# Geology of Two Base-Metal Deposits in the Slave Structural Province

Indian Mountain Lake 75 M/2
High Lake 76 M/7

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# INTRODUCTION

The Slave Province, is geologically similar to the Superior Province but fewer than a half-dozen good base-metal prospects are known within it and none of these is economic under present conditions. Most of these deposits have not been studied in detail nor has the metallogeny of the province received much study. The purpose of this report is to describé the geology of two base metal occurrences as an initial step in a metallogenic study of the Slave Province.

Metamorphosed volcanic rocks are the host for the deposits considered in this report. Although they have been metamorphosed and are thus metamorphic rocks, for the sake of comparison with other areas, they are referred to in terms of their original lithologies, except where these cannot be inferred. Classification of volcaniclastic rocks is taken, with slight modification, from Fisher (1961, 1966).

# HIGH LAKE COPPER-ZINC DEPOSIT

## INTRODUCTION

The High Lake copper-zinc deposit is located at 67°23'N, 110°51'30"W, immediately to the west and south west of High Lake and approximately 330 miles north-northeast of Yellowknife. Drill indicated reserves at High Lake consist of 5.2 million tons grading 3.5% copper, 2.5% zinc, 0.6 ounces/ton silver, 0.02 ounces/ton gold, and minor lead. . The deposit, which was discovered by Kennarctic Explorations during an airborne reconnaissance program in 1955, has been described briefly by McGlynn (1971). A total of three weeks was spent mapping and sampling the property during the summers of 1972 and 1973. Laboratory work included study of thin and polished sections, and a few preliminary chemical analyses.

## REGIONAL GEOLOGY

The volcanic belt was mapped on a reconnaissance scale by the Geological Survey of Canada, (Fraser, 1964) and more recently the High Lake area was mapped at a scale of one-half mile to the inch by Padgham *et. al.* (1974). The following account is taken mainly from these two sources, supplemented by this author's observations and descriptions from company reports.

The High Lake deposit occurs within an eight-mile wide belt of metavolcanics which extends from Gray's Bay on Coronation Gulf southwards for some 85 miles. The volcanic belt, which is bounded and intruded by granitic rocks, is comprised predominantly of felsic and intermediate rocks for the northernmost 50 miles, whereas south of this mafic and intermediate volcanic rocks are predominant. Felsic volcanic rocks are pale green to white, massive or foliated, and locally porphyritic. Mafic and intermediate volcanics are light to dark green, fine-grained and massive to foliated. Pillow structures are common and vesicular structure and agglomerate occur locally. At granite contacts, mafic volcanics have been recrystallized to dark green or black, medium- to coarse-grained amphibolite. Sedimentary rocks, mostly greywacke, are locally abundant, particularly in the southern part of the belt. Thin layers of black graphitic slate and carbonate are common within the volcanics.

In the area of High Lake, the volcanics consist of interbedded rhyolitic, dacitic, and andesitic flows, tuffs, breccias, and agglomerates, along the Kennarctic (Bradshaw) River, east of High Lake, the section includes calcareous tuffs and black slates.

Foliation within the volcanic rocks is generally steeply dipping and parallel to the trend of the belt. Faults and Proterozoic diabase dikes are common; most have northwesterly to north-northwesterly trends but a few strike northerly or northeasterly. A major northerly trending fault is inferred along the Kennarctic River.

Zones capped by gossans are scattered throughout the volcanic belt. Fraser (1964) notes that many carry disseminated pyrite and pyrrhotite and some carry chalcopyrite and arsenopyrite. Pyritic zones up to 200 feet wide occur in the felsic volcanic rocks. Those at Low Lake seven miles south-southeast of High Lake, and others a few miles to the north of High Lake (Chill Group) have only low copper values. These sulphide rich zones within predominantly felsic volcanics suggests that these rocks are part of a regional felsic volcanic centre similar to those recognized by Goodwin and Ridler (1970) within the Abitibi greenstone belt of the Superior Province.

## Local Geology

### Description of Rock Types

With the exception of Proterozoic diabase dykes, all rocks in the area of study see accompanying maps "High Lake Cu-Zn Deposit") are believed to be Archean in age. These include a large intrusive body which occurs along the western edge of the area and metamorphosed altered volcanic rocks with minor volcanic limestone, as shown in the Table of Formations (below).

**TABLE OF FORMATIONS**

| AGE | | LITHOLOGY |
|---|---|---|
| RECENT | | Sand, gravel, silt<br>Unconformity |
| PROTEROZOIC | | Diabase<br>Intrusive Contact |
| ARCHEAN | YELLOWKNIFE SUPERGROUP | Granodiorite, diorite, quartz diorite, gabbro<br>Intrusive Contact<br>Limestone and related rocks: calcite-cemented felsic or cherty breccia; calcareous intermediate tuff and lapillituff; dolomite; siderite<br>Felsic volcanic rocks (rhyolite, rhyodacite): white to grey, siliceous, fine-grained tuff (?); in places, pyritic<br>Felsic and intermediate volcanic rocks: tuff, lapilli-tuff, and tuff-breccia; minor cherty breccia; minor coarse-grained breccia<br>Intermediate volcanic rocks: (dacite, andesite); tuff and lapilli-tuff; massive flows; pillowed flows |

*Volcanic Rocks*

Volcanic rocks comprise a large part of the High Lake map-area. Stratigraphic tops have not been determined, but crude zoning within the sulphide bodies and the position of the alteration zone suggest tops are toward the west. A section through the stratigraphic sequence, from probable base to top, consists of three broad zones separated by gradational contacts.

