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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 67-49

GEOLOGY AND MINERAL DEPOSITS OF THE NIGADOO RIVER-MILLSTREAM RIVER AREA, GLOUCESTER COUNTY, NEW BRUNSWICK

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J. L. Davies, W. M. Tupper, D. Bachinski,
R.W. Boyle, and R. Martin

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

This paper describes the general geology and mineral deposits of the Nigadoo River-Millstream River area in the northern part of the Bathurst-Newcastle mineral belt, New Brunswick.

The country rocks are Ordovician and Silurian argillites, greywackes, phyllites, slates, graphitic schists, and conglomerates, intruded in places by diabase, gabbro, and diorite sills and irregular bodies. A quartz monzonite-granodiorite stock (Nicholas Dénys granitic stock) and a number of quartz-feldspar porphyry and aplite dykes and plugs, all of Devonian age, intrude the sedimentary rocks. Adjacent to the Nicholas Dénys granitic stock the sedimentary rocks are transformed to skarn and hornfels.

The Silurian sedimentary rocks are folded into a northeast-trending synclinorium, and the Ordovician sediments occur in tight isoclinal folds with a general northeast trend. Both ages of rocks are faulted in two major directions. The principal northeast-striking faults form part of a large system known as the 'Rocky Brook-Millstream Break'. The northwest-striking faults are widespread in the map-area, but occur mainly in the Silurian rocks. Some of the northwest-striking faults are mineralized and contain orebodies.

Both the Ordovician and Silurian rocks contain mineral deposits. The principal types are contact metamorphic lenses in skarn, and veins and lenses of sulphides in sheared and mylonitized zones and in northwest-striking faults and fractures.

The principal minerals in the contact metamorphic lenses are magnetite, various calc-silicates, chalcopyrite, and minor amounts of pyrite, sphalerite, pyrrhotite, arsenopyrite, molybdenite, and scheelite. None of the contact metamorphic deposits are exploited at the present time.

The veins and lenses in sheared and mylonitized zones and in northwest-striking faults contain a varied suite of minerals. Some have essentially pyrite, pyrrhotite, sphalerite, and galena; a few contain mainly chalcopyrite; others consist essentially of quartz, arsenopyrite, and gold; and still others have a suite comprising pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, and galena. The last type forms the main orebodies of the Nigadoo mine, the major sulphide deposit in the area.

Disseminated molybdenite occurs in altered fault and fracture zones in parts of the Nicholas Dénys granitic body. The mineral has also been noted as disseminations and in fractures in the skarn and hornfels associated with this body.

GEOLOGY AND MINERAL DEPOSITS OF THE NIGADOO RIVER-MILLSTREAM RIVER AREA, GLOUCESTER COUNTY, NEW BRUNSWICK

INTRODUCTION AND GENERAL GEOLOGY OF THE BATHURST-NEWCASTLE MINERAL BELT

R.W. Boyle

GENERAL STATEMENT

This paper contains three contributions to the geology and mineral deposits of the Nigadoo River-Millstream River area, Gloucester County, New Brunswick. This area is some 12 miles northwest of the town of Bathurst and comprises a part of the northern portion of the Bathurst-Newcastle lead-zinc-copper-silver mineral district.

The first contribution describes the regional geology and mineral deposits of the Nigadoo River-Millstream River area and provides a setting for the other two papers which deal with the geological and geochemical details of two types of mineral deposits that have been intensively explored in the area.

The present paper completes a part of an extensive geological and geochemical survey of the Bathurst-Newcastle mineral district now being carried out by the Geological Survey of Canada. Seven reports have been published to date (Roy, 1961; Boyle and Davies, 1964; Tauchid, 1964; Stockwell and Tupper, 1966; Boyle et al., 1966; Tupper et al., 1968; Tupper, 1968), and others dealing with various geological and geochemical projects carried out in the area will follow as field and laboratory work progresses.

GENERAL GEOLOGY OF THE BATHURST-NEWCASTLE DISTRICT

Early geological descriptions of the district were given in reports by Ells (1881, 1883), Young (1911), Shaw (1936), and Alcock (1935, 1941). More recent descriptions and geological maps have been published by Skinner and McAlary (1952), Skinner (1953, 1956), Holyk (1956), Smith and McAllister (1956), McAllister and Smith (1956), Jones and Smith (1957), Smith et al. (1957), Smith and Skinner (1958), Davies (1959), McAllister (1960), Jones (1962a, 1962b, 1964), Sims (1961), Dawson (1961), Anderson (1961), Rose et al. (1962), Boyle and Davies (1964), and Boyle et al. (1966).

MS received: 31 July, 1967

Two regional geological units can be recognized in the Bathurst-Newcastle district. These include a basement complex of Ordovician-Silurian-Devonian folded sediments and volcanics intruded by various basic and acidic rocks, and a discontinuous cover of relatively flat-lying Pennsylvanian conglomerates, siltstones, and sandstones. The basement complex is roughly divisible into two belts on a deformational basis – a southern Ordovician folded belt and a northern Silurian-Devonian folded belt. These belts are more or less separated by an extensive fault system known locally as the 'Rocky Brook-Millstream Break'. The sediments and volcanics in the southern Ordovician folded belt are much more severely folded and contorted than the sediments and volcanics in the northern Silurian-Devonian belt.

The age, stratigraphic sequence, and lithology of the various rocks are given in the Table of Formations and shown on Figure 1 (in pocket). Both the table and figure are considerably generalized, and no attempt will be made to discuss the complexities of the geology of the district.

The Ordovician folded belt underlies the southern part of the district and comprises highly folded and contorted volcanic and sedimentary rocks (Tetagouche Group) that are intruded by Ordovician and Devonian gabbro and diorite sills and dykes and by Devonian granitic stocks and masses.

The Tetagouche Group rocks are host to a number of massive sulphide deposits of large tonnage. The deposits occur mainly in drag-folded zones, in severely contorted and sheared zones, and in relatively well-defined shear and schist zones. The principal hypogene minerals in the massive sulphide deposits are pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, arsenopyrite, bornite, and tetrahedrite. Many of the massive sulsphide deposits have well-developed gossans consisting mainly of limonite with some quartz, anglesite, beudantite, barite, scorodite, and jarosite.

In addition to the massive sulphide deposits the Tetagouche Group and the granitic body southwest of Bathurst contain a variety of other mineral deposits. Chief among these are the sedimentary magnetite deposit at Austin Brook on Nepisiguit River, the manganese (manganite-pyrolusite) occurrence in quartz veins at Tetagouche Falls on Tetagouche River, the pyrite-pyrrhotite-sphalerite-galena veins in the Nigadoo River-Millstream area, and the molybdenite-beryl occurrence near the north end of Pabineau Lake in the Bathurst granite.

The Silurian-Devonian folded belt consists of volcanic and sedimentary rocks of Middle and Late Silurian age and Early and Middle Devonian age. The deformation of these rocks is not so intense as in the Ordovician folded belt. Locally the Silurian strata are intruded by gabbro and diorite sills and dykes, granitic stocks, quartz-feldspar porphyry dykes, sills, and plugs, and aplitic dykes, all of which are thought to be of Devonian age. The

CONDENSED TABLE OF FORMATIONS

ERA		PERIOD OR EPOCH	GROUP	FORMATION	LITHOLOGY
CENOZOIC		Pleistocene and Recent			Muskeg, soil, till, gravel, alluvium.
	PALEOZOIC	Pennsylvanian		Clifton	Grey sandstone, grey-green siltstone, minor olive green and red shale; coal seams.
				Bathurst	Red conglomerate and grit at base; red sandstone, siltstone, and shale.
		Marked Unconformity			
		Devonian	Intrusive and Granitized Contact		Granite, quartz diorite, quartz monzonite, granodiorite, and associated quartz and quartz-feldspar porphyries.
		Devonian and Silurian(?)	Intrusive Contact		Diabase, gabbro, diorite, and serpentinized peridotite.
		Lower Devonian		Dalhousie	Basic volcanic rocks: andesite and associated dykes and sills, andesite tuff; minor felsite and agglomerate. Sedimentary rocks: black shale and argillite, siltstone, limestone, and conglomerate.
		Upper Silurian	Chaleur Bay (in part)		Volcanic rocks: rhyolite, agglomerate, rhyolite tuff, porphyry, andesite, and basalt. Sedimentary rocks: argillite, phyllite, greywacke, mudstone, siltstone, conglomerate, and limestone. Skarn and hornfels in vicinity of granitic rocks.
		Ordovician(?)	Intrusive Contact		Diabase, gabbro, and diorite.
		Ordovician(?)	Elmtree (Probably equivalent to Tetagouche Group)		Phyllite, slate, argillite, greywacke, conglomerate, and siliceous limestone. Basic volcanic flows and breccia in lower part. Skarn and hornfels in vicinity of granitic rocks.
		Middle Ordovician	Tetagouche (in part)		Acid and basic volcanic rocks, augen schists; greywacke, phyllite, slate, graphitic schist, and iron-formation.

Devonian volcanic rocks and sediments are intruded by coarse-grained dioritic and gabbroic masses that may represent volcanic fissures and necks.

The Silurian rocks contain a number of magnetite deposits, sulphide veins, and molybdenum occurrences that are described in detail in the following papers. The Devonian rocks are not extensively mineralized but, contain scattered occurrences of copper sulphides, generally in silicified and altered zones near the intrusive dioritic and gabbroic masses.

Flat-lying Pennsylvanian conglomerates, siltstones, sandstones, and shales underlie the eastern part of the district, and small outliers, suggesting a once continuous cover, occur in several places, particularly near Tetagouche Lakes in the northern part of the district. The Pennsylvanian rocks rest unconformably on the older rocks and were probably laid down after the lead-zinc-copper sulphide and other deposits of the district were formed. The Pennsylvanian rocks are only sparsely mineralized. Locally, plant remains in the sandstones and conglomerates are replaced by pyrite and by chalcopyrite and chalcocite which alter to malachite. None of these occurrences are of economic importance.

GEOLOGY AND MINERAL DEPOSITS OF THE NIGADOO RIVER-MILLSTREAM RIVER AREA, GLOUCESTER COUNTY, NEW BRUNSWICK

J.L. Davies

INTRODUCTION

The area described lies some 12 miles northwest of Bathurst, is approximately 10 miles long and 4 miles wide, and is readily accessible by good paved and gravel roads which connect with New Brunswick Highway No. 11.

The Nigadoo River-Millstream River area has received much attention from geologists and prospectors since the late 1800s. The skarn-type magnetite deposits were discovered about 1890, and part of the Quebec Sturgeon River Mines, Ltd. sulphide deposit was found prior to 1891 (Jack, 1894). Both of these deposits have been investigated numerous times since. Lindeman (1909) and Young (1911) have described the magnetite-skarn occurrences, and Alcock (1935, 1941) gave a brief description of the area as a whole. The first comprehensive report of the area was that by MacKenzie (1951), who carried out an extensive exploration program in 1949 and 1950 on behalf of the Rocky Brook-Millstream Syndicate. Further work was carried out in 1953 by Sage (1953) on behalf of M.J. O'Brien, Limited. The regional geology of the map-area was also shown as part of the Bathurst map-area (Skinner, 1953).

Several sulphide and other mineral deposits occur within the map-area; some, viz. the Nigadoo and Beresford Copper, are described in separate contributions in this paper; the others are described briefly below.

ACKNOWLEDGMENTS

The writer thanks R. Martin, A. Kamili, D. Bachinski, and S. Lee for their assistance in the field work, as well as the officials of Quebec Sturgeon River Mines Ltd., Noranda Mines Ltd., and Drs. C. Cheriton and A.B. Baldwin for providing various types of geological information.

