, zinc, copper, and silver are dominant. Silica, sulphur, arsenic, antimony, gold, and tin show no clear-cut zoning with respect to horizontal distance from the granitic masses. There is in total more tin in the galena lodes than in the cassiterite impregnation zones near the granitic stocks.

Source of the Elements

Three possible sources for the elements in the hypogene deposits can be considered: an old weathered land surface, magmatic hydrothermal solutions derived during the crystallization of the granitic bodies, and the sediments and greenstones, particularly the graphitic pyritiferous schists, phyllites, and quartzites.

The arguments for and against derivation of the elements by the weathering of an old land surface, followed by their downward migration in groundwaters and consequent precipitation under reducing conditions in vein sites need not be pursued at length here. Such a process seems quite incapable of producing such varied types of deposits as are present in the Keno Hill area. Militating against such a concept are: the regional zonation of certain minerals and elements, the marked differences in elemental precipitation as mineralization progressed, and the remarkably low solubility of such elements as lead in normal ground waters under oxidizing conditions.

The amount of some characteristic ore elements in one cubic mile of the main rock types, compared with the amount won from the deposits are given in Table 62. These data indicate that the rocks richest in the ore elements are the graphitic sediments and quartzites, followed by the greenstones. The granitic rocks are poor sources.

Derivation of the ore elements by magmatic differentiation from the parent materials of the present granitic rocks seems unlikely on several counts. Chief among these is that the granitic rocks contain relatively small amounts of the principal ore elements, particularly sulphur and silver. It could be argued that most of the sulphur and other ore elements was drained off during differentiation and is now in the lodes. Such an assumption is entirely contradictory to present geochemical knowledge of the elemental contents of supposedly differentiated series of rocks. Thus, sulphur and most chalcophile elements are concentrated in basic rocks such as gabbros, and they decrease in content through the intermediate rock series, reaching a low value in granitic rocks. The trend is towards a decrease of sulphur and the chalcophile elements during differentiation, not an increase in the content of these elements as suggested by the classical theory. Lead is one of the exceptions to this trend. This element tends to increase with the acidic character of a rock because it is captured in potassium feldspars. In granites, however, most potassic feldspars are probably undersaturated with respect to lead, a feature suggesting that little if any of the element would be drawn off in hydrothermal solutions.

More pertinent to the argument against hydrothermal solutions as a source for the ore elements are the observations that the lodes show no close relationship to the granitic bodies, and that where the two are found together, the veins cut and offset both the granitic apophyses and the quartz-feldspar porphyries. This means that the granitic rocks were fully consolidated and the process of differentiation that might have produced hydrothermal solutions had ceased when the veins were formed. Furthermore, the rocks adjacent to the Dublin Gulch and Mayo Lake granitic bodies are not characterized by extensive hydrated and carbonated zones or by the development of abundant sulphide veins and impregnation zones—features that should prevail if differentiated products of the granitic magmas, such as water, carbon dioxide, and sulphur, were expelled outwards into the sedimentary and greenstone wall-rocks.

Considering now the various sediments and greenstones as a source, it can be seen from the data in Table 62 that a cubic mile of these rocks could easily have supplied all of the ore elements mined to date. When one considers that the main belt of mineralization on Keno and Galena Hills is some 15 miles long and 4 miles wide, the content of ore elements to a depth of one mile in this block of rock is enormous. Furthermore, the amount of ore elements mined, even if doubled or trebled, would represent only an infinitely small quantity compared with that present in the great reservoir of sedimentary and greenstone rocks enclosing the deposits. The problem is, therefore, not one of source as far as the sediments and greenstones are concerned but rather the mechanism by which the ore and gangue elements are concentrated. To this latter problem we shall now turn.

Geochemical Processes of Concentration

The concentration of elements in epigenetic deposits must be considered in three stages—mobilization, migration (or transport), and precipitation. The first and the last will be considered in the discussion that follows. The second requires brief comment.

At our present state of knowledge we can only speculate on the mode of transport or migration of elements during their concentration in deposits of the Keno Hill type. Perhaps they were carried by solutions or transported by diffusion processes. The writer prefers the latter hypothesis for two principal reasons. First, the deposits of all types in the Keno Hill-Galena Hill district are isolated bodies when considered in a broad sense. It is true that the major deposits occur in vein faults, but they are present only in the more dilatant or open parts of these structures. In the principal rocks of the region—the schists, thin-bedded quartzites, and phyllites—the vein faults are dissipated through a zone of tight fractures, sometimes barely traceable. Certainly none of these fractures exhibits evidence of having been the channelways for any considerable volume of flowing solutions. Furthermore, there is no intimate spatial relationships between any of the vein fault systems and granitic intrusions from whence solutions might have arisen. In fact, where the two are found together, the veins cut the granites and their apophyses and were formed after the consolidation of these bodies.

Secondly, the Keno Hill deposits appear to have formed at moderate depths and at medium temperatures according to the mineralogical relationships. In the temperature range at which the deposits were probably formed, water, as well as numerous other ore and gangue constituents, would be largely present in a gaseous state and would migrate more readily by diffusion.

Despite the fact that the mechanisms of diffusion of elements through rocks are practically unknown, there can be little doubt from the evidence in metamorphic terrains, in skarns, and in granitized zones that diffusion takes place over great distances in relatively short periods of geological time. It is the writer's opinion that large-scale diffusion of elements occurs principally through a nearly static flux of gaseous water which permeates the rocks along grain boundaries, micro- and macro-fractures, bedding planes, and other discontinuities. Large volumes of flowing water are thus ruled out by this hypothesis.

The factors that influence the mobilization and rate of diffusion of elements in rocks are many. Some of these have been discussed by the writer in a previous report (Boyle, 1961). They include the stimulating effects of intense shearing and comminution, the differential compressibilities of the elements, the initial binding energies of the elements, the degree of hydration an element may undergo, the pH and Eh of the environment, the presence of CO_2, H_2S, and S^{2-} in the system, elemental complex formation, and the effect of temperature, pressure, and concentration gradients.

Structures have played a leading part in the concentration of nearly all types of deposits in the Keno Hill-Galena Hill district. With the exception of the scheelite skarns, all the deposits are localized in faults and fractures, particularly in brecciated or open junctions or where openings and brecciated zones were formed at deflections such as occur where faults pass from competent greenstones or quartzites into schists and phyllites. Physicochemically, such sites, during their formation, constituted dilatant zones, characterized by low pressure and low chemical potential compared with other points in the country rocks. In order to establish chemical equilibrium throughout the system the natural tendency would be for mobile elements in the country rocks to move into these sites where they would be precipitated. Once the dilatant zones were filled, equilibrium was restored and the flow ceased. The magnitude of the dilatant zones, therefore, determined the size of the deposits, and probably also the elements that were concentrated from the country rocks. For quantitative treatment of the latter problem, however, experimental data are required that is non-existent at present. Inferences must therefore be drawn from field observations, particularly from the Keno Hill deposits where the mobility of the ore and gangue elements appears to have varied as mineralization progressed (Fig. 32).

During the first stage of mineralization mainly quartz was deposited, and this was accompanied by some calcite in the greenstones and by a little cassiterite and wolframite in those deposits nearest the granitic stocks. In some skarn bodies scheelite was deposited. Very little sulphur, carbon dioxide, lead, zinc, or other chalcophile elements accompanied this stage.

Deposits of the second stage contain large quantities of quartz, moderate amounts of pyrite and arsenopyrite, small quantities of sulphosalts, and a little gold. Galena and sphalerite are rare, and carbonates are only sparingly represented. During this period, therefore, silica, sulphur, iron, arsenic, antimony, and gold were relatively mobile whereas lead, zinc, cadmium, copper, silver, carbon dioxide, and manganese were largely immobile.

The third and main stage of mineralization produced deposits with only a little quartz but an abundance of siderite, pyrite, galena, sphalerite, freibergite, and chalcopyrite. Some arsenic was deposited with the pyrite and a little tin and gold accompanied the mineralization. The only constituents that were relatively immobile during this stage were silica and tungsten.

With the foregoing discussion in mind, the following explanation of the origin of the various types of deposits in the Keno Hill area is proposed.

The early quartz lenses, boudins, and stringers occur in all types of sedimentary rocks and in some of the greenstone bodies. They do not occur to any extent in the granitic rocks, nor do they show any direct relationships to these rocks either in frequency or spatial distribution. Their development is greatest in contorted parts of the schists, phyllites, quartzites, and greenstones, particularly in fractures, joints, small shear zones, drag-folds, and crushed zones. In this respect they exhibit a distinct relationship to early tectonism and regional metamorphism. They are isolated bodies, unconnected and unrelated to any fault or fracture system, and all contain minerals, the elemental components of which are abundantly present in the rocks enclosing them, e.g., SiO_2, Ca, etc.

These relationships suggest that the early quartz bodies originated by metamorphic differentiation processes. As small dilatant structures developed in the schists, quartzites, and greenstones they constituted zones of low pressure and chemical potential, into which the most mobile constituents in the country rocks (SiO_2, Ca, CO_2, etc.) were drawn and precipitated to establish equilibrium in the chemical system prevailing under the conditions of early regional metamorphism. This origin is essentially the same as that proposed by Godfrey (1954) who studied these particular quartz bodies in some detail. It is the metamorphic "secretion effect" enunciated by Ramberg (1952, pp. 217-219).

The scheelite skarns probably also owe their origin to metamorphic processes. Few geologists would deny that the common minerals in the skarns, such as scapolite, epidote, and pyroxene, have a metamorphic origin. Why, therefore, should the scheelite which is intimately intergrown with these minerals have some other origin?

From the data at hand it is best to assume that the tungsten had its source in the country rocks, particularly the phyllites, argillites, and various graphitic and sericitic sediments. These rocks are largely hydrolysates, and are the natural media in which tungsten is concentrated during sedimentation. In the Keno Hill area these rocks contain from 1 to 4 ppm W, a sufficient quantity to account for any of the small concentrations of scheelite found in the skarns and other deposits.

The process of concentration of scheelite in the skarns of the Dublin Gulch area may be illustrated diagrammatically as shown in Figure 34. As a result of granitic development and intrusion, the relatively high temperatures prevailing in the vicinity of the granitic bodies would mobilize much silica and other components, including tungsten, in the sediments. The tendency would be for the bulk of these constituents to migrate upwards and outwards, and on reaching limy beds they would react with the carbonates to produce the skarn minerals. The tungsten component of the diffusion front, probably in the form of hydrated alkali tungstate or some other complex of the element, would be precipitated by calcium carbonate according to the following reaction:

$$CaCO_3 + \text{—}\,WO_4 \rightarrow CaWO_4 \downarrow + \text{—}\,CO_3$$

A variation of this mechanism can also explain the small concentrations of wolframite and scheelite in quartz stringers in the borders of the granitic bodies and adjacent sediments as well as the tin impregnation zones. The only difference is in the formation of small dilatant zones after the consolidation of the granitic masses. During this period the temperature would remain high in and about the intrusions, and both tungsten and tin would have a high mobility. These elements, together with silica, boron, etc., would be drawn into the dilatant zones where they would be precipitated, thus establishing equilibrium in the chemical system prevailing.

The northwest-striking vein faults and their subsidiaries are characterized by two main periods of mineralization differing in their elemental constituents. The first is represented by a major introduction of SiO_2, with some S, As, Sb, Fe, and a little Au, the second by much CO_2, S, Fe, Mn, Zn, Cd, Pb, Ag, Cu, and a little SiO_2, As, Ca, Mg, and Sn (Fig. 32). These elemental differences are keyed to the progress of metamorphism and are intimately connected with the relative mobilities (mobilization, migration, and precipitation) of the various elements that took part in the mineralization and also with the timing and degree of the dilatancy of the vein faults. Unfortunately the state of our knowledge on all these matters is so meagre that few precise

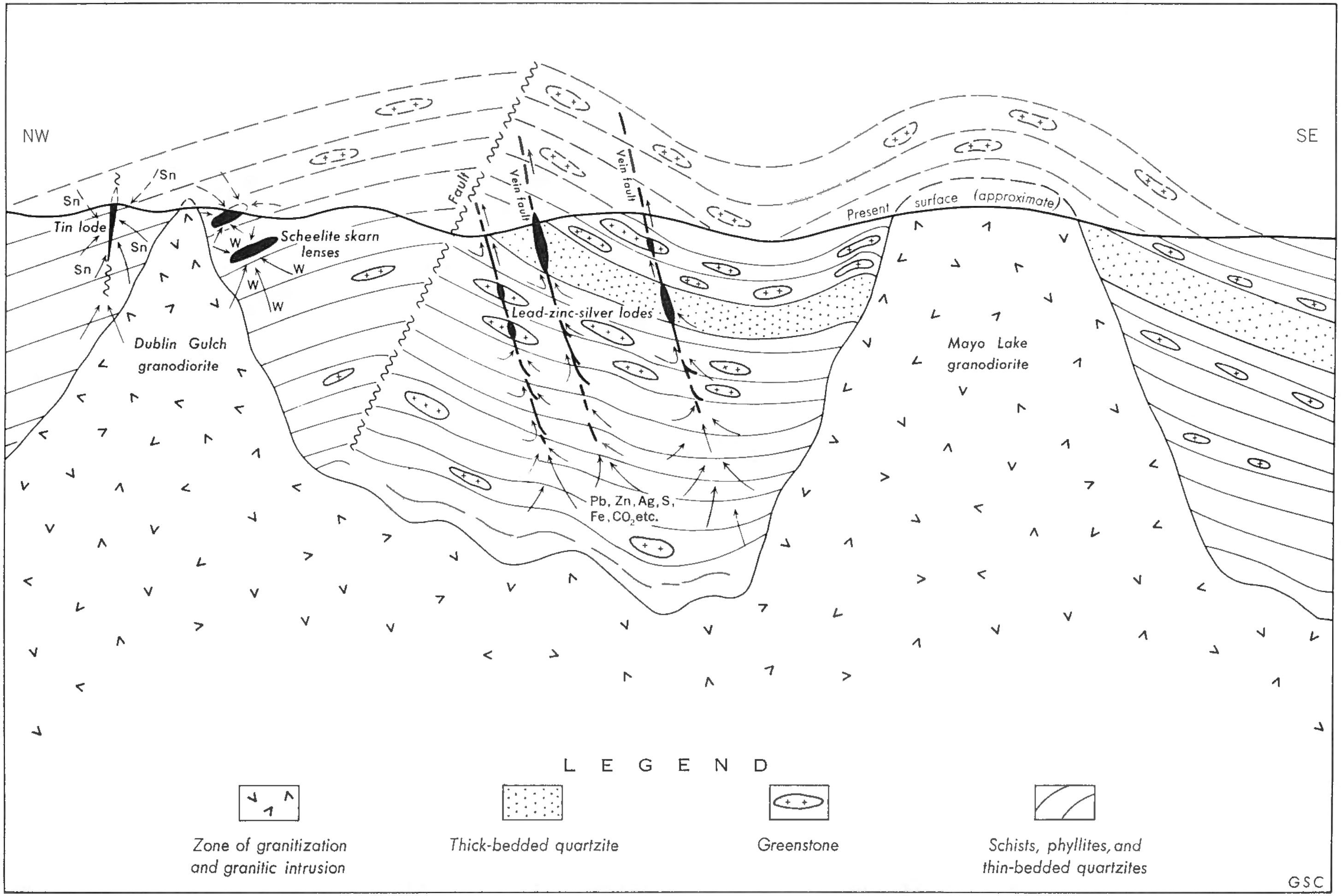

FIGURE 34. Schematic cross-section to illustrate formation of skarn lenses, tin lodes, and vein deposits, Keno Hill-Galena Hill area.

statements can be made. We have for instance no experimental data whatever on the relative mobilities of silica, carbon dioxide, and sulphur, or of lead, zinc, silver, etc., during diffusion processes.

We can assume however, from our knowledge of the effects manifest during diagenesis and low-grade metamorphism, that silica has a relatively high mobility at low temperatures. This mobility would be further enhanced by the presence of water vapour at relatively high temperatures as shown by Morey (1957) and others. If the carbon dioxide content of the system increased, however, the solubility, and hence the mobility of silica, would be markedly depressed. On the other hand, large quantities of carbon dioxide migrating through the rocks would greatly facilitate the mobility and hence migration of Fe, Mn, Ca, Mg, and Sr because of the formation of soluble (i.e., mobile) hydrogen carbonate complexes of the type $Fe(HCO_3)_2$. One would also expect that sulphur, either in the form of H_2S or sulphide ion, would have a similar effect on the mobility of the various chalcophile elements.

The marked persistence of the vein fault systems on strike suggests that they extend to considerable depths. Their dilatant effect would, therefore, extend over a considerable volume of sedimentary and greenstone country rock, and they would draw elements from considerable distances both laterally and vertically. As these elements migrated up and along the various fractures and faults constituting the systems, they would seek out the more dilatant parts where they would be precipitated to establish equilibrium. It will be noted in this respect that the more dilatant parts are in the competent quartzites and greenstones lying above a great series of graphitic schists, argillites, and thin-bedded quartzites, which, as shown in the previous section, are an ideal source for the ore and gangue elements.

The manner of formation of the two types of lodes in the vein faults may now be explained as follows. During the main period of regional metamorphism and granitic intrusion, water and carbon dioxide would be mobilized as a result of the rise of the geotherms through the sedimentary pile. Mobilization of SiO_2, S, As, Sb, Zn, Pb, Ag, Au, etc., would thereby be facilitated but little migration of any of these constituents, including H_2O and CO_2, would take place until the vein faults were formed. Once this took place the more mobile constituents, viz., SiO_2 and some S, As, Sb, Fe, and Au, would be drawn into the vein faults and would be precipitated in the more dilatant parts to form the quartz-pyrite-arsenopyrite lodes. Following this period of mineralization increased temperatures at depth coupled with renewed tectonic activity and the formation of more extensive dilatant zones would bring large quantities of CO_2 and S into the diffusion system. The CO_2 would strongly depress the mobility of silica, as mentioned above, but at the same time this constituent, together with sulphur, would greatly enhance the mobility of Fe, Mn, Mg, and the chalcophile elements, Zn, Pb, Ag, etc. All these constituents would be drawn into the extensive dilatant parts of the vein faults to form the siderite-galena-sphalerite-freibergite lodes.

The writer's view, therefore, on the formation of the Keno Hill-Galena Hill deposits is that all were formed by diffusion processes, and that both ore and gangue elements came from the sediments and greenstones. The diffusion processes were promoted by and were an integral part of the geological and physicochemical events of regional metamorphism, granitic intrusion, and dilatancy of vein faults.

History of Mineralization

The origin of the varied types of deposits in the Keno Hill area can best be summarized by the following historical synthesis of the mineralization processes. Figure 34 is a schematic diagram to illustrate this.

During late Precambrian or Palaeozoic time a thick series of marine sediments, consisting of graphitic shales, argillites, siliceous precipitates, sandstones, calcareous precipitates, and limestones, was laid down in an extensive basin in which reducing conditions prevailed. Abundant microcrystalline iron sulphide was precipitated with these sediments, probably both as a result of inorganic processes and the action of anaerobic bacteria. In addition large quantities of lead, zinc, silver, copper, gold, and tin were also precipitated in this reducing sulphide milieu. With the onset of diagenesis these elements were incorporated in the pyrite or were distributed among the various silicates, and along various grain boundaries, etc.