The lower 1500 feet, approximately, consists of andesite and dacite, which include tuff and lapilli-tuff, pillowed flows, and massive rocks which are probably flows. Massive andesite also occurs adjacent to the intrusion in the southern half of the map-area. Although similar in appearance to the rocks of the lower volcanic unit, the stratigraphic relationship of this andesite to the lower and middle units is not clear. The massive andesite is intruded by stringers of diorite, and in places is metamorphosed to hornblende hornfels facies making it harder and coarser grained; and resulting in widespread hornblende porphyroblasts.

The middle volcanic unit consists of felsic and intermediate pyroclastic rocks including tuff, lapilli-tuff, tuff-breccia, and breccia as the predominant types. Fragments range in composition from dacite to siliceous rhyolite, with minor zones of cherty fragments. Matrix, which appears to be more mafic than fragments, has the composition of andesite or dacite. Tuff and lapilli-tuff are generally green or grey-green and massive felsic rock is light-grey. East of the AB sulphide zone and generally in the centre of the map-area, the rhyolite is siliceous, highly fractured, and in places shows flow-banding and structures which resemble pillows. A coarse-grained volcaniclastic rock near the southwest corner of High Lake contains subangular to rounded, generally elongated fragments ranging up to 12 inches in length and 6 inches in width. Fragments, which are randomly distributed and show a good preferred orientation, comprise up to 50% of the rock, the remainder being tuffaceous matrix. The rock formed by pyroclastic or pyroclastic flow processes (e.g. landslide). Detailed stratigraphic relationships within the middle unit are obscured by the effects of pervasive alteration and contact metamorphism, and the gradational nature of contacts. A lack of distinctive marker units, limited structural information, and the lateral variation in rock types, are additional complications.

A broad zone occupying most of the northwestern part of the study-area consists of felsic volcanics. The most abundant of which is a fairly uniform, fine-grained, white- to light green-weathering, grey, siliceous rhyolite or rhyodacite tuff, with small amounts of breccia. In places this rock contains minor pyrite, and may be whiter and more siliceous. Near the contact with the intrusion, it is somewhat granular, probably as a result of contact metamorphism.

*Limestone and Related Rocks*

Carbonate rich rocks occur mostly within the lower part of the intermediate and felsic pyroclastic unit and the upper part of the intermediate unit. Calcareous intermediate tuff and lapilli-tuff consists of up to 50% calcite within the intermediate rock. Near the small lake south of High Lake, this rock has been dolomitized, possibly as a result of its proximity to a major fault.

Calcite-cemented breccia is abundant in a zone along the west shore of High Lake. It consists of angular to platy rhyolite and in places, chert fragments in a calcareous matrix which has weathered preferentially to give the rock a rough irregular surface. Extensive exposures of this rock type near the southwest corner of High Lake has been hydrothermally altered and contains abundant chlorite. Calcite within this altered rock is believed to be of exhalative origin, but could be an alteration product. Although individual layers and lenses within the study area cannot be traced much more than 200 feet, a possible continuation of the carbonate breccia north of High Lake has been traced for several thousand feet.

Small veins of siderite up to about two feet wide and 20 feet long occur at the north end of the small lake near the centre of the area and west of the AB zone. The origin of these veins is not clear but they appear to be related to faulting.

#### *Intrusive Rocks*

Granodiorite, diorite, quartz diorite, and gabbro form an intrusive complex up to one mile wide and three miles long. Adjacent to the sulphide zones the intrusion consists of granodiorite, diorite and quartz diorite, but near the north and south limits of the study area gabbro is common. Inclusions of intermediate volcanics occur throughout the intrusion. In addition to contact effects noted elsewhere, hybridization of volcanic and intrusive rocks, possibly complicated by faulting, occurs near the AB zone.

#### *Diabase*

North to northwesterly trending diabase dykes up to 50 feet wide and thinner sills occur within the study-area. The largest dyke passes through the middle or both the AB and D sulphide zones.

### Structure, Metamorphism, Age

There is limited structural information available within the study area. Bedding and a pervasive cleavage strike about 20 degrees either side of north and dip from 70 degrees to vertical. Deformation seems to have been accomplished by faulting and shearing, rather than by folding. Shearing is common within alteration zones and intermediate volcanics. The flattening of pillows is further evidence of the type of deformation. Northwest trending faults are the most obvious structural features; at least one major fault, and possibly two or three, can be inferred from aerial photograph lineaments, and by redening and brecciation of rock as seen in outcrop and drill core. These are probably Proterozoic and may be related to the Bathurst fault system. Kink bands in the intermediate volcanics may also be of this age.

Regional metamorphism to greenschist facies is indicated by the assemblage in andesite of quartz-chlorite-carbonate-epidote.

Although no direct dating of the volcanics has been done, structural and lithologic evidence indicates they are Archean in age. Thorpe (personal communication) obtained an Archean age for the ore lead.

## GEOLOGY OF THE DEPOSIT

### Sulphide Zones

The deposit consists of two sulphide zones, the AB and D, that occur within the zone of felsic and intermediate pyroclastics. In addition there are two zones which have very low metal values: the C zone between the AB and D, and the E zone about 600 feet east of the D zone. These will not be described further.

