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

by

HOWARD LAWRENCE LOWELL, B.Sc.

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

Carleton University
Ottawa, Ontario.
March, 1966
The undersigned hereby recommend to the Faculty of
Graduate Studies acceptance of this thesis, submitted by
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PETROLOGY, MINERALOGY, AND TRACE ELEMENT CHEMISTRY OF THE
ORVAN BROOK SULPHIDE DEPOSIT, RESTIGOUCHE COUNTY, NEW BRUNSWICK.

BY

HOWARD LAWRENCE LOVELL

ABSTRACT

The petrology, mineralogy, and distribution of trace elements
in the Orvan Brook host rocks at 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

The writer thanks Dr. W.M. Tupper of Carleton University for his assistance and advice in this project, and for providing the material. Thanks are due to Mr. P.E. Fox, for identification of feldspar megacrysts by x-ray methods, Mr. J.L. Jambor, for his comments on the sulphide minerals, and Mr. R.R. Potter, for his advice on the regional geology of the area; to New Calumet Mines, Limited, for the assays in Table 6 and plotted on the vertical sections of drill-holes; to Messrs. M.C. Jagoe and W. Yzerdraat, who prepared the thin sections and polished sections; to Mr. F.J. Cooke, who took the photographs; to Mrs. D.C. Mah, who made the trace element analyses; and to Drs. P.A. Hill and J.M. Moore, who read and commented on the manuscript.

Laboratory Methods

Thin sections and polished sections prepared from samples of surface exposures and diamond drill cores were used to study the
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 Nepisiquit 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>
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<th>Zn %</th>
<th>Ag %</th>
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<th>Footwall</th>
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<td>Silicic metasomatites rocks, in part micaschist</td>
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*Abbreviations: sap = arsenopyrite, ca = cassiterite, crv = corellite, hm = h bonite, go = greigite, td = tetrahedrite, bt = bismuth, ch = chalcopyrite, feld = feldspar, mo = micaschist, py = pyrite, br = bornite, cro = chalcopyrite, go = galena, mi = magnesite, sp = sphalerite
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<td>30 to 200</td>
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<td>2.8</td>
<td>4.4</td>
<td>py op gn sp asp td</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Fault zone in drag-fold on the limb of a syncline</td>
<td>Plane-grained massive sulphides</td>
</tr>
<tr>
<td>Eastwet</td>
<td>2600</td>
<td>5</td>
<td>450</td>
<td>0.7</td>
<td>4.7</td>
<td>4.3</td>
<td>py op gn sp asp td</td>
<td>Sedimentary and volcanic rocks</td>
<td>Fault (Inseam and veins cut sedimentary rocks)</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Fault</td>
<td>Massive</td>
</tr>
<tr>
<td>Sturgeon River (Brock Brook)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>py op gn sp asp td</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Quartz-feldspar porphyry, argillite</td>
<td>Fault</td>
<td>Massive</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1 - continued

<table>
<thead>
<tr>
<th>Name of Property</th>
<th>Length (feet)</th>
<th>Depth (feet)</th>
<th>Cu (%)</th>
<th>Pb (%)</th>
<th>Zn (%)</th>
<th>Ag (%)</th>
<th>Minerals</th>
<th>Host Rocks</th>
<th>Hanging-wall</th>
<th>Foot-rock</th>
<th>Ore Control</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaconda (Caribou)</td>
<td>3000</td>
<td>1200</td>
<td>2.4</td>
<td>3.6</td>
<td>2.2</td>
<td></td>
<td>Arthilite with “transformation” in clinozoisite schist</td>
<td>Chlorite-sericite schist</td>
<td>Chlorite-sericite schist, quartz-feldspar augen schist</td>
<td></td>
<td>Massive</td>
<td>Massive disorganized bands</td>
</tr>
<tr>
<td>Key Anaxom (New Lander MY)</td>
<td>1200</td>
<td>1700</td>
<td>2.4</td>
<td>3.6</td>
<td>2.2</td>
<td></td>
<td>Graphite, chlorite schist</td>
<td>Chlorite schist, &quot;transformation and quartz-feldspar augen schist</td>
<td>Bedding?</td>
<td>Massive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey Zinc (Fortuna Lake)</td>
<td>1000</td>
<td>75 max.</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td>Fragmental metarocky rocks</td>
<td>Fragmental metarocky rocks</td>
<td>Folds</td>
<td></td>
<td>Massive</td>
<td></td>
</tr>
<tr>
<td>Besso Self-Heating (Halfmile Brook)</td>
<td>1000</td>
<td>75 max.</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td>Fragmental metarocky rocks</td>
<td>Fragmental metarocky rocks</td>
<td>Folds</td>
<td></td>
<td>Massive</td>
<td></td>
</tr>
<tr>
<td>American Metal Co. (Devil's Elbow)</td>
<td>600</td>
<td>1200 max.</td>
<td>2.4</td>
<td>3.6</td>
<td>2.2</td>
<td></td>
<td>Chlorite schist</td>
<td>Sericite-sericite schist, quartz-feldspar augen schist</td>
<td>Breccia</td>
<td>Massive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Captain Mine</td>
<td>300</td>
<td>80</td>
<td>800</td>
<td>1.2</td>
<td></td>
<td></td>
<td>Metamorphosed chlorite tuff</td>
<td>Chlorite schist</td>
<td>Chlorite schist, quartz-augen schist</td>
<td>Folds</td>
<td>Massive</td>
<td></td>
</tr>
</tbody>
</table>

