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PETROLOGY, MINERALOGY, AND TRACE ELEMENT CHEMISTRY
OF THE ORVAN BROOK SULPHIDE DEPOSIT,
RESTIGOUCHE COUNTY, NEW BRUNSWICK

by

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A thesis submitted to the Faculty of
Graduate Studies in partial fulfilment
of the requirements for the degree of
Master of Science

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ABSTRACT

The petrology, mineralogy, and distribution of trace elements in the Orvan Brook host rocks and sulphide deposit are described, and the data used to determine the environment of deposition and possible origin of the sulphide zone.

Three parent rock types are represented in the area: rhyolite porphyry, andesite, and siliceous argillite.

The sulphide minerals are similar in physical appearance and metal content to the banded massive sulphides of the Bathurst-Newcastle mining district.

The pattern of distribution of metals in the host rocks suggests that their source is different from that of metals in the sulphide zone.

The textures, temperature of formation, sulphur isotope abundances and spatial associations of the sulphide minerals, as well as the shearing and alteration of the host rocks, suggest that the Orvan Brook sulphide deposit is of hydrothermal origin.

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INTRODUCTION

The Orvan Brook pyritic zinc-lead-copper deposit is in the Bathurst-Newcastle mining district, in the northern part of an area of highly deformed Lower Palaeozoic sedimentary and volcanic rocks that extends from northern New Brunswick into Maine (Map 1). The Orvan Brook sulphide deposit occurs in rocks of the Tetagouche Group, and is similar in mineralogy to most other deposits of the Bathurst-Newcastle district. It is, however, unique because of its extreme length (more than 8,000 feet), narrow width (less than 16 feet), and confinement to a long, narrow zone of schist.

Purpose of Study

The Orvan Brook sulphide zone is well banded, and, of all the sulphide bodies of the Bathurst-Newcastle mining district, is the most nearly conformable with its host rocks. The sulphides might, therefore, be of syngenetic origin. The purpose of the study is to examine and describe the geology and mineralogy of the host rocks and sulphide deposit, to determine the amount and distribution of zinc, lead, copper, and silver in the host rocks relative to the sulphide zone, and to synthesize the data in an effort to determine the environment of deposition and origin of the deposit. This work was carried out at Carleton University in 1964 and 1965. The writer has not visited the property; however, it was mapped by Dr. W.M. Tupper, and his data have been used in this study.

Location and Accessibility

The Orvan Brook sulphide deposit is in Restigouche County, New Brunswick, 24 miles west of Bathurst and 2 miles southwest of Lower Tetagouche Lake on the Tetagouche River (Map 2). The area can be reached over 12 miles of logging roads from the Caribou road of the Bathurst Power and Paper Company, and is 5 miles from a new gravel road that follows the north side of the Tetagouche River.

Acknowledgements

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Laboratory Methods

Thin sections and polished sections prepared from samples of surface exposures and diamond drill cores were used to study the

Map 2

FIGURE 11. Principal base metal deposits, Bathurst-Newcastle district, New Brunswick

Printed by the Survey and Mapping Branch

after Roy, S., (1961)

petrology of the host rocks and the sulphide mineralogy. Etch tests and optical properties served to identify the sulphide minerals.

The amounts of zinc, lead, and copper in the host rocks and sulphide zone were determined by colorimetric methods using pyrosulphate fusion, and dithizone as the colour indicator (Gilbert, 1959). To determine the content of the metal ion, the resultant solution was compared with known standards. Silver was determined by emission spectrography on a 1.5 metre Jarrel-Ash emission spectrograph.

REGIONAL GEOLOGY OF THE BATHURST AREA

The Bathurst area is underlain by tightly folded Ordovician metasedimentary and metavolcanic rocks of the Tetagouche Group. Silurian and Devonian strata exist north and west of the Bathurst area, and are separated from the Ordovician in part by the Rocky Brook-Millstream fault (Map 2). Devonian intrusive rocks occur both north and south of the fault. Detailed descriptions of the geology of the area were made by Alcock (1941), Skinner (1956), Smith (1957), Davies (1959), and Jones (1961). Their observations are used in this report.

Stratigraphy

Ordovician rocks of the Tetagouche Group occupy the central part of the Bathurst area, and include a core of silicic metavolcanic rocks interlayered with (and surrounded by) metasedimentary and mafic metavolcanic rocks (Map 2). The most important silicic metavolcanic rocks are known as the "Bathurst porphyry". They contain large grains of quartz and feldspar in a microcrystalline groundmass of quartz, feldspar, sericite, and chlorite, and their weathered surfaces are grey or white (Smith and Skinner, 1958). Other rocks of the Tetagouche Group are slates, schists, "iron-formation", and gneisses. Ordovician rocks are in part overlain unconformably by Silurian argillaceous and calcareous rocks (Naylor and Boucot, 1965) and are cut by mafic and silicic intrusive rocks of supposed Devonian age.

The age of the Tetagouche Group is based on a fossil locality near the mouth of the Tetagouche River, where argillaceous rocks contain graptolites of Middle Ordovician age (Alcock, 1941).

Silurian rocks of the Chaleur Bay Group are exposed north of the Rocky Brook-Millstream fault (Map 2). They are composed of greywacke, argillite, slate, limestone, and volcanic rocks, and are, in general, less deformed than the Ordovician rocks. The Silurian rocks (as well as the Ordovician rocks) are cut by gabbroic and granitic masses of supposed Devonian age. The Silurian and Ordovician rocks are either in fault contact, or are separated by an unconformity, or both (Potter, written communication 1965). In general, fossils are abundant in the Silurian strata, and are of early, middle, and late Silurian ages.

Devonian sedimentary rocks are exposed in the northern part of the Tetagouche River map-area of Alcock (1941), and include limestones and shale, with intercalated volcanic flows and fragmental rocks. Lower Devonian brachiopods, corals, and trilobites are abundant in the Upsalquitch Forks map-area to the northwest (Potter, 1965). Granitic rocks intrude the Tetagouche and Chaleur Bay groups. These are pink and coarse-grained, consisting of orthoclase, albite, quartz, biotite, accessory iron minerals and apatite, and secondary chlorite (Alcock, 1941). They are unconformably overlain by Carboniferous rocks along the Nepisiguit River. Potassium-argon determinations (Tupper and Hart, 1961) suggest a Devonian age (395 m.y.).

The Bathurst and Clifton formations, of Pennsylvanian age (Smith, 1957), unconformably overlie folded Ordovician strata of the Bathurst area. The Bathurst Formation consists of gently dipping beds of red sandstone and conglomerate, with minor amounts of shale. It is succeeded conformably by grey beds of the Clifton Formation containing abundant Pennsylvanian flora (Alcock, 1941). A small outlier of Pennsylvanian rocks lies three miles northwest of the Orvan Brook deposit (Map 2).

Structure

The major structural feature of the area is the large northeast-plunging anticline west of Bathurst, with Ordovician silicic metavolcanic rocks in its core. The anticline is bounded on the north by the Rocky Brook-Millstream fault.

Smith (1957) concluded that the Ordovician silicic metavolcanic strata of the central area were folded about northwest-striking axes (Taconic orogeny) and then re-folded about northeast-striking axes (Acadian orogeny). The Silurian and Devonian strata lying north of the Rocky Brook-Millstream fault were folded once, probably during the Acadian (Devonian) orogeny, and are less deformed than the Ordovician strata (Neale et al., 1961).

The Pennsylvanian strata are gently folded, and constitute a cratonic cover on the deformed Ordovician and Silurian strata.

Mineral Occurrences

The pyritic sphalerite-galena-chalcopyrite bodies in the area were described by Holyk (1957), McAllister (1960), Tupper (1960),

Roy (1961), Boyle and Davies (1963), and others. Most workers, e.g. McAllister and Roy, classify the sulphide bodies into those north of the Rocky Brook-Millstream fault, in Silurian strata, and those south of the fault, in Ordovician strata. The Nigadoo and Sturgeon River bodies are in Silurian strata northwest of Bathurst (Map 2). Other small occurrences containing sphalerite, galena, chalcopyrite, stibnite, and magnetite occur along the Rocky Brook-Millstream fault. The largest base metal bodies are, however, in Ordovician strata. They were described by McAllister (1960) and his data are included in Table 1, which contains a brief description of the sulphide bodies.

Table 1. GEOLOGICAL DATA OF SULPHIDE DEPOSITS, BATHURST-NEWCASTLE AREA, NEW BRUNSWICK

Name of Property	Length (feet)	Width (feet)	Depth (feet)	Cu %	Pb %	Zn %	Ag oz.	Minerals	Host Rocks	Hanging-wall	Foot-wall	Ore Control	Form
Consolidated Mining and Smelting (Nepisiguit "A")	700	60	400	low grade				py po op gn sp	Sericite argillite	Silicic meta-volcanic rocks, in part augen schists	Dark grey cherty argillite	Folded contact zone	Massive
Consolidated Mining and Smelting (Nepisiguit "B")	900	75	300					py po op gn sp	Black sericite argillite	Silicic meta-volcanic rocks, in part tuffaceous	Black argillite	Bedding?	Disseminated op in massive sulphides
Consolidated Mining and Smelting (Wedge)	850	50	500					Principally op and py - sp gn	Chloritic meta-sedimentary rocks, metamorphosed tuff	Quartz-feldspar augen schist	Chloritic meta-sedimentary rocks, tuff and argillites	Drag-fold on the edge of a metavolcanic-metasedimentary rock contact	Fine-grained massive sulphides with local bands
Heath Steele	600	50	800+	1.3	2.9	7.1	3.2	py po op gn sp asp td cv cc frei native Bi	Quartz-chlorite schist	Quartz-chlorite schist	Quartz-chlorite schist	Bedding?	Massive and fine-grained
Clearwater	650	650	30	1.0	1.6	3.4		py po op gn sp	Chlorite schist	Chlorite schist	Quartz-chlorite schist	Folds	Massive and disseminated zones
Kemco (Murray Brook)	1000	300	800					py op gn sp	Quartz-sericite schist	Graphite schist	"Iron-formation"	Shear zone	Massive and disseminated zones
Texas Gulf Sulphur (Middle River-Half-mile Lake)	1200	10 to 40						py po op gn sp asp cv	Metamorphosed chlorite tuff	Metamorphosed sericite-chlorite tuff with quartz-feldspar augen	Tuffaceous argillite and gabbro	Bedding?	Disseminated op in massive sulphides

*Abbreviations: asp - arsenopyrite ca - cassiterite cv - covellite hem - hematite po - pyrrhotite td - tetrahedrite
 Bi - bismuth cc - chalcocite frei - freibergite mc - marcasite py - pyrite
 bn - bornite sp - chalcopyrite gn - galena mt - magnetite sp - sphalerite