REGIONAL GEOLOGY

The rocks of the map-area (see Table of Formations and Map 16-1967) lie on the south limb of a broad synclinorium and include Middle Ordovician phyllites, graphitic schist, and subgreywacke and Upper Silurian greywackes, argillites, conglomerate, calcareous slates and phyllites, slates, argillites, and quartzose subgreywacke. These are intruded by Ordovician

TABLE OF FORMATIONS

ERA		PERIOD OR EPOCH	GROUP	LITHOLOGY
CENOZOIC		Pleistocene and Recent		Muskeg, soil, till, gravel and glacio-fluvial sediments.
	PALEOZOIC	Devonian		Aplite, feldspar and quartz porphyry, and quartz-feldspar porphyry. Quartz monzonite-granodiorite.
		Devonian or Silurian(?)		Diabase, diabasic gabbro, diorite, and serpentinized peridotite.
		Intrusive Contact		
		Upper Silurian	Chaleur Bay	Greenish grey slate, phyllite, argillite, and sandstone; minor red argillite, phyllite, sandstone, and limestone. Hornfels in vicinity of Nicholas Dénys granodiorite. Conglomerate, grit, greywacke, and argillite. Hornfels in vicinity of Nicholas Dénys granodiorite. Greywacke, argillite, and slate. Hornfels in vicinity of Nicholas Dénys granodiorite. Greywacke, argillite conglomerate and siliceous limestone. Skarn and hornfels in vicinity of Nicholas Dénys granodiorite.
		Fault - Unconformity		
		Ordovician	-	Diabase, diabasic gabbro, and diorite.
		Intrusive Contact		
		Middle Ordovician	Tetagouche	Dark grey phyllite, argillite, graphitic schist and phyllite, and quartzose subgreywacke. Minor siliceous limestone.

and Devonian sills, dykes and plugs of diabase, diabasic gabbro, diorite, serpentinized peridotite, and by dykes and plugs of quartz and feldspar porphyries and a quartz monzonite-granodiorite stock.

The south limb of the synclinorium is cut by a major lineament, the so-called 'Rocky Brook-Millstream Break', which appears to represent a wrench fault system in which the principal fault is associated with a zone of tight folding in the lower part of the Silurian rocks.

DESCRIPTION OF FORMATIONS

The rocks of the area belong to the Tetagouche and Chaleur Bay Groups. There are in addition a number of basic and acidic intrusives throughout the area. The age and lithology of the various rocks are given in the accompanying Table of Formations.

Tetagouche Group

The rocks of the Tetagouche Group (Alcock, 1941; Skinner, 1953) underlie the southern part of the area. They have suffered intense structural deformation, and lie in a series of tight isoclinal folds, a feature that precludes any estimate of their thickness.

The Tetagouche rocks consist chiefly of phyllite and argillite, the latter in part carbonaceous, especially in the western part of the area. Relatively minor lenses of quartzose subgreywacke, which increase in abundance eastward, occur in both rock types. The subgreywacke is a quartzose rock containing 30 to 60 per cent quartz grains varying in size from coarse sand to silt and set in an argillaceous matrix of chlorite, quartz, and sericite. Approximately 5 to 10 per cent of the quartz grains show secondary overgrowths. A poorly developed grain gradation is commonly present but most lenses are small and discontinuous, and only rarely are suitable for determining tops, etc.

Most of the rocks of the Tetagouche Group have suffered intense mechanical deformation, resulting in the obliteration of most primary structures. The intensity of mechanical deformation increases as the Rocky Brook-Millstream fault system is approached.

Silicification of the sedimentary rocks is present at contacts with the basic intrusive rocks, but this is a relatively minor feature. Inclusions or xenoliths of sedimentary rocks in the basic intrusions generally display better preserved primary structures such as bedding, and in places cross-bedding. A few fossil localities are also present near basic intrusions. It appears that the sedimentary inclusions occupied pressure shadow zones

during the deformation of the sedimentary rocks thereby escaping severe deformation; the fossils are relatively well preserved.

In places, thin quartz laminae are interlayered with the phyllitic layers generally parallel to the original bedding. In fault zones such as the one occurring in the vicinity of the Hachey and Shaft sulphide bodies of the Sturgeon River deposit (see Fig. 2, in pocket), the quartz-phyllite bands are crushed and crumpled and are cemented by quartz and calcite. Other alterations include chloritic seams and bands associated with films of pyrite; in some places serpentine and talc are developed.

The Tetagouche Group rocks are thought to be of Middle Ordovician age, a consideration based on one graptolite occurrence in similar rocks some 10 miles southeast of the map-area (Alcock, 1941). Two fossil localities, both near the Millstream River, are reported from the Tetagouche rocks of the Nigadoo River-Millstream River area. Sage (1953) mentions both localities, but Skinner (1953) shows only one. The writer and his co-workers were unable to find either of these fossil occurrences, and the locations shown on Map 16-1967 are those reported by Sage and Skinner. According to Sage severely deformed coral, brachiopod, and bryozoan fauna from the most easterly locality can be classified only according to phyla.

The rocks of the Tetagouche Group are in faulted contact with the overlying rocks of the Chaleur Bay Group, but the difference in the degree of deformation of the rocks of the two groups may indicate that an unconformity exists between them. An unconformity appears to occur west of the present map-area (Davies, 1959), but its presence within the Nigadoo River-Millstream River area is less certain.

Chaleur Bay Group

The rocks of the Chaleur Bay Group (Alcock, 1935, 1941; Skinner, 1956) occur in a broad northeasterly plunging synclinorium that underlies the northern part of the map-area. They can be divided into two general assemblages:

(a) a lower assemblage (units 3, 4 and 5, Map 16-1967) which consists of approximately 3,000 feet of coarse-grained, generally unfossiliferous, clastic sedimentary rocks, and

(b) an upper assemblage (unit 6) consisting of generally fine-grained, fossiliferous, calcareous clastic sedimentary rocks containing a greater proportion of limestone.

The lower assemblage has been subdivided into three units: unit 3, the oldest, consists of interbedded greywacke, argillite, conglomerate, and siliceous limestone (skarn); unit 4 which overlies unit 3 comprises 2,000 to

3,000 feet of finely laminated, thinly interbedded greywacke and argillite; unit 5 which overlies unit 4 consists of 500 to 2,000 feet of conglomerate and grit.

The oldest unit of the Chaleur Bay Group (unit 3) forms a narrow wedge along the Main fault of the Rocky Brook-Millstream fault system from the east boundary of the map-sheet to a point near the extreme southwest boundary of the map-sheet. This unit is distinguished from unit 4 by a greater proportion of conglomerate and the occurrence of a thin layer of siliceous limestone (skarn) of economic significance.

The greywacke-argillite rocks of this unit are similar to those in unit 4 to be described later. The greywacke facies grades locally into conglomerate, such as near and to the east of the Beresford Copper deposit, and northwest of the Shaft deposit (Quebec Sturgeon River Mines) on Rocky Brook. The conglomerate facies is variable in thickness and commonly occurs as highly irregular, discontinuous lenses which grade in places into fractured and altered rocks associated with the Main fault. Northwest of the Shaft deposit, a lens of this conglomerate appears on the north side of the Main fault and thickens as it is traced westward. A short distance farther west, the conglomerate appears on both sides of the Main fault. The beds on the north side face north, whereas those on the south side face south indicating that the Main fault in this area is a fracture along the crest of a tight anticline.

The conglomerate contains pebbles of quartz, green argillite, greenstone, jasper, rhyolite, trachyte, red argillite, and sandstone. The pebbles are generally rounded to subrounded, and in most places they are stretched and flattened parallel to a rude schistosity. Some of the finer clastic material (up to 5 mm) may be angular to subangular, and in places some grains have very irregular outlines. The pebbles are generally closely packed, although in many places only a few pebbles are set in a grit or greywacke matrix. The average size of the pebbles ranges from 10 to 30 millimetres, but some pebbles may be 25 centimetres in diameter. The matrix is generally a dark grey to greenish grey grit or greywacke with some calcareous material in most places. The conglomerate facies grades laterally and vertically into grit of the same composition. Within the aureole of the Nicholas Dénys stock, the greywacke and argillites are transformed to dense hornfelsic rocks.

On both sides of the Rocky Brook-Millstream fault system, and within the metamorphic aureole of the Nicholas Dénys stock, a skarn band, 60 to 120 feet wide, occurs as an interlayer in the greywacke-argillite sequence from Stephens Brook in the east to the mouth of Anne's Creek in the west. Outside of the aureole of the stock, the equivalent of the skarn is a siliceous limestone or dolomite or a limy argillite. Examples of these relatively unmetamorphosed rocks can be seen in the western part of the area along the Main fault near deposits 2, 3, 4, and 5.

The lower greywacke-argillite-conglomerate-skarn sequence is overlain by 2,000 to 3,000 feet of finely laminated, thin-bedded greywacke and argillite (unit 4). The greywacke and argillite are similar to those of unit 3, but in unit 4, conglomerate is a very minor constituent. The greywacke-argillite rocks are generally dark grey to greenish grey, finely bedded rocks, displaying graded bedding, scour and fill structures, and in some places a poorly developed small scale crossbedding. In thin section the greywackes consist of angular to subangular fragments of quartz and feldspar with a minor proportion of rock fragments set in a dark grey to greenish grey argillaceous matrix. The matrix in most places contains appreciable amounts of carbonate. The feldspar to quartz ratio is generally much greater in the Chaleur Bay Group greywackes than in the older Tetagouche Group subgreywackes. The greywackes of unit 4 grade laterally into a finer grained, more slaty facies north of the Main fault and to the west of Rocky Brook.

The greywacke-argillite sequence is overlain by a band of conglomerate and grit with minor argillite (unit 5). The conglomerate is similar to that in the underlying rocks except that it makes up a greater percentage of the unit, and is in general much coarser grained. Grit and argillite of similar composition are interlayered with the conglomerate. The conglomerate-grit band is approximately 2,000 feet thick on the west side of the Nicholas Dénys stock and decreases in thickness east of the stock. The amount of conglomerate in the band also decreases east of the stock. The conglomerate-grit band west of the Nicholas Dénys stock in places contains appreciable amounts of magnetite and gives rise to a prominent aeromagnetic anomaly.

The upper assemblage of rocks in the Chaleur Bay Group (unit 6) comprises a thick sequence of greenish grey calcareous slates, phyllites, siltstones, and argillites which are intercalated with red argillite, phyllite, sandstone, and limestone. These rocks are fossiliferous, but the fossils are generally poorly preserved and serve only to date the series as post-Ordovician. Fossils found by W.M. Tupper in the vicinity of the Nigadoo sulphide deposit, however, were identified as Silurian, and diagnostic Upper Silurian fossils have been found along the strike of these rocks southwest of the map-area (Naylor and Boucot, 1965).

Basic Intrusive Rocks

Basic rocks of two or more ages intrude the sediments within the map-area. A number of sills intrude the rocks of the Tetagouche Group and appear to have been emplaced prior to the folding of the Tetagouche rocks. Evidence for this is seen in the numerous inclusions of sedimentary rocks within the sills which display many primary features whereas similar features in the adjacent sedimentary rocks are nearly completely obliterated.

The sills that intrude the Tetagouche Group vary in thickness from 100 to 1,200 feet and are present throughout the length of the map-area. They are light to dark green, fine- to coarse-grained, intermediate to basic rocks with an ophitic or subophitic texture. In general the rocks are massive, except for sheared contact zones. Two or three joint systems are usually present, and these systems conform to the systems in the enclosing sediments.

The intrusions of intermediate to basic rocks in the Tetagouche Group are generally conformable, but the intervening sediments between two sills are generally tightly folded.

The Chaleur Bay Group sediments are intruded by a number of sills of diorite, diabase, diabasic gabbro, and serpentinized peridotite. In general, these basic intrusions, with the exception of the serpentinized peridotite and diabase associated with the Main fault, are fresher and less altered than their counterparts in the sediments of the Tetagouche Group. They are massive, fine- to coarse-grained, greenish grey rocks, composed mainly of albite and augite with accessory magnetite and secondary hornblende, chlorite, and epidote. In places they are slightly serpentinized.