**N.B.** - All of the above deposits are of Middle Ordovician (Enoic) age, except Nigado, Heyweb, and Sturgeon River-Hobby 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 Wallister (1960), Canadian Mines Handbook, Geological Survey of Mines, volume 2 of Structural Geology of Canadian Ore Deposits (1957), and weekly issues of the Geological Survey 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>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Group</th>
<th>Map-units</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td>Quaternary</td>
<td></td>
<td></td>
<td>glacial drift; alluvium</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>Ordovician</td>
<td>Tetagouche</td>
<td>9</td>
<td>massive and disseminated sulphides; arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>meta-andesite; chlorite schist; minor graphite schist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7b</td>
<td>similar to 7a, but possibly younger.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7a</td>
<td>banded quartz-chlorite-hematite schist; graphite schist; chlorite schist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6b</td>
<td>similar to 6a, but possibly younger.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6a</td>
<td>chloritic argillite, chlorite schist; minor meta-andesite, graphite schist, quartz-feldspar augen schist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>graphite schist (sheared)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>quartz-sericite schist (sheared).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>&quot;iron-formation&quot;; chlorite schist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>chloritic siliceous argillite, graphite schist, minor carbonate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1b</td>
<td>similar to 1a, but predominantly quartz-sericite schist, and possibly younger.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1a</td>
<td>quartz-feldspar augen schist, quartz-sericite schist.</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Rock types</th>
<th>Quartz**</th>
<th>Feldspar**</th>
<th>Muscovite</th>
<th>Chlorite</th>
<th>Hematite</th>
<th>Actinolite</th>
<th>Epidote</th>
<th>Calcite</th>
<th>Pyrite</th>
</tr>
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<tr>
<td>Quartz-feldspar augen schist</td>
<td>40 - 50</td>
<td>20 - 40</td>
<td>15 - 20</td>
<td>0 - 3</td>
<td></td>
<td></td>
<td></td>
<td>0 - 4</td>
<td>2</td>
</tr>
<tr>
<td>&quot;Iron-formation&quot;***</td>
<td>35 - 45</td>
<td>5 - 10</td>
<td>15 - 25</td>
<td>10 - 20</td>
<td>15</td>
<td>0 - 3</td>
<td>1 - 5</td>
<td>0 - 2</td>
<td></td>
</tr>
<tr>
<td>Quartz-sericite schist</td>
<td>45 - 60</td>
<td>10 - 20</td>
<td>20 - 35</td>
<td>0 - 1</td>
<td></td>
<td></td>
<td>1 - 2</td>
<td>3 - 8</td>
<td>3 - 4</td>
</tr>
<tr>
<td>Graphite schist****</td>
<td>50</td>
<td>5</td>
<td>35</td>
<td>0 - 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 - 5</td>
</tr>
<tr>
<td>Argillite</td>
<td>30 - 40</td>
<td>10 - 30</td>
<td>10 - 30</td>
<td>0 - 4</td>
<td>1 - 5</td>
<td></td>
<td></td>
<td>5 - 25</td>
<td>0 - 1</td>
</tr>
<tr>
<td>Banded quartz-chlorite-hematite schist</td>
<td>15 - 30</td>
<td>10 - 20</td>
<td>10 - 35</td>
<td>10 - 30</td>
<td>5 - 15</td>
<td>0 - 15</td>
<td>1</td>
<td></td>
<td>1 - 2</td>
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<td>Meta-andesite</td>
<td>5 - 10</td>
<td>30 - 40</td>
<td>15 - 30</td>
<td></td>
<td></td>
<td></td>
<td>2 - 10</td>
<td>5 - 15</td>
<td></td>
</tr>
</tbody>
</table>