Both the AB and D zones outcrop but their dimensions and the nature of their contacts with the wall-rocks are partly obscured by overburden and gossan, so that the AB zone may be somewhat smaller than shown in Figure 1. Both zones are cut by a diabase dyke and both lie near the contact of the granitic intrusion. As seen on surface, both appear to consist of lenses approximately parallel to the strike of the volcanics.

Drilling has shown that the AB zone contains approximately 2.4 million tons grading approximately 5.4% copper, 1.1% zinc, and 0.03 ounces/ton gold. Drilling results indicate zinc content is higher to the west of the diabase and also indicate the presence of a small zinc-rich, copper-poor sub-zone some 100 feet further west. Increase in zinc to copper toward the top of a sulphide zone is characteristic of volcanogenic massive sulphide deposits. Sphalerite was not observed in trenches and outcrop, and here chalcopyrite was the only economically valuable sulphide mineral. Massive sulphides exposed west of the diabase consist of pyrite metacrysts up to 2 inches in diameter surrounded by pyrrhotite, with minor magnetite and chalcopyrite. In polished section, the pyrite is fractured and somewhat rounded or anhedral; these textures suggest pyrite grew during an early stage of metamorphism, then was subjected to cataclasis and partial breakdown to pyrrhotite during deformation and increasing metamorphism which accompanied the intrusion of the quartz diorite/granodiorite. East of the diabase, textures suggest the same history, although pyrite crystals are much smaller and disseminated and stringer sulphides are common. Gangue is mainly chlorite, anthophyllite, and cordierite(?), with minor epidote and graphite.

The D zone contains approximately 2.8 million tons grading 3.6% zinc, 2.0% copper, 0.2% lead, 1.1 ounces/ton silver and 0.02 ounces/ton gold. The main exposure of this zone is a 30-foot section of poorly banded sphalerite-pyrite-chalcopyrite-galena in a trench to the west of the diabase. In polished section, pyrite is euhedral to subhedral, fractured, and zoned, with an inclusion-rich core. Sphalerite, chalcopyrite and galena fill fractures in pyrite and may have partly replaced it. The enclosing rock is less altered than that of the AB zone, and as with the AB zone, metamorphic effects predominate. East of the diabase, a 10-foot wide massive chalcopyrite vein and disseminated chalcopyrite with anthophyllite are exposed in trenches. These two exposures suggest an increase in the zinc to copper ratio toward the west. In the drill core, sulphides occur predominantly as disseminations, veinlets, and irregular small massive bodies. Primary layering was not observed.

## Alteration

Alteration is extensive within the felsic and intermediate pyroclastic unit. An attempt was made to map different alteration assemblages but the limits of occurrence of these assemblages are approximate only and some assemblages may occur more extensively than shown. There is a major alteration zone stratigraphically below(?) each of the major sulphide zones. These alteration zones, which lie subparallel to bedding, appear to represent "feeders" to the overlying(?) sulphide zone.

A Black Chlorite occurs extensively and represents the lowest degree of alteration. Near the D sulphide zone it has been thermally metamorphosed to biotite, the resultant rock becoming dense, black and slaty commonly with minor rhyolite fragments.

Dalmatianite, which represents a low to moderate degree of alteration, does not clearly define a zone. This rock usually consists of dark spots of chlorite or chlorite-sericite within a light-coloured sericite-quartz rock, but in places the spots are lighter than the matrix. As seen on outcrop, spots generally occur clustered near what appear to be intensely altered fractures. Dalmatianite of a different nature occurs within the more intensely altered rocks of the Ab sulphide zone within or adjacent to the area of occurrence of magnetite-anthophyllite. In this rock the spots, which are about 0.5 inch in diameter, are zoned concentrically and consist of chalcopyrite, pyrite, marcasite, magnetite, ilmenite, green spinel, chlorite, cordierite, and anthophyllite.

Dalmatianite similar to that described above is common near certain ore-bodies of the Noranda District, especially at the old Amulet mine. Although in the latter district spots commonly consist of cordierite, which is rare at High Lake, the occurrence of dalmatianite and the geological setting of the two areas are similar. De Rosen-Spence (1969) has attributed the occurrence of dalmatianite in the Noranda District to contact metamorphism by the Dufault Granodiorite. The dalmatianite at High Lake was probably formed, in a similar manner, by the contact metamorphism of the alteration minerals by the quartz diorite/granodiorite intrusion. The change from chlorite-sericite away from the intrusion to cordierite-anthophyllite-magnetite near the intrusion may be due to a combination of increased alteration higher in the alteration "pipe" and increased contact metamorphism closer to the intrusion.

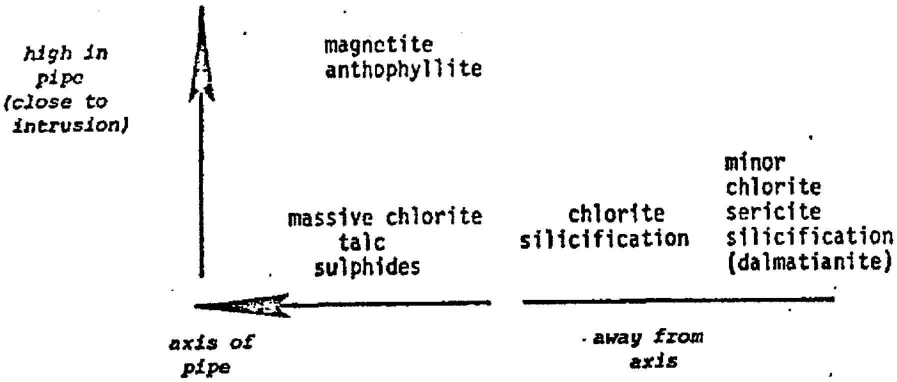
Zones of chloritization with silicification can be fairly well defined, with the reservation that it is not clear how much of the excess silica is due to alteration as opposed to primary volcanic processes. These are broad zones of fairly intense chloritization with white to grey quartz as small irregular masses and veinlets. In places, especially immediately to the east of both the AB and D zones, silicification has made the original rock more brittle so that it is highly fractured.