Later, gabbro and diabasic sills (now greenstones) were intruded along certain sedimentary horizons, particularly into the softer shales and argillites.

In Cretaceous (?) time a period of great orogeny took place, during which the sediments and greenstones were folded and in places intensely sheared. Near the end of this period, granitization at depth probably took place and some of the products of this process rose high into the sedimentary pile, forming the granitic stocks and plugs of the district. The stresses in the rocks during the latter part of the orogeny were relieved in part by the formation of northeast faults and numerous subsidiaries.

During the initial period of folding and regional low-grade metamorphism numerous small dilatant zones were formed in the quartzites and greenstones, and these were filled with the more mobile constituents in the country rocks (SiO_2, CO_2, Ca, etc.) to form the myriad stringers and lenses of quartz containing a few carbonates in places. In the hotter zones, near the intrusions, tungsten was mobilized in the sediments and was precipitated in calcareous rocks during the formation of the skarns. Similarly the mobile tin and a little tungsten were precipitated as cassiterite, wolframite, and scheelite in dilatant structures in and near the granitic bodies.

As the vein faults formed they constituted dilatant zones which initially drew in the more mobile constituents from the country rocks, viz., SiO_2, and some S, As, Sb, Fe, and Au, to form the early quartz-pyrite-arsenopyrite veins. Following this period of mineralization renewed tectonic activity resulted in the formation of more extensive dilatant zones in the vein faults, and much CO_2, S, Fe, Mn, Mg, Pb, Zn, Cu, and Ag were drawn in to form the siderite-pyrite-galena-sphalerite-freibergite lodes.

Late in Mesozoic time the rocks and deposits of the district were severely disrupted by a series of north- to northwest-striking faults.

In Tertiary time oxidation of the lodes began and has continued to the present.

Chapter VII

SUMMARY AND CONCLUSIONS

The geological, mineralogical, and geochemical features described in this report are as follows:

1. The consolidated sedimentary rocks underlying the Keno Hill-Galena Hill district belong to the Yukon Group and are probably of Precambrian or Palaeozoic age. They consist of graphitic, sericitic, and chloritic schists, phyllites, thick- and thin-bedded quartzites, argillites, and a few limestone beds and lenses. In a large part of the district these rocks fall into the greenschist class of metamorphic rocks. Near granitic bodies hornfels, biotite schists, staurolite schists, garnet schists, and skarns are developed, the latter chiefly from limestones and calcareous quartzites and schists.

2. The sedimentary rocks have been subdivided into three formations on Keno, Galena, and adjacent hills. These have been informally named as follows: lower schist formation, central quartzite formation, and upper schist formation. The rocks in the three formations dip gently southeast and appear to form the southern limb of a large open anticline whose axis follows the McQuesten River valley. The central quartzite formation is the principal focus of mineralization. This formation consists of three favourable members, the Galkeno, Hector-Calumet, and Silver King. Each contains massive thick-bedded quartzites in which the main orebodies occur. The lower schist formation contains one particularly favourable quartzite member, the No. 9 quartzite, as well as other quartzite members and numerous greenstone lenses that are favourable host rocks for mineralization. The upper schist formation is essentially barren.

3. The earliest intrusions were gabbro and diabase sills. These sills are now represented by a great series of discontinuous lenses or boudins of greenstone that lie conformably in the various schists and quartzites.

4. Granitic stocks and small plugs, probably of Cretaceous age or younger, outcrop northwest and southeast of the main mineral belt. These masses range in composition from granodiorite to quartz diorite and appear to be intrusive into the various sedimentary formations.

5. Quartz-feldspar porphyry sills and dykes are exposed at various places along the main mineralized belt, and a few biotite lamprophyre dykes occur at scattered points. These rocks cut the greenstone sills, but their relationships to the main granitic masses are unknown.

6. Two principal systems of faults occur in the district—a northeast-striking system of vein faults and a north-northeast- to northwest-trending series of late faults. The former contains an early generation of quartz-pyrite-arsenopyrite veins carrying a little gold, and a later generation of siderite-galena-sphalerite-freibergite lodes that constitute the economic deposits of the area. The late faults are barren.

7. The most favourable host rocks for the formation of epigenetic lodes and veins are thick-bedded quartzites and greenstones. Structurally the principal economic lodes are located in three sites: 1) at the junction of two or more vein faults, 2) at the junction of a vein fault and subsidiary fracture, and 3) in quartzites or greenstones at or near the sites where vein faults pass upwards from these rocks into schists or thin-bedded quartzites. Considered physicochemically, these three sites were dilatant (i.e., low pressure and low chemical potential) zones into which the various ore and gangue minerals were drawn.

8. Three types of surficial materials occur in the district: residual soils developed on schists, quartzites, and greenstones; glacial deposits, consisting principally of till, glacio-fluvial and glacio-lacustrine gravels, sand, and silt; and muck, peat, and half-bog soils developed on the north slopes of the hills and on low-lying poorly drained ground.

9. The residual soils exhibit poor profiles and are generally highly disturbed by solifluction and frost-boiling. Chemically the residual soils reflect the effects of mild laterization which has resulted in the leaching of silica and a general enrichment of alumina and iron compared with their parent bedrocks and the glacial tills. The glacial tills are relatively fresh and contain carbonates, indicating little weathering or leaching.

10. The residual soils and glacial tills are relatively low in organic matter (1-4 per cent), whereas the muck, peat, and half-bog soils contain up to 44 per cent. The base exchange capacity of the organic soils is several magnitudes greater than that recorded for the residual soils and tills, and their adsorption capacity for zinc and various other trace elements is very high. The pH of residual soils is around 5.5; that for till and organic soil, 7.5 and 6 respectively.

11. The distribution of silver, lead, copper, zinc, cadmium, arsenic, antimony, manganese, tin, and tungsten was determined in the various soil types and has been compared with their parent materials. The muck and half-bog soils exhibit an enrichment of silver and zinc, and the organic layers developed on residual soils show a general enrichment in copper and zinc. Other trace elements in the organic materials are either about equal to or lower in amount than in their parents. All residual soils show an enrichment in trace elements compared with the schists, quartzites, and greenstones underlying them. The highly aluminous soils and weathered debris overlying parts of the Dublin Gulch granodiorite body are greatly enriched in arsenic, antimony, tungsten, and zinc.

12. A series of leaching experiments, heavy mineral separations, and other mineralogical investigations were employed to determine the mode of binding of lead, zinc, cadmium, copper, silver, manganese, arsenic, antimony, tin, and tungsten in the various surficial materials. In general most of these elements is tightly bound up in mineral coatings, colloids, clay minerals, various iron and manganese oxides, in organic constituents, and in the lattices of the mineral constituents of the soils and other surficial materials. Only small amounts are adsorbed and lightly bound. Where large amounts of lead, silver, copper, arsenic, antimony, tin, and tungsten appear in the soils, the minerals cerussite, anglesite, galena, malachite, beudantite, wad, limonite, scorodite, cassiterite, scheelite, and wolframite are generally present.

13. The results of analyses of residual soils along a series of traverses across known mineralized vein faults indicate that in the vicinity of these structures the silver, lead, zinc, antimony, arsenic, and manganese contents of the soil rise several times above the background giving broad anomalies with strong contrast. Where lead deposits are present the anomalies are particularly marked and metal values tens, and in places hundreds, of times greater than background were obtained.

14. Analyses of near-surface glacial till and muck along traverses across known vein faults generally fail to detect the presence of the vein faults or deposits. Spot samples of glacial material taken close to bedrock, however, contain large amounts of all metals in the vicinity of the veins, indicating that deep sampling may effectively locate vein faults covered by glacial deposits.

15. Chemical analyses of all rock types are given. The chemical and mineralogical data on the sediments suggest that their constituents were derived by both mechanical and chemical processes. A part of the constituents of the quartzites, argillites, phyllites, and schists originated by the accumulation of mineral detritus, the remainder, including much silica, alumina, titania, potash, carbonate, and sulphur were probably derived by chemical precipitation as the result of hydrolytic processes, adsorption, and the action of primeval organisms.

Chemically the greenstones are similar to gabbros, but they have undergone extensive changes during metamorphism. Some silica, alumina, iron, and lime was lost, and a little soda, potash, water, carbon dioxide, and sulphur was gained. The latter constituents were probably drawn into the bodies from the enclosing sediments, and the silica, alumina, iron, and lime are probably now in quartz and quartz-carbonate-chlorite veins, which occur both in the greenstone bodies and in the adjacent sediments.

Most granitic bodies have a granodioritic composition. The border phases of some stocks are, however, more basic and approach the composition of quartz diorites.

16. The distribution of a suite of trace elements has been determined in all rock types. The graphitic schists, phyllites, quartzites, and greenstones provide an enormous reservoir of sulphur, arsenic, silver, lead, zinc, cadmium, copper, manganese, iron, and carbon dioxide, the major constituents of the deposits of the area. These elements were undoubtedly concentrated by sedimentation processes in the schists, phyllites, and quartzites and by magmatic processes in the greenstones. There was probably some rearrangement of the elements during the regional metamorphism, but the overall composition of the sediments and greenstones has probably changed little since they were formed.

17. Three major periods of hypogene mineralization are represented in the district.

The first is marked by the development of numerous quartz stringers, lenses, and irregular bodies in fractures, joints, small faults, drag-folds, shear zones, ruptured bedding planes, and contorted zones in the various sedimentary rocks and greenstones. In the sedimentary rocks some pyrite and a few carbonates accompany the quartz, and epidote, chlorite, and carbonate minerals are present in the quartz bodies in greenstone rocks. Near the granitic masses some scheelite and wolframite occur in small quartz stockworks, and cassiterite is present in impregnation zones. The skarn lenses were also probably formed during this period. Some of these carry scheelite.

The second period is represented by quartz-pyrite-arsenopyrite lenses containing a little gold. These occur principally in the northeast-striking vein faults.

The third period is represented by the economic siderite lodes containing essentially sphalerite, galena, pyrite, chalcopyrite, and freibergite.

18. The quartz-pyrite-arsenopyrite veins and siderite lodes are oxidized to depths varying from 20 to 600 feet. In some siderite lodes the zones of oxidation grade through zones of reduction varying from 2 to 20 feet in depth; in others the zones of oxidation grade imperceptibly into the hypogene zones. During the oxidation of the lodes and their enclosing rocks, residual deposits and placers containing gold, scheelite, and wolframite were formed in the soils and weathered debris in the vicinity of their respective hypogene deposits and in nearby streams.

19. The geological age of the deposits is uncertain. Some of those in the northeast-striking vein faults cut apophyses of the granitic bodies as well as the quartz-feldspar porphyries. This suggests that the hypogene deposits are of late Cretaceous age or younger. The principal period of oxidation was probably in the late Tertiary, but in many lodes the oxidation processes are active at present. Most of the placers were probably formed in late Tertiary time, although some reworking of the gravels also took place in post-Pleistocene time and in places is still continuing.

20. The principal hypogene minerals in the deposits are quartz, siderite, pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, and freibergite. Less common are barite, pyrrhotite, stibnite, boulangerite, jamesonite, meneghinite, bournonite, stephanite, polybasite, scheelite, wolframite, cassiterite, and tourmaline.

Galena, sphalerite, and freibergite are the economic minerals in the lodes. Freibergite is the most important silver-bearing mineral in the area.

21. The principal supergene minerals are limonite, wad, quartz, calcite, cerussite, smithsonite, anglesite, gypsum, beudantite, scorodite, bindheimite, malachite, azurite, native silver, pyrargyrite, and ice. Less abundant are pharmacosiderite, aurichalcite, brochantite, jarosite, rozenite, gunningite, senarmontite, various clay minerals, serpentine, sulphur, native zinc, acanthite, covellite, galena, sphalerite, hawleyite, marcasite, and pyrite.

Native silver and pyrargyrite are important economic minerals in some lodes.

22. The geochemistry of the hypogene stage of mineralization and the wall-rock alteration effects are dealt with in detail.

The first hypogene stage was marked principally by the introduction of silica throughout the area and by tin, tungsten, and a little bismuth near the granitic masses.

The second stage was characterized by an extensive introduction of silica which was precipitated as quartz lenses in dilatant zones in a series of northeast-trending vein faults. In addition to this constituent, considerable amounts of sulphur, arsenic, and iron and a little antimony, lead, copper, gold, and silver were introduced.

The third and major stage of mineralization culminated in an extensive introduction of carbon dioxide, iron, manganese, sulphur, antimony, lead, zinc, silver, cadmium, and a little arsenic and antimony into dilatant zones in the northeast-striking vein faults and their subsidiaries. These elements and constituents were partitioned into siderite which forms the main gangue, pyrite, chalcopyrite, galena, sphalerite, freibergite, boulangerite, and a few other sulphosalts. These minerals constitute the principal economic deposits of the mineral belt, yielding lead, zinc, silver, and cadmium.

The wall-rock alteration effects are relatively minor in the sedimentary rocks. In the greenstones chloritization, carbonatization, and sericitization are marked near some lodes.

23. The geochemistry of the surface and ground waters and the supergene processes in the deposits are discussed in detail.

The chemical factors that influence the mobility of the elements during oxidation are the Eh as manifested by the presence of free oxygen, the pH, and the solubility of the various elemental salts. Hydrolytic, colloidal, and adsorption phenomena also play their part.

Iron and manganese are markedly affected by the Eh and pH of the environment and by hydrolytic reactions. Both these elements are released from their primary minerals in their lowest oxidation states under acid conditions. As the solutions are neutralized by reaction with the carbonate gangue and silicate minerals of the wall-rocks, their soluble salts (sulphates and hydrogen carbonates) undergo oxidation and hydrolysis, with the precipitation of basic salts in the case of iron, and finally with the formation of hydroxides and hydrated oxides (limonite and wad). During the formation of these mineral aggregates small quantities of arsenic, antimony, lead, zinc, silver, cadmium, and other elements are coprecipitated with them or adsorbed to their surfaces and ultimately bound within their structures.

The mobility of calcium and magnesium is controlled mainly by the carbon dioxide content and pH of the solutions and the solubility of their sulphates. The high solubility of the sulphates of zinc and cadmium endows these elements with a marked mobility, whereas the reverse is true for lead. The mobility of silver and gold is influenced by the pH and Eh of the environment and especially by the relative concentrations of ferrous and ferric ions in the oxidizing solutions. The migration of arsenic and antimony depends essentially upon the solubility of their oxygen salts and upon various hydrolytic processes.

The precipitation of supergene minerals in the zone of reduction is determined by many special chemical conditions. Among these are the increasing pH of the solutions as they migrate downward, the availability of H_2S, and the presence of reactive sulphides such as pyrite, galena, and freibergite.

24. The oxidized zones are enriched in lead and silver and depleted in zinc and cadmium, as compared with the hypogene ores. This feature has an economic significance, as has also the development of native silver and pyrargyrite in some of the deeper parts of the oxidized zones and in the zones of reduction of a few veins.

25. Chemical evidence is presented to show that the greenstones and sediments, especially the pyritic graphitic schists, argillites, phyllites, and quartzites, are adequate sources for the hypogene ore and gangue elements. It is suggested that all the deposits were formed by diffusion processes, and that the ore and gangue elements came from the sedimentary and greenstone country rocks. The diffusion processes were promoted by and were an integral part of the geological and physicochemical events of regional metamorphism, granitic intrusion, and dilatancy of vein faults.

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[1] Published after the preparation of the report.

APPENDIX

Tables 2 to 62

Table 2

Structural Location of Orebodies[1] *and Mineralized Zones, Keno Hill-Galena Hill Area*

Property	STRUCTURAL LOCATION			WALL-ROCKS				Remarks
	Below schist capping	At or near vein fault junctions	Unknown	Thick-bedded quartzites	Greenstones	Thin-bedded quartzites, phyllites, and schists	Greenstone or quartzite on one wall, schist on the other	
GALENA HILL								
(1) Silver King	x	x		x		x	x	Two high-grade, lead-zinc-silver orebodies
(2) Elsa		x		x	x			Intensely oxidized lead-silver orebodies
(3) Dixie			x	x				Small pods of ore
(4) Coral and Wigwam	x			x		x		“ “
(5) Arctic and Mastiff	x			x		x	x	Small high-grade lead-zinc-silver orebodies
(6) Ruby			x	x		x		Small mineralized zones
(7) No Cash			x	x		x		Small high-grade lead-zinc-silver orebodies
(8) Betty			x			x	x	Small mineralized zones
(9) Cream	x			x	x	x	x	Small pods of ore
(10) Hector		x		x		x		Large high-grade lead-zinc-silver orebodies
(11) Calumet		x		x		x		“ “ “
(12) Dragon			x	x		x		Small pods of ore
(13) Formo	x				x	x	x	“ “
(14) Galkeno	x			x		x	x	Medium-sized lead-zinc-silver orebodies
(15) Eagle	x			x		x	x	Small mineralized zones
(16) Fisher Creek			x			x		Small mineralized zones (?)
(17) Bluebird	x				x	x		Small mineralized zones
(18) Tin Can	x				x	x		Small mineralized zones
(19) Rico			x	x		x		No mineralization seen
(20) Duncan Creek			x			x		Small mineralized zones
KENO HILL-SOURDOUGH HILL-BUNKERHILL								
(21) Moth	x			x	x			High-grade zinc orebody
(22) Onek		x		x				High-grade silver-lead orebody on upper levels. Low-grade silver-lead, high-grade zinc orebody on lower levels
(23) Klondyke-Keno	x				x	x	x	Small pods of ore
(24) Sadie-Friendship	x				x	x	x	High-grade lead-zinc-silver orebodies
(25) Ladue	x	x			x	x	x	High-grade lead-zinc-silver orebodies
(26) Bellekeno	x			x	x			High-grade lead-zinc-silver orebodies
(27) Mount Keno (Hogan vein)			x	x		x		Siderite and pyrite lenses

(28) Ankeno			x	x				Small mineralized zones
(29) Mount Keno (Runer vein)	x			x	x	x		Small high-grade lead-silver pods
(30) Dorothy			x	x	x			Coarse siderite lenses
(31) Kijo	x				x	x	x	Small mineralized zone
(32) Croesus No. 1	x				x	x	x	Coarse siderite lenses
(33) Black Cap and Shepherd	x			x		x		Small mineralized zones
(34) Lucky Queen		x		x		x		High-grade lead-silver orebodies
(35) Lake			x			x		Small mineralized zone
(36) Vanguard			x	x				Small mineralized zone
(37) Apex			x	x				Small mineralized zone
(38) Shamrock	x	x		x		x		Small high-grade lead-silver pods
(39) Highlander	x			x		x		Small pod of ore
(40) Cub and Bunny	x				x	x		Small pods of ore
(41) Stone	x				x	x	x	Small mineralized zones
(42) Homestake			x	x	x			“ “
(43) No. 6	x				x	x	x	Quartz-arsenopyrite-pyrite veins, some galena-sphalerite-siderite shoots
(44) Porcupine	x				x	x	x	Small high-grade lead-silver pods
(45) Comstock	x				x	x	x	Small high-grade lead-silver oreshoot
(46) No. 9	x	x		x	x		x	Small high-grade lead-silver orebodies
(47) No. 1		x(?)		x				Small high-grade lead-silver oreshoot
(48) Gambler			x	x		x		Small mineralized zones
(49) Main Fault and Nabob			x	x				Small mineralized zone at Nabob
(50) Lake View	x				x	x	x	Small mineralized zone
(51) Nabob No. 2			x			x		“ “
(52) Helen Fraction	x				x	x	x	“ “
(53) Gold Hill No. 2	x	x		x				“ “
(54) Ladue Fraction			x	x	x	x		“ “
(55) Fox	x			x				“ “
(56) Silver Basin	x			x				“ “
(57) Gold Queen	x			x				“ “
(58) Duncan			x	x				“ “
(59) Alice			x	x				“ “
(60) Caribou		x(?)	x	x				Small ore shoot
(61) Divide			x			x		Small mineralized zones
(62) Devon			x	x				“ “
(63) Faith			x	x				“ “
MOUNT HALDANE								
Lookout claim			x	x		x		“ “
DUBLIN GULCH AREA								
Quartz-arsenopyrite veins			x			x		Veins also cut granite and granodiorite dykes Assays show 0.10 to 0 50 oz/Au/ton
Tin veins			x			x		Cassiterite-tourmaline veins

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[1] Numbers before properties refer to locations on Figures 2 and 4.