Table 1 - continued

Name of Property	Length (feet)	Width (feet)	Depth (feet)	Cu %	Pb %	Zn %	Ag oz.	Minerals	Host Rocks	Hanging-wall	Foot-wall	Ore Control	Form
New Calumet (Orvan Brook)	8000	2	500+	0.2	3.3	7.1	2.5	py cp gn sp asp td	Quartz- sericite schist	Graphite schist	"Iron- formation"	Shear zone	Massive and disseminated zones
Stratmat "61"	600	100	500					py cp gn sp asp	Chloritic tuff	Sericite- chlorite tuff with quartz- feldspar augen	Tuffaceous argillite and gabbro	Bedding?	Dis- seminated op in massive sulphides
Brunswick No. 6	1100	100 to 300	1000+	0.4	2.5	6.3	2.1	py po cp gn sp asp td mc cv mt hem bn	Altered siliceous sedimentary rocks, meta- volcanic rocks, and "iron- formation"	"Iron- formation"	Quartz augen schist, chlorite- sericite schist	Fault zone in drag fold on the limb of a syncline	Fine- grained massive sulphides
Brunswick No. 12	1200	80 to 200	2500+	0.5	2.4	6.6	2.1	py po cp sp gn asp td cv mc mt hem	Altered siliceous sedimentary rocks, meta- volcanic rocks and "iron- formation"	Quartz-eye chlorite schist and sericite schist	Siliceous sedimentary rocks	Fault breccia zone in drag-fold on the limb of a syn- cline	Fine- grained massive sulphides
Nigadoo	3400	6.8	1400	0.3	3.0	2.8	4.4	py po cp gn sp asp td	Quartz- feldspar porphyry, argillite	Quartz- feldspar porphyry, argillite	Quartz- feldspar porphyry, argillite	Fault zone	Coarse- grained massive sulphides
Keymet	2600	5	450	0.7	4.7	4.3	1.4	py po cp gn sp asp td	Sedimentary and volcanic rocks			Fault (lenses and veins cut sedimentary rocks)	Coarse-grained massive sul- phides
Sturgeon River (Rocky Brook)					2.3	3.3	3.3	py po cp gn sp asp td				Fault	Massive

Table 1 - continued

Name of Property	Length (feet)	Width (feet)	Depth (feet)	Cu %	Pb %	Zn %	Ag oz.	Minerals	Host Rocks	Hanging-wall	Foot-wall	Ore Control	Form
Anaconda (Caribou)	3800	40 to 100	1200					PY po op gn sp asp cv mo co	Argillite and slaty "iron- formation" in chlorite schist	Chlorite- sericite schist, quartz- feldspar augen schist	Chlorite- sericite schist, greywacke, slate, meta- andesite	Trough of a syncline	Massive dis- seminated bands
Key Anacon (New Larder "gn")	1200		1500		2.4	6.4	2.2	PY po op gn sp asp cv mo co	Graphitic chlorite schist	Chlorite schist, "iron- formation and quartz- feldspar augen schist		Bedding?	Massive
New Jersey Zinc (Portage Lake)								PY op gn sp asp	Fragmental metavolcanic rocks	Fragmental metavolcanic rocks	Fragmental metavolcanic rocks	Folds	Dis- seminated
Texas Gulf- Conwest (Half- mile Brook)	1000	75 max.	1000									Folds	
American Metal Co. (Devil's Elbow)	800	150 max.						PY po op gn sp cobalt	Chlorite schist	Sericite- chlorite schist, quartz- feldspar augen schist	Quartz- feldspar augen schist	Breccia zone	Massive
Captain Mines	500	80	800	1.2				PY po op gn sp bn co cobalt Bi tellu- rides (gold)	Metamorphosed chlorite tuff	Chloritic argillite	Chloritic quartz augen schist	Folds	Dis- seminated

N.B. - All of the above deposits are of Middle Ordovician (Taconic) age, except Higadoo, Keynet, and Sturgeon River-Rocky Brook, which are fissure deposits in the Silurian folded belt.

The dimensions and grades of the deposits are approximate. Most figures are for the year 1960, and are subject to revision, mostly upward.

Table I was compiled from many sources, - notably McAllister (1960), Canadian Mines Handbook, Financial Post Survey of Mines, volume 2 of Structural Geology of Canadian Ore Deposits (1957), and weekly issues of the Financial Post and The Northern Miner.

GEOLOGY OF THE ORVAN BROOK AREA

The Orvan Brook area was mapped at a scale of 4 inches : 1 mile by Davies (1959). The table of map-units (Table 2) and geological Map 3, at the scale 1 inch : 200 feet, represent the immediate vicinity of the Orvan Brook sulphide deposit. They are based on field work by Tupper in 1961 and 1962. The names used for the rocks, which belong to the Tetagouche Group, are inferred from their structure and mineralogy. The rocks form long, narrow belts striking approximately east across the map-area and dipping steeply north. All contacts between map-units have been intersected in drill-holes. The principal rock types are quartz-feldspar augen schist, quartz-sericite schist, meta-andesite, and "iron-formation". Age relationships are not known; however, the rocks of map-unit 1 underlie the other map-units and are assumed to be the oldest. All rocks belong to the lower green-schist facies of regional metamorphism.

Near the sulphide body, Orvan Brook has cut a valley 175 feet deep. Away from the valley, the land is gently sloping, with a mantle of glacial debris. Striations on rock surfaces and directions of stoss and lee slopes indicate that the most recent ice movement was towards the east.

Description of Map-units

Quartz-feldspar augen schist (map-unit 1)

This map-unit consists mainly of quartz-feldspar augen schist, but locally contains quartz-sericite schist similar to

Table 2. Table of Map-units

Era	Period	Group	Map-units	Lithology
Genozoic	Quaternary			glacial drift; alluvium
Palaeozoic	Ordovician	Tetagouche	9	massive and disseminated sulphides; arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite.
			8	meta-andesite; chlorite schist; minor graphite schist.
			7b	similar to 7a, but possibly younger.
			7a	banded quartz-chlorite-hematite schist; graphite schist; chlorite schist.
			6b	similar to 6a, but possibly younger.
			6a	chloritic argillite, chlorite schist; minor meta-andesite, graphite schist, quartz-feldspar augen schist.
			5	graphite schist (sheared)
			4	quartz-sericite schist (sheared).
			3	"iron-formation"; chlorite schist.
			2	chloritic siliceous argillite, graphite schist, minor carbonate.
			1b	similar to 1a, but predominantly quartz-sericite schist, and possibly younger.
			1a	quartz-feldspar augen schist, quartz-sericite schist.

that of map-unit 4. The augen schist is a pale yellowish green rock that contains pale grey and yellowish white megacrysts and augen of feldspar and quartz in a fine-grained groundmass (Plates 1 and 2). The mineral composition of quartz-feldspar augen schist is given in Table 3.

Feldspar megacrysts and augen constitute 10 to 20 per cent of the rock, and most of them are 2 mm to 7 mm long. Most of the megacrysts (which are distinguished by their euhedralism and their lesser degree of replacement by later minerals such as quartz and calcite) are microperthite, but some are single feldspars. By means of a universal stage, several megacrysts of single feldspars were found to be biaxial negative, with axial angles from 65 to 72 degrees (within the range for orthoclase and microcline). X-ray powder patterns of feldspar megacrysts (made by P.E. Fox in 1964) confirmed the presence of microcline and albite. Feldspar megacrysts are partly sericitized, and contain "dusty" inclusions in the cores of the crystals (Figure 1). Quartz megacrysts, approximately 3 mm in diameter, constitute about 5 per cent of the rock. Quartz augen are more abundant.

The matrix of the quartz-feldspar augen schist is composed of muscovite, alkali feldspars, chlorite, and calcite, interbanded with quartz.

Gradations exist from quartz-feldspar augen schist to quartz-sericite schist within the area of map-unit 1. The contact of the augen schist with overlying "iron-formation" is sharp.

PLATE 1

Quartz-feldspar augen schist (also known as "porphyry").
: Note the feldspar megacrysts (pale grey). Scale in centimetres.

PLATE 2

Photomicrograph of quartz augen and a twinned microperthite phenocryst in quartz-feldspar augen schist. X45 Crossed nicols.

Table 3. Modal Composition of Rock Types at Orvan Brook*

Rock types	Quartz**	Feldspar**	Muscovite	Chlorite	Hematite	Actinolite	Epidote	Calcite	Pyrite
Quartz-feldspar augen schist	40 - 50	20 - 40	15 - 20	0 - 3				0 - 4	2
"Iron-formation"***	35 - 45	5 - 10	15 - 25	10 - 20	15	0 - 3	1 - 5	0 - 2	
Quartz-sericite schist	45 - 60	10 - 20	20 - 35	0 - 1			1 - 2	3 - 8	3 - 4
Graphite schist****	50	5	35	0 - 2					0 - 5
Argillite	30 - 40	10 - 30	10 - 30	0 - 4	1 - 5			5 - 25	0 - 1
Banded quartz-chlorite-hematite schist	15 - 30	10 - 20	10 - 35	10 - 30	5 - 15	0 - 15	1		1 - 2
Meta-andesite	5 - 10	30 - 40	15 - 30			2 - 10		5 - 15	

*Volume percentages of minerals were determined from thin sections by visual estimate.

**Volume percentages of quartz and feldspar represent megacrysts and matrix.

***The "iron-formation" contains 0 to 2 per cent magnetite.

****The graphite schist contains 5 to 10 per cent graphite.

There has been a proliferation of names for the quartz-feldspar augen schist, with resultant confusion. The rock is known as "porphyry" at the Heath Steele deposit; "acidic volcanic rocks" at the Wedge deposit; "quartz-feldspar crystal tuff" at Stratmat; and elsewhere as "quartz-feldspar porphyry", "rhyolite" or "feldspar augen schist". Primary sedimentary and volcanic textures have been identified in rocks called "Bathurst porphyry" (Smith and Skinner, 1958). Perhaps different types of rock are involved. Nomenclature may be resolved only after the entire Tetagouche Group has been mapped in detail, and the petrography studied.

Argillite and Graphite Schist (map-unit 2)

The lithology of this map-unit is similar to that of map-unit 6, which is described below.

"Iron-formation" (map-unit 3)

The "iron-formation" is fine-grained, with reddish brown and grey laminae from 1 mm to 15 mm thick. The mineral composition of "iron-formation" is given in Table 3.