The zones of chloritization and silicification envelope zones of more intense alteration. One type consists of red-stained, black, strongly sheared rock consisting almost entirely of chlorite with minor sulphides. Massive talc and talc-chlorite are also present, especially near sulphide-bearing zones.

An assemblage representing intense alteration is magnetite-anthophyllite, which outcrops just east of the diabase in what is interpreted to be the upper part of the AB alteration zone. This rock, which occurs as irregular masses less than 10 feet in diameter, consists of up to 70 per cent magnetite grains in a matrix of anthophyllite. In one polished section approximately 5% native silver occurs with the magnetite. Other sections show, in addition, ilmenite, chalcopyrite, and marcasite. Although not shown on the accompanying map, anthophyllite is abundant in places within and near the AB sulphide zone, where its presence is due to intense alteration and proximity to the quartz diorite/granodiorite intrusion.

Pods of quartz-pyrite-sericite-chlorite, which is in places a siliceous rhyolite breccia with a pyritic matrix, are believed to be replacement bodies, possibly of porous zones, although some appear to be related to faulting. This assemblage is widespread in the C zone, between the AB and D zones, where it also includes minor chalcopyrite. A polished section from one of these pods contains zoned pyrite metacrysts with numerous inclusions in the core of each grain but with inclusion - free margins. Galena, sphalerite, tetrahedrite, native silver, chalcopyrite, mackinawite, and graphite occur as inclusions in pyrite or as individual grains. Prominent massive pyrite zones occur at the south end of the D zone and at the south end of the small lake east of the D zone.

Although it is difficult to clearly define zones of increasing alteration, in general the pattern is as presented below; arrows represent increasing alteration.




GRAPH OF ALTERATION IN RELATION
TO AXIS OF ALTERATION PIPE AND PROXIMITY TO INTRUSION
(intensity greatest toward head of arrows.)

## SUMMARY AND INTERPRETATION

The High Lake sulphide zones occur within a unit of coarse-grained intermediate to felsic pyroclastic rocks in the middle of a section that changes gradationally from intermediate at the probable base to felsic at the top. Stratigraphic relationships in the immediate vicinity of the sulphide zones are not clear. The D zone appears to occur between the felsic and intermediate pyroclastics and overlying contact metamorphosed massive andesite. Stratigraphic relationships within the hangingwall (?) of the AB zone are obscured by lack of outcrop and and complexity due to the intrusive body. The sulphide zones formed toward the close of a period of explosive volcanism which laid down the pyroclastic rocks. Exhalation continued after the explosive activity and formed the sulphide zones with their associated zones of alteration. Ore textures and structures do not indicate whether the upper parts of the sulphide zones were deposited at the volcanic rock-sea water interface or whether they replaced porous zones within the pyroclastic pile as the lower part of the AB zone certainly did.

The ore zones differ somewhat in mineralogy and metal content. The AB zone is higher in copper than is the D zone, which has higher content of zinc, lead, and silver. Alteration zones associated with each also differ somewhat. The geometry and position of the AB alteration zone relative to the sulphide zone strongly suggests it is a "feeder" pipe. The alteration zone reaching north of the D zone is not as well exposed as that of the AB zone. It includes more quartz-pyrite zones; has been less affected by silicification; the intense magnetite-anthophyllite alteration has not been observed, and it is not so clearly related to the sulphide zone. However, it too is believed to show the effects of the passage of mineralizing solutions.

Deformation of the host rocks during regional metamorphism to the greenschist facies caused flattening of some structures and transposition of bedding so that the alteration zones and possibly also sulphide zones became sub-parallel to bedding. Intrusion of the quartz diorite/granodiorite body occurred at this time, probably under metazonal conditions. Some probable and possible effects of the intrusion are the production of dalmatianite, anthophyllite, and biotite within the alteration zones; production of pyrite metacrysts and minor remobilization of sulphides within the sulphide zones; and recrystallization of andesite and rhyolite at the intrusive contact.

# INDIAN MOUNTAIN LAKE ZINC-LEAD-SILVER-COPPER DEPOSIT

## INTRODUCTION

The Indian Mountain Lake deposit located 115 miles east-northeast of Yellowknife and about 10 miles north of MacLeod Bay on Great Slave Lake, consists of three sulphide bodies. Two are high in lead, zinc, and silver, and one is a low-grade copper body. The deposit, which was discovered during aerial reconnaissance in 1948, is owned by Indian Mountain Metal Mines Limited.

## REGIONAL GEOLOGY

The region has been mapped by Henderson (1941) and by Heywood and Davidson (1969). This description is taken mainly from the latter work. The deposits occur within a 15-mile wide by 30-mile long north-trending belt of supracrustal rocks bordered by granitic and migmatitic rocks. Volcanic rocks are confined to the western margin of the belt and are overlain conformably by greywacke, impure quartzite, slaty argillite and their metamorphic equivalents. They consist of massive or pillowed basalt and andesite, ampnibolite, and mafic schist overlain by felsic flow and pyroclastic rocks with minor limestone and are folded into a north-trending anticline and underlain in the core of the anticline by a meta-tonalite body locally separated from the volcanics by conglomerate-like rocks. Heywood and Davidson suggest the meta-tonalite may be basement to the Yellowknife Supergroup.