The serpentinized basic to ultrabasic body exposed along the Main fault of the Rocky Brook-Millstream system is a puzzling feature. It appears to be a sill-like body bounded by fault planes. MacKenzie (1951) named this rock serpentinized peridotite. The serpentinized peridotitic phase extends from just east of the Beresford Copper deposit to near the mouth of Bradley Brook, northwest of the Sturgeon River deposit. West of the mouth of Bradley Brook and east of Lavigne Brook its position is occupied by a diabase sill. MacKenzie (1951) suggested that the serpentinized peridotite lies along a thrust fault plane, but no positive evidence of thrusting was observed by the writer. Further description of this serpentinized peridotite is given in the contribution to this paper by Bachinski.

Acid Intrusive Rocks

The acid intrusive rocks within the map-area comprise:

(a) the Nicholas Dénys quartz monzonite-granodiorite stock, and

(b) numerous dykes, sills, and plugs of quartz porphyry, feldspar porphyry, and aplite.

The Nicholas Dénys stock underlies the central part of the map-area and intrudes the sedimentary rocks of the Chaleur Bay Group. The stock is poorly exposed, except along its southern contact; its northern boundary as shown on the map is largely inferred from aeromagnetic data and from a few diamond-drill holes. It is composed of massive coarse- to

medium-grained pink to grey quartz monzonite with associated phases of granodiorite. The granitic rocks are severely fractured in places, particularly where they are crossed by northwesterly trending faults.

From geological relations the age of the Nicholas Dénys stock is post-Upper Silurian. According to Tupper and Hart (1961) the K/Ar ratio indicates a Devonian age of 390 m.y.

The majority of the acid dykes that cut both Ordovician and Silurian rocks are feldspar porphyry. Only a few quartz and quartz-feldspar porphyry and aplite dykes were seen. In general, the greatest number of acid dykes occur between the Quebec Sturgeon River and Beresford sulphide deposits, where they appear to occupy northwesterly striking fractures within the metamorphic aureole surrounding the Nicholas Dénys stock.

The feldspar porphyry dykes are commonly light grey to dark grey rocks containing euhedral orthoclase and albite, glomeroporphyritic albite, and in places biotite phenocrysts set in a microcrystalline matrix of feldspar, quartz, and biotite. Feldspar laths comprise 60 per cent of the rock. Potash feldspar may make up 20 per cent of the rock, and quartz usually less than 10 per cent. Most feldspar phenocrysts are altered to kaolinite, sericite, calcite, and chlorite. Biotite phenocrysts are altered in part to chlorite, and according to Bachinski (personal communication) some mafic phenocrysts (biotite?) are altered to or replaced by calcite, epidote, and in places pyrite.

Quartz and quartz-feldspar porphyry occur at a few localities; one of these is the porphyry plug cut by the Nigadoo sulphide deposit described in the contribution to this paper by Tupper et al. The other occurrences are in the form of dykes, one of which cuts a diabase sill exposed on the south bank of Millstream River just south of the Half-Mile prospect. Another occurs just west of the Nicholas Dénys-Sormany road and north of Millstream River. It contains cream coloured albite up to 2 millimetres in diameter, as well as anhedral embayed quartz phenocrysts. The material in the embayments and that included in the quartz is similar to the material of the cryptocrystalline matrix. The matrix contains potash feldspar, plagioclase, biotite, and quartz. Biotite forms rare phenocrysts up to 1 millimetre in diameter. Apatite, zircon, calcite, pyrite and arsenopyrite are minor accessories.

Aplite dykes cut the hornfels developed in the metamorphic aureole of the Nicholas Dénys stock, and recent diamond drilling has intersected similar dykes in the stock itself. The aplites are pink to grey granular rocks that are porphyritic in places. Their mineralogy is similar to the Nicholas Dénys quartz monzonite-granodiorite stock.

Metamorphism

The majority of the sedimentary and early basic intrusive rocks in the map-area fall into the sericite-chlorite-carbonate regional metamorphic facies. In the vicinity of the Nicholas Dénys granitic body the sediments in particular have been subjected to thermal metamorphism resulting in the development of hornfels in some places and skarn bands in others. The skarn bands appear to have developed mainly from siliceous dolomites, dolomitic sandstones, and calcareous argillites and greywackes. The hornfels are derived principally from argillites and greywackes. Both the hornfels and skarn are described briefly above and in more detail by Bachinski in a later section of this report.

The width of the thermal aureole around the Nicholas Dénys granitic body is variable; it is some 6,000 feet at its widest point and 5,000 feet at its minimum point.

STRUCTURAL GEOLOGY

Folds

The Chaleur Bay Group sedimentary rocks are folded into a broad synclinorium whose axial plane trends N45°E and whose axis plunges gently to the northeast. A number of minor folds occur on the limbs of this large structure. These have a wavelength of approximately 400 to 600 feet whereas the wavelength of the large structure is some 4 miles. The Tetagouche Group sedimentary rocks occur in tight isoclinal folds whose wavelength in the vicinity of the Quebec Sturgeon River deposit is approximately 100 to 200 feet. In this area, the traces of the axial planes trend N65°E, and the axes of minor drag-folds on the limbs of the isoclinal folds plunge 30 to 60 degrees to the northeast. On the south limb of the synclinorium, two smaller folds appear in the Silurian rocks. These minor folds can be mapped from south of the Nigadoo deposit to the vicinity of the Beresford Copper deposit, but farther west the trace of the axial plane of the minor anticline coincides with the Main fault of the Rocky Brook-Millstream fault system. The trace of the synclinal axial plane can be followed almost to the Nicholas Dénys-Sormany road, but cannot be mapped with certainty west of this road to Rocky Brook. West of Rocky Brook the syncline is again mappable, although its presence in this area was not recognized by Sage (1953).

Faults

Faults are some of the most conspicuous geological features of the map-area, and are probably the most important structures responsible for the localization of mineral deposits of economic interest.

The faults within the map-area can be divided into two main categories according to their relationship to the general structural trend:

(1) Longitudinal faults, which strike north 60 to 80 degrees east.

(2) Transverse faults, consisting of three systems which strike:
   (a) north 40 to 70 degrees west;
   (b) north 20 degrees west to north-south;
   (c) east-west to north 80 degrees west.

Longitudinal Faults

The principal fault system in this category is the so-called 'Rocky Brook-Millstream Break' referred to in this report as the Rocky Brook-Millstream fault system. It forms a major lineament in the central part of the map-area, and appears to consist of a series of en echelon faults associated with tight folding in the lower part of the Silurian sequence and perhaps also in the adjacent Ordovician rocks.

The Rocky Brook-Millstream fault system probably consists of two principal faults, as follows:

(1) The Main fault, or 'Main Break' as it is generally known, which is entirely within the lower part of the Chaleur Bay Group south of the Nicholas Dénys stock.

(2) The Rocky Brook fault which in part separates Silurian rocks from Ordovician rocks. This fault may be a separate fault or it may be partly subsidiary to the Main fault.

The two faults trend approximately north 60 degrees east, but the Main fault has a more northerly strike in the eastern part of the map-area. Both faults cut across the strike of the rocks at small angles and appear to converge just west of the map-area, but diverge again as they are traced farther westward (Skinner, 1956; Smith et al., 1957).

The Main fault is the most prominent fault in the area and can be traced for at least 40 miles to the west of the map-area (Skinner, 1956; Potter, 1965). On aerial photographs the fault stands out as a pronounced lineament, and geologically it is marked by intrusions of serpentinized peridotite and diabase. Diamond-drill holes across the fault in many places indicate a fault-zone 200 to 400 feet wide (including in places the sill of serpentinized peridotite), with a steep dip to the south. The direction and nature of the movement along the fault is not well known. An analysis of drag-fold data near the fault-zone indicates a strike-slip movement resulting in the north block having moved northeastward relative to the south block. This observation is in accord with earlier interpretations made by MacKenzie

(1951) and Sage (1953). MacKenzie, however, thought that the Main fault was a rift or wrench fault superimposed on an earlier thrust fault with the Ordovician rocks thrust over the Silurian rocks. Sage (1953) reached similar conclusions but seemed to think that the Silurian rocks were thrust over the Ordovician rocks. As evidence of thrusting, MacKenzie cited:

(1) The width and complexity of the zone.
(2) The northward overturning of axial planes in the Silurian rocks, as well as the consistency of strikes, particularly in the north block.
(3) The presence of intrusive serpentinized peridotite along the Main fault zone.

The writer has mapped and studied the above features but has found no conclusive evidence in support of MacKenzie's hypothesis. In plan, along most of its length, the trace of the Main fault is coincident with what appears to be a tight, slightly overturned isoclinal anticline. This evidence is difficult to reconcile with that of a thrust plane. MacKenzie further thought that the edge of the thrust sheet lay a few hundred feet north of the Main fault, but the writer was unable to find any indication that this is the case.

The Rocky Brook fault lies in part between the Ordovician and Silurian rocks and gives rise to a less prominent lineament than the Main fault. The width and complexity of the Rocky Brook fault, however, are probably as great as that of the Main fault. Evidence of this can be seen in the valley of Rocky Brook near the Quebec Sturgeon River deposits, in the Millstream River valley in the eastern part of the map-area, and in the many diamond-drill cores retrieved from the fault zone.

The Rocky Brook fault trends approximately north 80 degrees east and appears to have a steep dip to the south, similar to the Main fault. Its topographic expression is evident from a point 7,500 feet west of the Quebec Sturgeon River Shaft deposit to the falls on the Millstream River some 7,000 feet east of the Nicholas Dénys-Sormany road. Less prominent topographic indications suggest a continuation of the fault to the east without displacement. Another topographic lineament having a similar trend begins farther east near the junction of Stephens Brook and the Millstream River, and appears to coalesce with the Rocky Brook fault. There is topographic evidence to suggest, however, that this easterly lineament is a continuation of the fault or faults marked by the Stephens Brook valley and the parallel stream to the west.

The nature and amount of movement along the Rocky Brook fault is difficult to determine. Drag-folds and distortion of minor fold axes near the fault indicate a right-hand strike slip movement similar to that of the Main fault.

Two other minor longitudinal lineaments occur southwest of the Quebec Sturgeon River deposit and north of Millstream River. These lineaments can be followed for only relatively short distances and appear to mark the schistose contacts between a diorite sill and the surrounding sedimentary rocks.

Transverse Faults

The transverse faults in Nigadoo River-Millstream River area can be divided into three systems, as follows:

(1) A system trending north 40 to 70 degrees west.

(2) A system trending approximately north-south to north 20 degrees west.

(3) A system trending approximately east-west to north 80 degrees west.

Many of the transverse faults shown on the areal map are inferred from topography, and probably some are actually joint systems exaggerated by erosion. It should be noted, however, that several joints are small scale faults with displacements of less than an inch to well over a foot.

The northwesterly trending faults occur principally north of the Main fault. Movements along some faults have resulted in the displacement of the east walls to the south relative to the west walls, i.e., an apparent right-hand movement. Along other faults the movements are left-handed. Displacements vary from less than a foot to about 200 feet. The northwesterly trending faults have economic significance, as the Nigadoo sulphide deposit is a filling of such a fracture, and several other occurrences of sulphide minerals appear to be related to them.

The east-west striking faults are mainly south of the Main fault. Evidence again shows that the north blocks moved eastward relative to the south blocks. The nature of these faults is not entirely clear, but their topographic expressions indicate that some may be continuations of the less prominent longitudinal faults.

A topographic lineament trending north 70 degrees west to east-west appears to mark a fault that cuts off the Main fault, and offsets the axial planes of the folds, some 4,000 feet northeast of Stephens Brook. Magnetic data (Geol. Surv. Can., Geophysics Paper 57) also suggests that this lineament marks a fault. The writer has indicated a substantial thickening of unit 3 northeast of the fault, but this interpretation is tentative because of paucity of outcrop and lack of drillhole data in this area.