Hematite, chlorite, and pale green muscovite are the principal iron-bearing minerals. Very little magnetite is present. Most of the hematite exists as anhedral masses that are so fine-grained (less than 0.1 mm long) that they appear to be isotropic. Near their centres, most hematite grains are opaque and have a metallic lustre, and on thin edges are translucent and reddish

brown. Chlorite forms a narrow, discontinuous inner rim on hematite grains, and muscovite forms a wide outer rim. The total amount of iron is estimated to be about 20 per cent, therefore the rocks may be described as "iron-formation" (Pettijohn, 1957; p. 449).

The matrix is composed of quartz, muscovite, epidote, and actinolite. Quartz forms a fine-grained mosaic. The habit of epidote grains (which are less than 0.3 mm in diameter) is blocky, with pseudo-hexagonal cross-sections. Many actinolite grains are euhedral.

Long axes of individual chlorite and hematite grains are aligned parallel to thin, continuous laminae of quartz and muscovite. This gives the "iron-formation" its banded or laminated texture (Plate 3). The laminae are composed of the following mineral assemblages: quartz-muscovite; quartz-muscovite-chlorite (with pyrite and calcite in some of these laminae); and quartz-muscovite-chlorite-hematite-epidote. The oxide and silicate-rich laminae of the "iron-formation" have gradational contacts. The laminae are approximately parallel to those in the argillites of map-units 2 and 6, and have the appearance of metamorphosed sedimentary beds.

The banding and mineralogy of the "iron-formation" are similar to those of the banded quartz-chlorite-hematite schists of map-unit 7. In both map-units, the oxide and silicate laminae

have gradational contacts. The chief difference is that map-unit 3 contains a greater amount of iron.

Quartz-sericite schist (map-unit 4)

The quartz-sericite schist is yellow, fine-grained, highly fractured, and schistose, and resembles rocks of map-unit 1. The mineral composition of quartz-sericite schist is given in Table 3.

Augen composed of brecciated megacrysts of quartz, microperthite, and microcline are abundant (Plate 4). Where the quartz-sericite schist does not contain augen, wider parts of the quartz laminae might be pseudomorphic after augen. The matrix is composed mainly of quartz, alkali feldspars, muscovite, and a much smaller amount of chlorite. Epidote grains (less than 0.1 mm long) are present in the muscovite-rich laminae.

Most of the contact of quartz-sericite schist with "iron-formation" is sharp, but chlorite is concentrated in the quartz-sericite schist along some parts of the contact. The chlorite may have been formed from muscovite by iron migrating from the "iron-formation" during metamorphism, or it may indicate an original gradation between the two rock types.

In map-unit 1, the contact between quartz-feldspar augen schist and quartz-sericite schist is gradational. The mineralogy, texture, and appearance of quartz-sericite schist of map-units 1 and 4 are similar, and the map-units may be genetically related.

PLATE 3

Photomicrograph of the banded "iron-formation". X25 Crossed nicols. The dark bands are composed mainly of hematite. The light bands are quartz, sericite, and chlorite.

PLATE 4

Augen in quartz-sericite schist. Scale in inches.

Graphite schist (map-unit 5)

Only one outcrop of this map-unit was found, indicating that its resistance to weathering is low. However, graphite schist of map-unit 5 was intersected in several drill-holes. It is composed of greyish black graphitic material inter-laminated with quartz. The mineral composition of graphite schist is given in Table 3.

The graphite schist is tightly folded and fractured, and weathered surfaces disintegrate rapidly. Because of its friable nature, it causes drilling problems, therefore all but two holes were drilled from the south side of the sulphide body. The intricate folds and offset laminae in the graphite schist are the result of slippage along cleavage planes, many of which are coated with graphite. The laminae are about 1 mm to 5 mm thick, and contain small local concentrations of pyrite. The contact of graphite schist with the underlying quartz-sericite schist is sharp, but that with the overlying argillite is gradational.

The graphite schist of map-unit 5 contains more quartz and less chlorite and hematite than graphite schists of map-units 2, 6, 7, and 8, but it is otherwise similar.

Argillite (map-unit 6)

Only three diamond drill-holes intersected rocks of map-unit 6, and, of the few outcrops found, most are near Orvan Brook. The argillite is greyish green to brownish white and

contains thin bands of quartz-feldspar augen schist, graphite schist, and meta-andesite. The argillite is fine-grained, and locally contains laminae and thin strata similar to the "iron-formation" of map-unit 3. A stratum of quartz-feldspar augen schist (map-unit 1b) is intercalated with the argillite. The mineral composition of argillite is given in Table 3.

The principal minerals are quartz (average diameter 0.05 mm) and muscovite. Some of the rocks of map-unit 6 contain subhedral to euhedral megacrysts of pink feldspar with "dusty" brown inclusions similar to those of feldspar megacrysts in the quartz-feldspar augen schist. Quartz and quartz-carbonate veins and lenses and quartz-carbonate and muscovite-hematite laminae are present. The laminae have the appearance of metamorphosed sedimentary beds. In some places the laminae are tightly folded, partly as a result of slippage along cleavage planes that are parallel to the axial planes of the folds. Quartz lenses exist in the crests and troughs of folds.

The argillite of map-unit 6 is basically similar to that of map-units 2, 3, 5, and 7, but some is brownish white rather than green.

Banded quartz-chlorite-hematite and graphite schists (map-unit 7)

This map-unit consists of two strata of similar lithology, 7a being south of, and 7b north of, the meta-andesite of map-unit 8. Graphite schist, which constitutes a major part of map-units 7a and 7b, is not exposed, but forms conductive zones

that are readily outlined by electrical geophysical methods. The mineral composition of banded quartz-chlorite-hematite schist is given in Table 3.

Laminae in the banded quartz-chlorite-hematite schist are, on the average, about 3 mm thick. They are composed of the same assemblages of minerals as the bands in "iron-formation" of map-unit 3. The assemblages are quartz-muscovite, quartz-muscovite-chlorite (with a small amount of pyrite and calcite in some laminae), and quartz-muscovite-chlorite-actinolite-hematite-epidote. On differentially weathered surfaces, quartz-muscovite laminae are white and stand out (Plate 5). The length of hematite and chlorite grains varies up to 0.4 mm. Much of the hematite is specular. Hematite and calcite veins cut some of the banded quartz-chlorite-hematite schist, and some schistosity planes are coated with graphite. Actinolite (less than 0.1 mm long) is present. Some laminae are crenulated or have chevron folds, and some are offset along small faults (Plates 6 and 7). Many folded quartz laminae have attenuated limbs and thickened axial areas.

The texture of map-units 2, 3, 5, and 7 is similar, and laminae of most of their rock types are found in each map-unit.

Meta-andesite and chlorite schist (map-unit 8)

Rocks of this map-unit are resistant, and form the east-trending ridge in the northern part of the map-area. The

PLATE 5

Resistant bands in quartz-chlorite-hematite schist standing out in relief on weathered surface. Note contorted bands. Scale in inches.

PLATE 6

Bands in quartz-chlorite-hematite schist, offset on slip cleavage. X45 Plane light.

meta-andesites are green rocks in which massive, relatively coarse-grained parts contain relict euhedral feldspars. The mineral composition of meta-andesite is given in Table 3.

Albite and actinolite megacrysts are present. Randomly oriented subhedral to euhedral laths of albite exist in a matrix consisting mainly of chlorite, muscovite, calcite, and quartz. Albite megacrysts (1 mm to 3 mm long) are embayed by calcite. Adjacent chlorite and muscovite laminae are warped around the megacrysts, and quartz fills the interstices. Laminae in the chlorite schist are crenulated, and are more distinct than in massive parts of the meta-andesite.

Discussion of Petrographic Data

Metamorphism

Most rocks in the Orvan Brook area consist of quartz, alkali feldspars, muscovite, chlorite, epidote; and, locally, calcite, hematite, actinolite, graphite, pyrite, and magnetite. These minerals are characteristic of the quartz-albite-muscovite-chlorite subfacies of the greenschist facies of regional metamorphism (Turner and Verhoogen, 1960; pp. 533-541).

Laminae in the argillites of map-units 2, 3, 5, and 7 represent either metamorphic banding or original bedding. Their shape, distribution, and thickness suggest that the laminae are metamorphosed sedimentary beds. Some of the argillaceous rocks are chlorite schists.

The gradational contact between quartz-feldspar augen schist and quartz-sericite schist of map-unit 1 is described as follows. Quartz-feldspar augen schist in which the megacrysts are not deformed (Plate 1 and Figure 1) grades into schist in which the megacrysts were rotated (Plates 8 and 9, and Figure 2). The shadow zones illustrated in Plate 9 and Figure 2 may have been caused by quartz occupying positions of minimum compressive stress when the feldspar megacrysts were rotated. Many of the megacrysts are crushed, and form "trains" parallel to the schistosity (Plate 10). Some megacrysts contain veins and replacements of quartz and calcite (Figures 3, 4, and 5). In quartz-sericite schist, the megacrysts have been further deformed into augen and narrow lenses approximately parallel to the schistosity (Plate 4). In some parts of the quartz-sericite schist, crushing and alteration have left aggregates of quartz, sericite, and chlorite in place of feldspar megacrysts and augen (Plate 11). In summary, some of the differences between quartz-sericite schist and quartz-feldspar augen schist result from more intense shearing of the quartz-sericite schist.

Their gradational contacts and similar mineralogy and appearance suggest that the quartz-feldspar augen schist and quartz-sericite schist of map-unit 1 originated from the same parent rock. The quartz-sericite schist of map-unit 4 is similar to that of map-unit 1 and may have a similar history. A mechanism for formation from a single parent rock was suggested by Pearce (1963). He contended that a parent rock near the

PLATE 7

Bands in quartz-chlorite-hematite schist, offset and dragged along the fault that traverses from the upper left to the lower right end of the drill core. Scale in inches.

PLATE 8

Photomicrograph of rotated perthite megacryst in quartz-feldspar augen schist. X45 Crossed nicols.

PLATE 9

Photomicrograph of quartz-feldspar augen schist. Note the "rotated" appearance of the perthite megacrysts, and the fine-grained quartz in the "shadow" areas. X25 Crossed nicols.

PLATE 10

Photomicrograph of fragments of a perthite phenocryst that has been crushed during metamorphism. The three smaller fragments and one part of the Carlsbad twin on the large fragment are extinct simultaneously. X45 Crossed nicols.

Figure 1

x24

Arrangement of inclusions in a feldspar megacryst

Figure 2

x16

Rotated feldspar megacryst

Figure 3
x16

Replacement of a rotated feldspar megacryst by quartz

Figure 4
x12

Replacement of a feldspar megacryst by quartz

Figure 5
x28

Quartz auge

PLATE 11

Photomicrograph of quartz-sericite schist. X25 Crossed
nicols.