*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 Tétagouche 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" (Fettijohn, 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 interlaminated 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 quartzfeldspar 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
Resistant bands in quartz-chlorite-hematite schist standing out in relief on weathered surface. Note contorted bands. Scale in inches.

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

Quartz mosaic
"Dusty" inclusions in feldspar megacryst. Inclusions are absent from the margins of the megacryst
White mica warped around the feldspar megacryst

Figure 1
x24
Arrangement of inclusions in a feldspar megacryst

Figure 2

Quartz filling areas that were probably under tension during rotation of the megacryst
Feldspar megacryst. Supposed direction of rotation is indicated by the curved arrow
Quartz filling areas that were probably under tension during rotation of the megacryst

Figure 2
x16
Rotated feldspar megacryst
Feldspar megacryst partly replaced by quartz along fractures in the megacryst. Under crossed nicols all fragments of the megacryst have simultaneous extinction.

Quartz vein with non-matching walls in megacryst

White mica

**Figure 3**

Replacement of a rotated feldspar megacryst by quartz

---

Rim of feldspar replaced by quartz

Quartz vein in feldspar, indicating that the quartz replaced feldspar

Carlsbad twin plane

Quartz mosaic

Original unaltered border of the feldspar megacryst

**Figure 4**

Replacement of a feldspar megacryst by quartz
Figure 5
x28
Quartz megacryst
Calcite replacing part of the quartz megacryst and exerting its crystal form

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.

<table>
<thead>
<tr>
<th>Parent Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>shearing (volume increased; gain SiO₂)</td>
</tr>
<tr>
<td>sericitization (Fe and Mg lost)</td>
</tr>
<tr>
<td>Quartz-sericite schist</td>
</tr>
<tr>
<td>Quartz augen gneiss</td>
</tr>
<tr>
<td>Quartz-feldspar augen gneiss</td>
</tr>
</tbody>
</table>

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 ryolitic (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 microfolds (Plates 5, 6, and 12). No graded bedding, cross-bedding, or
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 Brock 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, chalcopyrite, tetrahedrite, and arsenopyrite; the gangue minerals are quartz and calcite. No relationship was found between depth and grain size or mineral association.

Bandung 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

KEY TO SYMBOLS USED IN FIGURES 6 TO 19

- \texttt{asp}: arsenopyrite
- \texttt{cp}: chalcopyrite
- \texttt{g}_1: first generation of gangue
- \texttt{g}_2: 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

x 14

Colloform 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 exsolation (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

Second generation pyrite
First generation pyrite containing many flecks of a gangue mineral

Two generations of pyrite

Figure 11

Galena replacing sphalerite along crystalllographic planes in sphalerite
Galena along contacts of sphalerite with quartz and calcite

Replacement along crystalllographic 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

Sphalerite vein with matching walls cutting across pyrite and chalcopyrite

Figure 15
x300
Vein of chalcopyrite in galena and sphalerite

Chalcopyrite vein cutting sphalerite and galena
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 chalcopyrite (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
$x \times 380$
Close association of galena and tetrahedrite

Figure 17
$x \times 300$
Relationship of arsenopyrite with pyrite, sphalerite, and quartz (gangue)
Pyrite (and sphalerite) having smooth boundaries with arsenopyrite
Gangue (quartz) apparently embaying the arsenopyrite

Figure 18
x340
Arsenopyrite nucleus for precipitation of pyrite and sphalerite

Older gangue mineral (quartz)
Sphalerite-rich band in pyrite fragments that have matching boundaries
Vein of younger gangue minerals (quartz and calcite) cutting $g_1$ (quartz)

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.