Only a few north-south trending faults have been recognized within the map-area. The Stephens Brook valley appears to overlie such a fault. MacKenzie (1951) stated that the east wall of this fault is displaced from 200 to 300 feet south relative to the west wall. This fault apparently offsets the Main fault, but this relationship is not clear, according to Bachinski (personal communication).

Another fault trending north-south to north 10 degrees east is inferred from a topographic lineament that appears south of the Main fault 4,500 feet east of the Nicholas Dénys-Sormany road, whence it can be traced intermittently through Sormany for about 5 miles to the south. The nature of this fault is not known, but it may be a subsidiary of the Main fault.

Although the number of observed or inferred north-south striking faults is small, an aerial electromagnetic survey of the map-area indicates a number of anomalies trending north-south especially in the southern half of the map-area, which may indicate north-south faults. Aeromagnetic surveys have also indicated what may be important north-south structures just east of the map-area (Geol. Surv. Can., Geophysics Paper 57).

MINERAL DEPOSITS

Introduction

Although the Nigadoo-Millstream River area has been studied and prospected intermittently for some 70 years, the most intensive search for mineral deposits took place from 1949 to 1953. Numerous occurrences of metallic minerals were found, and many have subsequently been trenched or drilled. Since 1953, 95 per cent of the drill core obtained from over 150 holes has been lost, and the exploration trenches, now largely filled in, provide little or no information. Hence the writer, in gathering all available information on the known mineral occurrences, has relied heavily on the work of MacKenzie (1951) and several other geologists who were responsible for logging the diamond-drill core.

Almost all the mineral deposits in the Nigadoo River-Millstream River area are of the metallic variety; the non-metallic deposits are of little importance, but for completeness the writer has included both categories.

Metallic Mineral Deposits

The metallic mineral deposits are grouped according to their relative age and their predominant constituent metallic minerals. The groups are as follows:

1. Deposits in rocks of the Tetagouche Group and associated intrusives
   (a) pyrite-pyrrhotite-sphalerite-galena veins
   (b) chalcopyrite deposits.

2. Deposits in rocks of the Chaleur Bay Group and associated minor intrusives
   (a) skarn deposits containing: magnetite
   magnetite and sulphides
   essentially sulphides
   (b) quartz-arsenopyrite-gold veins
   (c) chalcopyrite deposits
   (d) pyrite-pyrrhotite-arsenopyrite-sphalerite-galena veins.

3. Molybdenite in the Nicholas Dénys stock.

1. Deposits in Rocks of the Tetagouche Group and Associated Intrusives

(a) Pyrite-pyrrhotite-sphalerite-galena veins

This group is represented by a number of occurrences the most important of which are those belonging to Quebec Sturgeon River Mines, Ltd., viz: deposits 9[1], 10, 11, 12, 13, and 14. These deposits occur along a fault zone some 2 miles long within rocks of the Tetagouche Group. No significant mineralized zones have been found in the adjacent rocks of the Chaleur Bay Group. Of the six deposits in this group, only 9, 10, 12, and 13 are considered in calculations of ore reserves. Underground development has been attempted only on the larger, higher grade, 9 and 10 deposits, which are known respectively as the Hachey and Shaft orebodies. The details of the geology surrounding the Hachey and Shaft orebodies are shown on Figure 2.

The rocks of the Tetagouche Group in the vicinity of the two orebodies consist of dark grey phyllite, schist, and argillite with minor quartzose subgreywacke. A few thin dykes of feldspar porphyry cut these rocks in places, but none were observed in or near the sulphide deposits. Due to severe faulting, the sedimentary rocks are now mylonites, breccias, and schists, almost totally lacking in primary structures. Less deformed rocks farther removed from the intense deformation exhibit graded bedding which indicates the presence of a number of highly compressed isoclinal folds; these folds plunge to the north, east, and northeast, and in places to the southeast. The Hachey and Shaft deposits occur in a zone of highly deformed, brecciated, and altered rocks of the Tetagouche Group which lie between less deformed rocks of the Chaleur Bay Group to the north, and a diabase-diorite

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[1] These numbers refer to deposits shown on Map 16-1967.

sill to the south. The intense mechanical deformation is a result of complex fault movements along the Rocky Brook fault which appears to join or cross the Main fault just west of the area shown on Figure 2.

The Shaft deposit lies just northeast of the junction of the Rocky Brook-Millstream fault and a northwest trending fault, and the Hachey deposit lies about 1,000 feet southeast of this junction. The sulphides in the deposits have two characteristic forms:

(1) A broad zone of sparsely disseminated grains and thin seams of pyrrhotite and pyrite with very minor amounts of sphalerite and galena.

(2) Local concentrations of sphalerite and galena veins enclosed in (1) above. In places these concentrations constitute ore shoots.

The broad zones of pyrite are irregularly shaped bodies up to 1,200 feet long and are up to 300 feet wide at their thickest points. Individual veins of zinc-lead sulphides are narrow, commonly 1 to 3 feet wide, but local vein concentrations occur over widths of 5 to 14 feet. The local concentrations constituting the ore shoots are fairly continuous, but individual veins pinch, swell, and bifurcate throughout the length of the shoots. According to MacKenzie (1957) the ore consists of two types. These are:

(a) A medium- to coarse-grained assemblage of pyrrhotite, pyrite, sphalerite, and galena with very minor amounts of chalcopyrite and arsenopyrite. The latter minerals are associated with quartz and calcite in most places.

(b) Very fine-grained pyrrhotite with sphalerite and lesser amounts of galena in a fine-grained silicified(?) rock rather than in distinct quartz veins. The latter type of ore occurs mostly on or near the 500-foot level. There are indications that individual beds or layers have been selectively replaced by this type of mineralization.

The Shaft deposit, as a whole, is over 900 feet long and approximately 80 feet wide, but only 250 feet of this length is considered of mineable grade and width. A number of other narrow shoots are indicated by underground drilling but are not considered in the present ore reserves. The ore zone varies from 5 to 11 feet in width and consists of a pinching and swelling vein associated with one or two narrower, closely spaced parallel veins. The zone strikes north 65 to 75 degrees east, and is nearly vertical; in places dips of 85 degrees south have been noted. The rake of the ore shoot is steep to the east. MacKenzie (1957) mentions an apparent rake of 65 degrees east.

According to MacKenzie (1957) the ore reserves in the Shaft deposit, to a depth of 500 feet, are as follows:

	Length (feet)	Width (feet)	Tons	Ag (oz/ton)	Pb %	Zn %
Probable ore	250	6.6	82,500	3.63	1.17	4.58
Possible ore	500	10.5	262,500	3.26	2.28	3.30

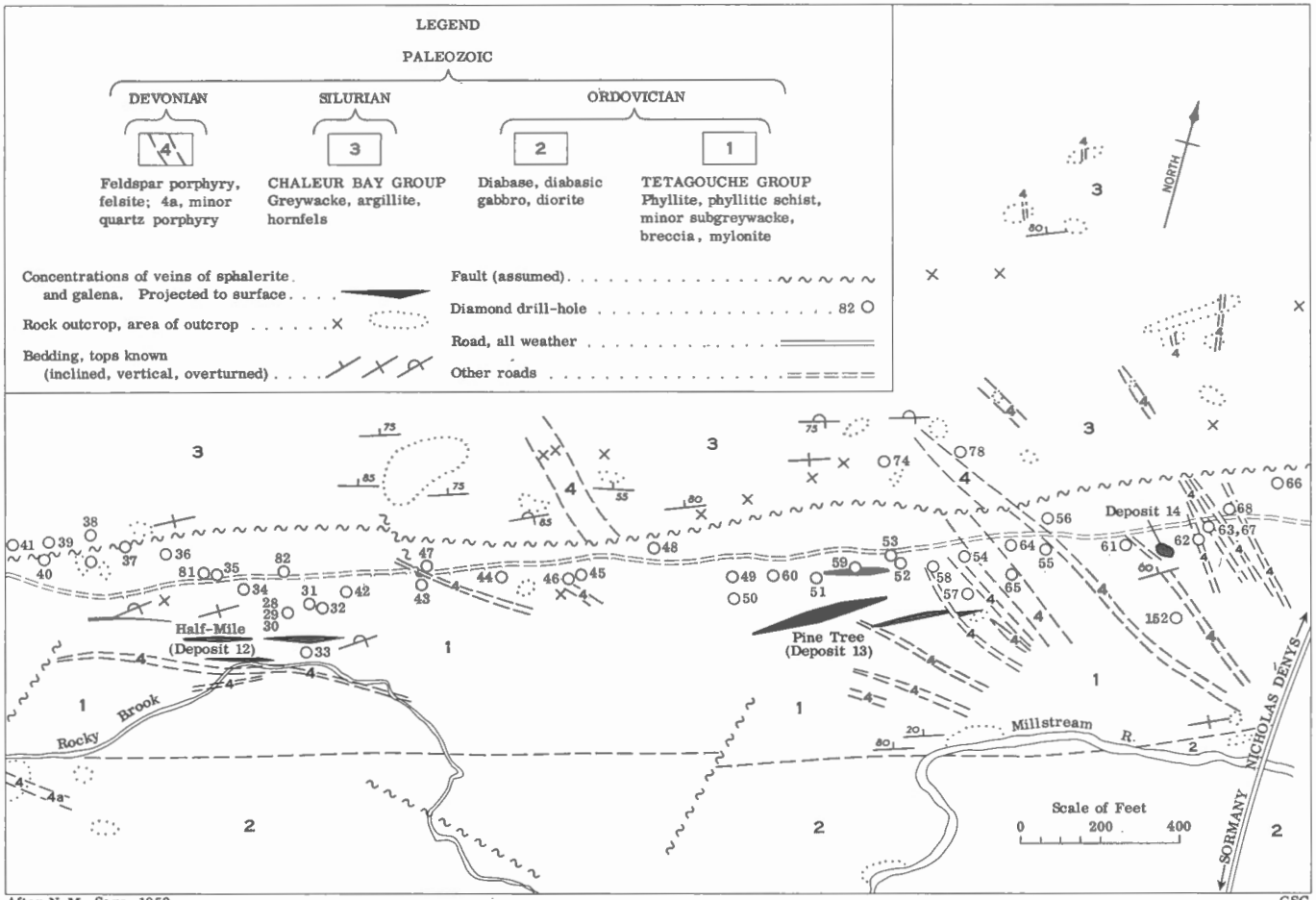
The Hachey deposit has a smaller content of ore, but the tenor of silver is generally higher than that of the Shaft deposit. The ore shoot has a general strike of north 65 degrees east and an average dip of 74 degrees northwest (MacKenzie, 1957), but according to the same author much flatter and even southward dips are indicated in places. The rake of the shoot is 69 degrees east. As the underground workings do not reach the Hachey ore shoot, ore reserves are classed by MacKenzie as possible ore. The tonnage and grade are as follows:

	Length (feet)	Width (feet)	Tons	Ag (oz/ton)	Pb %	Zn %
Possible ore						
(depth 200 feet)	150	13.5	42,000	7.9	1.78	2.71
(depth 500 feet)	150	13.5	105,000	not given	not given	not given

Of the remaining sulphide deposits to the east and also held by Quebec Sturgeon River Mines, Ltd. (viz. 11, 12, 13, and 14) only numbers 12 and 13 can be considered as possible orebodies. Deposit No. 11 represents only a minor occurrence of zinc and lead sulphides. The writer also found some sphalerite and galena 500 feet northeast of No. 11 deposit in Silurian greywackes (deposit No. 42). Deposits 13 and 14 are intimately associated with feldspar porphyry dykes, and part of the sulphide mineralization lies along the porphyry-sedimentary rock contacts. The details of the geology of these two deposits are shown on Figure 3.