C - calcite Q - quartz S - sericite

Brunswick No. 6 orebody was altered to quartz-sericite schist and quartz-feldspar augen gneiss by shearing and sericitization, accompanied by an increase in volume, a gain of silica, and a loss of iron and magnesium (Table 4).

Table 4 (after Pearce, 1963). The History of Quartz-Feldspar Augen Gneiss and Quartz-Sericite Schist.

The appearance of the quartz-sericite schist at Orvan Brook is "bleached", as though by hydrothermal solutions (the quartz-sericite schist contains more quartz, muscovite, and calcite than quartz-feldspar augen schist). The quartz-sericite schist at Orvan Brook, like that described by Pearce, might have originated from a parent rock by the addition of silica and the conversion of chlorite to muscovite by losing iron and magnesium and gaining water. The quartz-feldspar augen schist is less sheared, and seems to be less metasomatized than the quartz-sericite schist.

Parent Rocks

For reasons presented below, the writer believes that all rocks of the Orvan Brook area are derived from parent rocks of three major types.

The freshest quartz-feldspar augen schist is a massive rock with a fine-grained matrix. Most of the megacrysts are microperthite, and many are euhedral to subhedral (Plate 8), and are probably of igneous origin. From the mode, the composition was calculated to be rhyolitic (Turner and Verhoogen, 1960; p. 57). A tuffaceous origin for these rocks was suggested by Alcock (1941) and others. No shards or other primary structures were observed that support a tuffaceous origin for the quartz-feldspar augen schist at Orvan Brook. The structures might have been obliterated during metamorphism, hence the possibility that this rock was originally tuff cannot be dismissed. On the basis of mineralogy, texture, and composition of the quartz-feldspar augen schist, the parent rock was a rhyolite flow or tuff.

Map-units 2, 3, 5, 6, and 7 have similar textures, and most of their main rock types (argillite, "iron-formation", graphite schist, and banded quartz-chlorite-hematite schist) are present as thin laminae in each map-unit. The mineralogy of the map-units is somewhat similar, the presence or absence of hematite and graphite being distinctive differences. The textures and mineralogy of the argillite, graphite schist, "iron-formation" and chlorite schist are similar, and the rocks are probably genetically related. The presence of actinolite, calcite, relict bedding, and much quartz suggests that these rocks were originally siliceous shales cemented partly by calcite. Some of the calcite may also be a product of the breakdown of calcic plagioclase to albite during metamorphism. Similarly, banded quartz-chlorite-

hematite schist and "iron-formation" may be metamorphosed equivalents of ferruginous siliceous shale. Intercalated with these are carbonaceous rocks (now graphite schists). Possibly the environment of deposition in a sedimentary basin fluctuated from oxidizing to reducing conditions. Another possibility is that the rocks at Orvan Brook were laid down in an oxidizing environment, and graphite formed later as a result of the breakdown of carbonate material during metamorphism.

The ophitic texture and resistance to weathering of massive rocks of map-unit 8 suggest that the parent was a coarse-grained mafic volcanic rock or a diabase sill. Northeast-striking sheared parts of map-unit 8 (e.g. chlorite schist) suggest that the map-unit was folded during the Acadian orogeny. Whether map-unit 8 is a metamorphosed diabase sill or a mafic metavolcanic rock cannot be decided from the petrographic evidence alone; during the field mapping, however, map-unit 8 was considered to be meta-andesite of the Tetagouche Group.

The principal rocks of the Orvan Brook area are quartz-feldspar augen schist, meta-andesite, argillite, and related rocks. Their minerals are characteristic of the quartz-albite-chlorite-muscovite subfacies of the greenschist facies of regional metamorphism. In the Orvan Brook area, the Tetagouche Group and its relationships are similar to the lower volcanic rocks of the Michipicoten area (Goodwin, 1962). The clastic sediments of the Orvan Brook area might be erosion products of the volcanic rocks

(with a marked concentration of iron). The strata are thin, but widespread and of uniform thickness, suggesting deposition on a "volcanic pile" during a relatively quiescent period. The superposition of presumably younger mafic metavolcanic rocks (map-unit 8) on silicic metavolcanic rocks (map-unit 1), however, is contrary to the sequence in the rocks at Michipicoten.

Structure

The Orvan Brook sulphide deposit is on the northwest limb of a broad northeast-plunging anticline (Skinner, 1956), and is approximately 2,000 feet south of the northeast-trending Rocky Brook-Millstream fault (Map 2). Skinner (1956) showed an east-trending assumed fault in the vicinity of the sulphide deposit. Possibly the fault coexists with the rocks of map-unit 4, which are highly schistose. Rock units strike uniformly north 80 degrees east, and dip 75 degrees north to vertical. In most places the schistosity is parallel to the bedding. Skinner (1956) suggested that this relationship, together with the apparent great thickness and steep dip of the strata, indicates isoclinal folding. The attitude of minor folds (Plate 12) is similar throughout the Orvan Brook area, and may correspond to the northeast-plunging anticline. The lamination (S_1) and principal cleavage (S_2) are parallel, and the laminae are offset on an oblique strain-slip cleavage (S_3) that is axial plane to the micro-folds (Plates 5, 6, and 12). No graded bedding, cross-bedding, or

PLATE 12

Minor folds in banded quartz-chlorite-hematite schist.
Scale in inches.

other criteria were found that could be used for determinations of tops or bottoms of beds, i.e. direct evidence is not sufficient to determine whether the section is upright or overturned.

GEOLOGY OF THE ORVAN BROOK SULPHIDE DEPOSIT

The Orvan Brook sulphide deposit is owned by Tetagouche Exploration Company, Limited, a wholly-owned subsidiary of New Calumet Mines, Limited. To a depth of 400 feet, a block of 150,000 tons contains 7.13 per cent zinc, 3.27 per cent lead, 0.20 per cent copper, and 2.52 ounces of silver and 0.017 ounce of gold per ton (Canadian Mines Handbook, 1965).

History

In 1937, glacial erratics containing sulphide minerals were traced westward along the Tetagouche River by a party working for Hans Lundberg, Limited (Alcock, 1941). The work was taken over by Tetagouche Exploration Company, Limited, and an outcrop containing sulphide minerals was discovered in the bed of Orvan Brook. The discovery was the first in Ordovician rocks of a body of the type now providing most of the ore in the Bathurst-Newcastle mining district. Development work, including 6,281 feet of diamond drilling, was carried out in 1938 and 1939. In both directions from the discovery site, trenches and test pits were put down at intervals of 50 to 100 feet for 2,800 feet along the strike of the deposit. The zone of sulphide minerals,

as indicated by 31 holes drilled at intervals of 200 feet, was 6,200 feet long and more than 200 feet deep.

In 1945, a resistivity survey was carried out over the sulphide zone and its possible extensions by American Smelting and Refining Company. This work outlined two conductive zones: one of base metal sulphides, and a parallel zone of graphite schist 300 feet north of the sulphide zone.

A total of 16,154 feet of diamond drilling in twenty-nine holes was completed by New Calumet Mines, Limited, in 1953 and 1954 (Map 3). Using the information from this drilling, the known length and depth of the deposit were extended to about 8,000 feet and 400 feet, respectively.

Diamond drilling completed in 1963 did not appreciably extend the known limits of the deposit.

General Description

The Orvan Brook deposit is a tabular zone of massive and disseminated sulphide minerals. The sulphide zone is banded, and the host rock is a thin, folded, sheared stratum of quartz-sericite schist near its contact with overlying graphite schist (Map 3, and vertical sections in Appendix I). In most places the contact of the sulphide zone with quartz-sericite schist and graphite schist is sharp, although a little pyrite is disseminated locally in the quartz-sericite schist. The rock

underlying the quartz-sericite schist is low-grade banded "iron-formation". The maximum width of the sulphide zone, as indicated by diamond drilling, is 16 feet, but the average width is only 2 to 3 feet. The rake and plunge of the zone have not been definitely established, but minor folds and lineations in the wall-rocks indicate that it plunges 45 to 55 degrees east.

Mineralogy

In physical appearance and metal content, the sulphide minerals, except for the absence of pyrrhotite, are typical of the banded pyritic zinc-lead-copper deposits in the Bathurst area. Most of the sulphide minerals are very fine-grained (average 0.02 mm), and form an intimately intermixed aggregate that is hard, and difficult to crush and grind. All sulphide minerals are present in both fine- and relatively coarse-grained parts of the sulphide zone. In order of decreasing abundance, the sulphide minerals are pyrite, sphalerite, galena, chalcopryrite, tetrahedrite, and arsenopyrite; the gangue minerals are quartz and calcite. No relationship was found between depth and grain size or mineral association.

Banding in the sulphide minerals is caused by different proportions of sphalerite to pyrite (the grey bands being rich in sphalerite and the yellow bands rich in pyrite) and by different proportions of gangue minerals to sulphides. Each band is 5 mm to less than 1 mm thick, and relatively continuous.

Banding is more distinct in parts of the sulphide zone that are rich in sphalerite and galena. In general, the bands conform to the schistosity of the wall-rocks (Plate 13). The minerals and their relationships are described below.

Pyrite is the most abundant metallic mineral. Its grain size varies from 3 mm to less than 0.001 mm, the average being about 0.04 mm. Pyrite occurs in three habits: massive; separate subhedral grains in a matrix of gangue and other sulphide minerals; and colloform. Two generations may be present. Massive pyrite, and subhedral grains of pyrite partly replaced by gangue and other sulphide minerals, belong to the older generation. The massive pyrite occurs in a variety of textures. In Plate 14 and Figure 6, subhedral grains of pyrite are partly replaced by sphalerite. In Figure 7, pyrite is cut by a vein of galena and quartz. The vein has matching walls, and is as wide where it consists of quartz as where it consists of galena. This suggests that the galena precipitated preferentially on the pyrite, but did not replace it. In composite veins cutting massive pyrite, mutual boundaries between chalcopyrite, galena, sphalerite, and tetrahedrite suggest that they were introduced contemporaneously (Figure 8).

Colloform pyrite (Figure 9) has gradational contacts with massive pyrite of the older generation. Some of the colloform pyrite contains composite veins of gangue minerals, galena, and tetrahedrite that have matching walls ("cavity-filling"). In

PLATE 13

Photomicrograph of bands of sphalerite (sp) and quartz (g). Pyrite (py) also is present. X260 Plane reflected light.

PLATE 14

Photomicrograph of subhedral pyrite in a groundmass of sphalerite and gangue (dark). X260 Plane reflected light.