<table>
<thead>
<tr>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
</tr>
<tr>
<td>Arsenopyrite (and gold?)</td>
</tr>
<tr>
<td>Pyrite (and gold?)</td>
</tr>
<tr>
<td>Sphalerite</td>
</tr>
<tr>
<td>Chalcopyrite</td>
</tr>
<tr>
<td>Brecciation</td>
</tr>
<tr>
<td>Quartz and calcite</td>
</tr>
<tr>
<td>Galena</td>
</tr>
<tr>
<td>Tetrahedrite (and silver?)</td>
</tr>
<tr>
<td>Gold (?)</td>
</tr>
<tr>
<td>Fracturing</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Depth Range (feet below the average surface elevation)</th>
<th>Number of drill-holes</th>
<th>Core length (feet)</th>
<th>Average (oz. per ton)</th>
<th>Average (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>8</td>
<td>6.7</td>
<td>trace</td>
<td>1.64</td>
</tr>
<tr>
<td>100-200</td>
<td>13</td>
<td>4.7</td>
<td>0.012</td>
<td>3.00</td>
</tr>
<tr>
<td>200-300</td>
<td>7</td>
<td>3.9</td>
<td>0.022</td>
<td>2.80</td>
</tr>
<tr>
<td>300-400</td>
<td>7</td>
<td>4.4</td>
<td>0.017</td>
<td>2.32</td>
</tr>
<tr>
<td>Below 400</td>
<td>6</td>
<td>11.1</td>
<td>0.027</td>
<td>2.66</td>
</tr>
</tbody>
</table>
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 Brock 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 58+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 ± 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 meta-
morphism. 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 $370 \pm 20$ 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 $491 \pm 12^\circ C$. (At combined partial pressures of sulphur and arsenic equal to 1,035 bars, arsenopyrite and pyrite can coexist at temperatures up to $509 \pm 10^\circ C$. 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 Clea-water 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.
Sorensen (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 Brock 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 $\frac{S^{32}}{S^{34}}$ 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).

Volatile associated with igneous activity could have been channelled into favourable structural traps, where \( \text{H}_2\text{S} \) 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 $\frac{s^{32}}{s^{34}}$ 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.
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Turner, F.J., and Verhoogen, J.  
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.
APPENDIX 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, ZPHALERITE, 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, 21, 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

OFF SECTION

D. D. H. T-9

1.0', 6.40, 2.64, 0.38, 0.025, 3.56
APPENDIX II

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 analysed colorimetrically for zinc, copper, and lead. About 100 mg of the sample was fused with KHSO₄ 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 SiO₂, 0.105 gm TiO₂, 1.534 gm Al₂O₃, 0.474 gm Fe₂O₃, 0.309 gm MgO, 0.924 gm CaCO₃, 0.384 gm Na₂CO₃, and 0.313 gm K₂CO₃.

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

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Sample No.</th>
<th>Zn ppm</th>
<th>Cu ppm</th>
<th>Pb ppm</th>
<th>Ag ppm</th>
<th>Approximate Location</th>
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<td>6+00 W; 2+10 N</td>
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<td>5</td>
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<td>4+50 W; 1+50 N</td>
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<td>10.0</td>
<td>7+50 W; 0+00</td>
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<td>Quartz-sericite</td>
<td>OBST-12</td>
<td>0</td>
<td>100</td>
<td>60</td>
<td>*tr.</td>
<td>8+00 W; T-12(637 ft.)</td>
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<td></td>
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<td>3980</td>
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<td>&gt;75</td>
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<td></td>
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<td>&gt;200</td>
<td>110</td>
<td>&gt;75</td>
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<td>8+00 W; T-5(185 ft.)</td>
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<td>&gt;75</td>
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<td>90</td>
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<td>**3961</td>
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<td>160</td>
<td>60</td>
<td>&lt;0.5</td>
<td>0+00 ; T-2 (193 ft.)</td>
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*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

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<th>Rock type</th>
<th>Sample No.</th>
<th>Zn ppm</th>
<th>Cu ppm</th>
<th>Pb ppm</th>
<th>Ag ppm</th>
<th>Approximate Location</th>
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<td>150</td>
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Traverse southward, between 38+00 E and 50+00 E

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<th>Pb ppm</th>
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<td>44+00 E; 38+00 N</td>
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Traverse southward, between 52+00 E and 61+00 E

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

SCALE 1 INCH : 200 FEET