According to Smith (1955) the grades and tonnages of deposits 12 and 13 are as follows:

	Length	Width	Tons per vertical foot	Depth	Tons	Ag (oz/ton)	Pb %	Zn %
Deposit No. 12	400	4.3	172	100	17,200	2.5	4.47	3.90
	100	6.3	62.5	100	6,250	3.36	2.24	3.27
Deposit No. 13	700	11.6	812	130	105,560	2.35	2.82	3.40



After N. M. Sage, 1953

GSC

Figure 3. Geology of the Half-Mile and Pine Tree showings, Quebec Sturgeon River Mines, Ltd., (deposits 12, 13 and 14, Map 16-1967)

Deposit Nos. 24 and 38, currently held by Bathurst Silver Mines, Ltd. are similar to deposit Nos. 13 and 14. The sulphides occur in highly deformed Tetagouche Group sedimentary rocks, which are intruded by feldspar porphyry dykes. The veins appear to strike north 65 degrees east, but some have an east-west to northwest-southeast trend. Surface trenching has revealed interesting amounts of silver, lead and zinc, and a number of drill-holes have shown sulphides at depth. The occurrence of the sulphides is, however, characteristically erratic and discontinuous, and up to the present, no economic ore shoots have been found.

Deposit No. 39 is a minor occurrence that may also belong in this group. It consists of small veinlets of sphalerite and galena, containing some silver.

Deposit No. 40, located near the west boundary of the map-area, is similar to that mentioned above, except that it contains appreciable amounts of jamesonite, as well as chalcopyrite and sphalerite. Trenching has revealed narrow veins of sulphides that trend north 65 degrees east to approximately south 80 degrees east, and dip 70 to 85 degrees to the north-west. Subsequent drilling showed that these veins extend to a depth of at least 140 feet. A summary of three of the holes is given below:

Hole	Footage	Width (feet)	Ag (oz/ton)	Zn %	Pb %	Cd %	Sb %
1							
Bearing-magnetic south, dip 45 °	27.1-28.3	1.2	2.75	1.40			
	36.7-38.1	1.4	1.97	0.20			
	43.7-53.7	10.0	minor sulphides				
	53.7-55.3	1.6	11.6	5.20			
	93.9-105.6	11.7	minor sulphides				
	105.6-107.2	1.6	1.79	0.72			
	107.2-112.1	4.9	minor sulphides				
2							
(50 feet west of No. 1 along strike)	37.4-37.6	0.2	7.27	1.38			
	47.2-48.0	0.8	6.30	2.05			
Bearing-magnetic south, dip 45°	97.4-98.4	1.0	1.16				2.74
3							
(50 feet west of No. 2 along strike)	65.8-67.2	1.4	6.41	9.20		0.08	
	93.2-95.5	2.3	17.4		3.05		
Bearing-magnetic south, dip 45°	99.5-100.5	1.0	50.8	5.30		0.05	

(b) Chalcopyrite deposits

The known chalcopyrite deposits in the Tetagouche Group rocks of the map-area are of minor importance. They are represented by two occurrences, deposits Nos. 8 and 35. Deposit No. 8, located in the southwest part of the map-area, consists of disseminated chalcopyrite in silicified argillaceous rocks near their contact with a sill of diabasic gabbro. As far as the writer knows, no work has been attempted on this deposit since it was mentioned by MacKenzie (1951).

Deposit No. 35 consists of a small amount of disseminated chalcopyrite in diabase near the Rocky Brook fault. Little is known about this occurrence.

2. Deposits in Rocks of the Chaleur Bay Group

(a) Skarn deposits

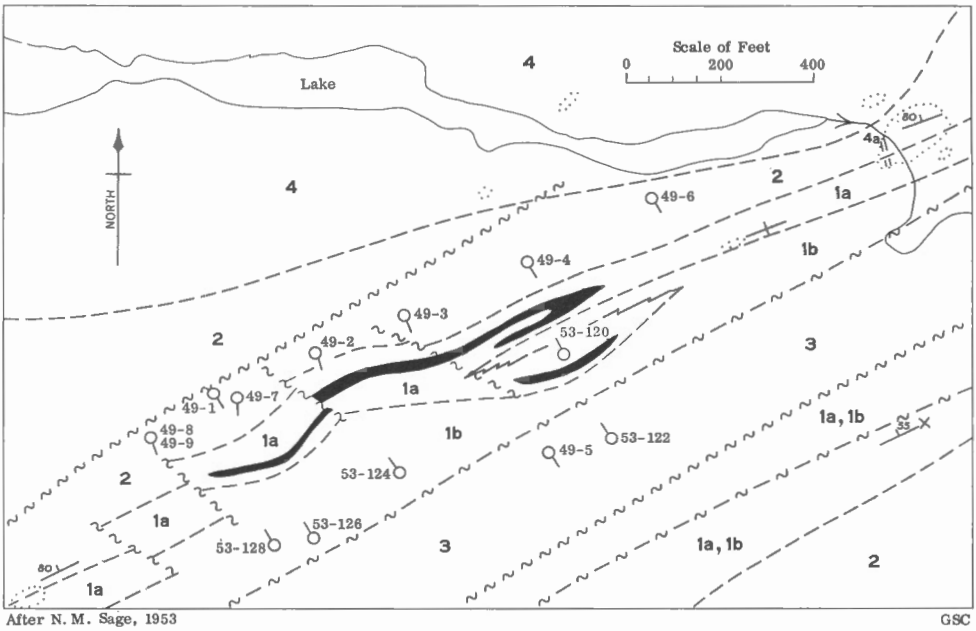
The rocks of the Chaleur Bay Group are generally calcareous, though the upper part is much more so than the lower part. Skarn rocks probably occur in a number of places within the aureole of the Nicholas Dénys stock, but only one zone of importance has been found. This lies within the lower part of the Chaleur Bay Group (unit 3) on both sides of the Main fault, south of the Nicholas Dénys stock. It extends from just east of Stephens Brook in the east, to Anne's Creek in the west. Its western extension is represented by calcareous argillite and limestone. Metallic mineral deposits occur at intervals throughout the length of the skarn on both sides of the Main fault. The deposits on the north side of the fault are perhaps more important, and hence have been more closely investigated. The skarn deposits can be subdivided into three categories as follows:

(1) Magnetite deposits.

(2) Magnetite-sulphide deposits.

(3) Sulphide deposits without appreciable magnetite.

Occurrences of magnetite without appreciable sulphides occur at intervals along the skarn zone, on both sides of the Main fault from near deposit 16 in the west to the Beresford Copper deposit (Nos. 31 and 32) in the east. These deposits are Nos. 17, 18, 21, 22, 23, and 26. The occurrences appear to be lens-shaped and contain minor amounts of pyrrhotite and/or chalcopyrite. The magnetite is commonly fine- to medium-grained and occurs in streaks, irregular layers, and lenses interlaminated with a skarn mineral assemblage of andradite, hornblende, diopside, epidote, and actinolite. The magnetite layers and lenses are commonly only a few inches thick, but in places massive sections a few feet in width are present.



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LEGEND

PALEOZOIC

DEVONIAN

4 Quartz-monzonite and granodiorite; 4a, feldspar porphyry

SILURIAN

3 Serpentinized peridotite, fault gouge and breccia; may include some 1

CHALEUR BAY GROUP (1, 2)

2 Greywacke, argillite, minor conglomerate

1 1a, skarn rocks; may include some 1b; 1b, greywacke, conglomerate and argillite

Magnetite lenses: massive to nearly massive magnetite with chalcopyrite, pyrrhotite, molybdenite, scheelite, arsenopyrite

Rock outcrop, area of outcrop . . . . . ×

Geological boundary (approximate, faulted) . . . . . — — — ~ — ~

Bedding (inclined, vertical) . . . . . / ×

Fault (assumed) . . . . . ~ ~ ~ ~ ~

Diamond drill-hole (inclined) . . . . . —O 53-122

Figure 4. Geology of the Millstream Iron deposit, (deposit 20, Map 16-1967)

Deposit Nos. 16, 20, 25, 27, 28, 31, and 32 are magnetite occurrences containing appreciable pyrrhotite and chalcopyrite. The sulphide minerals occur in small irregular masses, veinlets, and disseminations cutting the magnetite-skarn bands. The most important of these deposits is the Beresford Copper deposit, Nos. 31 and 32, which is described below by Bachinski. Deposit No. 20 is another important example of this type.

This deposit, known as the Millstream Iron deposit, and the Ellis Iron Mine (Lindeman, 1909; Young, 1911; Lindeman et al., 1917; MacKenzie, 1951) consists of two magnetite-rich lenses (Fig. 4). The larger lens is about 900 feet long; the smaller has a length of 250 feet. The lenses have a maximum width of 40 feet, and have been investigated to a depth of approximately 250 feet. According to Lindeman (1909), the magnetite iron ore is 4 to 14 feet wide with an average composition as follows:

Sample No.	Fe %	S %	P %	Insoluble Matter, %
1	19.2	--	--	58.6
2	48.2	0.82	0.04	21.0
3	45.2	--	--	27.7
4	48.4	0.23	0.02	28.9

Young (1911) reported a copper content of up to 6 per cent over a few inches, but no attempt was made at that time to outline the extent of the chalcopyrite mineralization. The drill core obtained in 1949 and 1953 revealed rather widespread though generally low amounts of copper. A summary of the assayed sections of some of the drillholes is tabulated below (for locations see Fig. 4).

Drillhole number	Footage	Width	Ag oz/ton	Cu %	Zn %	Fe %
49-7	257.5-266	8.5	2.25	3.33	0.47	no Fe assay given
49-2	103-128	25.0	0.38	1.20	0.54	
	112.3-140	27.7				23.2
	124-136	12.0				36.5
49-3	138.4-190.5	52.1				27.5
	162.5-190.5	28.0				37.5
	128-166.5	38.5	0.1	0.1-0.8		
49-4	150-191.5	41.5		0.82		
	150-182	32.0				25.6
	162-178	16.0		1.35		31.87

Drillhole number	Footage	Width	Ag oz/ton	Cu %	Zn %	Fe %
49-6	146-154	8.0	nil	0.31		
53-128	311-314.7	3.7	0.84	3.24	1.69	
53-126	278.5-293.5	15.0		0.38	nil	
53-124	290-291	1.0		2.33		
53-122	242.7-251.8 298-300	9.1 2.0		1.02 1.56	nil nil	
53-120	95-110	15.0		1.92	nil	

In addition to chalcopyrite, the skarn in places contains appreciable amounts of molybdenite, which was not recognized in the drill core obtained in 1949 and 1953. The writer noted molybdenite in outcrops of the skarn rocks west of the Nicholas Dénys-Sormany road near diamond-drill hole 49-1 (see Fig. 4), and later molybdenite was recognized by Dr. A.B. Baldwin (personal communication) in a diamond-drill hole in the vicinity of deposit No. 25. This drillhole revealed an interesting thickness of disseminated molybdenite, which renewed interest not only in the Millstream Iron deposit, but also in a large area to the north and northeast. Subsequent work has revealed abnormal contents of molybdenum in the soils of a number of areas and diamond drilling has shown that molybdenite is present in places in the Nicholas Dénys granitic body and its adjacent rocks. These occurrences are discussed below. The presence of abnormal amounts of molybdenum in the rocks near the Millstream Iron deposit (No. 20) was also indicated by stream sediment analyses (Tauchid, 1964). A white or silvery mineral was mentioned in the logs of the 1949 drillholes; some of this was undoubtedly molybdenite. Molybdenite was probably mistakenly identified as specular hematite, arsenopyrite, or graphite. Dr. Baldwin has also observed finely disseminated scheelite in cores from some 1949 drillholes. Subsequent assays have confirmed its presence.

Small amounts of molybdenite (deposit No. 37) are present northwest of the Nicholas Dénys stock in hornfels. This occurrence may also be associated with skarn, indicating that the northern part, and possibly the western part of the thermal metamorphic aureole, are favourable prospecting areas for molybdenite.