KEY TO SYMBOLS USED IN FIGURES 6 TO 19

arsenopyrite
chalcopyrite
first generation of gangue
second generation of gangue
galena
pyrite
sphalerite
tetrahedrite

Figure 6
x250

Rim replacement of pyrite by sphalerite,
and relict pyrite in sphalerite

Figure 7
x140

Galena vein with matching walls in pyrite

Figure 8

x 500

Contemporaneous introduction of sulphide minerals into fractures in pyrite

Figure 9

x14

Celloform pyrite

some places, however, relict pyrite is present in the galena, indicating that galena replaced pyrite. In Figure 10 and elsewhere, the older generation of pyrite is anhedral to subhedral, and contains many flecks of a gangue mineral. Pyrite grains found in veins composed mainly of sphalerite are fresh (unreplaced) and euhedral, and belong to a younger generation of pyrite.

Sphalerite is the second most abundant sulphide mineral. Its grain size varies from 0.5 mm to less than 0.001 mm. Its colour is medium grey, indicating that it contains moderate amounts of iron. An older generation of sphalerite has partly replaced pyrite (Figure 6) and is partly replaced by galena (Figure 11). Blebs of chalcopyrite in a regular arrangement along crystallographic planes in sphalerite are characteristic of exsolution (Figure 12). In Figure 13, one vein has non-matching walls, indicating that the sulphide minerals replaced quartz. The matching walls of the sphalerite vein indicate that the sphalerite fills a fracture in the quartz. Much of the galena and chalcopyrite exists along the walls of sphalerite veins, suggesting that the galena and chalcopyrite either filled cavities at contacts of the sphalerite veins, or were the first minerals to precipitate from a solution containing lead, copper, and zinc. The texture in Figure 14 suggests that chalcopyrite replaced pyrite. A subsequent fracture was filled by a younger generation of sphalerite.

Galena (grain size from 0.5 mm to less than 0.001 mm) is the third most abundant sulphide mineral. Like sphalerite,

Figure 10
x220

Two generations of pyrite

Figure 11
x300

Replacement along crystallographic planes of sphalerite by galena

Figure 12

x500

Exsolved chalcopyrite along crystallographic planes in sphalerite, and rim replacement of sphalerite and (or) tetrahedrite by chalcopyrite

Figure 13

x250

Veins with matching and non-matching walls

galena occurs in irregular areas, with crystals intergrown so that their outlines can be observed only after the galena has been etched. Most of the galena replaced sphalerite (Figure 11), but some filled fractures in pyrite (Figure 7), or replaced it.

Chalcopyrite, with grain size similar to that of sphalerite and galena, is present in much smaller amounts. Most of the chalcopyrite is associated with pyrite-rich bands. This suggests that the formation of chalcopyrite by the addition of copper to pyrite ("apparent" replacement of pyrite by chalcopyrite) occurred to a greater extent than "complete" replacement of sphalerite by chalcopyrite. Chalcopyrite, veins of which cut all other sulphide minerals (Figure 15), was the last of the first generation of sulphide minerals to be deposited.

Tetrahedrite (grain size from 0.2 mm to less than 0.001 mm) is a pale grey mineral typically associated with galena (Figure 16). The two minerals have interlobed "mutual" boundaries, in contrast to the sharp, planar boundaries between tetrahedrite and sphalerite. In parts of the sulphide zone, tetrahedrite is more abundant than galena (Figures 8 and 12). The pale grey colour of the tetrahedrite is caused by a low Sb/As ratio or a high silver content.

Small amounts of arsenopyrite are present as anhedral to euhedral grains varying from 0.5 mm to less than 0.001 mm. The grains are embedded in pyrite and sphalerite, more arsenopyrite being associated with pyrite than with any other sulphide mineral.

Figure 14
x160

Cavity — filling by a sphalerite vein

Figure 15
x300

Vein of chalcopyrite in galena and sphalerite

In Figure 17, euhedral arsenopyrite is shown exerting its crystal form in pyrite, embayed by sphalerite, and having a "mutual" boundary with quartz. These textural relationships suggest that the quartz and arsenopyrite are contemporaneous, and the pyrite and sphalerite are younger. Subhedral arsenopyrite shown in Figure 18 served as a nucleus for the formation of sphalerite and euhedral pyrite.

Paragenesis

The paragenesis of the sulphide minerals at Orvan Brook follows the "normal" sequence (Bateman, 1958; p. 107). If the inferred paragenetic sequence (Table 5) is correct, they were introduced in the following order.

Arsenopyrite, which served as a nucleus for deposition of pyrite and sphalerite (Figure 18) and is characteristically euhedral, is the oldest sulphide mineral. The first generation of pyrite has been replaced by gangue and all other sulphide minerals except arsenopyrite, and is the second oldest sulphide mineral. For example, pyrite was replaced by the first generation of sphalerite (Figure 6). A small amount of chalcopryrite (the first generation) then exsolved from the sphalerite (Figure 12). After brecciation and disorientation of the fragments of banded pyrite and sphalerite, quartz and calcite were deposited in open spaces between breccia fragments (Figure 19). Galena and tetrahedrite replaced pyrite and sphalerite (Figures 8, 9, 11, and 12). The galena and tetrahedrite are spatially

Figure 16
x380

Close association of galena and tetrahedrite

Figure 17
x 300

Relationship of arsenopyrite with pyrite, sphalerite, and quartz (gangue)

Figure 18
x340

Arsenopyrite nucleus for precipitation of pyrite and sphalerite

Figure 19
x22

Brecciated sulphide minerals

associated, and were probably introduced contemporaneously (Figure 16). Gold might have been introduced at this time, or in solid solution with arsenopyrite (Clark, 1960), or pyrite. The sulphide and gangue minerals were then fractured, and a second generation of chalcopyrite formed veins in sphalerite and galena (Figure 15). Second generations of pyrite (Figure 10) and sphalerite (Figure 14) were the last sulphides to be deposited.

Table 5. Paragenetic sequence of Minerals in the Orvan Brook Deposit.

CHEMISTRY OF THE ORVAN BROOK SULPHIDE DEPOSIT AND RELATED ROCKS

The distribution of trace elements, the sulphur isotope abundances, and the geothermometry are discussed with reference to the origin of the Orvan Brook sulphide deposit in the following pages.

Trace Element Chemistry

In the parts of the sulphide zone intersected by 41 diamond drill-holes, five of the metals are distributed as shown in Table 6. Most of the holes were drilled at an inclination of 65 degrees from positions south of the sulphide zone, which dips steeply north, so the true width is less than half the core length.

Table 6. Distribution of Metals in Diamond Drill Cores of the Sulphide Zone (compiled from records of New Calumet Mines, Limited)

Depth Range (feet below the average surface elevation)	Number of drill-holes	Core length (feet)	Average (oz. per ton)		Average (per cent)		
			Gold	Silver	Zinc	Lead	Copper
0-100	8	6.7	trace	1.64	6.49	2.65	0.18
100-200	13	4.7	0.012	3.00	6.20	3.45	0.31
200-300	7	3.9	0.022	2.80	6.92	3.48	0.45
300-400	7	4.4	0.017	2.32	5.74	2.03	0.21
Below 400	6	11.1	0.027	2.66	6.34	2.59	0.24

The above table shows that the metals of greatest economic importance are zinc, lead, and silver, and that their average concentrations are fairly uniform throughout the length and depth of the deposit.

In the host rocks, the metals are present in rock-forming minerals and disseminated sulphides. The trace amounts of zinc, copper, lead, and silver were determined by Mrs. D.C. Mah; sample localities and results of analyses are recorded in Appendix II. The samples were divided into groups representing four traverses across the deposit (Map 4). Vertical sections of the four traverses, with concentrations of metals corresponding to rock types, are shown in the form of histograms (Figures 20, 21, 22, and 23). Each bar represents one to four analyses. The approximate concentrations of base metals in the sulphide zone are taken from Table 6. The rock types that have no metal values on the histograms were not sampled, and are included simply to show the stratigraphic succession and thickness. The scale of the vertical sections is approximately 1 inch : 100 feet. More detailed information is shown in four vertical sections (scale 1 inch : 100 feet) in Appendix I.

Each metal is discussed below, and comparisons are made between the concentrations of the metals in the different host rocks.

Zinc--In general, the concentration of zinc decreases towards the sulphide zone in the western part of the area, and increases in

Figure 20. Quantitative analyses for zinc, copper and lead, and semi-quantitative analyses for silver in the host rocks and sulphide zone of the Orvan Brook deposit. (North-south traverse, between 8+00W and 0+00.)

Figure 21. Quantitative analyses for zinc, copper and lead, and semi-quantitative analyses for silver in the host rocks and sulphide zone of the Orvan Brook deposit. (North-south traverse, between 2+00E and 10+00E.)

Figure 22. Quantitative analyses for zinc, copper and lead, and semi-quantitative analyses for silver in the host rocks and sulphide zone of the Orvan Brook deposit. (North-south traverse, between 38+00E and 50+00E.)

Figure 23. Quantitative analyses for zinc, copper and lead, and semi-quantitative analyses for silver in the host rocks and sulphide zone of the Orvan Brook deposit. (North-south traverse, between 52+00E and 61+00E.)

the east. For the two western traverses, the concentration of zinc in the host rocks is greatest in the two map-units farthest from the sulphide zone: meta-andesite and quartz-feldspar augen schist. Except for the area of the east central traverse, the rocks of map-unit 1 contain high concentrations of zinc. Map-units 3 and 7, which are the richest in hematite, are almost barren of zinc.

Lead--A definite affinity for certain rock types is shown by lead, which is concentrated in rocks of map-units 1 and 4. Furthermore, the concentrations of lead in rocks of map-unit 1 (predominantly quartz-feldspar augen schist) and map-unit 4 (predominantly quartz-sericite schist) are similar. Possibly the lead is contained in the potash feldspars.

Copper--In general, the concentration of copper increases towards the sulphide zone, but is greatest in rocks of map-units 2, 5, and 7. The increase in the concentration of copper from meta-andesite to argillaceous rocks (towards the sulphide zone) probably depends on the rock type, not on the distance from the sulphide zone. For example, rocks of map-unit 1, some of which are only 200 feet from the sulphide zone, have a low concentration of copper.

Silver--The pattern of distribution of silver is erratic. Silver is concentrated in the sulphide zone of the two eastern traverses, only trace amounts being present in the host rocks. However, appreciable amounts of silver exist in some host rocks of the

western traverses. In map-units 1a, 7, and 8 of Figure 20, and map-units 1a and 6a of Figure 21, the silver content (2 ppm to 5 ppm) is higher than in similar "normal" rocks (Goldschmidt, 1954; pp. 191-195). Although lead is concentrated in the quartz-feldspar augen schist and quartz-sericite schist, silver is not, and the degree of concentration of silver does not correspond to that of lead in these rocks.