Table 3

Chemical Composition of Residual Soils, Glacial Tills, and Muck, Keno Hill-Galena Hill Area

Constituent	Bedrocks[1] %	Residual Soils[2] %	Glacial Tills[3] %	Muck[4] %	Remarks
SiO_2	78.0	72.0	75.7	66.9	Determination made on ash
Al_2O_3	6.4	13.2	7.1	14.6	" " " "
Fe_2O_3[5]	0.7	6.3	5.9	4.4	" " " "
CaO	3.9	1.3	4.1	7.3	" " " "
MgO	1.3	1.9	2.3	2.4	" " " "
Na_2O	0.5	1.1	1.1	0.9	" " " "
K_2O	0.8	1.9	1.6	1.2	" " " "
TiO_2	0.5	0.9	0.6	0.7	" " " "
P_2O_5	0.2	0.3	0.4	0.2	" " " "
MnO	0.1	0.2	0.3	0.1	" " " "
Total	92.4	99.1	99.1	98.7	
Loss on ignition	—	7.47	6.03	47.12	Determinations made on soil as received
Total H_2O	1.6	5.42	2.48	21.48	" " " " " "
FeO	2.2	1.86	1.64	3.25	" " " " " "
CO_2	2.8	0.11	2.62	0.35	" " " " " "
S	0.3	0.01	0.00	0.04	" " " " " "
Analyst	G. Bender	G. Bender	G. Bender	G. Bender	Geological Survey of Canada
Organic matter	—	3.7	1.3	43.6	Determination made on soil as received
Total nitrogen	—	0.16	0.05	0.97	" " " " " "
Base exchange capacity (me/100g)	—	10.2	4.4	94.7	" " " " " "
Exchangeable bases (me/100g)					
Ca	—	2.2	22.6	74.9	" " " " " "
Mg	—	1.1	1.4	11.6	" " " " " "
K	—	0.13	0.12	0.22	" " " " " "
Na	—	0.24	0.25	0.59	" " " " " "
pH 1:1	—	5.2	7.5	6.1	" " " " " "
Analyst	— —	R. L. Halstead S. I. M. Skinner	R. L. Halstead S. I. M. Skinner	R. L. Halstead S. I. M. Skinner	Soil Chemistry Unit, Department of Agriculture, Ottawa

[1] Weighted average of bedrock analyses; 5 quartzite: 2 schist: 1 greenstone (Tables 17, 19, and 22).

[2] Residual soils—a composite sample of equal amounts of 200 residual soil samples—Keno, Galena, and Sourdough Hills.

[3] Glacial tills—a composite sample of equal amounts of 20 till samples—Keno and Galena Hills.

[4] Muck—a composite sample of equal amounts of 15 muck and half-bog soils—Keno and Galena Hills.

[5] Total iron in ash as Fe_2O_3.

Table 4

Average Metal Content of Muck, Residual Soils, and Tills Compared with their Probable Source Materials

Sample Description	Elemental Concentration in ppm									Remarks
	Ag	Pb	Cu	Zn	As	Sb	Sn	W	Cd	
Muck and half-bogs on glacial tills	0.6	13	16	100	5.7	1.4	<2	<4	<2	Average of 4 samples
Glacial till	0.5	21	28	70	11	1.5	2	<4	<2	Average of 20 samples
Organic layer (A_1), peat, and half-bog soils on residual soils	0.4	22	52	150	12.5	2.4	2	<4	<2	Average of 15 samples
All types of residual soils	0.5	43	37	80	18	3.0	2.5	<4	~2	Average of 60 samples
Residual soils on quartzites, phyllites, and schists	0.5	39	35	95	17	2.4	2.2	<4	~2	Average of 47 samples
Quartzite, phyllite, and schist	0.37	9	26	48	9	2.2	2	<4	<2	Average of 73 composite samples
Residual soils on greenstones	0.5	32	76	83	24	2.2	2.5	<4	<2	Average of 8 samples
Greenstones	0.32	5	132	73	6	1	3	<4	<2	Average of 27 composite samples
Residual soils on granodiorites, granites, etc., Dublin Gulch area	1.2	17	5	70	462	10.5	9.6	5000	<2	Average of 4 samples
Granodiorites, granite, etc., Dublin Gulch area	<0.1	17	6	50	12.5	<1	<5	<4	<2	Average of 2 composite samples
Residual soils on schists and quartzites, north of Dublin Gulch	0.36	23	32	83	56	15	21	8	<2	Average of 12 samples

Table 5

Metal Content of Composite Samples of Peat, Muck, and Half-bog Soils Compared with their Underlying Soils, Tills, etc.

Sample No.	Elemental Concentration of Original Sample in ppm[1]						Weight of sample in Grams	Weight of Ash in Grams	Remarks
	Ag	Pb	Cu	Zn	As	Sb			
1A	2	115	17	161	4.0	1.0	1	0.115	Upper layer of slightly compressed, undecomposed peat and moss. Silver King mine area
3A	1	21	27	50	10.0	1.5			Till and gravel, underlying sample No. 1A
2A	0.5	14	17	74	5.7	1.4	1	0.568	Decomposed organic layer-muck. Below sample No. 1A. Silver King mine area
3A	1	21	27	50	10.0	1.5			Till and gravel underlying sample No. 2A
8A	2	102	28	400	7.7	1.5	1	0.514	Organic layer (A_1) Ladue mine area
9A	1	220	25	480	15.0	3.0			Grey to greyish brown clayey soil below sample No. 8A
10A	1	75	92	117	25.1	2.9	1	0.418	Peat interlayered with sand, gravel, and till. Northwest slope of Galena Hill
11A	0.8	33	29	220	10.4	2.5	1	0.416	Organic layer (A_1), some peat and muck. Vicinity of No. 6 vein, Keno Hill. Composite sample
12A	0.9	20	30	150	25.0	3.6			Residual soil below sample No. 11A. Vicinity of No. 6 vein, Keno Hill
14A	0.6	139	10	93	6.6	2.7	1	0.664	Organic layer (A_1), some peat and muck. Vicinity Hector-Calumet mine
15A	7	97	25	112	17.0	3.0			Residual soil below sample No. 14A, Hector-Calumet mine area, Galena Hill

[1] *Ag* analyses by W. H. Champ and W. F. White; all others by M. A. Jardine

Table 6

Metal Content of Soils on Traverse A across No. 6 Vein Fault, Keno Hill[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–20	3	200	80	100	40	9.0	1000	Residual soil on greenstone. Horizon B
20–40	1	200	80	100	45	7.0	1000	” ” ” ” ” ”
40–60	3	400	30	200	40	6.0	1000	” ” ” ” ” ”
60–80	3	400	30	100	15	5.0	1000	” ” ” ” ” ”
80–100	1	300	30	100	35	10.5	1000	Residual soil on greenstone. Horizon B Projected outcrop of vein at 100′
100–120	20	1500	400	100	50	16.5	1000	Residual soil on greenstone. Horizon B
120–140	10	800	160	100	45	15.5	1000	” ” ” ” ” ”
140–160	10	600	100	200	50	12.5	1000	” ” ” ” ” ”
160–180	10	800	100	700	50	24.0	1000	Residual soil on greenstone. Horizon B Projected outcrop of vein at 180′
180–200	10	800	100	100	65	18.5	1000	Residual soil on greenstone. Horizon B
200–220	3	90	100	100	50	3.5	1000	” ” ” ” ” ”
220–240	5	200	100	100	50	4.5	1000	” ” ” ” ” ”
240–260	10	400	100	100	60	10.5	1000	” ” ” ” ” ”
260–280	8	600	160	100	50	9.0	5000	” ” ” ” ” ”
280–300	10	400	160	100	50	10.5	1000	” ” ” ” ” ”
300–320	8	100	160	300	110	12.0	1000	” ” ” ” ” ”
320–340	5	600	40	100	40	5.0	1000	” ” ” ” ” ”
340–360	10	800	160	200	240	12.5	1000	” ” ” ” ” ”
360–380	10	400	160	200	280	13.0	1000	” ” ” ” ” ”
380–400	10	800	80	200	1400	49.0	1000	” ” ” ” ” ”

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[1] Traverse A—200 feet northeast of main shaft on No. 6 vein. *See* Figure 20

[2] Ag, Pb, Cu, Zn, Mn analyses by W. H. Champ and W. F. White
As, Sb analyses by M. A. Jardine

Table 7

Metal Content of Soils on Traverse C across No. 6 Vein Fault, Keno Hill[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–20	1	50	40	100	20	2.5	1000	Residual soil on graphitic schist and phyllite. Horizon B
20–40	1	70	40	100	15	3.5	500	” ” ” ” ” ” ” ” ”
40–60	1	50	40	100	25	3.0	1000	” ” ” ” ” ” ” ” ”
60–80	1	50	40	100	15	2.5	500	” ” ” ” ” ” ” ” ”
80–100	1	50	40	100	20	2.5	1000	” ” ” ” ” ” ” ” ”
100–120	1	100	40	100	15	2.5	1000	” ” ” ” ” ” ” ” ”
120–140	3	400	30	500	15	4.5	1000	” ” ” ” ” ” ” ” ”
140–160	2	400	30	500	15	3.0	1000	Residual soil on graphitic schist and phyllite. Horizon B Projected outcrop of vein at 150′
160–180	1	350	40	100	20	4.5	1000	Residual soil on graphitic schist and phyllite. Horizon B
180–200	1	300	40	100	15	5.5	1000	” ” ” ” ” ” ” ” ”
200–220	1	300	40	100	30	7.0	1000	” ” ” ” ” ” ” ” ”
220–240	2	300	60	100	60	10.5	1000	” ” ” ” ” ” ” ” ”
240–260	1	200	60	150	220	9.0	1000	” ” ” ” ” ” ” ” ”
260–280	1	200	40	200	180	9.5	2000	” ” ” ” ” ” ” ” ”
280–300	1	200	40	500	60	5.5	1000	” ” ” ” ” ” ” ” ”

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[1] Traverse C–900 feet southwest of main shaft on No. 6 vein. *See* Figure 20

[2] Ag, Pb, Cu, Zn, and Mn analyses by W. H. Champ and W. F. White
As, Sb analyses by M. A. Jardine

Table 8

Metal Content of Soils on Traverse D across No. 6 Vein Fault, Keno Hill[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–30	<1	50	40	100	20	2.0	500	Residual soil on greenstone. Horizon B
30–60	<1	30	40	110	35	2.5	500	” ” ” ” ” ”
60–90	<1	50	50	80	25	2.5	500	” ” ” ” ” ”
90–120	<1	30	60	70	25	2.5	500	Residual soil on graphitic schist and phyllite. Horizon B
120–150	<1	20	60	40	20	2.0	200	” ” ” ” ” ” ” ” ”
150–180	<1	40	60	100	20	2.0	1000	Residual soil on graphitic schist and phyllite. Horizon B. Projected outcrop of vein at 160′
180–210	2	100	60	200	100	8.5	1000	Residual soil on graphitic schist and phyllite. Horizon B
210–240	10	150	60	200	1000	44.0	1000	” ” ” ” ” ” ” ” ”
240–270	10	80	40	800	920	50.0	1000	” ” ” ” ” ” ” ” ”
270–300	10	1000	50	300	590	40.0	1000	” ” ” ” ” ” ” ” ”
300–325	9	600	40	100	400	31.0	1000	” ” ” ” ” ” ” ” ”
325–350	9	800	40	200	760	30.0	1000	” ” ” ” ” ” ” ” ”
350–375	4	400	40	200	270	18.5	300	” ” ” ” ” ” ” ” ”
375–400	5	500	40	200	410	25.0	300	” ” ” ” ” ” ” ” ”
155–165	3	300	40	500	5200	41.0	2000	Reddish residual soil, 3′ from surface. Directly over No. 6 vein. Not on traverse
155–165	10	90	60	1000	2700	100.0	4000	Reddish residual soil, 3′ from surface. Directly over No. 6 vein. Not on traverse

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[1] Traverse D–2080 feet southwest of main shaft on No. 6 vein. *See* Figure 20

[2] Ag, Pb, Cu, Zn, and Mn analyses by W. H. Champ and W. F. White
As and Sb analyses by M. A. Jardine

Table 9

Metal Content of Soils on Traverse across Porcupine-Kinman Vein Fault, Keno Hill[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–20	<1	70	40	100	15	2.5	500	Residual soil on graphitic schist, sericite schist, and phyllite. Horizon B
20–40	<1	70	40	100	20	5.0	200	" " " " " " " " " "
40–60	<1	20	40	100	10	2.5	200	" " " " " " " " " "
60–80	<1	50	30	100	20	2.5	200	" " " " " " " " " "
80–100	<1	70	30	100	20	4.0	200	" " " " " " " " " "
100–120	<1	50	30	100	20	3.5	200	" " " " " " " " " "
120–140	<1	20	30	100	15	2.5	200	Residual soil on graphitic schist, sericite schist, and phyllite. Horizon B Projected outcrop of vein at 140′
140–160	<1	50	30	100	35	4.5	200	Residual soil on graphitic schist, sericite schist, and phyllite. Horizon B
160–180	4	500	30	500	100	12.5	1000	" " " " " " " " " "
180–200	5	400	30	500	90	12.5	1000	" " " " " " " " " "
200–220	3	400	40	500	90	12.5	1000	" " " " " " " " " "
220–240	3	300	30	800	120	14.0	1000	" " " " " " " " " "
240–260	9	400	40	500	80	20.0	500	" " " " " " " " " "
260–285	9	800	40	100	45	25.0	200	" " " " " " " " " "
285–310	5	400	40	100	40	14.5	100	" " " " " " " " " "
310–335	<1	40	40	100	60	14.0	100	" " " " " " " " " "
335–360	3	100	40	100	60	14.0	100	" " " " " " " " " "

[1] Northwest—southeast traverse—1000 feet southwest of Porcupine shaft

[2] Ag, Pb, Cu, Mn analyses by W. H. Champ and W. F. White
As and Sb analyses by M. A. Jardine

Table 10

Metal Content of Soils on Traverse across Bellekeno 48 Vein[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–25	<1	30	40	100	10	1.0	200	Grey residual soil on quartzites, schists, and phyllites. Horizon B
25–50	<1	50	30	200	10	1.0	200	” ” ” ” ” ” ” ” ” ”
50–75	<1	30	30	100	15	1.0	200	” ” ” ” ” ” ” ” ” ”
75–100	<1	30	30	100	10	1.0	200	” ” ” ” ” ” ” ” ” ”
100–125	<1	30	30	200	20	2.0	200	” ” ” ” ” ” ” ” ” ”
125–150	<1	30	30	200	25	2.0	200	Grey residual soil on quartzites, schists, and phyllites. Horizon B. Projected outcrop of vein at 150′
150–175	<1	50	30	200	30	2.5	200	Grey residual soil on quartzites, schists, and phyllites. Horizon B
175–200	<1	40	30	300	25	1.5	300	” ” ” ” ” ” ” ” ” ”
200–225	<1	50	30	500	20	2.0	300	” ” ” ” ” ” ” ” ” ”
225–250	<1	40	30	200	20	1.0	300	” ” ” ” ” ” ” ” ” ”
250–275	<1	30	30	100	15	1.5	200	” ” ” ” ” ” ” ” ” ”
275–300	<1	40	30	100	15	1.5	300	” ” ” ” ” ” ” ” ” ”
300–325	<1	30	30	100	10	1.0	300	” ” ” ” ” ” ” ” ” ”

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[1] Northwest–southeast traverse across 48 vein, Bellekeno system, 525′ southwest of main adit

[2] Ag, Pb, Cu, Zn and Mn analyses by W. H. Champ and W. F. White
As and Sb analyses by M. A. Jardine

Table 11

Variation in Metal Content of Soils with Depth, Onek Vein, Keno Hill[1]

Sample interval in feet	Elemental Concentration in ppm[2]									
	Ag	Pb	Cu	Zn	As	Sb	Mn	Sn	Cd	
0–6″	9	480	21	280	27	18	200	50	2	Humus layer. Horizon A_1
1′–3′	3	700	30	200	50	20	500	50	17	Reddish brown residual soil: Heavy concentrates contain a few small galena cubes encrusted with cerussite and anglesite, cerussite, anglesite, limonite, and wad. Horizon B
3′–6′	70	4000	60	300	160	430	500	150	17	Reddish brown residual soil: Heavy concentrates contain some cerussite, anglesite, small galena cubes, pyrite, limonite, and wad. Horizon B
6′–7′	120	5000	150	1000	500	2000	500	300	40	Reddish brown residual soil mixed with oxidized vein debris. Heavy concentrates contain much galena coated with cerussite and anglesite, cerussite, anglesite, limonite, bindheimite, and some wad. Horizon B + C
Vein (average assay) oxidized ore-surface to 50 foot level.	88.12 oz/ton	42.0%	0.87%	0.67%	0.38%	0.18%	4%	0.046%	0.027%	Average assay[3] of oxidized ore; surface to 50 foot level. Ore contains galena, cerussite, anglesite, freibergite residuals, pyrite, minor sphalerite, and much limonite and wad

[1] Samples taken above vein 200 feet northeast of Fisher shaft

[2] Ag, Pb, Cu, Zn, Sn and Cd analyses by W. H. Champ and W. F. White
As and Sb analyses by M. A. Jardine

[3] Assay of ore by Mines Branch, Ottawa

Table 12

Metal Content of Glacial Till on Traverse across Silver King Veins[1]

Sample interval in feet	Elemental Concentration in ppm[2]							Remarks
	Ag	Pb	Cu	Zn	As	Sb	Mn	
0–50	<1	20	40	50	10	1.5	200	Grey glacial till and gravel, some organic muck
50–100	<1	20	30	50	10	1.5	200	” ” ” ” ” ” ” ”
100–130	<1	30	20	80	10	1.5	200	” ” ” ” ” ” ” ”
130–160	<1	20	20	70	10	1.5	200	Grey glacial till and gravel, some organic muck Hawthorne (202) vein at 150′
160–220	<1	20	20	70	10	1.5	200	Grey glacial till and gravel, some organic muck
220–270	<1	20	20	60	10	1.0	200	” ” ” ” ” ” ” ”
270–320	<1	20	20	80	10	1.5	200	” ” ” ” ” ” ” ”
320–370	<1	20	20	50	10	1.5	200	” ” ” ” ” ” ” ”
370–420	<1	10	10	70	10	1.0	200	” ” ” ” ” ” ” ”
420–470	<1	20	40	40	15	1.5	200	” ” ” ” ” ” ” ”
470–520	<1	20	40	80	15	1.0	200	Grey glacial till and gravel, some organic muck. Silver King (206 vein) at 490′
520–570	<1	30	40	40	15	1.5	200	Grey glacial till and gravel, some organic muck
570–620	<1	20	30	40	20	1.0	400	” ” ” ” ” ” ” ”
620–670	<1	30	30	40	25	1.0	400	” ” ” ” ” ” ” ”
206 vein	200	4000	70	100		100		Till and gravel 6″ above 206 vein