Deposit No. 16 is the most westerly occurrence of magnetite. The magnetite is associated with sphalerite and chalcopyrite and occurs in finely laminated skarn near its contact with dark argillite. According to MacKenzie (1951), trenching revealed a patch of sulphides associated with a northwesterly

trending fracture at this site. Chip samples of the mineralized material contained 6.45 per cent copper, 10.84 per cent zinc, and 2 ounces silver per ton.

The remaining deposits of magnetite with associated sulphides (Nos. 25, 27, and 28) occur east of the Nicholas Dénys-Sormany road. Deposit No. 28 was trenched and drilled in 1937, and sphalerite and galena were observed in the trenches over a length of 14 feet, in what was reported to be chloritic argillite overlying a skarn bed (MacKenzie, 1951). Three diamond-drill holes were put down, but only one penetrated significant amounts of mineralized material. The mineralized section gave the following assays:

Drillhole number	Footage	Width (feet)	Zn %	Pb %	Cu %	Ag oz/ton
1	378-381.2	3.2	3.03	4.38	--	0.66
	386.2-387.7	1.5	3.24	2.70	trace	0.52

Deposit No. 25 consists of a small exposure of pyrite, sphalerite, minor galena, and arsenopyrite, associated with magnetite. It occurs near a northwesterly-trending fracture where the skarn appears to wedge out westward (MacKenzie, 1951). Recent drilling in the vicinity of deposit No. 25, has shown the presence of pyrrhotite, pyrite, sphalerite, chalcopyrite, and molybdenite.

Sulphides have also been reported in a magnetite lens occurring south of the Main fault (deposit No. 27), although nothing is known about the nature of this lens.

Occurrences of sulphide without appreciable magnetite are represented by deposit Nos. 15 and 19. Deposit No. 15, located near the west end of the skarn zone, was investigated in 1950 by six diamond-drill holes. The deposit consists of nearly massive to disseminated pyrrhotite, sphalerite, chalcopyrite, pyrite, and galena. According to MacKenzie (1951), the sulphides occur as fracture fillings cutting a grey cherty argillite (skarn). The fractures trend mainly northwest-southeast, but some are parallel to the bedding. The sulphide zone plunges westward, is 100 to 150 feet long, 12 to 30 feet wide, and extends to a depth of 200 feet. The assay data from two of the 1950 drillholes are given below. A drillhole completed in 1953 failed to duplicate the tenor indicated in the earlier holes.

Drillhole number	Footage	Width (feet)	Zn %	Pb %	Cu %	Ag oz/ton	Au oz/ton
50-10	116.3-121.3	5	0.91		0.21	1.30	0.01
	121.3-126.6	5.3	1.45	0.13	0.29	2.83	0.02
	126.6-129	2.4	9.42	0.30	0.52	2.97	0.01
	116.3-129	12.7	2.74	0.11	0.30	2.25	0.01
	129-134	5	1.36	0.10	0.47	0.24	0.01
	134-139	5	1.26	0.05	0.52	0.31	0.04
	139-144	5	3.56	0.05	0.71	0.40	0.05
	144-149	5	3.37	0.07	1.28	0.99	0.01
	149-154	5	3.18	0.07	0.26	0.97	0.01
	154-159	5	2.25	trace	0.47	0.43	0.02
	154-163.6	4.6	1.52	trace	0.37	0.24	0.01
	126.6-159	32.4	3.01				
50-11	43-48	5	5.10	--	0.18	nil	0.01
	72.3-76	3.7	6.4	--	0.08	nil	0.01
	92.3-95.7	3.4	1.25	--	1.02	0.30	0.01

Deposit No. 19 is described by MacKenzie (1951) as follows: "The mineralization is chalcopyrite with some, but not conspicuous pyrite, disseminated in a much fractured cherty argillite and chloritic schist, chiefly the latter, and associated in places with or in quartz stringers. Calcite is a common filling in fractures. The main fractures and shears strike northeast and dip 60 to 70 degrees southeast. The chalcopyrite was detected at intervals along the contact for nearly 300 feet, though scarcely apparent in places. The chalcopyrite is most evident in the chloritic, sheared rock near the east end of this 300 feet. A heavy gossan is present in the section rendering sampling difficult, so two drillholes were put down to test the occurrence. However, chalcopyrite of the quantity appearing at the surface was not intersected". The cherty argillite mentioned by MacKenzie is undoubtedly a skarn rock, whereas the chloritic schist is probably a schistose phase of the serpentinized peridotite.

(b) Quartz-arsenopyrite-gold veins

Although the quartz-arsenopyrite-gold veins are treated as a distinct type of deposit, they may also occur in limestone or skarn along the Main fault. They show a certain spatial relationship to the pyrite-sphalerite-galena and chalcopyrite deposits and are probably genetically related (Lindgren, 1933; p. 725).

Deposit Nos. 2, 29, 30 and 33 are examples of this type of deposit. Deposit No. 33 is probably the best studied example. According to MacKenzie (1951) the arsenopyrite, containing a little gold, occurs in lenses up to 8 inches or more in width and several feet in length, in finely laminated, fine-grained argillites and greywackes just north of their contact with skarn rocks, which in turn are in contact with serpentinized peridotite. The deposit is structurally controlled by a north-south to northwest trending fault. The main part of the deposit is some 200 feet wide and lies on the east side of the fault. The quartz-arsenopyrite lenses, as well as calcite veins, trend north and northeast and are interpreted by MacKenzie as fillings of tension fractures. Several northwesterly trending veinlets of quartz-arsenopyrite are also present northeast of the main deposit. The arsenopyrite in the main deposit is commonly accompanied by small amounts of pyrrhotite and chalcopyrite. Channel samples collected in 1937 revealed 0.09 ounces gold per ton over 40 inches and up to 2.09 ounces silver per ton over 19 inches. According to Hurst (1927), samples of mineralized rock assayed 22 to 23 per cent arsenic and contained 80 cents to 7 dollars worth of gold, based on the price of gold in 1927 ($20.00 per ounce).

Deposit Nos. 29 and 30 are small quartz-arsenopyrite veins that occur on the west side of Lavigne Brook. They are referred to briefly by MacKenzie (1951) and apparently have not been investigated in detail.

Deposit No. 2 consists of minor arsenopyrite in quartz veins cutting limy argillite and fine-grained greywacke near the Main fault, and outside the thermal aureole of the Nicholas Dénys stock. The veins appear to be part of a larger network of veins that include some sphalerite, galena, and pyrite veins (deposit Nos. 4 and 5). One sample of arsenopyrite was found to contain 0.84 ounces gold per ton and 0.46 ounces silver per ton (MacKenzie, 1951).

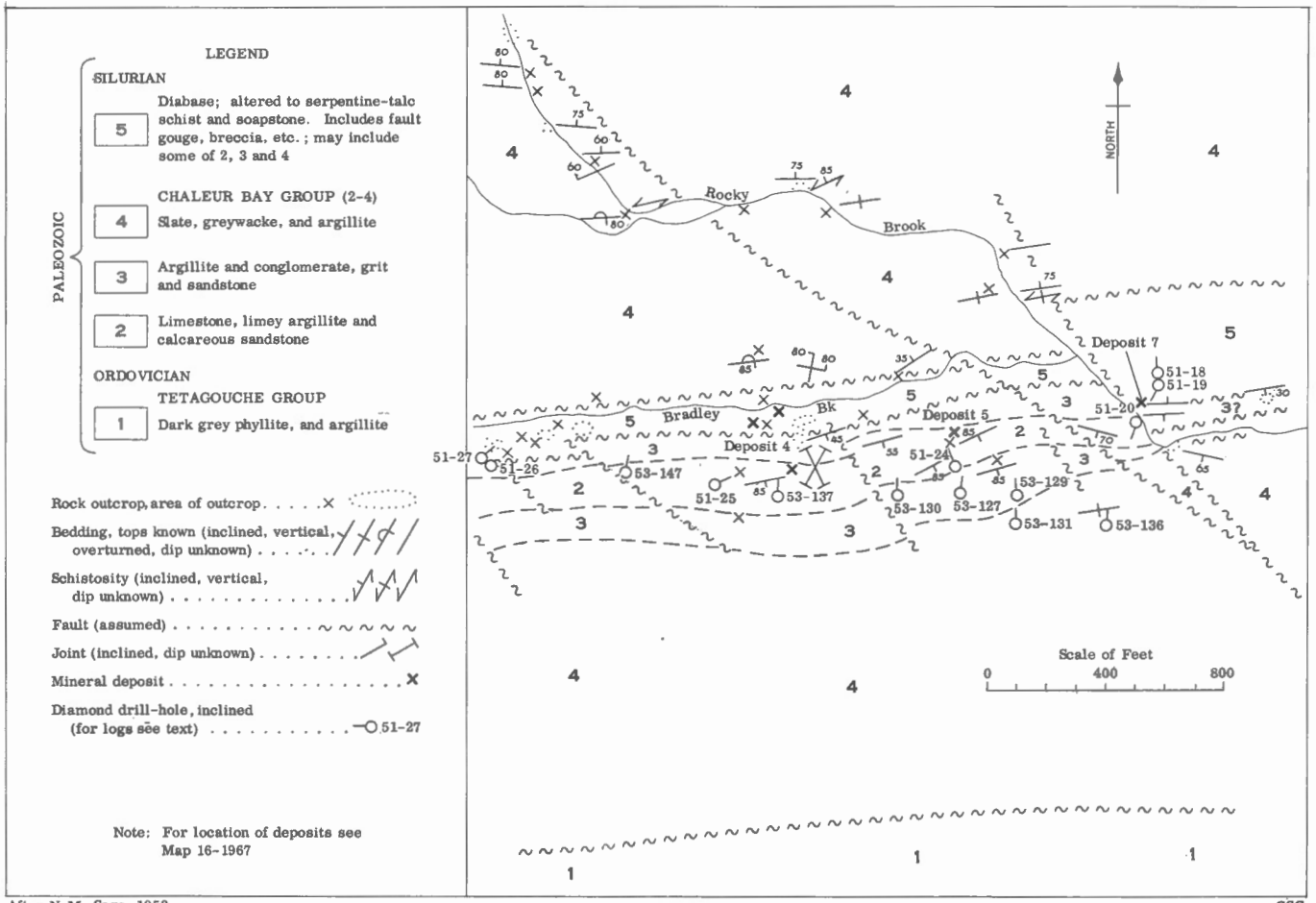
(c) Chalcopyrite deposits

This group includes deposit Nos. 1, 3, and 6. Deposits 1 and 6 are small occurrences of disseminated chalcopyrite in the slaty facies of unit 4 near a thin diabase sill. The deposits are spatially related to northwesterly trending fractures marked by relatively straight stream valleys.

Deposit No. 3 consists of a little chalcopyrite in a quartz vein. It belongs to the network of veins which include deposits 2, 4, and 5.

(d) Pyrite-pyrrhotite-arsenopyrite-sphalerite-galena veins

This group is represented by deposit Nos. 4, 5, 34, 36, and 41. Deposit No. 36, the Nigadoo mine, is the most important example and is described by Tupper et al. in a later section of this paper. The Nigadoo deposit



After N. M. Sage, 1953

GSC

Figure 5. General geology of deposits 4, 5 and 7

is a series of veins occupying northwesterly trending fractures that cut a small plug of quartz-feldspar porphyry intruding calcareous siltstones and phyllites.

Deposits 34 and 41 are minor occurrences. Deposit 34 consists of sphalerite in a calcite vein associated with the Rocky Brook fault. Deposit 41 is a 2-inch vein of galena in the bed of the Millstream River.