Summary and Conclusions of the Trace Element Chemistry

The distribution of zinc, lead, copper, and silver in the host rocks of the Orvan Brook sulphide deposit is complex, and no consistent primary (hypogene) or secondary geochemical dispersion pattern is detectable. Map-unit 9 (the sulphide zone) is the only one consistently rich in all the metals. The metal concentration in the host rocks does not definitely increase or decrease towards the sulphide zone. The reason for this may be one (or more) of the following:

1. A drastic change in the conditions of sedimentation caused the precipitation of the metals in the sulphide zone.
2. Metamorphic differentiation (possibly) caused the partial depletion of metals in the wall-rocks and their concentration in the sulphide zone.
3. No genetic relationship exists between the metals in the sulphide zone and those in the host rocks.

McAllister (1960) suggested that the sulphide deposits of the Bathurst-Newcastle area are a facies of "iron-formation" associated with the magnetite facies. The "iron-formation" near

the Orvan Brook deposit is of the hematite facies. It has low concentrations of all the metals determined, and is almost barren of zinc, the principal metal in the sulphide zone.

The pattern of distribution of metals in the host rocks of the Orvan Brook sulphide deposit might result from an incomplete migration of the metals from the wall-rocks to the sulphide zone. However, in most places the contact between the host rocks and the sulphide zone is sharp. Probably the concentration of metals in the host rocks is related to rock type. The rocks of map-units 2, 5, and 7 (mainly graphite schist and banded quartz-chlorite-hematite schist) contain higher concentrations of copper than do the rocks of the other map-units. Also, lead is concentrated (about equally) in rocks of map-units 1 and 4. In the sulphide zone, galena and silver-bearing tetrahedrite are spatially associated. In almost every assay of sulphide samples (Table 6, and vertical sections in Appendix I) the figure for the number of ounces of silver per ton $\pm$ 50 per cent or less equals the percentage of lead. In the host rocks, however, the ratio of concentration of lead and silver varies greatly. For example, the concentration of silver in rocks of map-unit 1 is low, whereas compared with other host rocks the concentration of lead is high. Possibly the source of the lead and silver in the sulphide zone is different from that of the lead and silver in the host rocks. In the quartz-feldspar augen schist of map-unit 1, the concentration of lead may be related to the concentration of potassium in the alkali feldspars. As explained under "Metamorphism",

the scarcity of feldspar phenocrysts in the quartz-sericite schist is probably the result of their transformation into augen and replacement by quartz, calcite, and sericite during metamorphism. Apparently the concentration of lead was not altered. The similarity of the concentration of lead in the rocks of map-units 1 and 4 is further evidence of their derivation from the same parent rock.

The relative concentrations and associations of zinc, lead, copper, and silver in the host rocks are not similar to their relative concentrations and associations in the sulphide zone. The dissimilarity suggests that the source of metals in the host rocks is different from the source of metals in the sulphide zone.

Isotopic Chemistry

The isotopic chemistry of sulphide deposits of the Bathurst area, including the deposit at Orvan Brook, was studied by Tupper (1960). He made the following assumptions: deposits derived from sedimentary sulphides have a broad range of S^{32}/S^{34} ratios, whereas sulphide deposits of hydrothermal origin have a narrow range. Tupper found that sulphur isotopes in the Bathurst sulphide deposits are homogeneous, and the ratios fall into two groups: the massive sulphide deposits (21.87 to 22.09); and the fissure deposits (22.18 to 22.21). The narrow range of these ratios suggests two separate but closely related hydrothermal sources for the sulphide minerals. The ratios of S^{32}/S^{34} in the sulphide minerals at Orvan Brook (21.98 to 22.07) are within the range established for the massive sulphide deposits.

Geologic ages determined by the potassium-argon method for three granitic intrusions in rocks of the Bathurst area are about 395 million years (Tupper and Hart, 1961). A mean model lead age from five of the deposits is 370 ± 20 million years (Tupper and Hart, 1961). This suggests that either the granitic bodies and sulphide minerals were emplaced during the same major orogenic event, or the galena was recrystallized during an orogeny that also involved the emplacement of granite.

Geothermometry

The paragenetic data indicate that arsenopyrite and pyrite were introduced early in the history of the sulphide body (earlier than some quartz gangue, i.e. g_2 of Figure 19). Inclusions of arsenopyrite are present in pyrite (Figure 17), but the reverse relationship was not found. Generally the pyrite conforms to the euhedral surface of the arsenopyrite. The absence of reaction rims at their mutual boundaries indicates that arsenopyrite and pyrite coexisted in equilibrium. Clark (1960, p. 1642) found that arsenopyrite and pyrite cannot coexist above approximately $491 \pm 12^\circ\text{C}$. (At combined partial pressures of sulphur and arsenic equal to 1,035 bars, arsenopyrite and pyrite can coexist at temperatures up to $509 \pm 10^\circ\text{C}$. However, Clark believed that the partial pressures of sulphur and arsenic are lower in the natural environment of ore deposition). The relationship of arsenopyrite and pyrite in the Orvan Brook sulphide deposit suggests that one or both of these minerals formed below that range

of temperature. At Orvan Brook, chalcopyrite exsolution blebs exist along crystallographic planes in sphalerite (Figure 12). Buerger (1934, p. 530) found that chalcopyrite is significantly soluble in sphalerite at not less than 350°C in a partial vacuum. These data suggest that the sulphide minerals in the Orvan Brook deposit were formed at temperatures between approximately 350°C and 500°C. This range of temperature is "hypothermal" according to Lindgren's classification (Lindgren, 1933; p. 212).

ORIGIN OF THE ORVAN BROOK SULPHIDE DEPOSIT

Two types of sulphide deposits occur in the Bathurst-Newcastle mining district - fissure-filling and massive. The physical appearance, metal content, and host rocks of the sulphide deposit at Orvan Brook are typical of the massive sulphide deposits. For the massive sulphides, the following modes of origin have been advocated: source bed (Sullivan, 1957), syngenetic (McAllister, 1960), and hydrothermal (Tupper, 1960). The Orvan Brook sulphide deposit is, on the average, only 2 to 3 feet thick, and is confined for its entire length of 8,000 feet to a single stratum of quartz-sericite schist that is less than 40 feet thick. Banding (lamination) in the sulphide zone is approximately conformable with the quartz-sericite schist, and parallel to beds in argillaceous country rocks and "iron-formation". Throughout the sulphide zone, little difference exists in grain size, texture, or mineralogy. Furthermore, the distribution of trace elements suggests a closer relationship between the rock types and the metal content than between the metal content and distance from the sulphide zone. These characteristics suggest that the sulphides may be syngenetic. McAllister (1960) thought the sulphide deposits of the Bathurst-Newcastle area are a facies of "iron-formation" associated with the magnetite facies. The only "iron-formation" near the Orvan Brook sulphide deposit is of a hematite facies, and it contains a very low concentration of base metals.

If the Orvan Brook sulphide deposit is syngenetic, it has been metamorphosed to the extent that several of its characteristics cannot be distinguished from those of hydrothermal occurrences. For example, the geothermometry of the sulphide minerals indicates they were formed at temperatures of 350°C to 500°C. This range of temperature may be attained during the greenschist facies of regional metamorphism (Turner and Verhoogen, 1960; p. 534). Replacement textures, which are abundant in the sulphide minerals, might not be primary; they are abundant also in the host rocks (Figures 3, 4, and 5), in which replacement is the result of redistribution of elements and minerals during metamorphism. Possibly the replacement textures in the sulphide minerals also are metamorphic. Banding in the sulphide zone might be the result of primary deposition, selective replacement, metamorphic differentiation, or any combination of these processes. If the banding is relict from primary deposition, the evidence may have been destroyed during metamorphism. Replacement would not be selective enough to create the thin continuous laminations characteristic of the Orvan Brook sulphide zone, but metamorphic differentiation of massive sulphides could have produced them. According to Lindgren (1933, p. 749) some sulphide minerals are deformed plastically by gliding and twinning, whereas pyrite is competent and is deformed by brecciation (e.g. the pyrite in Figure 19). Sulphides that are mobilized plastically may move into shear zones and areas of low pressure caused by deformation. Such a process probably modified the banding in the Orvan Brook sulphide zone.

Sullivan (1957) believed that the massive sulphide deposits of the Bathurst area were formed by mobilization of metals from tuffaceous source beds (such as quartz-feldspar augen schist) when they were being metamorphosed. This is a possibility at Orvan Brook, where the concentration of lead, and to a lesser extent zinc, is high in the rocks of map-unit 1. However, in the sulphide zone the concentration of silver is proportionate to that of lead; this is not so in the rocks of map-unit 1. Smith and Skinner (1958) rejected the idea that the minerals of the massive sulphide deposits were introduced by the "porphyry" (quartz-feldspar augen schist). They believed that the formation and deformation of the "porphyry" preceded metallization. They pointed out that the "porphyry" is not present in the New Larder "U" and Clearwater sulphide zones.

Some characteristics of the Orvan Brook sulphide deposit suggest that it is hydrothermal. The sulphide zone is in quartz-sericite schist (i.e. sheared, altered quartz-feldspar augen schist) less than 2,000 feet from a regional fault (the Rocky Brook-Millstream fault). In most places the contacts of the sulphide zone with the host rocks are sharp. Quartz-sericite schist exists as barren strata in the area of map-unit 1, where its lack of mineralization might be explained as follows.

According to Tupper (1960, p. 1705), a geological interpretation suggests that granite should be encountered at depths of one to five miles throughout most of the Bathurst area.

Sorenson (1963) believed that secondary magmatic solutions form a fluid envelope that saturates the country rock around a magma chamber. Secondary solutions cause some of the wall-rock alteration, but the sulphide minerals are transported by primary magmatic solutions that come directly from the magma chamber. The quartz-sericite schist that is barren may have been affected only by secondary magmatic solutions. The quartz-sericite schist that contains the sulphide deposit may have been dynamically metamorphosed and later altered by hydrothermal solutions, some of which transported the sulphide minerals.

The results of the trace element work for the Orvan Brook area show that the relative concentrations of metals in the sulphide zone are different from those in the host rocks. Also, certain metals are concentrated in certain types of rock. Possibly, then, the metals in the sulphide zone and those in the host rocks are from different sources. The geothermometry (sphalerite-chalcopyrite, and arsenopyrite-pyrite) indicates that the sulphide minerals were formed at hypothermal temperatures (350°C to 500°C). The colloform pyrite that is 350 to 500 feet deep in the sulphide zone is either hypogene, or reached its present position as a result of folding or supergene enrichment. The breccia, fracture-filling, and replacement textures suggest that the sulphide minerals were introduced into the host rock. According to Tupper (1960) the narrow range of S^{32}/S^{34} ratios indicates a hydrothermal source.