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[1] Southeast–northwest traverse across 202 and 206 veins

[2] Ag, Pb, Cu, Zn and Mn analyses by W. H. Champ and W. F. White
As and Sb analyses by M. A. Jardine

Table 13

Metal Content of Soils on Traverse A-B across Tin Impregnation Zone, Dublin Gulch (See Figure 18)

Sample interval in feet	Elemental Concentration in ppm									Remarks
	Sn[1]	Sn[2]	Cu[3]	Pb[3]	Zn[3]	As[3]	Sb[3]	B[4]	Ag[4]	
A. 0–525	160	56	20	20	85	10	5.5	240	0.90	Residual soil. Small amount of cassiterite in heavy concentrates. Horizon B[5]
525–855	2600	1000	40	10	60	15	14.5	2700	0.38	Residual soil over impregnation zone. Abundant cassiterite and tourmaline in heavy concentrates. Horizon B[5]
855–1185	90	80	40	23	84	18	17.5	1100	0.40	Residual soil. Small amount of cassiterite in heavy concentrates. Horizon B[5]
1185–1515	40	41	20	15	75	10	6.0	150	0.36	Residual soil. Cassiterite in heavy concentrates of local samples. Horizon B[5]
1515–1910	20	40	40	18	75	170	15.0	280	0.36	” ” ” ”
1910–2340	25	22	30	15	80	15	11.5	210	0.38	” ” ” ”
2340–2670	20	8	30	20	85	15	14.0	140	0.22	” ” ” ”
2670–3060	25	65	30	30	90	120	15.5	140	0.34	” ” ” ”
B. 3060–3400	15	3	25	35	85	200	27.5	120	0.25	” ” ” ”

[1] Tin analyses by M. A. Jardine; colorimetric method using gallein

[2] Tin analyses by W. H. Champ; spectrographic method

[3] Cu, Pb, Zn, As, Sb analyses by M. A. Jardine

[4] B and Ag analyses by G. Patenden and W. F. White; spectrographic method

[5] Depth of sampling—1′–2′

Table 14

Extraction of Metals from Soils by Various Solvents

Sample No.	Zn (ppm)					Cu (ppm)					Pb (ppm)					Sample No.
	25% HNO_3 (hot)	$KHSO_4$ fusion	Extraction A	Extraction B	Extraction C	25% HNO_3 (hot)	$KHSO_4$ fusion	Extraction A	Extraction B	Extraction C	25% HNO_3 (hot)	$KHSO_4$ fusion	Extraction A	Extraction B	Extraction C	
2	65	55	0.5	4	2*	10	20	nd	nd	2*	10	15	0.5	1	nd	2
3	85	100	0.5	3	2*	10	30	nd	2.5	Emulsion	15	15	0.5	2.5	0.5	3
4	70	115	1	5.5	1	30	30	nd	1.5	1.5	10	10	0.5	3	0.5	4
6	125	155	nd	5	1	40	40	nd	2.5	3	35	40	nd	5.5	0.5	6
8	500	380	3.5	192	88	10	10	nd	1	2*	115	140	1	23	5	8
9	450	510	1	42	20	20	30	nd	2	Emulsion	250	190	0.5	96	4.5	9
10	105	100	1.5	46	16*	60	80	nd	3	Emulsion	70	45	1	15.5	2.5	10
12	135	160	nd	2.5	1*	20	40	nd	1	2*	15	25	0.5	3	0.5	12
13	80	90	0.5	1	2*	160	190	nd	6	6*	5	10	nd	0.5	0.5	13
15	105	120	nd	2.5	2*	20	30	nd	1	2	120	75	0.5	10.5	3	15
17	150	170	0.5	2	0.5	20	30	nd	1	1	1300	1600	0.5	600	80	17
18	300	300	nd	3	1	30	30	nd	2	1.5	220	240	0.5	52	1.5	18
22	75	140	nd	1	1	30	40	nd	1	1	100	85	nd	17	2	22

Extraction A—Metal-free water pH 5.5
Extraction B—Sodium acetate—acetic acid buffer solution pH 5.0
Extraction C—Ammonium citrate—ammonia—hydroxylamine hydrochloride solution pH 8.5

nd Not detectable
*Solution formed an emulsion; approximate answer only

All analyses by diphenylthiocarbazone methods

Analyst M. A. Jardine

Sample Descriptions:

Sample No.
2. Muck, decomposed organic layer; Silver King mine area, Galena Hill.
3. Clay till below 2; Silver King mine area, Galena Hill.
4. Glacial sand and gravel below 3; Silver King mine area, Galena Hill.
6. Glacial sand and gravel; Lightning Creek, 1 mile SW of Keno Hill townsite, Galena Hill.
8. Decomposed black organic layer below peaty layer; Ladue mine area, Keno Hill.
9. Grey to greyish brown residual (?) clayey soil below 8; Ladue mine area, Keno Hill.
10. Peat interlayered with sand and gravel, northeastern slope Galena Hill.
12. Residual soil, vicinity No. 6 vein; top of Keno Hill.
13. Residual soil overlying greenstone; vicinity of triangulation station, top of Galena Hill.
15. Residual soil, Hector-Calumet mine area, Galena Hill.
17. Residual soil, Onek mine area, 5 feet above vein, Keno Hill.
18. Residual soil, Onek mine area, 4 feet above vein, Keno Hill.
22. Residual soil, Mount Keno system, 3 feet above Hogan vein, Keno Hill.

Table 15

Metal Content of Superpanner Concentrates[1] *from Soils, Keno Hill-Galena Hill*

Soil No.	Elemental Concentration in ppm[2]											Remarks
	Ag	Pb	Cu	Zn	As	Sb	Sn	Cd	Bi	W[3]	Radioactivity[4] % U_3O_8 equivalent	
1	0.5	5	20	500	1000	100	<50	<50	<10	<4	0.01	Clay till, Silver King mine area, Galena Hill
4	0.5	10	20	500	1000	100	<50	<50	<10	<4	0.013	Glacial sand and gravel, Silver King mine area, Galena Hill
7	0.5	60	5	500	1000	100	<50	<50	<10	<4	0.01	Residual soil, in part slope wash, on schists, phyllites and quartzites, Ladue mine area, Keno Hill
12	10	350	20	500	1000	100	<50	<50	<10	<4	0.07	Residual soil on graphitic schist and phyllite, vicinity No. 6 vein; top of Keno Hill
13	1	300	20	500	1000	100	50	<50	<10	<4	0.034	Residual soil overlying greenstone; vicinity of triangulation station, Galena Hill
15	1	300	10	500	1000	100	50	<50	<10	<4	0.01	Residual soil on quartzites and schists, Hector-Calumet mine area, Galena Hill
17	50	1000	100	500	1000	100	200	<50	<10	<4	0.035	Residual soil on quartzites and schists, Onek mine area, 5 feet above vein, Keno Hill
18	10	1000	5	500	1000	100	200	<50	<10	<4	0.024	Residual soil on quartzites and schists, Onek mine area, 4 feet above vein, Keno Hill
19	10	1000	50	500	1000	100	100	<50	<10	<4	0.01	Residual soil on quartzites and schists, Onek mine area, 1 foot above vein, Keno Hill
22	5	1000	20	500	1000	100	100	<50	<10	<4	0.051	Residual soil on quartzites and schists, Mount Keno system, 3 feet above Hogan vein, Keno Hill
25	10–100	100	100	500	500	100	50	<50	<10	~10,000		Residual soil on granodiorite, south of Dublin Gulch

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[1] Lists of the heavy concentrates in residual soils and tills are given on pp. 91-92

[2] Semiquantitative analyses by W. H. Champ and W. F. White

[3] Analyses by M. A. Jardine

[4] Radioactivity analyses by W. Smith

Table 16

Metal Content of Vegetation[1]

Description	Average ppm Cu of twigs	Average % Cu in ash	Average ppm Zn of twigs	Average % Zn in ash	Average ppm Pb of twigs
Labrador tea (*Ledum* sp.) growing in muck overlying glacial till and gravel, Silver King mine area	8.7	0.036	160.6	0.685	0.43
Black spruce (*Picea mariana*) growing in muck overlying glacial till and gravel, Silver King mine area	10.5	0.040	330.7	1.26	0.40
Dwarf birch (*Betula glandulosa*) growing in muck overlying glacial till and gravel, Silver King mine area	9.1	0.045	449.0	2.24	0.63

[1] Average values for Cu, Pb, and Zn were calculated from data supplied by McLeod White, Exploration Manager, United Keno Hill Mines. Analyst C. H. Gross, Biogeochemistry Laboratory, University of British Columbia, Vancouver, B.C.

Table 17

Analyses of Composite Samples of Argillite, Slate, Graphitic Schist, and Graphitic Phyllite, Keno Hill-Galena Hill Area

Constituent	A-464 Graphitic schist and phyllite—Sourdough Hill—composite sample %	A-619 Graphitic schist, phyllite, argillite, and slate—Keno Hill—composite sample %	A-697 Graphitic schist, argillite, phyllite, and slate—Galena Hill—composite sample %
SiO_2	66.9	65.7	63.6
Al_2O_3	16.7	12.2	15.5
Fe_2O_3	2.1	1.4	1.7
FeO	1.79[1]	1.93[1]	2.44[1]
CaO	1.3	2.3	2.4
MgO	1.7	1.1	1.5
Na_2O	0.2	1.1	0.7
K_2O	2.7	2.3	2.7
H_2O (total)	2.7	3.49	2.82
TiO_2	0.9	0.7	0.8
P_2O_5	0.2	0.4	0.4
MnO	0.3	0.2	0.0
CO_2	2.25	4.66	2.05
S	0.72	0.56	1.18
C	1.37	1.00	1.34

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[1] Values uncertain because of the presence of large amounts of carbon

Table 17 *(Concluded)*

Analyses of Composite Samples of Argillite, Slate, Graphitic Schist, and Graphitic Phyllite, Keno Hill-Galena Hill Area

Constituent	A-464 Graphitic schist and phyllite—Sourdough Hill—composite sample %	A-619 Graphitic schist, phyllite, argillite, and slate—Keno Hill—composite sample %	A-697 Graphitic schist, argillite, phyllite, and slate—Galena Hill—composite sample %
Total	101.8	99.0	99.1
Less O≡S	0.3	0.2	0.5
Total	101.5	98.8	98.6
Powder density	2.755	2.763	2.798
Analysts	G. Bender	K. G. Hoops	K. G. Hoops

Table 18

Analysis of Composite Sample of Quartz-Sericite Schist

Constituent	A-692 Quartz-Sericite schist—composite—Galena Hill %
SiO_2	80.8
Al_2O_3	7.5
Fe_2O_3	0.8
FeO	2.33
CaO	1.4
MgO	1.2
Na_2O	0.3
K_2O	1.3
H_2O (total)	1.91
TiO_2	0.4
P_2O_5	0.0
MnO	0.0
CO_2	0.51
S	0.21
C	—
Total	98.7
Less O≡S	0.1
Total	98.6
Powder density	2.717
Analyst	K. G. Hoops

Table 19

Analyses of Composite Samples of Quartzite, Keno Hill-Galena Hill Area

Constituent	A-698	A-622	A-620	A-694	A-463	A-695
	Composite of all samples of thick- and thin-bedded quartzite, Keno-Galena Hills %	Composite of medium- and thick-bedded grey quartzite, Keno-Galena Hills %	Composite of thin-bedded quartzite and phyllite, Keno-Galena Hills %	Composite of white cherty quartzite, Galena Hill %	Composite of calcareous quartzite, Sourdough Hill %	Composite of calcareous quartzite, Galena Hill %
SiO_2	88.9	88.2	66.9	97.4	75.8	81.5
Al_2O_3	1.5	2.1	8.4	0.6	1.9	1.1
Fe_2O_3	0.2	0.3	0.8	0.0	0.4	0.2
FeO	1.05	1.10	1.72	0.34	0.46	0.74
CaO	3.2	1.5	7.7	0.9	10.3	7.4
MgO	0.0	1.1	0.8	0.0	0.9	0.3
Na_2O	0.2	0.4	1.1	0.1	0.1	0.0
K_2O	0.2	0.3	1.6	0.1	0.3	0.2
H_2O (total)	0.71	0.56	0.9	0.15	0.44	0.32
TiO_2	0.2	0.2	0.5	0.1	0.2	0.1
P_2O_5	0.1	0.1	0.2	0.0	0.2	0.1
MnO	0.1	0.1	0.1	0.0	0.0	0.0
CO_2	2.94	2.94	7.97	0.00	8.42	7.24
S	0.10	0.17	0.52	0.02	0.25	0.00
C	—	0.09	0.29	—	—	—
Total	99.4	98.7	99.5	99.7	99.7	99.2
Less O≡S	0.0	0.1	0.2	0.0	0.1	0.0
Total	99.4	98.6	99.3	99.7	99.6	99.2
Powder density	2.668	2.690	2.726	2.684	2.701	2.670
Analysts	K. G. Hoops	K. G. Hoops	K. G. Hoops	K. G. Hoops	G. Bender	K. G. Hoops

Table 20

Analyses of Composite Samples of Limestone, Keno Hill-Galena Hill Area

Constituent	A-730 Banded white to grey crystalline limestone %	A-731 Black brecciated limestone %
SiO_2	17.96	1.35
Al_2O_3	0.00	0.00
Fe_2O_3	0.27	0.36
FeO	0.32	1.74
CaO	44.50	30.26
MgO	0.72	19.66
Na_2O	0.17	0.06
K_2O	0.04	0.01
H_2O+	0.13	0.13
H_2O-	0.00	0.01
TiO_2	0.03	0.03
P_2O_5	0.05	0.02
MnO	0.38	0.36
CO_2	35.55	45.70
S	0.02	0.01
C	0.12	0.53
Total	100.26	100.19
Less O=S	0.00	0.00
Net total	100.26	100.19
Powder density	2.725	2.882

Analyst: K. Hoops

Table 21

Analyses of Typical Skarn, Keno Hill-Galena Hill Area

Constituent	A-735 Scheelite skarn Ray Gulch; Dublin Gulch area %	A-733 Skarn, Ray Gulch; Dublin Gulch area %	A-734 Dense greenish scheelite skarn, Cement Creek %	A-732 Sulphide—scheelite skarn, Cement Creek %
SiO_2	55.56	59.98	41.45	37.01
Al_2O_3	0.52	6.21	9.53	10.07
Fe_2O_3	0.06	0.67	1.77	21.17
FeO	5.74	11.28	12.47	not obtainable
CaO	21.19	15.64	19.65	13.00
MgO	7.09	0.48	1.41	1.78
Na_2O	0.09	1.21	0.64	0.39
K_2O	0.01	0.14	0.15	0.08
H_2O+	0.13	0.48	0.63	0.19
H_2O-	0.09	0.28	0.15	0.29
TiO_2	0.06	0.17	0.35	0.27
P_2O_5	0.08	0.04	0.14	0.12
MnO	0.12	0.31	0.49	0.24
CO_2	6.88	2.86	2.72	0.52

Table 21 *(Concluded)*

Analyses of Typical Skarn, Keno Hill-Galena Hill Area

Constituent	A-735 Scheelite skarn Ray Gulch; Dublin Gulch area %	A-733 Skarn, Ray Gulch; Dublin Gulch area %	A-734 Dense greenish scheelite skarn, Cement Creek %	A-732 Sulphide—scheelite skarn. Cement Creek %
S	NF	NF	0.38	7.44
C	0.03	0.05	0.11	0.15
WO_3	2.43	0.00	7.80	11.58
Total	100.08	99.80	99.84	not obtainable
Less O≡S	0.00	0.00	0.14	2.79
Net total	100.08	99.80	99.70	—
Powder density	3.000	2.942	3.365	3.574

Analysts: J. A. Maxwell and S. Courville.

Table 22

Analyses of Composite Samples of Greenstone, Keno Hill-Galena Hill Area

Constituent	A-621 Composite sample greenstone lenses Keno Hill %	A-691 Composite sample greenstone lenses Galena Hill %	Average gabbro[1] %
SiO_2	49.7	46.3	48.36
Al_2O_3	15.3	13.8	16.84
Fe_2O_3	2.6	0.8	2.55
FeO	8.07	10.12	7.92
CaO	9.3	12.9	11.07
MgO	6.3	4.5	8.06
Na_2O	2.2	1.7	2.26
K_2O	0.2	0.2	0.56
H_2O (total)	2.90	4.05	0.64
TiO_2	1.7	1.7	1.32
P_2O_5	0.2	0.2	0.24
MnO	0.0	0.1	0.18
CO_2	0.31	2.56	
S	0.03	0.14	
C	—	—	
Total	98.8	99.1	
Less O≡S	0.0	0.1	
Total	98.8	99.0	
Powder density	3.032	2.975	

Analyst: K. G. Hoops

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[1] Average gabbro as given by Nockolds, S. R.—Average chemical compositions of some igneous rocks; *Bull. Geol. Soc. Amer.*, vol. 65, pp. 1007–1032, 1954.

Table 23

Chemical Changes Resulting from Regional Metamorphism of Gabbro (greenstone), Sourdough Hill

Constituent	A-466[1] %	A-462[2] %	Adjusted[3] %	Gains and losses in constituents	Percentage gains and losses
SiO_2	48.0	47.6	44.27	−3.73	− 7.7
Al_2O_3	17.2	13.8	12.83	−4.37	− 25.4
Fe_2O_3	4.2	1.7	1.58	−2.62	− 62.3
FeO	6.58	6.43	5.98	−0.60	− 0.9
CaO	11.0	10.6	9.86	−1.14	− 10.3
MgO	5.0	6.0	5.58	+0.58	+ 1.1
Na_2O	1.5	1.9	1.77	+0.27	+ 1.8
K_2O	0.1	0.4	0.37	+0.27	+270.0
H_2O+ H_2O-	3.06	4.04	3.76	+0.70	+ 2.2
TiO_2	2.5	1.7	1.58	−0.92	− 3.6
P_2O_5	0.1	0.2	0.19	+0.09	+ 90.0
MnO	0.2	0.1	0.09	−0.11	− 55.0
CO_2	1.16	4.36	4.05	+2.89	+249.1
S	0.03	0.05	0.046	+ .016	+ 53.3
Total	100.6	98.9			
Less O ≡ S	0.0	0.0			
Net total	100.6	98.9			
Specific gravity	3.01	2.80			

Analyst: G. Bender

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[1] A-466—Composite sample of relatively fresh gabbro, Bellekeno mine area, Sourdough Hill.

[2] A-462—Composite sample of altered schistose greenstone, Bellekeno mine area, Sourdough Hill.

[3] Adjusted % = percentage of A-462 multiplied by the factor 2.80/3.01 to reduce to a common volume.