In addition to the Indian Mountain Lake Deposits, occurences of sulphides are found elsewhere in the greenstone belt: two miles east at the same stratigraphic position, seven miles north within a thick section of the same felsic volcanics, and six miles east in a highly metamorphosed anticlinal belt which may be correlated with felsic volcanics at the Indian Mountain Lake deposit.

## LOCAL GEOLOGY

Except for the base of the mafic volcanics, which have been migmatized, a stratigraphic section representative of the entire greenstone belt is present in the map-area (see accompanying map "Indian Mountain Lake Zn-Pb-Ag-Cu Deposit", and table below).

### Description of Rock Types

#### *Mafic Volcanics*

An 800 foot basal section of mafic volcanic rocks consisting predominantly of tuffs, with minor massive and pillowed flows, occurs near the western margin of the map-area. The tuff includes approximately 25% felsic beds. The presence of very thin beds, which vary in thickness from less than 1 mm. to 1 m. and in places appear to show graded bedding, suggests the tuffs are water-lain. Except for a few small folds, bedding is parallel to mineral foliation. These rocks are now fine- to medium-grained amphibolites.

## TABLE OF FORMATIONS

| AGE | | | LITHOLOGY |
|---|---|---|---|
| RECENT | | | Sand, gravel, silt |
| | | | Unconformity |
| ARCHEAN | YELLOWKNIFE SUPERGROUP | | Granitic rocks: biotite granite; granite with mafic inclusions; pegmatite |
| | | | Intrusive Contact |
| | | | Migmatite and high grade gneiss |
| | | | Gradational Contact |
| | | | Sedimentary rocks: greywacke, argillite, and metamorphic equivalents |
| | | | Exhalite: limestone, limy tuff, limestone-cemented breccia; pyritic, siliceous tuff, in places with graphite or magnetite |
| | | | Felsic volcanic rocks (rhyolite, rhyodacite): massive to foliated tuff or flows, lapilli-tuff, breccia, ignimbrite, quartz porphyry, quartz-feldspar porphyry, gneiss, brecciated and silicified alteration |
| | | | Intermediate volcanic rocks (andesite, dacite): massive and pillowed flows, pillow breccia, dacite breccia, tuff, includes alteration zone |
| | | | Mafic volcanic rocks (basalt): massive and pillowed flows, breccia, well-bedded tuff |

### *Intermediate Volcanics*

Intermediate volcanics comprise a unit approximately 800 feet thick, the lower part of which is very similar to the underlying mafic unit in that it consists of tuff and massive and pillowed flows. Since this lower part of the section is moderately to highly altered, it is not clear whether it was originally basaltic or andesitic. The alteration, which will be discussed in detail in a later section, is characterized in the most intense part by the presence of garnet, cordierite, anthophyllite, cummingtonite, and sulphides, and in the less intense part by muscovite, biotite, and sillimanite.

A 300 to 400 foot thick unit of andesitic pillowed flows, pillow breccia and dacitic breccia stratigraphically overlies the altered rocks. Pillows are fine-grained with biotite-rich selvedges. Fragments in the dacitic breccia contain up to 25% quartz-eyes, some up to 3 mm. in length. Matrix, which is similar to pillow selvedges, is always darker and more deeply weathered than fragments and comprises 50% of the rock. The fragments are monomictic, poorly sorted, and irregular in form but have rounded edges. They range in length from 0.5 to 18 inches on the outcrop surface. Length to width ratio varies from 1:1 to 4:1 so that the fragments have been stretched in a near-vertical direction and show a weak alignment parallel to the trend of layering. Although the origin of the dacitic breccia is uncertain, the monomictic nature and irregular shape of fragments suggests it may consist of bombs as well as pyroclastic fragments.

### *Felsic Volcanics*

The felsic volcanic unit, some 1200 feet thick, includes rocks of rhyolite and rhyodacite composition. Much of the rock is essentially massive with only a weak foliation, defined partly by biotite, which trends parallel to the boundaries of the unit. In the absence of primary structures it is not possible to determine if these rocks are flows, tuffs, or even intrusive bodies.

However, a large wedge of noticeably massive, dense quartz porphyry which occurs just north of Kennedy Lake may be intrusive, possibly into a felsic dome. Felsic volcanics, weather light grey, white, or pink, and most are fine-grained except for the common occurrence of rounded quartz, and less commonly feldspar grains in quartz porphyry and quartz-feldspar porphyry. It is not known if the quartz grains, which range up to 3 mm. in length, are crystal fragments in tuff, or phenocrysts in flows or intrusive rocks.

The felsic volcanic rocks southeast of Kennedy Lake are more strongly foliated and have more gentle dips than those to the northwest. In addition, the lower part of the volcanic sequence from mafic volcanics up to and including the lower felsic breccias is not present or not recognizable because it has been migmatized. Near the BB sulphide zone, cherty rhyolite layers and pyritic tuff occur within this unit.