Age determinations showed that either the lead minerals and the Acadian granite bodies were emplaced during the same orogenic event, or the galena was recrystallized during the orogeny that also involved emplacement of the granite. If the Orvan Brook sulphide deposit is hydrothermal, it was probably formed during the Acadian orogeny. The following paragraph is summarized from Tupper's paper (Tupper, 1960).

Volatiles associated with igneous activity could have been channelled into favourable structural traps, where H_2S reacted with iron in ferruginous slates and "iron-formation" to produce pyrite. Such processes can account for the association of deposits with "iron-formation", the relatively competent "porphyry", and structural traps. They also account for the conformability of the deposits with the host rocks, the replacement nature of the sulphides, the fine-grained textures, and the banding in the sulphide minerals.

The textures, temperature of formation, sulphur isotope abundances, and spatial associations of the sulphide minerals, as well as the shearing and alteration of the host rocks, suggest that the Orvan Brook sulphide deposit is of hydrothermal origin.

SUMMARY AND CONCLUSIONS

The Orvan Brook sulphide deposit occurs in fractured, sheared quartz-sericite schist and graphite schist, and is 8,000 feet long, with an average width of 2 to 3 feet. The principal rocks of the Orvan Brook area are quartz-feldspar augen schist, quartz-sericite schist, meta-andesite, chlorite schists, argillites, and low-grade "iron-formation" of the hematite facies. The rocks contain quartz, feldspars, muscovite, chlorite, hematite, calcite, epidote, graphite, actinolite, pyrite, and magnetite; these minerals are characteristic of the "greenschist" facies of regional metamorphism. Possibly the rocks are sheared, altered equivalents of rhyolite porphyry (flows or tuffs), andesite, and siliceous argillite. The gradation from quartz-feldspar augen schist to quartz-sericite schist is not a reliable guide to sulphide concentrations, because it exists in barren areas as well as in wall-rocks of the sulphide zone.

The pattern of distribution of trace elements in the host rocks indicates a closer relationship between the rock types and metal content than between the metal content and distance from the sulphide zone. The source of metals in the host rocks is probably different from the source of metals in the sulphide zone. In most places the contacts of the sulphide zone with the host rocks are sharp, suggesting that the sulphide zone is epigenetic. The metals in the host rocks are probably syngenetic.

The sulphide minerals are similar in physical appearance and metal content to minerals of the banded massive sulphide bodies of the Bathurst-Newcastle mining district. Throughout the Orvan Brook sulphide zone, the grain size, mineral association, and grade is uniform. The mineralogy of the sulphides (in paragenetic order) is: arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, and tetrahedrite; and replacement, fracture-filling, colloform, exsolution, and breccia textures are present. The arsenopyrite-pyrite association and the chalcopyrite exsolution blebs along crystallographic planes in sphalerite suggest that the sulphide minerals were formed at temperatures between 350°C and 500°C. The range of S^{32}/S^{34} ratios (21.98 to 22.07) is narrow and suggests a hydrothermal source.

The textures, temperature of formation, sulphur isotope ratios, and spatial associations of the sulphide minerals, as well as the shearing and alteration of the host rocks, suggest that the Orvan Brook sulphide deposit is of hydrothermal origin.

REFERENCES

- Alcock, F.J.
1941: Jacquet river and Tetagouche river map-area, New Brunswick; Geol. Surv. Can., Mem. 227, p. 46.
- Bateman, A.M.
1958: Economic mineral deposits; Second ed., John Wiley & Sons, New York, p. 916.
- Boyle, R.W., and Davies, J.L.
1963: Geology of the Austin Brook and Brunswick No. 6 sulphide deposits, Gloucester county, New Brunswick; Geol. Surv. Can., Paper 63-24, p. 23.
- Buerger, N.W.
1934: The unmixing of chalcopyrite from sphalerite; Am. Miner., vol. 19, pp. 525-530.
- Clark, L.A.
1960: The Fe-As-S System: phase relations and applications; Econ. Geol., v. 1. 55, No. 8, pp. 1631-1652.
- Davies, J.L.
1959: Parts of the Tetagouche, Jacquet, and Nigadoo rivers, Gloucester and Restigouche counties, New Brunswick; Mines Branch, Dept. Lands and Mines, New Brunswick, Prelim. Paper 59-1, p. 12.
- Financial Post, The
1966: Survey of Mines; Maclean-Hunter Publishing Co. Ltd., Toronto, p. 322.
- Gilbert, M.A.
1959: Laboratory methods for determining copper, zinc, and lead; Geol. Surv. Can., Paper 59-3, p. 21.
- Goldschmidt, V.M.
1954: Geochemistry, The Clarendon Press, Oxford, England, p. 730.
- Goodwin, A.M.
1962: Structure, stratigraphy, and origin of iron formations, Michipicoten area, Algoma district, Ontario, Canada; Bull. Geol. Soc. Amer., vol. 73, No. 5, pp. 561-586.
- Holyk, W.
1957: Structure of northern New Brunswick; in Structural Geology of Canadian Ore Deposits, vol. 2, pp. 485-492.

- Jones, R.A.
1961: Head of Forty Mile brook and Tetagouche river, Restigouche, Northumberland and Gloucester counties, Mines Branch, Dept. Lands and Mines, New Brunswick, Prelim. Map 60-3.
- Lindgren, Waldemar
1933: Mineral deposits; Fourth ed., McGraw-Hill, Toronto, p. 930.
- McAllister, A.L.
1960: Massive sulphide deposits in New Brunswick; Trans. Can. Inst. Mining Met., vol. 63, 1960, pp. 55-60.
- Naylor, R.S., and Boucot, A.J.
1965: Origin and distribution of rocks of Ludlow age (Late Silurian) in the northern Appalachians; Am. J. Sci., vol. 263, pp. 153-169.
- Neale, E.R.W., Beland, J., Potter, R.R., and Poole, W.H.
1961: A preliminary map of the Canadian Appalachian region based on age of folding; Trans. Can. Inst. Mining Met., vol. 64, pp. 405-412.
- Northern Miner Press Limited, The
1965: The Canadian Mines Handbook; The Northern Miner Press Limited, Toronto, p. 410.
- Pearce, T.H.
1963: The petrochemistry and petrology of the quartz-feldspar porphyry, Bathurst, New Brunswick; Univ. of Western Ontario, unpubl. M.Sc. thesis, p. 60.
- Pettijohn, F.J.
1957: Sedimentary Rocks; Second ed., Harper & Brothers, New York, p. 718.
- Potter, R.R.
1965: Upsalquitch Forks, New Brunswick; Geol. Surv. Can., Prelim. Map 14-1964.
- Roy, S.
1961: Mineralogy and paragenesis of lead-zinc-copper ores of the Bathurst-Newcastle district, New Brunswick; Geol. Surv. Can., Bull. 72, p. 19.
- Skinner, R.
1956: Tetagouche Lakes map-area, New Brunswick; Geol. Surv. Can., Prelim. Map 55-32.
- Smith, C.H.
1957: Bathurst-Newcastle map-area; Geol. Surv. Can., Map 1-57.

- Smith, C.H., and Skinner, R.
1958: Geology of the Bathurst-Newcastle mineral district;
Trans. Can. Inst. Mining Met., vol. 61, pp. 78-83.
- Sorenson, A.H.
1963: A re-examination of some suggested mechanisms for re-
mobilization of sulfide orebodies; Econ. Geol.,
vol. 58, No. 7, pp. 1071-1088.
- Sullivan, C.J.
1957: Classification of metalliferous provinces and
deposits; Trans. Can. Inst. Mining Met., vol. 50,
pp. 333-335.
- Tupper, W.M.
1960: Sulfur isotopes and the origin of the sulfide
deposits of the Bathurst-Newcastle area of northern
New Brunswick; Econ. Geol., vol. 55, No. 8,
pp. 1676-1707.
- Tupper, W.M., and Hart, S.R.
1961: Minimum age of the Middle Silurian in New Brunswick
based on K-Ar method; Bull. Geol. Soc. Amer., vol. 72,
pp. 1285-1288.
- Turner, F.J., and Verhoogen, J.
1960: Igneous and metamorphic petrology; Second ed.,
McGraw-Hill, New York, p. 694.

BIOGRAPHY

I was born Howard Lawrence Lovell, June 25, 1932 in Kirkland Lake, Ontario. I attended Ontario elementary schools in Haileybury, St. Andrew's College, Aurora, and Orangeville, from 1938 to 1945, and high school at Orangeville from 1946 to 1949. From 1950 to 1956 I served in Canadian infantry regiments in Canada, Asia, and Europe. My first two years of university were partly financed from Korean war re-establishment credits. I graduated from Carleton University with B.Sc. (geology) in May, 1961. In 1963 I was awarded a Graduate Fellowship from Carleton University. My field experience consists of four seasons with the Geological Survey of Canada, and four with the Ontario Department of Mines.

A P P E N D I X I

Vertical sections compiled from diamond drill-hole information
obtained from New Calumet Mines, Limited.

ORVAN BROOK SULPHIDE DEPOSIT

LEGEND FOR SECTIONS

- MASSIVE AND DISSEMINATED SULPHIDES ;
PYRITE , SPHALERITE , GALENA , CHALCOPYRITE
- META-ANDESITE , CHLORITE SCHIST (PROBABLY DERIVED FROM ANDESITE) ;
MINOR GRAPHITE SCHIST.
- BANDED QUARTZ — CHLORITE — HEMATITE SCHIST , GRAPHITE SCHIST ,
CHLORITE SCHIST
- CHLORITIC ARGILLITE AND GREYWACKE , CHLORITE SCHIST.
MINOR ANDESITE , GRAPHITE SCHIST , FELDSPAR AUGEN SERICITE SCHIST.
- GRAPHITE SCHIST (SHEARED)
- SERICITE SCHIST (SHEARED).
- IRON — FORMATION ; CHLORITE SCHIST , MAGNETITE - HEMATITE - CHERT.
- CHLORITIC SILICEOUS ARGILLITE , GRAPHITE SCHIST ;
MINOR CARBONATE.
- FELDSPAR AUGEN SERICITE SCHIST , SERICITE SCHIST , META-RHYOLITE

SYMBOLS

GEOLOGICAL CONTACTS

FAULTS ZONE , SHEAR ZONE

5,3,2.1, 0.013, 343 Zn,Pb,Cu,Au,Ag.