Deposits 4 and 5 occur in a network of veins cutting calcareous argillite, greywacke, and conglomerate of unit 3, and a diabase sill along the Main fault (Fig. 5). The veins consist of coarse- to medium-grained sphalerite and galena with pyrite, chalcopyrite, and arsenopyrite, intermixed with quartz and calcite. The veins are irregular in shape and size. According to MacKenzie (1951) their maximum thickness is 5 feet. The system consists of veins having the following trends (a) northwest-southeast and dipping 30 to 80 degrees southwest to 65 degrees northeast (b) south to southwest and vertical, and (c) parallel to the Main fault. The veins seen on the surface occur in a much altered and mechanically deformed diabase sill which lies south of the Main fault. Diamond drilling, however, shows that the veins also occur in a sequence of interbedded calcareous argillite, greywacke, and conglomerate near the diabase contact. The most important assay data obtained from the drilling of 1951 and 1953 are summarized below. The holes were drilled to the north and northeast at dips of 45 and 65 degrees.

Drillhole number	Footage	Width (feet)	Ag oz/ton	Pb %	Zn %
53-147	140-141.3	1.3	0.08	nil	1.43
51-25	116.7-122.7	6.0	0.36	0.4	trace
	122.7-125.7	3.0	0.30	0.2	trace
	125.7-139.5	13.8	minor amounts of sulphides		
	139.5-140.7	1.2	1.18	1.7	3.30
	163.8-171	7.2	minor amounts of sulphides		
	235-237.0	2.0	1.46	2.4	trace
	254-259	5.0	minor amounts of sulphides		
	280-287.9	7.9	minor amounts of sulphides		
	322-325	3.0	0.66	1.4	trace
	327-329.2	2.2	0.42	0.9	trace

Drillhole number	Footage	Width (feet)	Ag oz/ton	Pb %	Zn %
	352-355.8	3.8	0.38	0.8	trace
53-137	112.5-114.8	2.3	1.68	2.02	2.69
	119.1-121.9	2.8	1.32	1.83	2.44
53-130	210-212.5	2.5	minor amounts of sulphides		
	227.5-235.0	7.5	minor amounts of sulphides		
51-24	45-50	5.0	0.66	0.6	0.1
	60-65	5.0	2.0	1.0	0.6
	65-70	5.0	0.76	0.1	trace
	70-75	5.0	1.30	0.7	trace
	75-80	5.0	1.80	0.7	0.9
	80-85	5.0	2.42	0.8	1.6
	85-90	5.0	2.54	0.8	0.9
	90-95	5.0	5.08	1.7	2.0
	95-100	5.0	0.70	1.2	0.9
	100-104	4.0	0.96	0.9	0.6
	104-108	4.0	0.90	0.7	0.6
	108-112	4.0	1.90	2.1	1.6
	112-116	4.0	1.54	1.4	1.8
	116-120	4.0	2.84	1.4	1.9
	80-95	15.0	3.34	1.1	1.5
	108-120	12.0	2.02	1.46	1.77
53-127	91.1-95.4	4.3	2.84	0.88	0.99
	95.4-100.4	5.0	1.14	0.15	0.05
	122.5-125	2.5	1.76	0.60	1.29
	125-127.5	2.5	1.88	2.41	1.59
	127.5-130.6	3.1	0.36	0.24	nil
	130.6-133.1	2.5	0.60	0.93	1.04
	133.1-135.6	2.5	0.88	0.82	1.24
	135.6-141.4	5.8	1.66	1.32	0.99
	122.5-141.4	18.9	1.25	1.07	0.99
	164.4-167.8	3.4	0.60	1.54	0.59
	173.5-175.0	1.5	0.80	2.19	0.94

Drillhole number	Footage	Width (feet)	Ag oz/ton	Pb %	Zn %
53-129	178.4-180.9	2.5	0.60	0.19	nil
	180.9-182.9	2.0	2.86	0.08	nil
	200-204	4.0	0.59	nil	nil
	262.2-265.0	2.8	1.76	1.43	0.94
	265.0-267.5	2.5	0.72	1.32	0.64
	267.5-270.0	2.5	1.72	3.94	3.57
	270.0-272.5	2.5	1.96	4.38	4.56
	262.2-272.5	10.3	1.55	2.73	2.39
	267.5-272.5	5.0	1.84	4.14	4.08
53-131	293-296	3.0	0.83	0.08	nil
	296-299	3.0	1.17	0.22	nil
	510-512.5	2.5	0.46	0.39	1.78
	512.5-515	2.5	0.96	0.93	4.12

3. Molybdenite in the Nicholas Dénys Stock

In addition to molybdenite in the skarn and hornfels associated with the Nicholas Dénys stock, there are occurrences of the mineral in the stock itself that have recently been indicated by stream sediment analyses (Tauchid, 1964) and soil analyses by a private company. Some of these occurrences of molybdenite have been proven by diamond drilling and are denoted by numbers 43, 44, 45, and 46.

The molybdenite in the Nicholas Dénys stock tends to occur in the monzonitic phases in or near closely spaced fractures and altered northwest-striking fault zones. The molybdenite occurs as rosettes and disseminated flakes, as seams in quartz stringers and in sericitized and epidotized monzonite. Principal associated minerals are pyrite and chalcopyrite. In places there are also minor amounts of galena and sphalerite. Small amounts of disseminated molybdenite have also been noted in thin aplite dykes that traverse the granitic rocks.

Non-Metallic Mineral Deposits

MacKenzie (1951) mentions only one non-metallic mineral deposit of interest within the map-area. This deposit (No. 7) consists of talc which was found in three drillholes that were put down to investigate a gossan

associated with minor galena, sphalerite, and pyrite (see Fig. 5). MacKenzie (op. cit.) had intended to ascertain the quality of the talc obtained, but a forest fire damaged the core before this could be done.

The presence of asbestos associated with the more massive occurrences of serpentinized peridotite (unit 7a, Map 16-1967) has not been investigated to the writer's knowledge. MacKenzie (op. cit.) thought the part of the sill east of the Nicholas Dénys-Sormany road would probably be the most interesting in this respect.

Summary

The salient geological features of the Nigadoo River-Millstream River area can be summarized as follows:

1. The country rocks are Ordovician and Silurian argillites, greywackes, phyllites, slates, graphitic schists and conglomerates intruded in places by diabase, gabbro and diorite sills.

2. These rocks are intruded by the Nicholas Dénys stock and a number of associated quartz-feldspar porphyry and aplite dykes and plugs, all thought to be of Devonian age. Adjacent to the granitic stock the Silurian sediments are transformed to skarn and hornfels. A sill-like serpentinized peridotite body occurs along the Main fault, south of Nicholas Dénys.

3. The Silurian sedimentary rocks are folded into a northeast-trending synclinorium, and the Ordovician sedimentary rocks occur in a series of tight isoclinal folds that trend northeast.

4. All of the rocks in the area are faulted in two principal directions. The principal northeast-striking faults form part of a large system known as the 'Rocky Brook-Millstream Break'. The northwest-striking faults are distributed over the map-area, but occur mainly in Silurian rocks. Some of the northwest-striking faults are mineralized and contain orebodies.

5. Both the Ordovician and Silurian rocks contain mineral deposits. The principal types are contact metamorphic lenses in skarn, and veins and lenses of sulphides in sheared and mylonitized zones and in northwest-striking faults and fractures.

6. A number of contact metamorphic lenses are known, the two most important being the Millstream Iron deposit and the Beresford Copper deposit. The principal minerals in the contact metamorphic deposits are magnetite, various calc-silicates, chalcopyrite, and minor amounts of pyrite, sphalerite, pyrrhotite, arsenopyrite, molybdenite, and scheelite. None of the contact metamorphic deposits are exploited at the present time.

7. The principal sulphide deposits in the area are the Nigadoo deposit and the Quebec Sturgeon River deposit. The Nigadoo deposit, presently under development, occurs in a series of northwest-striking faults that cut Silurian argillites and a Devonian intrusive stock of quartz-feldspar porphyry. The principal minerals in the deposit are galena, sphalerite, chalcopyrite, pyrite, pyrrhotite, and arsenopyrite. The Quebec Sturgeon River deposit consists of two northeast-trending disseminated and massive sulphide bodies in severely faulted, brecciated, and mylonitized Ordovician phyllites, schists, and argillites. The principal minerals in the sulphide bodies are galena, sphalerite, pyrite, pyrrhotite, arsenopyrite, and chalcopyrite.

8. Disseminated molybdenite occurs in altered fault and fracture zones in parts of the Nicholas Dénys granitic body. The mineral has also been noted as disseminations and in fractures in the skarn and hornfels associated with this body.

THE GEOLOGY AND GEOCHEMISTRY OF THE NIGADOO SULPHIDE DEPOSITS, GLOUCESTER COUNTY, NEW BRUNSWICK

W.M. Tupper, R.W. Boyle, and R. Martin

INTRODUCTION

This report describes the geology and geochemistry of the Nigadoo sulphide deposits and the geology of their enclosing rocks. The deposits are a series of narrow sulphide veins and lenses in faults transecting quartz-feldspar porphyry and argillite. Field work was begun in 1958 and completed in 1962. Material was collected for petrographic examinations, sulphur isotope analyses, and chemical analyses.

The Nigadoo deposits are 4 miles west of the village of Nigadoo, Gloucester County, New Brunswick (see Fig. 1). Nigadoo is on Highway 11, 9 miles north of Bathurst, New Brunswick. The deposits are in a farming area and can be reached by good paved and gravel roads.

ACKNOWLEDGMENTS

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GEOLOGY OF THE NIGADOO AREA

The area in the vicinity of the Nigadoo deposits is covered with a thin mantle of glacial till and locally with fluvioglacial deposits. The topography is flat or gently undulating and slopes eastward. The only large stream, the Nigadoo River, possesses a youthful valley. Rock exposures are scarce except along the river and in roadside ditches.

The principal sedimentary rocks underlying the Nigadoo area are Silurian argillites and greywackes of the Chaleur Bay Group (Map 16-1967). These are folded into a northeast-trending synclinorium and are intruded by granite, diorite, diabase, and quartz-feldspar porphyry. Numerous northwest-striking faults, many of which are mineralized with sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, arsenopyrite and jamesonite occur in the area. The Nigadoo deposits occur in these faults. The northwest-striking faults appear to be subsidiary to the so-called 'Rocky Brook-Millstream

TABLE OF FORMATIONS

ERA	PERIOD OR EPOCH	GROUP	LITHOLOGY
CENOZOIC	Recent and Pleistocene		Soil, till, and gravel.
PALEOZOIC	Devonian(?)		Quartz-feldspar porphyry.
			Gabbro, diorite, and diabase.
	Intrusive Contact		
	Upper Silurian	Chaleur Bay	Grey limy argillite and slate, greywacke, red and green slate; minor mafic lava.
			Conglomerate and greywacke.
			Greenish grey slate, argillite, and greywacke.

The formations that occur in the area are listed above and shown on Figure 6 (in pocket).

Break' which extends from the coast, 8 miles north of Bathurst, southwestward for more than 40 miles. This 'Break' or major fault system separates in part the Ordovician Tetagouche Group and the Silurian Chaleur Bay Group.

A small bun-shaped stock of grey-pink granodiorite intrudes the Silurian rocks 3 miles southwest of the Nigadoo deposit. This granodiorite is marked by the development of a thermal metamorphic aureole and has numerous associated granite porphyry dykes that intrude the Silurian rocks. The granodiorite body has been dated by the potassium-argon method at 390 m.y. (Tupper and Hart, 1961).

DESCRIPTION OF ROCKS

The rocks in the map-area are a thick series of argillites, slates, and greywackes separated into two units by a thin band of conglomerate. These sedimentary rocks are intruded by an irregular body of quartz-feldspar porphyry.

Conglomerate

A thin band of polymictic conglomerate with lenses of interbedded greywacke cuts across the southeast part of the map-area and separates older greyish green greywackes and argillites from younger grey, limy slates and argillites. The conglomerate strikes northeast, dips 85 degrees to 90 degrees northwest, and faces northwest.