Overlying the intermediate pillow and breccia unit is a unit of mixed felsic and intermediate coarse pyroclastics, approximately 200 feet thick, which represents a transition into the thick felsic volcanic section. The thickest beds within this pyroclastic unit consist of a breccia with 20% felsic fragments, 50% mafic and intermediate fragments and 30% tuffaceous matrix. This rock which contains poorly sorted, mostly angular fragments is considered to be an ignimbrite in the sense that Fisher (1966) defines the word, that is, it is a rock produced by flow of pyroclastic material , in this case probably a landslide. It grades upward into a breccia in which felsic fragments predominate; this in turn is overlain by thin-bedded felsic tuff, lapilli-tuff, tuff-breccia, and finally by the more massive rock of the felsic unit.

Felsic breccias interlayered with intermediate rocks at the base of this "ignimbrite" have been described in the preceding section. A zone of alteration, some 200 feet thick, occurs at the top of the felsic volcanic unit. Rocks within this zone show an irregular and poorly defined foliation which in places cuts across the trend of the volcanic units and they are highly fractured, bleached, and silicified, with net type alteration common along thin fractures. The altered rock adjacent to these fractures is more resistant to weathering than the bulk of the rock, which is rich in biotite with minor hornblende, garnet, and feldspar. This alteration is most intensely developed near the BB zone, where it generally lies stratigraphically above the exhalite and sulphide zone. Small lenses of limestone and breccia with a limy matrix are also common. This alteration is believed to have been caused by hydrothermal solutions circulating within the top layers of the felsic volcanics during the waning stages of volcanism.

*Exhalite*

Exhalite occurs below or within the altered part of the felsic volcanics and includes both limestone or limestone-cemented breccia and a siliceous, rusty weathering, pyritic tuff in places with graphite or magnetite. These commonly, but not always, occur together in a unit that may be as thick as 30 feet, but averages 5 to 10 feet. Although difficult to trace, it appears to outline a syncline near BB Lake. The best exposure of limestone is on the ridge just northwest of the BB zone where it is overlain by highly altered felsic volcanics, underlain by rubbly rhyolite breccia, and cut by pegmatite dykes and by irregular veins and masses of blue quartz, up to 2 feet thick. In places the limestone, which contains minor disseminated sulphides, is intensely deformed.

The main sulphide body, the BB zone, is at approximately the same stratigraphic position as the exhalite, and both limestone and pyritic tuff are exposed in a trench at the south end of the sulphide zone. Here, a 5-foot section of well-layered, medium-grained, grey to pink, siliceous rock with up to 50% pyrite and occasional pyroclastic fragments is directly overlain by 2 feet of limestone. Also in the area of the BB zone, the felsic volcanics directly overlying the sulphide body are very siliceous or cherty. Both the limestone and pyritic, siliceous rock are thought to be exhalative in the sense that they were deposited on the ocean floor by the action of fumarolic exhalations near the close of felsic pyroclastic volcanism.

*Sedimentary Rocks*

Sedimentary rocks, which were studied only briefly, include greywacke-argillite with graded bedding, and more commonly quartz-feldspar-biotite gneiss with varying proportions of sillimanite, cordierite, staurolite, and andalusite.

*Migmatite and High Grade Gneiss*

Migmatite and high grade gneiss common within the area are usually sufficiently recrystallized, and probably metasomatized, that their origin is uncertain. Most are medium-grained, well-foliated, highly contorted, and grey to tan in colour, with a rough-weathering surface. Foliation is due mainly to two types of layers, one mainly quartz and oligoclase, and the other rich in biotite with sillimanite and minor potash feldspar. Irregular masses of quartz commonly 3 to 12 inches long, make up about 10% of the rock. Contact with the mafic tuff is gradational over 1 or 2 feet and approximately parallel to bedding, whereas the contact with the biotite granite is generally sharper. This evidence suggests that the migmatite was derived by high grade regional metamorphism and migmatization of volcanics and sediments and was subsequently intruded by small biotite granite stocks and dykes during the waning stages of metamorphism.

*Granitic Rocks*

A large body of structureless, homogeneous biotite granite occurs near the western margin of the map-area. This is a medium-grained, grey rock containing equal amounts of quartz and potash feldspar, with 15% plagioclase, much of it myrmekitic, and 5% biotite. It also occurs within the migmatite and mafic tuff as dykes and irregular masses up to 20 feet wide. Dips in migmatite at the granite contact flatten out in places indicating the granite body may underlie the migmatite at depth. A similar rock containing abundant small mafic inclusions occurs south of Kennedy Lake and south of the map-area. Inclusions which show a strong preferred orientation, are particularly common within 5 or 10 feet of the margins.

Quartz-potash feldspar pegmatite as dykes and irregular bodies is common within the map-area, notably along inferred faults southwest of Kennedy Lake, near the BB zone, and as a 1200 foot long dyke east of Kennedy Lake. Pegmatite in the alteration zone east of Kennedy Lake appears to be mainly later than shearing or faulting although where this pegmatite crosses the main fault valley between volcanics and sediments it may be displaced about 100 feet. This and the displacement of the small pegmatite on top of the ridge by movement within the limestone bed, indicate some faulting has probably occurred after pegmatite emplacement.

Structure

The Indian Mountain Lake deposits occur at the south end of the volcanic belt where the dominant north-trending anticlinal structure has been complicated by extensive faulting and cross-folding. Bedding and foliation in the study-area generally strike northwesterly and dip at moderate to steep angles toward the northeast, except in the centre of the study-area where the strike is approximately east-west.