Table 24

Analyses of Composite Samples of Granitic Rocks, Keno Hill-Galena Hill Area

Constituent	A-703 Granodiorite composite Dublin Gulch area %	A-702 Granodiorite stock west of Hanson Lake %	A-699 Quartz diorite -monzonite-aplite. Marginal facies of batholith north of Mayo Lake %	A-701 Granodiorite-quartz monzonite phase. Batholith north of Mayo Lake %	A-700 Porphyritic quartz monzonite from core of batholith north of Mayo Lake %	A-696 Quartz feldspar porphyry. Galena Hill-Mount Haldane %	Average granodiorite, Nockolds[1] %
SiO_2	66.2	70.1	61.3	68.8	64.9	67.0	66.88
Al_2O_3	16.7	15.5	16.6	16.5	16.5	16.7	15.66
Fe_2O_3	0.3	0.3	0.3	0.5	0.8	0.6	1.33
FeO	2.91	2.36	3.59	1.50	2.82	2.31	2.59
CaO	3.0	2.6	7.0	2.9	3.6	1.9	3.56
MgO	2.0	1.2	2.5	1.2	1.2	0.7	1.57
Na_2O	2.5	2.5	2.6	2.9	3.0	3.6	3.84
K_2O	4.6	3.3	3.4	4.5	4.1	2.9	3.07
H_2O (total)	0.80	0.80	0.56	0.50	0.57	1.50	0.65
TiO_2	0.5	0.4	0.5	0.3	0.7	0.3	0.57
P_2O_5	0.2	0.1	0.2	0.1	0.4	0.0	0.21
MnO	0.0	0.0	0.0	0.0	0.1	0.0	0.07
CO_2	0.06	0.00	0.10	0.00	0.00	1.07	
S	0.01	0.00	0.02	0.02	0.01	0.01	
C	—	—	—	—	—	—	
Total	99.8	99.2	98.7	99.7	98.7	98.6	
Powder density	2.684	2.679	2.750	2.678	2.717	2.789	

Analyst: K. G. Hoops

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[1] Average granodiorite as given by Nockolds, S. R.—Average chemical compositions of some igneous rocks; *Bull. Geol. Soc. Amer.*, vol. 65, pp. 1007–1032, 1954.

Table 25

Analysis of Composite Sample of Biotite-Lamprophyre, Galena Hill

Constituent	A-693 Biotite-lamprophyre %
SiO_2	51.1
Al_2O_3	12.6
Fe_2O_3	0.5
FeO	6.07
CaO	7.4
MgO	6.2
Na_2O	2.1
K_2O	2.2
H_2O (total)	3.23
TiO_2	0.8
P_2O_5	0.4
MnO	0.1
CO_2	5.84
S	0.30
C	—
Total	98.8
Less $O \equiv S$	0.1
Net total	98.7
Powder density	2.787

Analyst: K. G. Hoops

Table 26

Minor and Trace Elements in Rocks of Keno Hill-Galena Hill District

All values in parts per million

Con-stituent	Skarn (6 composite samples)		Greenstones (27 composite samples)		Biotite lamprophyre (2 composite samples)		Quartz-feldspar porphyry (6 composite samples)		Granodiorite Dublin Gulch (2 composite samples)		Granodiorite North of Mayo Lake (4 composite samples)		Con-stituent
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	
Pb	5–21	9	2–10	5	13–28	21	2–46	17.4	8–29	17	5–37	17	Pb
Zn	5–130	50	30–140	73	80–90	85	45–110	68.3	45–55	50	25–45	36	Zn
Cd		<2		<2		<2		<2		<2		<2	Cd
Ag	0.1–0.15	0.10	0.10–1.50	0.32	0.15–0.17	0.16	0.10–0.33	0.24	<0.1	<0.1	<0.1–0.17	<0.1	Ag
Cu	5–2700	25	30–200	132	50–65	60	5–120	36	4–12	6	4–8	6	Cu
Ga	5–70	25	2–50	20	5–6.8	3	5–26	12	6.3–9.1	7.7	5–5.4	5	Ga
In	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<.05	<0.5	<0.5	<0.5	<0.5	In
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	Mo
Sn	5–73	>5	2–11	3	<5	<5	<5–6.6	<5	<5	<5	<5	<5	Sn
W	30–75000		<4	<4	<4	<4	<4	<4	<4	<4	—	—	W
Bi	2–120		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	Bi
Ba	100–200	160	100–3000	475	800–1000	900	100–2000	700	3000	3000	1000–2000	1250	Ba
Sr	200–1000	380	50–500	130	500–800	650	100–1000	533	300	300	800–2000	1450	Sr
Cr	<100–100	<100	50–600	164	500–800	650	100–500	160	<100–100	<100	<100	<100	Cr
Ti	360–2400	1300	10000–15000	12000	4000–5600	4800	500–8000	3733	3000	3000	1800–4200	2900	Ti
Mn	930–3800	2250	500–1000	775		775	200–700	500	800–1200	1000	200–1000	425	Mn
As	7.5–20	11	2–25	6	8–15	11.5	4–40	15	10–15	12.5	2–3	2.5	As
Sb	1	1	<1.0–1.0	~1	<1.0–1.0	~1	1–1.5	1	<1.0–1.0	<1.0	<1.0–1.0	<1.0	Sb
S	NF–7.44%		300–1400	850		3000		100		100	100–200	165	S

Table 26 *(Concluded)*

Minor and Trace Elements in Rocks of Keno Hill-Galena Hill District

All values in parts per million

Con-stituent	Graphitic argillites schists, and phyllites (29 composite samples)		Quartz-sericite schist (8 composite samples)		Thick- and thin-bedded grey quartzites (27 composite samples)		Siliceous white quartzites (9 composite samples)		Calcareous quartzites (3 composite samples)		Limestones (3 composite samples)		Con-stituent
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	
Pb	5–38	15	5–25	7	2–20	7	2–15	6	5–8	5	5–10	7.6	Pb
Zn	25–120	62	65–160	90.5	5–85	30	5–30	10	15–50	27	5–35	22	Zn
Cd	0–2	<2		<2		<2		<2		<2		<2	Cd
Ag	0.17–1.60	0.50	0.12–1.1	0.44	0.13–1.30	0.31	0.17–0.37	0.25	0.24–0.54	0.36	0.1–0.27	0.15	Ag
Cu	10–180	31	10–90	46	2–60	12	5–33	14	5–8	7	5–7.6	5	Cu
Ga	5–54	18.3	5.2–35	16	0–17	4	5–14	5	<5	<5	5	5	Ga
In	<0.5	<0.5	<0.5–0.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	In
Mo	5–52	8	5–22	10	0–25	~5	<5	<5	<5–11	<5	<5	<5	Mo
Sn	2–15	4	5–6.3	5	<5	<5	<5	<5	<5	<5	<5	<5	Sn
W	<4–4	<4	<4	<4	<4	<4	<4	<4	<4	<4	4–14	5	W
Bi	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	Bi
Ba	100–15000	2240	1000–15000	3200	100–1000	310	100–500	200	100–1000	400	100–1000	400	Ba
Sr	100–2000	195	100–1000	~100	<100	<100	<100	<100	<100	<100	300–3000	1300	Sr
Cr	50–900	235	100–500	<100	100–900	<100	<100	<100	<100	<100	100–200	100	Cr
Ti	4000–5500	4800	2000–3000	2500	600–3000	1300	400–800	600	600–1200	900	100–250	180	Ti
Mn	620–2300	1500	500–1500	1000	500–1000	775	200–400	300	100–300	200	2800–3000	2900	Mn
As	2–75	18.5	2–15	6	2–35	7.6	1–15	5	3–10	7	5–10	6	As
Sb	1.0–7.0	3.1	1–1.5	1	1.0–6.0	1.5	<1–1	<1	<1.0–1.0	<1	1	1	Sb
S	5600–11800	8200		2100	1000–5200	2635		200	100–2500	1200	100–200	150	S

Analyses by M. A. Jardine, G. Mihailov, W. H. Champ, and W. White by colorimetric and spectrographic methods.

Table 27

Minor Elements in Pyrite from Country Rocks

All values in parts per million
m = content 1 – 10%
NF = not found

Description	Si	Al	Ti	Mn	Ni	Co	Zn	Pb	Cu	Cd	Ag	Sn	Sb	As
In graphitic schist and phyllite, Wernecke area	> 1000	> 1000	> 1000	NF	1000	200	2300	210	110	< 10	50	10	15	1540
As above—core sample	> 1000	> 1000	> 2000	< 10	100–1000	100–1000	50	35	20	< 10	< 10	NF	25	920
In graphitic schist, Christal Creek	> 1000	> 1000	> 1000	50	600	200	130	160	130	< 10	< 10	10	10	1000
In graphitic schist, and phyllite, Cream area	> 1000	> 1000	> 1000	10	100	400	70	15	< 10	< 10	< 5	10	5	2000
In phyllite and thin-bedded quartzite, Hector-Calumet portal	> 1000	> 1000	100–1000	20	100	20	160	25	190	< 10	< 10	10	10	330
In graphitic quartzite, 1st level Hector-Calumet mine	> 1000	> 1000	> 1000	20	100	100	60	15	220	< 10	100	10	40	880
In graphitic schist, Hector-Calumet mine, 1st level	> 1000	> 1000	> 1000	NF	500	200	120	120	75	< 10	10	10	20	960
In graphitic schist and phyllite, Hector-Calumet mine, 1st level	> 1000	> 1000	~500	NF	200	200	230	130	210	< 10	40	10	45	1700
In siliceous quartzite, Hector-Calumet mine, 1st level	> 1000	> 1000	> 1000	NF	100	NF	60	15	220	< 10	50	10	135	900

As, Sb, Cu, Pb, Zn analyses by colorimetric methods; analysts M. A. Jardine and G. Mihailov. Other elements by spectrographic methods, analyst W. H. Champ. For gold assays of pyrite *see* Table 57.

Table 28

Trace Element Content of Heavy Concentrates in Principal Country Rocks

Rock type, principal minerals, and location	Zn[1] ppm	Cu[1] ppm	Pb[1] ppm	As[1] ppm	Sb[1] ppm	Ag[2] ppm
Quartzites, graphitic schist and phyllite: carbonates, chlorite, pyrrhotite, Galena Hill—Keno Hill area	1450	370	70	115	10	<10
Greenstones: amphibole, ilmenite, epidote, Galena Hill—Keno Hill area	70	330	5	4	1	<10
Granodiorite: amphibole, pyroxene, epidote, allanite, sphene, Dublin Gulch	70	70	100	48	1	<10

[1] Zn, Cu, Pb, As, and Sb analyses by M. A. Jardine and G. Mihailov by colorimetric methods

[2] Ag analyses by W. H. Champ by spectrographic methods

Table 29

Analyses of Composite Samples of Calcite

Constituent	A-457 Crystalline calcite in early quartz lenses in quartzite, Bellekeno area	A-456 Supergene calcite surrounding ore fragments—Bellekeno mine, 48 vein, 2nd level	A-459 Supergene calcite in vug, Bellekeno mine, 48 vein
SiO_2	2.68	0.01	0.00
Al_2O_3	0.12	0.09	0.00
Fe_2O_3	0.23	0.45	0.36
FeO	1.42	1.46	0.86
CaO	52.39	52.25	54.18
MgO	0.68	0.41	0.32
Na_2O	0.09	0.09	0.09
K_2O	0.00	0.00	0.00
H_2O+	0.04	0.00	0.00
H_2O-	0.00	0.00	0.00
TiO_2	0.00	0.00	0.00
P_2O_5	0.10	0.10	0.08
MnO	0.24	1.40	0.48
CO_2	42.45	43.45	43.80
Total	100.44	99.71	100.17
Specific gravity	2.72	2.68	2.71

Analyst: S. Courville

Table 30

Analyses of Composite Samples of Fresh, Oxidized, and Highly Oxidized Siderite

Constituent	A-428 Fresh siderite, Sadie—Friendship lode, Keno Hill	A-471 Fresh siderite, Onek lode, Keno Hill	A-427 Slightly oxidized siderite, Bellekeno lode, Sourdough Hill	A-426 Oxidized siderite, Bellekeno lode, Sourdough Hill	A-429 Highly oxidized siderite, Bellekeno lode, Sourdough Hill	A-458 Wad and limonite derived from siderite, Bellekeno lode, Sourdough Hill
SiO_2	0.10	0.50	0.00	0.39	10.14	2.25
Al_2O_3	0.01	0.00	0.00	0.12	2.64	1.32
Fe_2O_3	0.06	0.09	1.23	29.54	53.36	70.67
FeO	37.98	44.23	40.41	20.00	*	*
CaO	0.80	0.31	0.90	0.50	0.41	0.13
MgO	4.98	1.20	1.35	1.48	0.15	0.03
Na_2O	0.05	0.03	0.06	0.05	0.05	0.06
K_2O	0.01	0.02	0.02	0.03	0.06	0.05
H_2O+	0.02	0.15	0.03	3.05	8.04	10.34
H_2O-	0.11	0.03	0.05	1.39	2.72	0.90
TiO_2	0.00	trace	0.00	0.00	0.00	trace
P_2O_5	0.05	0.77	0.06	0.04	0.05	0.07
MnO	16.12	13.71	17.12	15.80	12.96	10.46
CO_2	39.30	37.75	38.10	27.10	10.40	8.25
S	0.00	0.02	0.00	0.02	0.16	0.20
Total	99.59	99.81	99.33	99.51		
Less $O \equiv S$	0.00	0.01	0.00	0.01		
Net total	99.59	99.80	99.33	99.50		
Specific gravity	3.82	3.74	3.80	3.58	3.05	3.03

Analyst: S. Courville

*FeO not determinable in these samples

Table 31

Minor and Trace Element Content of Carbonates

All values in parts per million
NF = not found

Description	Sr	Ba	Ni	Co	V	Zn	Cu	Pb	Ag	Sn	As	Sb	Sc	Y	Yb	La	S
A–457—Crystalline calcite in early quartz lenses, Bellekeno mine area	1,500	5	<10	<5	<10	35	5	20	NF	NF	8	<1	10–100	10–100	10–100	10–100	trace
A–428—Fresh siderite, Sadie–Friendship mine	NF	5	NF	NF	<10	170	5	65	NF	NF	1	NF	NF	NF	NF	NF	trace
A–471—Fresh siderite, Onek mine	NF	5	NF	NF	<10	10,000	5	35	NF	NF	1	<1	NF	NF	NF	NF	200
A–427—Slightly oxidized siderite, Bellekeno mine	NF	5	NF	NF	<10	2,500	50	95	NF	NF	4	<1	NF	NF	NF	NF	trace
A–426—Oxidized siderite, Bellekeno mine	50	5	<10	<5	<10	8,000	45	1,250	NF	NF	4	5.5	NF	NF	NF	NF	200
A–429—Highly oxidized siderite and wad, Bellekeno mine	NF	10	<10	NF	<10	12,000	760	16,000	50	50	700	6	10–100	NF	NF	NF	1,600
A–458—Wad and limonite derived from siderite, Bellekeno mine	50	10	NF	<5	50	3,800	<10	380	NF	NF	95	2	10–100	NF	NF	NF	2,000
A–459—Supergene calcite, Bellekeno mine	60	<5	NF	<5	10	160	<10	15	NF	NF	1	<1	NF	NF	NF	NF	trace
A–456—Supergene porous calcite, Bellekeno mine	200	<5	30	10	<10	3,400	<10	65	<10	NF	3	8	NF	NF	NF	NF	trace

Sr, Ba, Ni, Co, V, Ag, Sn, Sc, Y, Yb, La analyses by semiquantitative spectrographic methods; analyst W. H. Champ
Zn, Cu, Pb. As, Sb analyses by colorimetric methods; analyst M. A. Jardine

Table 32

Minor and Trace Element Content of Barite

All values in parts per million
NF = not found

Description	Fe	Ca	Mg	Mn	Sr	Co	Zn	Cd	Cu	Pb	Ag	As	Sb	Cr
Crystalline barite, Bellekeno system, Sourdough Hill........	30	100	<100	<10	~5000	<10	<5	NF	<5	8	NF	1	<1	NF
Crystalline barite, Bellekeno system, Sourdough Hill........	200	50	<100	10	~5000	<10	10	NF	<5	<5	NF	NF	<1	5
Massive and crystalline barite, Porcupine vein, Keno Hill............................	50	50	<100	50	1000	<10	370	NF	<5	18	5	2	2	NF

Fe, Ca, Mg, Mn, Sr, Co, Ag, Cr analyses by semiquantitative spectrographic methods; analyst W. H. Champ
Zn, Cu, Pb, As, Sb analyses by colorimetric methods; analyst M. A. Jardine

Table 33

Minor and Trace Elements in Pyrite and Marcasite from Deposits

All values in parts per million
NF = not found

Description and Location	Si	Al	Ti	Mn	Ni	Co	Zn	Pb	Cu	Cd	Ag	Sn	Sb	As
Massive, No. 6 vein Keno mine	>1000	>1000	~50	20	NF	NF	500	130	<10	<50	100	NF	<10	2900
Massive, Bellekeno mine, 2nd level	~500	>1000	100	NF	100	30	50	830	20	<50	200	300	<10	1100
Crystals, Bellekeno mine, 3rd level	~500	>1000	100	20	100	30	350	880	340	<50	200	1000	110	8600
In seams in wall-rock, Onek mine	>1000	>1000	~500	NF	100	100	150	270	40	<50	10	100	<10	2000
Crystals, Onek mine	~500	>1000	~50	30	50	50	4200	1150	240	<50	200	800	120	4700
Massive, associated with arsenopyrite, Klondyke-Keno E-W vein	~500	>1000	~50	NF	NF	30	8800	1900	10	<50	50	NF	40	>2%
Crystals, Klondyke-Keno N-S vein	>1000	>1000	~500	30	100	50	150	630	420	<50	500	NF	400	7800
Massive lens, Mount Keno mine, Hogan vein	>1000	>1000	~500	100	NF	NF	30	20	<10	<50	NF	NF	310	100
Crystalline with siderite, Sadie-Friendship mine	>1000	>1000	~50	100	NF	NF	30	510	<10	<50	100	NF	130	1400
Late pyrite in fault, Sadie-Friendship mine, Keno Hill	>1000	>1000	~50	NF	NF	NF	30	10	<10	<50	NF	NF	120	110
Massive, Galkeno mine, 1st level	~500	>1000	100	80	30	40	50	1250	10	<50	20	>1000	40	>2%
Massive, Galkeno mine, 2nd level	~500	>1000	~50	NF	100	80	130	330	150	<50	10	NF	<10	2200
Massive, Galkeno mine, 3rd level	~500	>100	~50	NF	30	20	70	400	<10	<50	<10	200	<10	2300