ORVAN BROOK

SECTION 0+00

SCALE 1"=100'

W.M.T. 20-6-62

ORVAN BROOK
 SECTION 6 + 00 E
 SCALE 1"=100'
 W.M.T. 20-6-62

ORVAN BROOK
SECTION 46+00E
SCALE 1"=100'
W.M.T. 3-7-62

ORVAN BROOK
SECTION 52+00E
SCALE 1"=100'
W.M.T., 3-7-62

A P P E N D I X I I

Chemical Methods and Data

METHODS USED FOR TRACE ELEMENT DETERMINATIONS

Samples weighing from 1/8 to 1/4 lb. were chosen from the host rocks and sulphide zone, and divided into groups representing four traverses across the deposit. Each sample was broken into fragments by means of a manually-operated rock splitter. A characteristic chip was kept for thin section or additional hand specimen descriptions. On a ceramic buckboard, the remainder of the sample was ground to a diameter of 1/4 inch or less. Then the samples were passed through a Braun pulverizer fitted with ceramic grinding plates. Metal plates were used for samples of massive sulphide minerals, which are very fine-grained, hard, and difficult to grind. Each sample was passed through the pulverizer 8 to 10 times, and each time the minus 200 (-200) mesh fraction was removed by sieving. By this method, the sample was ground to minus 200 (-200) mesh.

Trace Element Analyses

Seventy-one samples of the host rocks and sulphide zone were analyzed colorimetrically for zinc, copper, and lead. About 100 mg of the sample was fused with KHSO_4 and made up to volume with weak HCl and metal-free water. This method gives total solution of zinc, lead, and copper. The mean accuracy of the determinations, over a range of 10 to 200 ppm, is ± 20 per cent (Gilbert, 1959).

The concentration of silver was determined semi-quantitatively on a 1.5 metre Jarrel-Ash emission spectrograph. No reference checks were made. Electrodes of spectroscopically pure graphite were used; slit width was 15 microns and its height was 2 mm; and arc gap was 2 mm. SA No. 1 film was used. Standards are 0.5, 1, 2, 5, 10, and 50 ppm silver oxide in a rock base consisting of 5.91 gm SiO_2 , 0.105 gm TiO_2 , 1.534 gm Al_2O_3 , 0.474 gm Fe_2O_3 , 0.309 gm MgO , 0.924 gm CaCO_3 , 0.384 gm Na_2CO_3 , and 0.313 gm K_2CO_3 .

The sample and spectroscopically pure graphite were mixed in equal proportions and burned for two minutes in a carbon arc in the emission spectrograph, using a current of four amperes. Iron (wavelength 3287 Å) was used as the internal standard, and samples were compared with standards on the densitometer (wavelength 3280 Å). The range of detection is 0.5 ppm to 10 ppm.

Traverse southward, between 8+00 W and 0+00

Rock Type	Sample No.	Zn ppm	Cu ppm	Pb ppm	Ag ppm	Approximate Location
Meta- andesite	6030	0	75	25	5.0	6+00 W; 2+10 N
	6027	85	5	62.5	<0.5	4+00 W; 3+10 N
	6023	5	10	25	6.5	6+00 W; 4+50 N
	6028	0	0	62.5	7.5	4+50 W; 1+50 N
Quartz- chlorite schist	6025	5	150	37.5	<0.5	5+00 W; 4+65 N
	6032	0	75	25	2.5	0+00 ; 0+70 N
	6020	0	25	25	10.0	7+50 W; 0+00
Quartz- sericite schist	OBT-12	0	100	60	*tr.	8+00 W; T-12(637 ft.)
Sulphides	3963	>200	25	>75	>10.0	0+00 ; T- 2(391 ft.)
	3980	>200	165	>75	10.0	0+00 ; T-10(487 ft.)
	3966	>200	110	>75	tr.	8+00 W; T- 5(185 ft.)
	3968	>200	100	>75	3.0	8+00 W; T- 5(274 ft.)
Quartz- feldspar augen schist	6047	125	40	75	N.D.	6+40 W; 11+00 S
	6043	0	50	35	>10.0	4+00 W; 6+00 S
	3960	0	25	90	<0.5	2+00 W; T-1 (258 ft.)
	**3961	7000	160	60	<0.5	0+00 ; T-2 (193 ft.)

*Abbreviations tr. - trace amount

- N.D. - not detectable

**Disregarded because it contains disseminated sulphide minerals.

N.B. Under the heading "Approximate Location", the numbers preceded by "T-" denote diamond drill-holes, and the numbers in brackets indicate depths. The co-ordinates refer to map 3.

Traverse southward, between 2+00 E and 10+00 E

Rock type	Sample No.	Zn ppm	Cu ppm	Pb ppm	Ag ppm	Approximate Location
Meta- andesite	6038	75	0	70	4.0	4+00 E; 4+00 N
	6073	0	5	25	<0.5	8+00 E; 26+50 N
	6039	135	120	50	<0.5	6+00 E; 46+50 N
	6075	0	160	25	N.D.	9+60 E; 42+50 N
Quartz- chlorite schist	6066	5	50	25	tr.	4+00 E; 2+50 S
	6037	5	0	25	3.5	4+00 E; 22+50 S
	6041	0	100	25	tr.	6+00 E; 0+00
	6077	5	150	25	<0.5	10+00 E; 1+50 S
Argillite	6062	5	5	25	tr.	4+00 E; 17+50 S
	6065	10	150	30	N.D.	3+75 E; 7+50 S
	6067	125	50	45	>10	6+00 E; 8+00 S
	6068	0	150	45	<0.5	6+00 E; 12+50 S
Sulphides	3973	>200	40	>75	8.5	4+00 E; T-8(435 ft.)
	3982	>200	100	>75	0.5	2+00 E; T-13(517.5 ft.)
	3964	>200	100	>75	tr.	2+00 E; T-3 (414 ft.)
"Iron- formation"	6059	35	0	25	< 0.5	4+00 E; 3+50 S
	XN17	0	140	50	tr.	4+00 E; T- 8(386 ft.)
	XN19	0	100	10	< 0.5	7+00 E; T- 9(287 ft.)
	XN16	5	0	58	2.0	7+00 E; T-9 (310 ft.)
Quartz- feldspar augen schist	6069	125	10	60	2.3	6+00 E; 4+90 S

Traverse southward, between 38+00 E and 50+00 E

Rock Type	Sample No.	Zn ppm	Cu ppm	Pb ppm	Ag ppm	Approximate Location
Meta-andesite	6129	0	25	25	<0.5	48+00 E; 80+00 N
	6131	0	50	37.5	<0.5	51+60 E; 78+50 N
Quartz-chlorite schist	6118	15	75	37.5	<0.5	44+00 E; 38+00 N
	6112	10	175	50	<0.5	45+00 E; 38+00 N
	XN20	120	135	50	tr.	46+00 E; T-26 (372 ft.)
	XN24	5	160	55	<0.5	46+00 E; T-26 (244 ft.)
Quartz-sericite schist	6110	0	75	30	<0.5	45+65 E; 1+60 N
	XN21	5	0	70	<0.5	46+00 E; T-26 (475 ft.)
Argillite	XN26	0	25	25	<0.5	46+00 E; T-26 (190 ft.)
	XN27	135	150	25	<0.5	46+00 E; T-26 (45 ft.)
	XN 9	>200	130	75	<0.5	46+00 E; T-26 (98 ft.)
Graphite schist	BH 7	0	90	40	tr.	46+00 E; T-23 (521 ft.)
Sulphides	BH 8	>200	90	>75	10.0	48+00 E; T-24 (640 ft.)
	BH 9	>200	60	>75	2.5	48+00 E; T-24 (648 ft.)
	BH 6	>200	120	>75	4.0	46+00 E; T-23 (487 ft.)
Quartz-sericite schist	XN 2	0	75	55	<0.5	38+50 E; T-19 (293 ft.)
Graphite schist	BH 4	10	125	35	tr.	46+00 E; T-23 (336 ft.)
Quartz-feldspar augen schist	BH 2	0	60	50	<0.5	44+00 E; T-22 (406 ft.)
	XN 4	5	0	60	N.D.	40+50 E; T-18 (180 ft.)

Traverse southward, between 52+00 E and 61+00 E

Rock Type	Sample No.	Zn ppm	Cu ppm	Pb ppm	Ag ppm	Approximate Location
Meta- andesite	6135	0	90	25	<0.5	60+00 E; 69+00 N
Argillite	6134	5	0	25	< 0.5	56+00 E; 21+00 N
	6132	5	125	25	<0.5	52+00 E; 21+00 N
Graphite schist	6136	0	120	40	tr.	60+00 E; 18+00 N
Sulphides	BH13	>200	100	>75	2.0	56+00 E; T-28(636 ft.)
	BH14	>200	25	>75	10.0	60+00 E; T-29(745.5 ft.)
	BH15	>200	25	>75	5.0	60+00 E; T-29(748.5 ft.)
	BH11	>200	0	>75	7.5	52+00 E; T-27(650 ft.)
	BH12	>200	140	>75	< 0.5	52+00 E; T-27(658 ft.)
Quartz- sericite schist	6137	0	25	40	tr.	60+00 E; 0+35 N
	BH10	175	60	70	tr.	52+00 E; T-27(300 ft.)
	XN11	152	150	60	tr.	52+00 E; T-27(254 ft.)
"Iron- formation"	XN13	0	0	45	< 0.5	52+00 E; T-27(602 ft.)
Graphite schist	XN10	0	75	50	< 0.5	52+00 E; T-27(330 ft.)
Quartz- feldspar	XN 7	80	50	40	< 0.5	52+00 E; T-27(225 ft.)
augen schist	XN 8	40	10	80	< 0.5	52+00 E; T-27(76 ft.)

MAP 3
THE GEOLOGY
OF
THE NEW CALUMET MINES LTD
ORVAN BROOK SULPHIDE BODY

RESTIGOUCHE COUNTY

NEW BRUNSWICK

SCALE 1 INCH : 200 FEET

5+00 N

0+00

THE NEW CALUMET MINES LTD
ORVAN BROOK SULPHIDE BODY

SCALE 1 INCH = 200 FEET

NOTE: IN AREAS OF FEW OUTCROPS, GEOLOGY DETERMINED FROM DIAMOND DRILL DATA

[illegible]

NOTE: IN AREAS OF FEW OUTCROPS, GEOLOGY DETERMINED FROM WINDING TRAIL

(INCLINED, VERTICAL, DIP UNKNOWN)
LINEATION (INCLINED, VERTICAL, DIP UNKNOWN)

B+00 N