Although analysis of structural features of the area is incomplete, some preliminary statements can be made. There appear to be three tectonic episodes. The first tectonic episode, $D_1$, produced tight isoclinal folds whose axial planes are parallel or subparallel to the bedding ($S_0$). The only good indication of these folds so far observed are non-parallelism of bedding, and a few minor fold closures with amplitudes of 1 to 3 feet in the thin-bedded mafic tuffs, but some evidence suggests they are also present in the sediments. Only a few fold axes were measured and these plunge northward at moderate angles.

The second tectonic episode, $D_2$, produced the major folds in the area which are mainly responsible for the general outcrop pattern. This event deformed the $S_0/S_1$ bedding and foliation into a broad syncline, whose south limb has been refolded into a northeasterly-plunging anticline centred on the BB sulphide zone. The north limb of the syncline is not in the study area. This syncline has a steep axial plane which strikes approximately 100°; the axis plunges steeply, probably toward the east. An important effect of this folding is the production of a strong lineation, $L_2$, which, along the south limb of the syncline, generally plunges northerly at moderate to steep angles. One type of lineation is the stretching of pillows and breccia fragments to an estimated 10 times their original size. This lineation, the result of mainly vertical movement, was probably caused by diapiric uprise of granites suggesting that the metatonalite is probably intrusive into, rather than basement to the supracrustal rocks. Metamorphic minerals are generally aligned parallel to foliation, suggesting that the foliation developed with $F_1$ and that the peak of metamorphism pre-dated $D_2$.

In the northeast part of the map-area graded bedding in sediments tops to the south on the south side of the hill and to the north on the north side. The schistosity, $S_2$, defined mainly by biotite and sillimanite, has a fairly constant attitude but swings slightly. This evidence suggests the sediments were folded during $D_1$, which was followed by the peak of metamorphism. A second deformation $D_2$ folded the schistosity slightly. This deformation is seen in outcrops north of Kennedy Lake, in which foliation defined by sillimanite and striking about 150° is superimposed on bedding which strikes about 80°.

The BB sulphide zone occurs along the nose of a gentle anticlinal structure on the south limb of the syncline where planar structures in the volcanics dip at moderate angles to the northeast. That is, the planar structures dip more gently here than in the volcanics northwest of Kennedy Lake. Lineations defined by the intersection of $S_0/S_1$ and cleavage, as well as stretched fragments and mineral lineations, plunge to the northeast. The parallelism of the sulphide body to the prominent lineation suggests that it has been smeared or stretched out by the same forces which produced the lineation.

$D_3$ is poorly defined, by crenulation cleavage, in the alteration zone and in the metasediments, and by jointing, and possibly by the major faults that are inferred within the study-area. $D_3$ timing is uncertain but it may be much later than the other deformations possibly related to regional predominantly northeast-trending vertical faults, which in turn may be related to the MacKenzie Fault system. Schistosity in the migmatites is highly deformed and cannot be attributed to any one of these events.

A number of faults are inferred within the study-area. A major fault, also described in drill logs, is marked by a prominent topographic depression along the volcanic-sedimentary contact, as is a major fault along the north side of Kennedy Lake. Many of the faults shown on the map are inferred from air photographs. Bedding-plane faults and shears are common and several axial plane faults in the area of the BB sulphide zone have been inferred.

### Metamorphism and Age

Metamorphism within the region has been studied by Davidson (1967) who found that regional metamorphic grade reaches middle cordierite-amphibolite facies of the low pressure andalusite-sillimanite facies series in the vicinity of the area covered by this report.

Heywood and Davidson (1969) report four potassium-argon age determinations of granitic rocks in the region rangeing from 2455±80 to 2625±80 m.y.

## GEOLOGY OF THE DEPOSIT

### General

The Indian Mountain Lake deposit consists of three sulphide zones: the BB zone, 970,000 tons grading 9.5% lead, and 3.4 ounces/ton silver; the Kennedy Lake zone, 43,000 tons grading 7.3% zinc, 1.1% lead, and 4.0 ounces/ton silver; and the Kennedy Lake West zone, 610,000 tons grading 1.1% copper. The Kennedy Lake zone is not exposed and will not be discussed further. An extension of the Kennedy Lake West zone can be traced to BB Lake; since this low-grade copper zone is believed to be part of the alteration zone; it is described in the section on alteration.

### BB Sulphide Zone

Drilling of the BB zone, the most important of the three zones, has shown a strike length of 250 feet, a width of 30 to 40 feet and an extent of at least 1,000 feet along the $45^{0}$ plunge. This work shows the zone consists of a series of closely-spaced lenses interbedded with and grading into beds of highly altered siliceous limestone. The lenses appear to pinch out along strike but may also be cut off by faults.

The zone is exposed in 5 trenches. At the most southerly trench limestone is underlain by a pyritic, cherty tuff overlain by altered volcanic rocks and underlain by normal rhyolite. The same cherty, pyritic tuff layer, approximately 2 feet thick, occurs above, and below 10 feet of massive sulphides in the next trench. This tuff, which also occurs in the trench to the west of the main zone, appears to be a lateral extension of the sulphide body but also partly envelops it.