Crystals, Yukeno mine, Galena Hill	>1000	>1000	~500	NF	100	100	330	270	100	<50	40	100	<10	4900
Massive, Cream vein	~500	~500	~50	NF	NF	NF	30	110	<10	<50	<10	NF	<10	6500
Massive and crystalline, 1st level, Hector-Calumet mine	>500	>1000	~500	NF	30	NF	130	1990	480	<50	200	NF	325	3350
Massive, 2nd level, Hector-Calumet mine	>1000	>1000	~50	300	20	NF	580	505	195	<50	60	NF	50	2450
Massive and crystalline, 400-foot level, Hector-Calumet mine	>1000	>1000	~50	NF	35	NF	105	695	45	<50	15	100	17	2935
Crystalline, 525-foot level, Hector-Calumet mine	>1000	>1000	~300	<20	65	60	1240	945	110	<50	30	<100	305	21,120
Crystalline, 650-foot level, Hector-Calumet mine	>1000	>1000	~500	30	60	15	310	2100	80	<50	35	NF	38	5165
Crystalline, 775-foot level, Hector-Calumet mine	>1000	>1000	~500	<10	60	25	85	710	57	<50	44	NF	34	6760
Crystalline, 900-foot level, Hector-Calumet mine	~500	>1000	~200	25	35	<20	280	590	77	<50	40	NF	172	3275
Crystalline, 1165-foot level, Hector-Calumet mine	~500	>1000	~50	20	100	80	110	500	30	<50	30	NF	<10	4200
Crystalline, Silver King mine	>1000	>1000	~500	80	60	NF	180	540	<10	<50	350	NF	265	1700
Marcasite, Silver King mine	>1000	~500	~500	100	<10	<10	30	<10	30	<50	<10	<10	<10	25
Massive, Dublin Gulch area	>1000	>1000	~500	NF	NF	80	130	250	800	<50	50	NF	1020	4900
Marcasite, Dublin Gulch area	>1000	>1000	~500	<10	<10	<10	30	<10	<10	<50	<10	<10	<10	20

As, Sb, Cu, Pb, Zn analyses by colorimetric methods; analysts M. A. Jardine and G. Mihailov
Other elements by spectrographic methods; analyst W. H. Champ

Table 34

Analyses of Sphalerite, Galena Hill-Keno Hill Area[1]

Description	Constituents in Percentages[1]					Powder Density[2]
	Zn	Cd	Fe	Mn	S	
A–472—Massive black sphalerite Sadie-Friendship mine	57.83	0.94	7.08	0.09	32.87	4.068
A–473—Massive black sphalerite Onek mine	59.03	0.71	6.58	0.05	32.76	4.030
A–535—Massive dark brown sphalerite Lucky Queen mine	61.85	0.95	2.53	0.03	32.43	4.077
A–568—Massive black sphalerite Klondyke-Keno vein	57.83	1.16	7.39	0.08	32.65	4.039
A–708—Massive black sphalerite. Slight oxidation Galkeno mine, 2nd level	53.81	0.82	11.54	0.20	33.33	4.004
A–710—Black sphalerite crystals 650-foot level Hector-Calumet mine	61.44	0.83	4.45	0.14	32.78	4.072
A–709—Massive black sphalerite 775-foot level Hector-Calumet mine	59.44	0.88	6.58	0.07	33.22	4.054
A–711—Massive dark brown sphalerite, 1165-foot level Hector-Calumet mine	58.83	0.79	5.67	0.82	31.60	4.047
A–718—Crystalline reddish brown resinous sphalerite, Gambler vein	64.06	0.73	0.63	0.005	32.54	4.134
A–719—Massive dark brown sphalerite, Gambler vein	63.65	0.73	2.63	0.01	33.06	4.080

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[1] Analyses by Mines Branch, Ottawa on samples split from composite samples comprising several pounds of sphalerite from the locations or veins noted in the description.

[2] Powder density determinations by K. G. Hoops

Table 35

Minor and Trace Element Content of Sphalerite

All values in parts per million
M = major constituent, Content > 10%
m = minor constituent, Content 1–10%
NF = not found

Description	Zn	Cd	Fe	Mn	Ag	Cu	Pb	Sn	In	As	Sb	Si	Al	Ti	Ni	Co	Ge
Dark brown sphalerite, 2nd level Bellekeno mine, Sourdough Hill	M	7500	m	1000	20	500	100	NF	10–100	5	<5	100–1000	10–100	NF	<20	<10	<50
A-472 Massive black sphalerite, Sadie-Friendship mine, Keno Hill	M	9400	m	900	5000	7000	<100	<100	NF	10	3800	100–1000	10–100	NF	<20	<10	<50
A-473 Massive black sphalerite, Onek mine, Keno Hill	M	7100	m	500	100	2000	300	800	10–100	<5	70	100–1000	10–100	NF	<20	<10	<50
A-535 Massive dark brown sphalerite, Lucky Queen mine, Keno Hill	M	9500	m	300	5000	2000	700	200	10–100	<5	1900	100–1000	100–1000	100–1000	<20	<10	<50
A-568 Massive black sphalerite, Klondyke-Keno mine, Keno Hill	M	11600	m	800	300	500	500	NF	NF	<5	210	10–100	10–100	10–100	<20	<10	<50
A-708 Massive black sphalerite, Galkeno mine, Galena Hill	M	8200	M	2000	5	200	200	NF	NF	5	10	10–100	10–100	NF	<20	<10	<50
A-710 Black sphalerite crystals, 650-foot level Hector-Calumet mine, Galena Hill	M	8300	m	1400	10	500	1000	300	NF	5	15	10–100	10–100	10	<20	<10	<50
A-709 Massive black sphalerite, 775-foot level Hector-Calumet mine, Galena Hill	M	8800	m	700	100	500	100	100	NF	5	70	10–100	10–100	NF	<20	<10	<50
A-711 Massive dark brown sphalerite, 1,165-foot level Hector-Calumet mine, Galena Hill	M	7900	m	8200	50	200	100	100	NF	NF	30	10–100	10–100	NF	<20	<10	<50
A-718 Crystalline, reddish brown resinous sphalerite, Gambler vein, Keno Hill	M	7300	6300	50	30	200	500	100	NF	15	40	>1000	100–1000	10–100	<20	<10	<50
A-719 Massive dark brown sphalerite, Gambler vein, Keno Hill	M	7300	m	100	400	500	1000	100	NF	<5	410	10–100	10–100	NF	<20	<10	<50

Cd, Mn analyses by Mines Branch, Ottawa
As, Sb analyses by M. A. Jardine and G. Mihailov
Other elements; spectrographic analyses by W. H. Champ

Table 36

Minor and Trace Elements in Galena

Description	Ag	Sn	Cu	Zn	Cd	As	Sb	Bi	Mn	Fe	Ti	Ni	In
Galena crystals in quartz, Helen Fraction, Keno Hill (early generation)	6000	100	50	<200	200	<5	4200	8000	<10	50	NF	NF	NF
Cleavage pieces of pure galena in quartz, Klondyke-Keno-E-W vein (early generation?)	6300	60	60	400	<10	<5	6600	<10	<10	400	NF	NF	NF
Galena crystals associated with barite, Bellekeno system, Sourdough Hill	2950	<100	50	<200	<10	<5	3600	<10	<10	500	NF	NF	NF
Cleavage pieces of pure splendent galena, Bellekeno system, Sourdough Hill	6100	200	300	<200	<10	<5	6600	<10	<10	500	NF	NF	NF
Cleavage pieces of pure galena, Bellekeno system, Sourdough Hill	4650	100	20	<200	<10	<5	5400	<10	NF	50	NF	NF	NF
Slightly sheared cleavage pieces of pure galena, Comstock-Keno mine, Keno Hill	4400	100	300	<200	<10	<5	4900	30	30	500	NF	NF	NF
Gneissic galena, Silver Basin. Keno Hill	1650	<100	20	<200	<10	<5	2400	<10	<10	10	NF	NF	NF
Microcrystalline galena, Sadie-Friendship mine, Keno Hill	6250	<100	300	5000	<10	<5	6200	<10	60	5000	NF	NF	NF
Schistose galena, Hector-Calumet mine, Galena Hill	5750	<100	400	400	<10	<5	5100	<10	NF	500	<10	NF	NF
Cubo-octahedrons of galena, Hector-Calumet mine, Galena Hill	3700	<100	20	<200	<10	<5	4500	<10	NF	50	NF	NF	NF
Cleavage pieces of pure galena, 2nd level, Hector-Calumet mine	4400	<100	20	<200	<10	<5	5400	<10	NF	500	<10	NF	NF
Cleavage pieces of pure galena, 525′ level, Hector-Calumet mine, Galena Hill	4050	<100	50	<200	<10	<5	5100	<10	NF	50	<10	NF	NF
Cleavage pieces of pure galena, Hector-Calumet mine, Galena Hill	5900	<100	200	<200	<10	<5	6100	<10	<10	50	NF	NF	NF
Cubo-octahedrons, 525′ level, Hector-Calumet mine, Galena Hill	3900	<100	20	<200	<10	<5	4600	<10	200	400	NF	NF	NF
Supergene microcrystalline galena, Bellekeno mine, Sourdough Hill	5000	100	5000	>10000	3000	40	2400	<10	30	8000	30	30	~5

Ag analyses by chemical methods; analyst G. Bender
Sn, Cu, Zn, Cd, Bi, Mn, Fe, Ti, Ni analyses by spectrographic methods; analyst W. H. Champ
Sb and As analyses by colorimetric methods; analysts G. Mihailov and M. A. Jardine

All values in parts per million
NF = not found

Table 37

Minor and Trace Element Content of Chalcopyrite

All values in parts per million
M = major constituent, content >10%
m = minor constituent, content 1–10%
NF = not found

Description	Fe	As	Sb	Pb	Cu	Zn	Cd	Ag	Sn	Co	Ni	Al	Si	Mn
Massive chalcopyrite; Cream prospect, Galena Hill	M	110	25	200	M	1000	NF	1280	100	50	1000	100–1000	100–1000	<10

As and Sb analyses by colorimetric methods; analysts M. A. Jardine and G. Mihailov
Ag by assay, Mineral Sciences Division, Mines Branch, Ottawa
All other elements by spectrographic methods; analyst W. H. Champ

Table 38

Minor and Trace Element Content of Arsenopyrite

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1%—10%
NF = not found

Description	Fe	As	Sb	Pb	Cu	Zn	Cd	Ag	Ni	Ti	Al	Si	Cr
Massive arsenopyrite in quartz, No. 6 vein, Keno Hill	M	M	560	NF	200	300	NF	20	NF	5	100–1000	100–1000	NF
Massive arsenopyrite in quartz, Comstock vein, Keno Hill	M	M	1160	5000	700	100	NF	400	NF	5	100–1000	>1000	NF
Massive arsenopyrite in vein, Sadie-Friendship mine, Keno Hill	M	M	690	1000	200	<50	NF	100	NF	NF	10–100	100–1000	NF
Arsenopyrite crystals in quartz, Dorothy prospect, Keno Hill	M	M	380	NF	200	<50	NF	10	300	10–100	100–1000	100–1000	5
Arsenopyrite nodules in placer, Dublin Gulch area	M	M	190	NF	80	<50	NF	20	NF	NF	10–100	>1000	NF
Arsenopyrite nodules in placer, Dublin Gulch area	M	M	170	NF	80	<50	NF	2	NF	NF	10–100	100–1000	NF

Sb analyses by colorimetric methods; analysts M. A. Jardine and G. Mihailov
All other elements by spectrographic methods; analyst W. H. Champ

Table 39

Minor and Trace Element Content of Freibergite

All values in parts per million except silver
M = major constituent, content >10%
m = minor constituent, content 1%–10%
NF = not found

Description	Cu	Sb	As	Pb	Ag	Zn	Cd	Fe	Sn	Al	Si	Mn
Early freibergite in comb quartz, E.W. vein, Klondyke-Keno mine, Keno Hill	M	M	7000	100	5.36%	m	500	~5000	NF	10–100	10–100	<10
Massive freibergite, minor amounts of pyrargyrite and chalcopyrite, Sadie-Friendship mine, Keno Hill	M	M	2500	700	M	m	2000	~5000	NF	10–100	100–1000	<10
Crystalline freibergite, Hector-Calumet mine, Galena Hill	M	M	2500	NF	17.73%	m	1000	~5000	100	10–100	100–1000	<10
Pure crystalline freibergite, Bellekeno mine, Sourdough Hill	M	M	5000	1000	M	m	1000	~5000	NF	10–100	10–100	<10

As analyses by colorimetric methods; analyst M. A. Jardine
All other elements by spectrographic methods; analyst W. H. Champ

Table 40

Minor and Trace Element Content of Sulphosalts

All values in parts per million
M = major constituent, content >10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Pb	Fe	Zn	Cd	Cu	Ag	Sn	Bi	Sb	As	Mn	Al	Ti	Si
Grey massive boulangerite, Dragon prospect, Galena Hill	M	m	NF	NF	40	230	NF	NF	M	40	>1000	NF	NF	10–100
Jamesonite associated with pyrite vein, Dublin Gulch area	M	m	500	NF	60	240	200	60	M	160	400	10–100	10	100–1000
Jamesonite nodules in placer, Dublin Gulch area	M	m	NF	NF	100	200	NF	500	M	40	500	10–100	10	100–1000
Boulangerite nodules in placer, Dublin Gulch area; 4 nodules analyzed	M	m	NF–1000	NF	40–5000	40–250	NF–50	30–300	M	80	50–100	10–100	10–100	10–1000

As analyses by colorimetric methods; analysts M. A. Jardine and G. Mihailov
All other elements by spectrographic methods; analyst W. H. Champ

Table 41

Minor and Trace Element Content of Cassiterite, Wolframite, Scheelite

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Sn	W	Ca	Fe	Mn	Mg	Ba	Ti	Al	Sc	V	Cr	Co	Ni
Cassiterite concentrate, in lode, Dublin Gulch	M	100–1000	10–100	>1000	10–100	1000	<10	100–1000	>1000	10–100	100–1000	10–100	<10	<10
Cassiterite, nodules in placer, Dublin Gulch	M	100–1000	10–100	>1000	10	100–1000	<10	100–1000	>1000	100–1000	100–1000	<10	<10	NF
Wolframite, placer, Dublin Gulch	10–100	M	100–1000	M	m	100–1000	100–1000	100–1000	>1000	10–100	NF	<10	NF	NF
Scheelite in quartz veins in granodiorite, Dublin Gulch	10–100	M	M	100–1000	10	100–1000	10–100	1000	100–1000	NF	NF	NF	NF	NF
Scheelite, placer, Dublin Gulch	NF	M	M	10–100	10	100–1000	10–100	100–1000	100–1000	NF	NF	NF	NF	NF

Table 41 *(Concluded)*

Description	Cu	Zn	Cd	Ga	As	Sr	Y	Yb	La	Zr	Nb	Mo	Ag	Sb	Pb	Bi	B
Cassiterite concentrate, in lode. Dublin Gulch	100	NF	NF	10–100	100	<10	10–100	10–100	<10	10–100	100–1000	NF	<10	100	100	100–1000	>1000
Cassiterite, nodules in placer. Dublin Gulch	10–100	NF	NF	NF	NF	<10	10–100	10–100	<10	<10	10–100	NF	<10	100	10–100	NF	100–1000
Wolframite, placer, Dublin Gulch	<10	NF	NF	NF	NF	10–100	10–100	10–100	10–100	NF	NF	NF	NF	NF	NF	NF	NF
Scheelite in quartz veins in granodiorite, Dublin Gulch	NF	NF	NF	NF	NF	>1000	10–100	NF	10–100	NF	NF	100–1000	NF	NF	NF	NF	NF
Scheelite, placer, Dublin Gulch	NF	NF	NF	NF	NF	>1000	100–1000	NF	10–100	NF	NF	100–1000	NF	NF	NF	NF	NF

Semiquantitative spectrographic analyses by W. H. Champ

Table 42

Minor and Trace Elements in Limonite and Wad

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Fe	Mn	Si	Al	Ti	Ca	Mg	Sr	Ba	Zn	Cd
Limonite, Bellekeno mine, Sourdough Hill	M	>1000	>1000	>1000	NF	100–1000	10–1000	100	100	>5000	100–1000
Limonite, McLeod vein, Galkeno mine, Galena Hill	M	m	M	m	m	m	m	NF	100–1000	m	>1000
Limonite, Calumet mine, Galena Hill	M	>1000	M	m	>1000	100–1000	100–1000	<100	100–1000	m	100–1000
Limonitic precipitate, Hector-Calumet mine, Galena Hill	M	m	m	1000	500	m	1000	NF	NF	8000	NF
Limonitic precipitate, spring, Williams Creek area, Galena Hill	M	m	m	2000	500	M	>1000	200	NF	65	NF
Botryoidal wad, Bellekeno system, Sourdough Hill	M	M	m	m	100–1000	100–1000	100–1000	100–1000	<100	m	<100
Manganese oxides in siderite, Bellekeno mine, Sourdough Hill	M	M	M	m	100–1000	m	100–1000	<100	100–1000	1800	100–1000
Manganese oxide precipitate, Hector-Calumet mine, Galena Hill	1500	M	m	500	NF	5000	1000	NF	NF	m	1000

Table 42 *(Concluded)*

Minor and Trace Elements in Limonite and Wad

All values in parts per million
M = major constituent, content >10%
m = minor constituent, content 1%–10%
NF = not found

Description	Cu	Pb	Sn	Ag	As	Sb	Sc	Ni	Co	Zr	B	Cr
Limonite, Bellekeno mine, Sourdough Hill	3000	m	NF	<100	1600	2440	NF	100–1000	<100	NF	NF	NF
Limonite, McLeod vein, Galkeno mine, Galena Hill	>5000	>1000	100–1000	100–1000	>1000	>1000	NF	100–1000	<100	>1000	100–1000	100–1000
Limonite, Calumet mine, Galena Hill	>1000	m	100–1000	>1000	6000	2400	<100	NF	NF	NF	100–1000	100–1000
Limonitic precipitate, Hector-Calumet mine, Galena Hill	20	35	NF	<0.5	6400	580	NF	NF	NF	NF	NF	NF
Limonitic precipitate, spring, Williams Creek area, Galena Hill	5	75	NF	<0.5	320	5	NF	NF	NF	NF	NF	NF
Botryoidal wad, Bellekeno system, Sourdough Hill	<20	110	NF	<100	1280	19.0	<100	<100	NF	NF	NF	NF
Manganese oxides in siderite, Bellekeno mine, Sourdough Hill	<20	220	NF	100–1000	60	14	NF	100–1000	NF	NF	100–1000	NF
Manganese oxide precipitate, Hector-Calumet mine, Galena Hill	100	130	NF	0.5	115	35.0	NF	500	300	NF	NF	NF

Fe, Mn, Si, Al, Ti, Ca, Mg, Sr, Ba, Cd, Sn, Ag, Sc, Ni, Co, Zr, B, and Cr analyses by semiquantitative spectrographic methods; analyst W. H. Champ
Zn, Cu, Pb, As, Sb analyses by colorimetric methods; analyst M. A. Jardine

Table 43

Minor and Trace Element Contents of Various Supergene Minerals

All values in parts per million
M = major constituent content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Pb	Zn	Cu	Ag	Cd	Fe	Mn	Ba	Sr	Ca	Mg	Sb	As	Bi
Cerussite crystals, Hector-Calumet mine	M	500	500	<50	NF	500	<100	<100	NF	<100	<100	NF	NF	NF
Smithsonite and minor calcite, Bellekeno mine, Sourdough Hill	100–1000	M	<100	<50	1000	m	m	NF	100–1000	M	1000	NF	>100	NF
Beudantite, Bellekeno mine, Sourdough Hill	M	>1000	100–1000	100–1000	100–1000	M	100–1000	<100	<100	100–1000	100–1000	m	m	NF
Scorodite, Bellekeno system, Sourdough Hill	100–1000	NF	<100	50–100	NF	M	>1000	<100	<100	100–1000	100	8	M	NF
Bindheimite, Dragon Prospect, Galena Hill	M	100–1000	<100	100–1000	>1000	m	>1000	100–1000	<100	1000	100–1000	M	>1000	100–1000
Bindheimite, Arctic and Mastiff mine, Galena Hill	M	<100	100–1000	100–1000	100–1000	m	>1000	100–1000	NF	100–1000	100–1000	M	100–1000	NF
Pyromorphite, Shamrock mine, Keno Hill	M	NF	<100	100–1000	NF	>1000	>1000	100–1000	NF	100–1000	100–1000	100–1000	100–1000	NF
Senarmonite, Dublin Gulch area	m	NF	<100	100–1000	100–1000	m	<100	<100	100–1000	>1000	<100	M	m	>1000
Rozenite, Comstock-Keno mine, Keno Hill	100–1000	m	<100	NF	NF	M	m	NF	NF	100–1000	m	5	200	NF