Massive sulphides exposed in 3 trenches on the BB zone consist mainly of various combinations of the 3 minerals, sphalerite, pyrrhotite, and pyrite, with minor amounts of galena, chalcopyrite, marcasite, magnetite, and tetrahedrite. Quartz is the most abundant gangue mineral, constituting 20 to 40% of the rock. Pyrite occurs in crude bands as rounded to euhedral metacrysts, up to 1 cm. but commonly 1 to 2 mm. across. These show some resorption by sphalerite. Galena and chalcopyrite commonly occur as inclusions in pyrite or in the spaces between pyrite grains. Such textures indicate final recrystallization of pyrite after deformation ceased, possibly during retrograde metamorphism. Galena often occurs as rims replacing inclusions of wall rock in massive sphalerite. The wall-rock contact is well exposed in only one trench. Here, within a few inches of the upper contact with rhyolite, the massive sulphides contain fragments of wall-rock, up to 2 inches long, and small patches of coarse-grained pegmatite. The contact is sharp but irregular, with small masses and dykelets of sulphides extending into the wall-rock which suggest the sulphides were remobilized during deformation.

A trench 150 feet to the west of the main line of trenches exposes the pyritic siliceous rock below (?) a highly altered, sheared, sphalerite-rich rock which has abundant sillimanite, cordierite (?), microcline, biotite, and muscovite. Its position in the presumed footwall, and its mineralogy, suggest this may be part of a metamorphosed potassic alteration zone, although it could also be the product of shearing much later than the ore-forming process.

### Alteration and the Kennedy Lake West Copper Zone

Copper mineralization occurs in a zone of distinctive lithology from Kennedy Lake to BB Lake. The best values are in the Kennedy Lake West zone which is mostly under the lake. Here, as determined by drilling, copper mineralization occurs in 2 bands roughly 600 feet long and 25 to 40 feet in average width. A vertical projection of the zone, including lower grade material, is shown on the accompanying map. This zone is also exposed in a large trench where the host rocks consist mainly of garnet-cordierite-anthophyllite-quartz, within which thin stringers and layers of chalcopyrite or chalcopyrite with pyrrhotite occur parallel to the foliation. Chalcopyrite is also found along small joints, a feature which suggests late remobilization. The main copper-rich layer which is about 5 feet wide, contains a black amphibole which appears to be associated with the higher copper content. Within this higher-grade band, chalcopyrite appears in massive seams up to 2 inches wide and more rarerly as coarse crystals with quartz.

Copper mineralization is also exposed in a trench near BB Lake. This is referred to in this report and in the accompanying map as the BB Lake copper zone. As in the Kennedy Lake West zone, chalcopyrite occurs within coarse-grained, garnet-cordierite-amphibole zones mainly as massive seams but also as disseminations and as thin fracture fillings. Polished thin sections from this zone have abundant poikiloblastic garnet with numerous inclusions, especially of ilmenite and green spinel. Also abundant are anthophyllite, cummingtonite, quartz, cordierite and biotite. Chalcopyrite, pyrrhotite, pyrite, magnetite, and chlorite are present in lesser amounts. Within the two copper zones, sulphide minerals are most abundant within bands containing abundant garnet, and with possible relict pillow structures. The unusual mineralogy of these rocks suggests they are the product of magnesian alteration of mafic or intermediate volcanic rocks followed by amphibolite facies metamorphism. Sulphide minerals, which were either deposited with the original volcanics or introduced by the hydrothermal solutions which altered the host rocks, were remobilized into small shears during metamorphism to attain their present configuration.

The broad zone within which the copper mineralization occurs consists of an intensely altered inner zone and a less altered fringing zone. It should be noted however, differences may be only partly the result of different intensity of alteration and may be in part due to differences in original rock type. The inner zone is characterized by some or all of the minerals listed in the preceding paragraph plus muscovite and sillimanite in rocks of more felsic composition. The outer alteration zone is characterized by biotite, quartz, and chlorite, with varying amounts of muscovite, sillimanite, plagioclase, and possibly cordierite.

Alteration is also present east of Kennedy Lake, although it is not as well exposed. Intense alteration is not common near the BB zone although there are small areas of biotite-rich rusty-weathering rock. In general, the alteration zone west of the BB zone consists of rusty areas within the felsic volcanics, which may be at least partly the result of shearing.

## SUMMARY AND INTERPRETATION

The deposit occurs within felsic volcanics at the top of a differentiated mafic to felsic volcanic sequence. The presence of coarse pyroclastic or pyroclastic flow deposits in the middle of the section suggests these rocks may have been deposited on the flank of a felsic volcanic pile. A zone of alteration along the top of the felsic volcanics and just below the contact with sediments indicates the volcanism was accompanied by extensive hydrothermal activity. The BB zone is a massive sphalerite-pyrrhotite-pyrite body localized on the nose of an open anticline and attenuated along the axis of the anticline. An exhalite zone of limestone and siliceous pyritic tuff partly envelops the massive sulphide body and extends discontinuously along the entire length of the upper part of the felsic volcanics. A metamorphosed magnesian alteration zone extends from the BB zone through Kennedy Lake to BB Lake, a distance of some 4500 feet. Zones with low values of copper are common within the alteration zone, which may have been a "feeder" pipe to both of the lead-zinc bodies. Structural data indicates the region may have been affected by 3 tectonic episodes, one or more of which caused the massive sulphide bodies and their alteration zone to assume their present elongated configuration.

## CONCLUSIONS

The deposits studied show all the salient features of volcanogenic massive sulphide deposits as they have been described from many areas in the Superior Province. The apparent paucity of these deposits in the Slave Province is probably a direct consequence of two important factors: relatively little exploration for such deposits has been done in the Slave Province, and felsic volcanic rocks, the usual hosts for these deposits are not abundant.

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