Table 43 *(Concluded)*

Minor and Trace Element Contents of Various Supergene Minerals

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1%—10%
NF = not found

Description	Sn	Ni	Co	Cr	Al	Ti	B	Si	P	Mo	V	La	Y	Yb
Cerussite crystals, Hector-Calumet mine	NF	NF	NF	NF	100–1000	NF	NF	100–1000	NF	NF	NF	NF	NF	NF
Smithsonite and minor calcite, Bellekeno mine, Sourdough Hill	200	100–1000	<100	NF	>1000	<100	NF	>1000	NF	NF	NF	NF	NF	NF
Beudantite, Bellekeno mine, Sourdough Hill	>1000	<100	NF	<100	m	>1000	>1000	m	NF	NF	NF	10–100	NF	NF
Scorodite, Bellekeno system, Sourdough Hill	NF	NF	NF	NF	>1000	<100	NF	m	NF	NF	NF	NF	NF	NF
Bindheimite, Dragon Prospect, Galena Hill	100–1000	NF	NF	NF	>1000	NF	NF	m	NF	NF	NF	NF	NF	NF
Bindheimite, Arctic and Mastiff mine, Galena Hill	100–1000	NF	NF	NF	>1000	NF	NF	m	NF	NF	NF	NF	NF	NF
Pyromorphite, Shamrock mine, Keno Hill	NF	NF	NF	>1000	m	>1000	<100	m	m	100–1000	<100	NF	10–100	10–100
Senarmonite, Dublin Gulch area	100–1000	<100	NF	NF	>1000	100–1000	NF	m	NF	NF	NF	NF	NF	NF
Rozenite, Comstock-Keno mine, Keno Hill	NF	<100	100	NF	100–1000	NF	NF	>1000	NF	NF	NF	NF	NF	NF

As and Sb analyses by colorimetric methods; analysts G. Mihailov and M. A. Jardine
All other elements by semiquantitative spectrographic methods; analyst W. H. Champ

Table 44—*Minor and Trace Elements in Malachite*

Description	Cu	Fe	Zn	Cd	Pb	Ag	Sb	Sn	Mn	Ni	Ti	Mg	Ba	Si	Al
Malachite, Lucky Queen mine, Keno Hill	M	>1000	>1000	NF	100–1000	100–1000	>1000	NF	100–1000	100–1000	10–100	10–100	10–100	m	m
Malachite, Onek mine, Keno Hill	M	m	>1000	NF	>1000	100–1000	>1000	>1000	>1000	10–100	10–100	10–100	10–100	m	m

Semiquantitative spectrographic analyses by W. F. White

Table 45—*Minor and Trace Elements in Anglesite*

Description	Pb	Fe	Mn	Ca	Mg	Ba	Sr	Al	Si	Zn	Cd	Cu	Ag	Sn	Bi	As	Sb
Anglesite, Bellekeno mine, Sourdough Hill	M	>1000	<100	m	<100	<100	100–1000	100–1000	m	<100	>1000	100–1000	>1000	100–1000	100–1000	NF	m
Anglesite, Comstock Keno mine, Keno Hill	M	m	100–1000	m	<100	<100	100–1000	>1000	m	100–1000	>1000	100–1000	>1000	<100	100–1000	<100	m

As analyses by M. A. Jardine and G. Mihailov
All other elements by semiquantitative spectrographic methods; analyst W. H. Champ

Table 46—*Minor and Trace Element Content in Gypsum*

Description	Fe	Mg	Mn	Ba	Sr	Zn	Cd	Cu	Pb	Ag	As	Sb
Gypsum crystals, Bellekeno mine, No. 48 vein	<10	<10	<10	<10	<10	45	NF	<5	15	NF	<1	1
Gypsum crystals, Bellekeno mine, No. 48 vein	<10	<10	<10	<10	<10	50	NF	<5	20	NF	NF	1

Fe, Mg, Mn, Ba, Sr, and Ag analyses by spectrographic methods; analyst W. H. Champ
Zn, Cu, Pb, As, Sb analyses by colorimetric methods; analyst M. A. Jardine

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Table 47—*Spectrographic Analysis of Jarosite*

Description	Major Elements 10–100%	Minor Elements 1–10%	Trace 0.1–1%	Not Detected <0.1%
Jarosite, Hector-Calumet mine, Galena Hill	Fe, Pb	Ca, Ag, Cu	Al, As, Cd, Mn, Mg, Si, Sn, Zn, P	Sb, Ba, Bi, Cr, Co, Au, Hg, Mo, Ni, B

Spectrographic analysis by J. L. Jambor (1957)

Table 48—*Spectrographic Analysis of Gunningite*

All values in parts per million M = major constituent, content > 10% m = minor constituent, content 1% — 10%

Description	Zn	Cd	Mn	Fe	Ca	Mg	Si	Co	Ba	Cu	Ag	Al	Ni	Pb
Gunningite-Hector-Calumet mine	M	8700	m	4600	100–1000	100–1000	100–1000	<100	<100	<100	<100	<100	<100	<100

Spectrographic analysis by H. W. Champ

Table 49—*Minor and Trace Element Content of Pyrargyrite and Marcasite*

All values in parts per million
M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Ag	Pb	Zn	Cu	Cd	Sb	As	Fe	Mn	Ti	Si	Al
Pyrargyrite, Sadie mine, Keno Hill[1]	M	>1000	>1000	100–1000	>1000	M	100–1000	100–1000	100–1000	NF	NF	NF
Marcasite, Silver King mine, Galena Hill[1,2]	<10	<10	30	30	<50	<10	25	M	100	~500	>1000	~500
Marcasite, Dublin Gulch[1,2]	<10	<10	30	<10	<50	<10	20	M	<10	~500	>1000	>1000

[1] Semiquantitative spectrographic analyses by W. F. White

[2] Pb, Zn, Cu, As and Sb analyses of marcasite by G. Mihailov and M. A. Jardine

Table 50

Minor and Trace Elements in Gold

M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Au	Ag	Fe	Cu	Pb	Hg	Al	Mg	Mn	Ti	Ni
Gold nugget, Taylor placer, Dublin Gulch....	M	M	10–100	10–100	NF	>1000	>1000	10–100	10–100	100–1000	10–100
Gold nugget, Haggart Creek...........................	M	m	10–100	10–100	10–100	m	>1000	10–100	10–100	100–1000	10–100

Table 50 *(Concluded)*

M = major constituent, content > 10%
m = minor constituent, content 1% — 10%
NF = not found

Description	Bi	Co	Sn	Zn	Cd	Pt	Te	Zr	W	Si	Ba	Sr
Gold nugget, Taylor placer, Dublin Gulch........	NF	NF	NF	NF	NF	NF	NF	100–1000	NF	100–1000	10–100	10–100
Gold nugget, Haggart Creek..............................	NF	NF	NF	NF	NF	NF	NF	NF	NF	100–1000	NF	NF

Semiquantitative spectrographic analyses by W. F. White

Table 51

Chemical Changes Produced by Alteration of Greenstone, Composite Samples, Sadie-Friendship Mine

Constituent	A-461[1] %	A-460[2] %	Adjusted[3] %	Gains and Losses in Constituents	Percentage Gains and Losses
SiO_2	46.53	42.45	40.06	−6.47	−13.9
Al_2O_3	15.62	18.40	17.36	+1.74	+11.2
Fe_2O_3	1.69	0.00	0.00	−1.69	−100.0
FeO	8.47	8.53	8.05	−0.42	−4.9
CaO	11.18	5.93	5.60	−5.58	−49.9
MgO	7.29	4.37	4.12	−3.17	−43.4
Na_2O	2.08	0.07	0.07	−2.01	−96.6
K_2O	0.20	2.98	2.81	+2.61	+1305.0
H_2O+	3.45	4.48	4.23	+0.78	+22.6
H_2O-	0.01	0.32	0.30	+0.29	+2900.0
TiO_2	0.73	0.60	0.57	−0.16	−21.9
P_2O_5	0.21	0.17	0.16	−0.05	−23.8
MnO	0.19	2.27	2.14	+1.95	+1030.0
CO_2	2.27	8.63	8.14	+5.87	+259.0
S	0.02	0.52	0.49	+0.47	+2350.0
Total	99.94	99.72			
Less O≡S	0.01	0.20			
Net total	99.93	99.52			
Specific gravity	3.02	2.85			

Analyst: S. Courville

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[1] A-461—Composite sample of relatively fresh greenstone, Sadie-Friendship mine, Keno Hill

[2] A-460—Composite sample of altered greenstone adjacent to siderite vein, Sadie-Friendship mine, Keno Hill

[3] Adjusted % = percentage of A-460 multiplied by the factor 2.85/3.02 to reduce to a common volume

Table 52

Chemical Changes Produced by Alteration of Greenstone, Composite Samples, Hector-Calumet Mine

Constituent	A-704[1] %	A-705[2] %	Adjusted[4] %	Gains and losses in Constituents	Percentage Gains and Losses	A-706[3] %	Adjusted[4] %	Gains and Losses in Constituents Compared with A-704	Percentage Gains and Losses
SiO_2	50.18	46.93	48.61	−1.57	−3.13	49.20	50.96	+0.78	+1.5
Al_2O_3	17.15	14.72	15.25	−1.90	−11.0	16.20	16.78	−0.37	−2.2
Fe_2O_3	1.09	0.15	0.16	−0.93	−85.3	0.13	0.13	−0.96	−88.0
FeO	11.57	11.52	11.93	+0.36	+3.2	9.22	9.55	−2.02	−17.5
CaO	1.40	2.88	2.98	+1.58	+113.0	1.66	1.72	+0.32	+22.8
MgO	7.62	5.32	5.51	−2.11	−27.2	1.85	1.92	−5.70	−74.8
Na_2O	0.04	0.53	0.55	+0.51	+1275.0	0.21	0.22	+0.18	+450.0
K_2O	0.22	1.31	1.36	+1.14	+518.0	3.00	3.11	+2.89	+1313.0
H_2O+	7.43	4.14	4.29	−3.14	−42.3	2.43	2.52	−4.91	−66.0
H_2O-	0.29	0.16	0.17	−0.12	−41.4	0.21	0.22	−0.07	−24.1
TiO_2	1.73	1.55	1.61	−0.12	−6.9	1.48	1.53	−0.20	−11.5
P_2O_5	0.22	0.17	0.18	−0.04	−18.2	0.16	0.17	−0.05	−22.7
MnO	0.18	1.83	1.90	+1.72	+955.6	3.57	3.70	+3.52	+1960.0
CO_2	0.76	7.05	7.30	+6.54	+861.0	8.75	9.06	+8.30	+1090.0
S	0.10	0.37	0.38	+0.28	+2800.0	0.67	0.69	+0.59	+5900.0
PbO	NF	0.24	0.25	+0.25		0.35	0.36	+0.36	
ZnO	NF	1.00	1.04	+1.04		1.46	1.51	+1.51	
Total	99.98	99.87				100.55			
Less O≡S	0.04	0.14				0.25			
Net total	99.94	99.73				100.30			
Specific gravity	2.80	2.90				2.90			

Analyst: S. Courville

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[1] A–704—Composite chip and channel sample of slightly chloritized greenstone, 525-level, Hector-Calumet mine

[2] A–705—Composite chip and channel sample of chlorite-carbonate altered zone over 6 inches, 525-level Hector-Calumet mine

[3] A–706—Composite chip and channel sample of carbonate-chlorite altered zone over 1 inch, 525-level Hector-Calumet mine

[4] Adjusted % = percentage of A–705 and A–706 multiplied by the factors 2.90/2.80 and 2.90/2.80 respectively to reduce to a common volume

Table 53

Chemical Changes Produced by Alteration of Quartzite, Composite Samples, Hector-Calumet Mine

NF = not found

Constituent	A–698[1] %	A–707[2] %	Gains and Losses	Percentage Gains and Losses
SiO_2	88.9	88.40	−0.50	−0.5
Al_2O_3	1.5	1.04	−0.46	−30.6
Fe_2O_3	0.2	0.18	−0.02	−10.0
FeO	1.05	3.32	+2.27	+216.0
CaO	3.2	0.28	−2.92	−91.2
MgO	0.0	0.37	+0.37	
Na_2O	0.2	0.03	−0.17	−85.0
K_2O	0.2	0.12	−0.08	−40.0
H_2O+ H_2O-	0.71	0.13	−0.58	−81.7
TiO_2	0.2	0.18	−0.02	−10.0
P_2O_5	0.1	0.03	−0.07	−70.0
MnO	0.1	1.70	+1.60	+1600.0
CO_2	2.94	3.52	+0.58	+19.7
S	0.10	0.29	+0.19	+190.0
PbO	NF	0.29	+0.29	
ZnO	NF	0.20	+0.20	
Total	99.40	100.08		
Less O≡S	0.0	0.11		
Net total	99.40	99.97		
Specific gravity	2.668	2.73		
Analyst	K. G. Hoops	S. Courville		

[1] A–698 Composite chip sample of all samples of thin- and thick-bedded quartzites, Keno Hill-Galena Hill area

[2] A–707 Composite chip and channel sample of leached and altered quartzite containing some veinlets and seams of siderite with galena and sphalerite, 650-foot level, Hector-Calumet mine

Table 54

Alteration in Tin Lodes, Dublin Gulch Area

Constituent	A–698[1] %	A–697[2] %	A–849[3] %
SiO_2	88.9	63.6	52.9
Al_2O_3	1.5	15.5	15.9
Fe_2O_3	0.2	1.7	13.1[4]
FeO	1.05	2.44	—
CaO	3.2	2.4	0.44
MgO	0.0	1.5	2.00
Na_2O	0.2	0.7	0.68
K_2O	0.2	2.7	0.13
H_2O+ H_2O-	0.71	2.82	3.0
TiO_2	0.2	0.8	0.51
P_2O_5	0.1	0.4	0.07
MnO	0.1	0.0	0.08
CO_2	2.94	2.05	0.56
S	0.10	1.18	0.09
C	0.00	1.34	0.00
Sn	0.0002	0.0004	2.46
B	0.003	0.010	1.07
Total	99.4	99.1	
Less O ≡ S	0.0	0.5	
Net total	99.4	98.6	
Specific gravity	2.668	2.798	

Analyst: K. G. Hoops

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[1] A–698 Composite chip sample of all samples of thin- and thick-bedded quartzites, Keno Hill-Galena Hill area

[2] A–697 Composite chip sample of all samples of graphitic schist, argillite, phyllite, and slate, Keno Hill-Galena Hill area

[3] A–849 Composite sample, tin impregnation zone, Dublin Gulch area

[4] Total iron as Fe_2O_3

Table 55

Distribution of Trace Elements in Wall Rocks of Deposits

All values in parts per million
NF = not found

Location	Pb	Zn	Cd	Cu	Ag	In	Sn	As	Sb	Ga
BELLEKENO MINE										
Quartzite, country rock	3	22	<2	12	0.4	NF	NF	5	1	5.0
Graphitic schist and phyllite, country rock	6	48	<2	44	0.4	NF	5.6	11.4	2.5	
Quartzite, 15–10 feet from vein	800	9000	73	18	3.8	NF	5.7	15.0	2.0	8.5
Quartzite, 10–2 feet from vein	250	1400	54	20	1.7	1.3	7.8	40	3.0	10.0
Quartzite, 2 feet–1 foot from vein	420	4800	127	410	5	5.8	37	200	18.0	15.0
HECTOR-CALUMET MINE										
Quartzite, main adit, 1000–1500 feet from vein	6	70	<2	5	0.3	NF	NF	4	1	5
Quartzite, main adit, 500–1000 feet from vein	5	55	<2	5	0.2	NF	NF	5	1	NF
Quartzite, main adit, 150–500 feet from vein	5	50	<2	5	0.3	NF	NF	4	1.5	NF
Quartzite, 20–30 feet from vein	45	80	2–5	30	30	NF	NF	100	35	NF
Graphitic schist and phyllite, main adit, 1000–1500 feet from vein	25	50	<2	10	1.2	NF	5	6	3.5	7.4
Graphitic schist and phyllite, main adit, 150-500 feet from vein	20	115	<2	40	1.6	NF	5	5	9	11
Chloritized greenstone, 525-foot level. A–704	10	520	<2	140	0.2	NF	2.0	5	7	11
Chlorite-carbonate altered zone over 6 inches, 525-foot level. A–705	2250	8000	25	120	50	NF	7.5	15	46.5	8.2
Carbonate-chlorite-sericite altered zone over 1 inch, 525-foot level. A–706	3260	12000	85	55	50	NF	60	125	52	5

Pb, Zn, Cu, As, Sb analyses by colorimetric methods; analysts G. Mihailov and M. A. Jardine
Other elements by spectrographic methods; analyst W. H. Champ

Table

Composition of Oxidized and Unoxidized

All values in per cent except gold and silver[1]

Description	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Total H_2O	TiO_2	P_2O_5	MnO
No. 6 Vein, Keno Hill:											
A-651 Composite sample of highly oxidized part of quartz-arsenopyrite vein, SW of shaft	48.3	17.4	15.9	0.52	0.50	ND	ND	7.1	1.8	0.24	0.96
A-652 Composite sample of quartz-arsenopyrite vein, near shaft	58.3	0.67	22.6	0.26	0.14	ND	ND	0.44	0.04	0.02	0.25
Tin Vein, Dublin Gulch:											
A-849 Composite sample, tin impregnation zone	52.9	15.9	13.1	0.44	2.00	0.68	0.13	3.0	0.40	0.07	0.08
Bellekeno Mine:											
A-608 Composite sample of oxidized ore, 1st level	14.8	1.5	25.7	2.3	0.16	ND	ND	4.9	0.08	0.02	5.6
A-609 Composite sample of oxidized ore, 2nd level	29.7	1.4	20.1	2.9	0.31	ND	ND	2.6	0.10	0.02	4.2
A-610 Composite sample of oxidized ore, 3rd level	8.2	1.2	37.3	1.2	0.38	ND	ND	4.5	0.13	0.03	6.8
A-611 Composite sample of oxidized ore, 4th level	13.1	1.8	17.7	0.25	0.16	ND	ND	2.6	0.14	0.02	4.1
Onek Mine:											
A-612 Composite sample oxidized ore, surface—50-foot level	3.5	0.47	29.7	0.04	0.05	ND	ND	4.8	0.12	0.02	5.0
A-613 Composite sample unoxidized ore, 400-foot level	14.1	2.0	26.0	0.30	0.40	ND	ND	0.30	0.07	0.02	5.4
Hector-Calumet Mine:											
A-842 Composite sample oxidized ore, 100-foot level, No. 3 vein	12.3	0.90	12.6	0.06	0.06	0.05	0.17	2.1	0.17	0.14	1.1
A-843 Composite sample oxidized ore, 300-foot level, No. 3 vein	10.1	1.3	14.7	0.20	0.23	0.05	0.08	0.96	0.12	0.02	2.3
A-844 Composite sample unoxidized ore, 400-foot level, No. 3 vein	10.7	2.7	18.3	0.81	0.70	0.04	0.12	0.34	0.14	0.02	6.9
A-845 Composite sample unoxidized ore, 525-foot level, No. 3 vein	5.9	3.6	20.9	0.79	0.90	0.05	0.09	0.38	0.09	0.02	9.8
A-846 Composite sample unoxidized ore, 650-foot level, No. 3 vein	9.0	2.1	17.4	0.72	0.80	0.06	0.07	0.30	0.09	0.03	7.0
A-847 Composite sample unoxidized ore, 775-foot level, No. 3 vein	5.5	2.5	14.7	0.40	0.47	0.02	0.05	0.20	0.04	0.02	4.8
A-848 Composite sample unoxidized ore, 900-foot level, No. 3 vein	3.6	4.4	19.7	0.40	0.43	0.04	0.06	0.34	0.05	0.07	6.1

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[1] Analyses by Mines Branch and K. G. Hoops, Geological Survey of Canada.

[2] No volume corrections have been made, mainly because the ores at different levels are not strictly comparable due to inherent primary variations. It will be noted, however, that the powder densities of the primary ores are generally nearly equal to or slightly less than their oxidized counterparts. In the latter case the effect would be to reduce slightly the weight percentage values given for the oxidized ores.

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Ores, Keno Hill-Galena Hill Area

NF = not found, less than 0.01%
ND = not determined

CO_2	S	As	Sb	Au oz/ton	Ag oz/ton	Zn	Cd	Pb	Cu	Sn	Ni	Mo	B	Powder^2 Density
0.16	0.21	1.38	0.01	0.015	0.71	0.38	NF	0.04	0.03	NF	ND	ND	ND	2.89
0.74	12.0	8.20	0.48	0.215	3.36	0.60	NF	1.50	0.02	NF	ND	ND	ND	3.28
0.56	0.09	0.33	ND	Tr.	0.04	NF	NF	ND	0.04	2.43	ND	ND	1.07	2.98
6.6	3.80	0.09	0.11	0.017	94.88	1.52	0.023	29.5	0.17	0.037	0.06	0.04	0.008	4.28
8.6	5.47	0.11	0.18	0.015	130.97	2.90	0.052	20.9	0.32	0.035	0.08	Tr.	0.009	3.75
11.6	5.48	0.21	0.29	0.027	174.13	1.54	0.040	19.3	0.55	0.033	Tr.	Tr.	0.015	4.21
10.2	8.03	0.22	0.34	0.025	180.07	8.00	0.15	33.4	0.78	0.046	0.06	Tr.	0.006	4.40
3.7	6.04	0.38	0.18	0.017	88.123	0.67	0.027	42.0	0.87	0.046	Tr.	Tr.	Tr.	5.05
16.4	13.2	0.038	0.05	0.03	17.185	17.4	0.25	6.97	0.56	0.077	0.07	Tr.	0.02	3.85
3.7	8.32	0.32	0.44	0.03	234.05	0.52	0.05	52.8	0.35	NF	ND	ND	ND	5.10
5.0	14.2	0.22	0.55	0.02	198.80	6.40	0.10	46.1	0.40	NF	ND	ND	ND	5.09
12.8	13.4	0.17	0.36	0.015	99.50	12.4	0.10	23.6	0.22	NF	ND	ND	ND	4.15
17.8	10.6	0.17	0.33	0.015	85.90	11.2	0.10	23.9	0.18	NF	ND	ND	ND	4.23
13.5	13.8	0.15	0.36	0.02	109.15	15.2	0.10	24.5	0.24	NF	ND	ND	ND	4.33
8.5	15.5	0.11	0.36	0.02	99.75	11.6	0.10	41.4	0.07	NF	ND	ND	ND	4.98
10.6	15.3	0.15	0.19	0.01	45.40	24.4	0.36	16.1	0.08	0.03	ND	ND	ND	4.32

Table

Gold Content of Sulphides, Sulphosalts, Gangue Minerals,

M = major constituent, content >10%
m = minor constituent, content 1%–10%

Description and Location of Mineral	Au oz/ton	Au ppm	As ppm	Sb ppm
COUNTRY ROCKS				
Composite sample of pyrite from quartzite, phyllite, and schist	0.057	1.9	1140	20
Composite sample of pyrite from quartzite and schist wall-rocks, Silver King mine	0.039	1.3	1700	265
Composite sample of pyrite from quartzite and schist wall-rocks, Onek mine	0.03	1.0	2000	10
VEIN SULPHIDES				
Pyrite—Bellekeno mine	0.0025	0.08	1100	10
Pyrite—No. 6 vein—associated with arsenopyrite	0.46	15.7	2900	10
Pyrite—Yukeno mine	0.0075	0.2	4900	10
Pyrite—Cream vein—associated with arsenopyrite	0.19	6.5	6500	10
Pyrite—Hector-Calumet mine 2nd level	0.07	2.4	2450	50
Pyrite—Hector-Calumet mine 775-foot level	0.18	6.1	6760	34
Pyrite—Hector-Calumet mine 900-foot level	0.045	1.5	3275	172
Pyrite—Silver King mine	0.005	0.17	1700	265
Pyrite—Dublin Gulch veins	0.075	2.6	4900	1020
Arsenopyrite—No. 6 vein	0.505	17.3	M	560
Arsenopyrite—Cream vein	0.285	9.7	M	ND
Arsenopyrite—Dublin Gulch veins	0.07	2.4	M	180
Chalcopyrite—Cream vein	0.026	0.9	110	25
Sphalerite—Onek mine	0.01	0.3	5	70
Sphalerite—Sadie mine	0.015	0.5	10	3800
Sphalerite—Hector-Calumet mine	0.01	0.3	5	15–70
Galena—Bellekeno mine	0.01	0.3	5	6600
Galena—Helen Fraction, quartz vein	0.10	3.4	5	4200
Galena—Klondyke-Keno E-W quartz vein	0.19	6.5	5	6600
Galena—Hector-Calumet mine 1st level	0.005	0.2	5	5400
Galena—Hector-Calumet mine 650-foot level	0.045	1.5	5	5000
Galena—Hector-Calumet mine 775-foot level	0.0175	0.6	5	5000
VEIN SULPHOSALTS				
Freibergite—Klondyke-Keno mine E-W quartz-pyrite vein	1.31	44.8	7000	M
Freibergite—in siderite lodes Hector-Calumet mine	0.32	10.9	2500	M

and Oxidation Products, Keno Hill-Galena Hill Area

NF = not found
ND = not determined

Description and Location of Mineral	Au oz/ton	Au ppm	As ppm	Sb ppm
VEIN SULPHOSALTS—Concluded				
Massive boulangerite Dragon prospect	0.015	0.5	40	M
Jamesonite and boulangerite Dublin Gulch veins	0.02	0.7	80–160	M
CASSITERITE, WOLFRAMITE, AND SCHEELITE				
Cassiterite—Dublin Gulch area composite of veins and placers	Trace	0.08	100	100
Wolframite—Dublin Gulch placers	0.005	0.17	100	NF
Scheelite—Dublin Gulch placers	~0.001	0.03	100	ND
GANGUE MINERALS				
Siderite—Hector-Calumet mine	0.005	0.17	5	1
Siderite—Arctic and Mastiff mine	0.005	0.17	5	1
Siderite—No Cash mine	Trace	0.08	5	1
Barite—Bellekeno mine	0.0025	0.08	1	1
Barite—Porcupine mine	Trace	0.08	2	2
OXIDATION PRODUCTS				
Limonite—Ankeno mine	0.0025	0.08	2000	ND
Limonite—Mackeno mine	0.0025	0.08	1000	1000
Limonite and cerussite—Hector-Calumet mine	0.02	0.7	6000	2400
Wad and minor limonite—Bellekeno system	0.0025	0.08	1280	19
Limonite, scorodite and other oxidation products, No. 6 vein	0.015	0.5	M	1000
Scorodite, Bellekeno system (transported)	NF	NF	M	8
Scorodite and limonite—Dublin Gulch veins (residual)	0.30	10.26	M	1000
Anglesite—Bellekeno mine	0.005	0.17	NF	m
Anglesite—Comstock mine	0.015	0.5	100	m
Bindheimite—Dragon prospect	0.02	0.7	1000	M
Pyromorphite and cerussite, Shamrock mine	0.005	0.17	100	100
Gypsum, Bellekeno system	NF	NF	1	1
Various sulphates of iron and zinc, Silver King dumps	Trace	0.08	70	19

Gold analyses by Mineral Sciences Division, Mines Branch, Ottawa

Table 58

Water Analyses, Keno Hill-Galena Hill Area

All values in parts per million
NF = not found

Source of Water	Spring, Basin Creek, Keno Hill	Composite Sample of Underground Water, Hector-Calumet Mine
Temp. at sampling (°C)	3°	2–3°
Temp. at analysis (°C)	23.0	23.2
Oxygen consumed by $KMnO_4$	1.7	5.6
Carbon dioxide (CO_2)	none	5.2
Odour	none	none
Taste	astringent	slightly astringent
Precipitates, etc.	fair amount of iron ppte. on standing	fair amount of iron ppte. on standing
pH at source	6	6.9
Colour	5	5
Residue on evaporation, dried at 105°C	1744	450
As above, ignited at 550°C	1440	411
Conductance, microohms at 25°C	2253	593.6
Hardness[1] as $CaCO_3$—		
Total	1038	330.5
Carbonate	NF	54.5
Non-carbonate	1038	266.0
Calcium (Ca^{++})	213	74.7
Magnesium (Mg^{++})	102	18.1
Strontium (Sr^{++})	NF	NF
Sodium (Na^+)	1.0	1.4
Potassium (K^+)	0.6	0.4
Lithium (Li^+)	NF	NF
Iron—Dissolved	0.36	trace
(Fe^{++}) total	4	1.3
Aluminum (Al^{+++})	11	0.4
Manganese (Mn^{++})	8.1	25
Copper (Cu^{++})	0.9	NF
Zinc (Zn^{++})	4.5	14
Lead (Pb^{++})	NF	NF
Ammonia (NH_4^+)	NF	NF
Carbonate (CO_3^{2-})	NF	NF
Bicarbonate (HCO_3^-)	NF	66.4
Sulphate (SO_4^{2-})	1119	256
Chloride (Cl^-)	1.0	0.5
Fluoride (F^-)	0.5	0.3
Nitrate (NO_3^-)	NF	0.6
Silica $(SiO)_2$	9.0	7.9
Sum of constituents	1478	432
Saturation index[2]	−6.3	−0.6
Stability index[2]	15.5	8.5
Per cent sodium	0.2	0.9

Analyses by Industrial Waters Section, Mines Branch, Ottawa

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[1] Total hardness includes hardness due to metals etc.

[2] At temperature of analysis.

Table 59

Dissolved Constituents in Underground Waters, Keno Hill-Galena Hill Area

Constituent	*Content (range in ppm)*
Calcium (Ca^{++})	50–200
Magnesium (Mg^{++})	10–120
Strontium (Sr^{++})	0.1–1.0
Barium (Ba^{++})	present, <0.1
Potassium (K^{+})	0.4–0.6
Sodium (Na^{+})	1–3
Lithium (Li^{+})	Present, <0.01
Rubidium (Rb^{+})	Present, <0.01
Cesium (Cs^{+})	Present, <0.005
Iron (Fe) (total)	1–5
Aluminum (Al^{+++})	1–15
Manganese (Mn^{++})	5–25
Copper (Cu^{++})	0.001–0.65
Zinc (Zn^{++})	0.001–80.0
Lead (Pb^{++})	0.0002–1.00
Cadmium (Cd^{++})	0.001–1.00
Arsenic	~0.002
Antimony	~0.001
Silver (Ag^{+})	~0.001
Nickel (Ni^{++})	Present, <0.001
Cobalt (Co^{++})	Present, <0.001
Zirconium	Present
Titanium	Present
Bicarbonate (HCO_3^{-})	5–100
Sulphate (SO_4^{2-})	200–1200
Chloride (Cl^{-})	0.1–1.0
Fluoride (F^{-})	0.3–0.5
Nitrate (NO_3^{-})	0.1–0.6
Silica (SiO_2)	5–10
Boron	Present

Table 60

Chemical Composition of Natural Precipitates at Spring Orifices, Keno Hill-Galena Hill Area

M = major constituent content, 10–100%
m = minor constituent content, 1–10%
NF = not found
ND = not determined

Description	Si	Al	Fe	Ca	Mg	Mn	Sr	Ba	Ti	Zr	Na	K	B
Iron precipitate, spring, Basin Creek, Keno Hill....	>1000	1000	m	M	1000	200	300	NF	NF	NF	NF	NF	NF
Manganese precipitate, Hector-Calumet mine same location as sample below....	>1000	500	1500	5000	1000	M	NF	NF	NF	NF	200	NF	NF
Iron precipitate, Hector-Calumet mine same location as sample above....	m	1000	M	1000	1000	m	NF	NF	500	NF	NF	NF	NF
White precipitate, Hector-Calumet mine....	M	m	m	1000	1000	500	NF	100	100	50	NF	NF	100
Iron and manganese precipitate, Bermingham adit, Galena Hill....	M	3000	M	500	1000	m	NF	NF	800	NF	1000	2000	NF
Limonitic precipitate, spring, Williams Creek, Galena Hill....	m	2000	M	5	5000	m	200	NF	500	NF	<200	NF	NF
Iron precipitate, Thompson Creek, SW of Galena Creek....	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Spring, Mount Haldane....	M	m	m	<500	500	100	NF	NF	100	NF	NF	NF	50

Table 60 *(Concluded)*

Chemical Composition of Natural Precipitates at Spring Orifices, Keno Hill-Galena Hill Area

M = major constituent content, 10–100% NF = not found
m = minor constituent content, 1–10% ND = not determined

Description	Cu	Zn	Cd	Pb	Ni	Co	As	Sb	Ag	Sn	Bi	Tl	In	Ge
Iron precipitate, spring, Basin Creek, Keno Hill	50	200	NF	NF	NF	NF	10	<5	NF	NF	NF	NF	NF	NF
Manganese precipitate, Hector-Calumet mine same location as sample below	100	m	1000	130	500	300	115	35	~0.5	NF	NF	NF	NF	NF
Iron precipitate, Hector-Calumet mine same location as sample above	20	8000	NF	35	NF	NF	6400	580	NF	NF	NF	NF	NF	NF
White precipitate, Hector-Calumet mine	500	m	1000	50	100	NF	1000	<50	10	NF	NF	NF	NF	NF
Iron and manganese precipitate, Bermingham adit, Galena Hill	240	m	2000	500	NF	NF	2650	ND	~0.5	NF	NF	NF	NF	NF
Limonitic precipitate, spring, Williams Creek, Galena Hill	10	65	NF	75	NF	NF	320	5	<0.5	NF	NF	NF	NF	NF
Iron precipitate, Thompson Creek, SW of Galena Creek	<20	100	ND	150	ND	ND	>2%	1.0	ND	ND	ND	ND	ND	ND
Spring, Mount Haldane	140	30	NF	15	NF	NF	15	2	NF	NF	NF	NF	NF	NF

Cu, Zn, Pb, As, and Sb by colorimetric methods; analysts M. A. Jardine and G. Mihailov
Other elements by spectrographic methods; analyst H. W. Champ

Table 61

Analyses of Underground Springs

Metal values in parts per million
NF = not found

Sample No.	Zn	Cu	Pb	pH[1]	T°C
1	78.3	0.65	1.00	6.4	3°C
2	50	NF	NF	4.4	3°C
3	0.75	NF	NF	7.2	3°C
4	0.006	NF	NF	7.4	2°C
5	1.66	NF	NF	6.7	2°C
6	0.11	NF	NF	7.3	2°C
7	1.33	NF	NF	6.8	3°C
8	80	NF	0.01	6.4	4°C
9	66	NF	0.10	7.2	3°C
10	0.01	NF	NF	7.5	3°C
11	46	NF	NF	7.0	3°C
12	0.03	NF	NF	7.4	—
13	0.31	NF	NF	7.8	—
14	3	NF	NF	7.7	—

[1] pH determinations made with Beckman N-2, pH meter

Sample No.	
1	100-foot level (1-2 N drift) Hector-Calumet mine. Water leaching mineralized zone. No iron precipitates.
2	100-foot level (1-11 S drift) Hector-Calumet mine. Water issuing from Jock fault (post ore fault). Iron and manganese precipitates.
3	300-foot level (3-4 drift) Hector-Calumet mine. Water issuing from diamond drill hole in hanging-wall of vein fault. Iron and manganese precipitates.
4	300-foot level (3-4-1 S drift) Hector-Calumet mine. Water issuing from diamond drill hole in hanging-wall vein fault. No iron or manganese precipitates.
5	300-foot level (3-4-1 S drift) Hector-Calumet mine. Same location as No. 4. Water issuing from diamond drill hole in foot-wall of vein fault. This drill hole cuts the Jock fault (post ore fault). Abundant iron and manganese precipitates.
6	300-foot level (3-4 480 x-cut) Hector-Calumet mine. Water issuing from fractures. Abundant iron and manganese precipitates.
7	300-foot level (3-4 drift) Hector-Calumet mine. Water issuing from fractures in Jock fault zone. Abundant reddish iron and black manganese precipitates.
8	300-foot level (x-cut to 3-2 N drift) Hector-Calumet mine. Water issuing from fracture in Hector fault zone. Iron precipitates.
9	300-foot level (3-2 N drift) Hector-Calumet mine. Water issuing from ore shoot. Bluish white precipitate on walls.
10	400-foot level (4-4 S drift) Hector-Calumet mine. Water issuing from diamond drill hole in hanging-wall of vein fault. Iron precipitates.
11	400-foot level (4-4 S drift) Hector-Calumet mine. Water issuing from brecciated vein fault.
12	650-foot level (6-4 S drift) Hector-Calumet mine. Water issuing from drill hole in hanging-wall of vein fault.
13	650-foot level (6-4 S drift) Hector-Calumet mine. Water issuing from drill hole in hanging-wall of vein fault.
14	650-foot level (6-4 SN drift) Hector-Calumet mine. Water issuing from vein fault.

Table 62

Contents of Some Characteristic Elements in One Cubic Mile of Rock Compared with Those Won from Deposits to 1960

All values in tons × 10^6

Rock Type	S	As	Sb	Pb	Zn	Cu	Ag	Mn
Granitic rocks[1] (average of Dublin Gulch and Mayo Lake bodies)	1.9	0.11	0.007	0.25	0.63	0.08	0.0007	10.5
Greenstones[1]	12.5	0.08	0.007	0.07	1.0	1.9	0.005	11.4
Graphitic schists, phyllites and quartzites[1]	120.5	0.27	0.04	0.22	0.91	0.45	0.007	22.0
Thick- and thin-bedded quartzites[1]	38.7	0.11	0.02	0.10	0.44	0.17	0.004	11.4
Lead-zinc-silver deposits—Keno-Galena Hills[2]	0.28	0.003	0.007	0.18	0.15	0.004	0.005	0.10

[1] Contents calculated from average elemental content given in Table 26

[2] Contents calculated from all available mine and government records, 1915–60

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