The pebbles are well-rounded, and consist of red and green chert, white opalescent quartz, green and black slate, quartzite, and felsite. They are commonly closely packed, but in places are widely separated with only a few isolated pebbles in an argillaceous matrix. The long axes of the pebbles vary in length from 3 to 30 millimetres with an average length of 10 millimetres. The pebbles are elongated parallel to the bedding planes and are embedded in a fine-grained, green calcareous-argillaceous matrix. The intercalated greywacke lenses are similar to those described below.

Slates, Argillites, and Greywackes

These rocks form isolated outcrops over most of the map-area and consist of fresh greenish grey to grey, limy slates, greywackes, and argillites. They strike northeast, dip steeply northwest and southeast, and form open parasitic folds in the synclinorium.

South of (i.e. stratigraphically below) the conglomerate bed shown on the map, dark greywackes predominate in the sequence. The greywacke beds are up to 10 or 12 inches thick, show graded bedding, and consist

mainly of fine quartz and argillite chips. These older greywackes and argillites grade upwards and westwards into 'shelf type' limy sedimentary rocks.

The younger Silurian rocks above the conglomerate contain a few thin beds of red slate, show graded bedding, are lighter coloured, finer grained, slightly more limy, and contain less coarse clastic material and more argillaceous material than the lower beds.

In the upper argillite there is a thin calcirudite band in which rounded rod-like fragments of fossil debris up to 7 millimetres long are embedded in a calcareous matrix. Two fossil exposures were also found from which the following were identified:[1]

Dalmanites sp. Barrande 1852 - a pygidium only
bryozoan cf. Striatopora
gastropod - indet.
crinoid columnal
brachiopod ornament
septate inorganic structures

Gabbro and Diorite

These rocks are exposed at two localities - along Nigadoo River due north of the mine, where diorite intrudes the sedimentary rocks, and along the main road southwest of the mine.

Quartz-feldspar Porphyry

This rock forms a steeply plunging irregular stock in the centre of the map-area. Another smaller body has been found, some 1,500 feet southeast of the Nigadoo shaft. Other porphyry bodies may exist in the general area as porphyry float is widespread. No outcrops of porphyry are known, but it is now exposed in several trenches and has been intersected in numerous drillholes and in the underground workings. The main porphyry stock has been described in detail by Martin (1963).

The porphyry consists of quartz and feldspar phenocrysts embedded in an aphanitic quartzo-feldspathic matrix. The quartz phenocrysts are

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[1] Fossils were identified by L.M. Cumming, Paleontology Section, Geological Survey of Canada. The pygidium was too sheared to permit counting of the segments, and hence its age can only be given as Silurian to Lower Devonian; the other fossils are less diagnostic. Middle Silurian fossils have, however, been identified outside the area on the strike of these beds (Potter, 1965; Skinner, 1953; Naylor and Boucot, 1965).

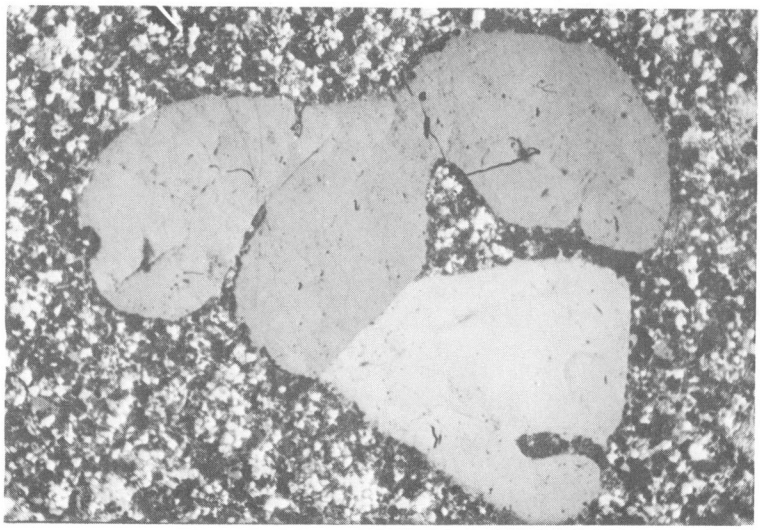

Plate 1. Photomicrograph showing a quartz phenocryst from the Nigadoo quartz-feldspar porphyry. Note the large embayments, the fine-grained quartzo-feldspathic matrix, and the matrix material filling the embayments. Polarized light. x25.

glassy, angular to subrounded crystals ranging in diameter from 1 millimetre to 5 millimetres. Some of the crystals have the dipyramidal habit of high (or β) quartz and are similar to those found in silicic volcanic rocks. Euhedral crystals are rare and many of the quartz phenocrysts are partly resorbed, a feature suggested by the presence of large embayments filled with aphanitic groundmass material (Plate 1). Some embayments extend deeply into the quartz, in many places nearly half way across the crystals. Locally, the quartz phenocrysts are fractured and shattered, a phenomena observed more frequently as the contact with the sedimentary rocks is approached.

The feldspar phenocrysts are up to 1 centimetre long, and consist of optically homogeneous sanidine and plagioclase (An_{35}), which have been wholly or partly altered to a complex assemblage of sericite, kaolinite, calcite, and epidote. A number of the large grey feldspar phenocrysts contain grains of specular hematite, some of which are up to 1 millimetre in diameter.

The matrix, containing the quartz and feldspar phenocrysts, is buff coloured, fine grained, holocrystalline, and consists essentially of quartz and feldspar. The quartz grains are anhedral and commonly strained.

The feldspar is highly altered and is less abundant than the quartz. Both plagioclase and potash feldspars were identified in the fresh rock.

Small blebs and seams of pyrite and carbonate are common in much of the porphyry. In some cases these minerals appear to have crystallized with the porphyry; in other cases they have obviously been introduced after the crystallization of the porphyry.

The sericitization and kaolinization noted above, although more pronounced nearer the veins, pervades the entire stock. Because of its pervasive nature the alteration is probably of deuteric origin dating from the time of intrusion. Alternatives are that the alteration is related to the mineralization processes or to the action of meteoric water. These possibilities are discussed below. In the case of deuteric alteration the altering volatiles (mainly H_2O and CO_2) could have originated either in the cooling igneous mass, or in the intruded sedimentary rocks from which they were drawn into the porphyry as a result of differences in the partial pressures of the components between the sedimentary rocks and the hot, but cooling porphyry mass. The necessary components probably existed in the sedimentary rocks, but the notably small metamorphic aureole developed in the sediments adjacent to the porphyry tends to discredit the hypothesis that the sediments were the source of the volatiles.

Narrow zones and small patches of altered porphyry, recognized by differences in colour, are found near and adjacent to the veins and are probably related to the mineralization processes. A light greenish yellow, a reddish brown, and a grey phase have been distinguished. It is, however, difficult to relate colour changes to specific mineralogical changes because the alteration is, in large part, confined to the aphanitic matrix. The light greenish yellow phase, the most common, contains abundant sericite and epidote, formed from the feldspars. The colour of the reddish brown phase is due to the presence of small blebs of sulphides, now largely oxidized to limonite and hematite, and to stains of hematite along fractures and grain boundaries. The grey phase, the least abundant, has a highly baked and leached appearance, the feldspars in the matrix are chloritized, and in places the feldspar phenocrysts are likewise affected. The chlorite minerals belong to the amesite-chamosite group.

At the sediment-porphyry contact the sedimentary rocks and the porphyry are locally brecciated and fragments of the former are found in the porphyry. Flow banding was also noted in places in the porphyry. These relations, together with the discordant nature of the porphyry, suggest that the porphyry intruded the sedimentary beds. No hornfels was found in the contact zone.

The porphyry was probably intruded as a relatively cool, partly crystalline, viscous mass along a zone of weakness. The large quartz and feldspar phenocrysts probably grew while the silicate mass was enclosed in a

chamber at depth where the temperature was above 573°C as evidenced by the presence of β quartz. As the silicate mass rose from the chamber, the temperature and pressure decreased, resulting in the partial resorption of the quartz phenocrysts, followed by the later crystallization of the aphanitic groundmass.

The host rocks of the quartz-feldspar porphyry stock, containing Middle Silurian fossils, have a minimum age of about 415 m.y. (Kulp, 1961). Lead isotope age determinations from the area date the episode of mineralization at 370±20 m.y. (Tupper, 1960). Therefore, the intrusion of the stock probably occurred between 415 and 370 m.y. ago, that is during Devonian time. The granodiorite stock at Nicholas Dénys was emplaced during the same interval (Tupper and Hart, 1961).

STRUCTURAL GEOLOGY

The sedimentary rocks strike northeast and are folded into a major syncline, the axial trace of which trends northeast. In addition, numerous smaller parasitic folds are developed on the limbs of the major syncline. Several northeasterly-trending parasite folds occur in the vicinity of the sulphide deposit. The folded Silurian rocks were intruded by the quartz-feldspar porphyry stock, and both were then locally faulted.

With these facts in mind the structural history of the map-area can be interpreted chronologically as follows:

(1) Folding of the Silurian sedimentary rocks into simple, open, northeasterly plunging folds.

(2) Intrusion of the quartz-feldspar porphyry stock and small satellite bodies.

(3) Development of northwesterly and northerly trending faults, some of which are mineralized and contain the main sulphide veins. The stresses responsible for this development were either associated with further shortening in the syncline or were coincident with movement along the 'Rocky Brook-Millstream Break', a fault system that lies to the south. Miniature step folds were also formed during the faulting.

(4) Cross-faulting resulting in the movement of the northern section of the main sulphide vein 400 feet to the northeast. The main loci of faulting is a zone along the northern contact of the competent porphyry stock. This dislocation probably resulted from an easterly to northeasterly oriented shear couple.

The shear couples that gave rise to the northwesterly and northerly striking vein faults and the northeasterly and easterly striking cross-faults were probably closely related in time, and may have been tectonically related. The porphyry stock, a rigid, competent mass, may have acted as a nucleus of discontinuity, causing the localization of the faults. The early northwest and north-striking faults provided an access for the mineralizing solutions and a place for the deposition of sulphides, carbonates, etc. Total movement along the main northwest-striking fault was not great since the porphyry and conglomerate show only a small strike separation.

NIGADOO SULPHIDE DEPOSITS

History

The Nigadoo sulphide deposits were discovered in 1953 by Anthonian Mining Corporation, which had been exploring in the area since 1951, using the methods of tracing vein float, soil testing, and geophysical surveys.

A 900-foot shaft was sunk in 1956 and several thousand feet of lateral development on six levels followed. In 1957 the property was transferred to Billiton Maatschappij N.V., Canada Ltd., which continued development until 1958. From 1958 to 1964 the property lay idle and the mine workings were flooded. In 1964 the property was purchased by East Sullivan Mines, Ltd., and Sullivan Consolidated Mines, Ltd. Further diamond drilling was carried out, and the shaft was deepened to 1,750 feet. Production is scheduled for 1967.

Geology and Mineralogy

The main Nigadoo sulphide deposit consists of a series of narrow sulphide veins and lenses along a northwesterly trending fault. This fault cuts the sedimentary beds at a high angle and continues through the porphyry stock as a series of en echelon tension fractures. The fault and sulphide lenses can be traced for 3,600 feet.

Several smaller sulphide-bearing faults occur both in the porphyry stock and in the argillites to the northeast, southeast, and southwest of the main fault. The largest of these occurs 1,000 feet east of the main shaft and is over 1,000 feet long. This mineralized fault strikes northwest and dips nearly vertically. Near the intersection with the porphyry the fault consists of a mineralized stockwork some 75 feet or more in width.

The main fault dips vertically to steeply southwest and although its true vertical extent is unknown, it has been intersected at a depth of 1,750 feet. The sulphide lenses pinch and swell and change character both vertically

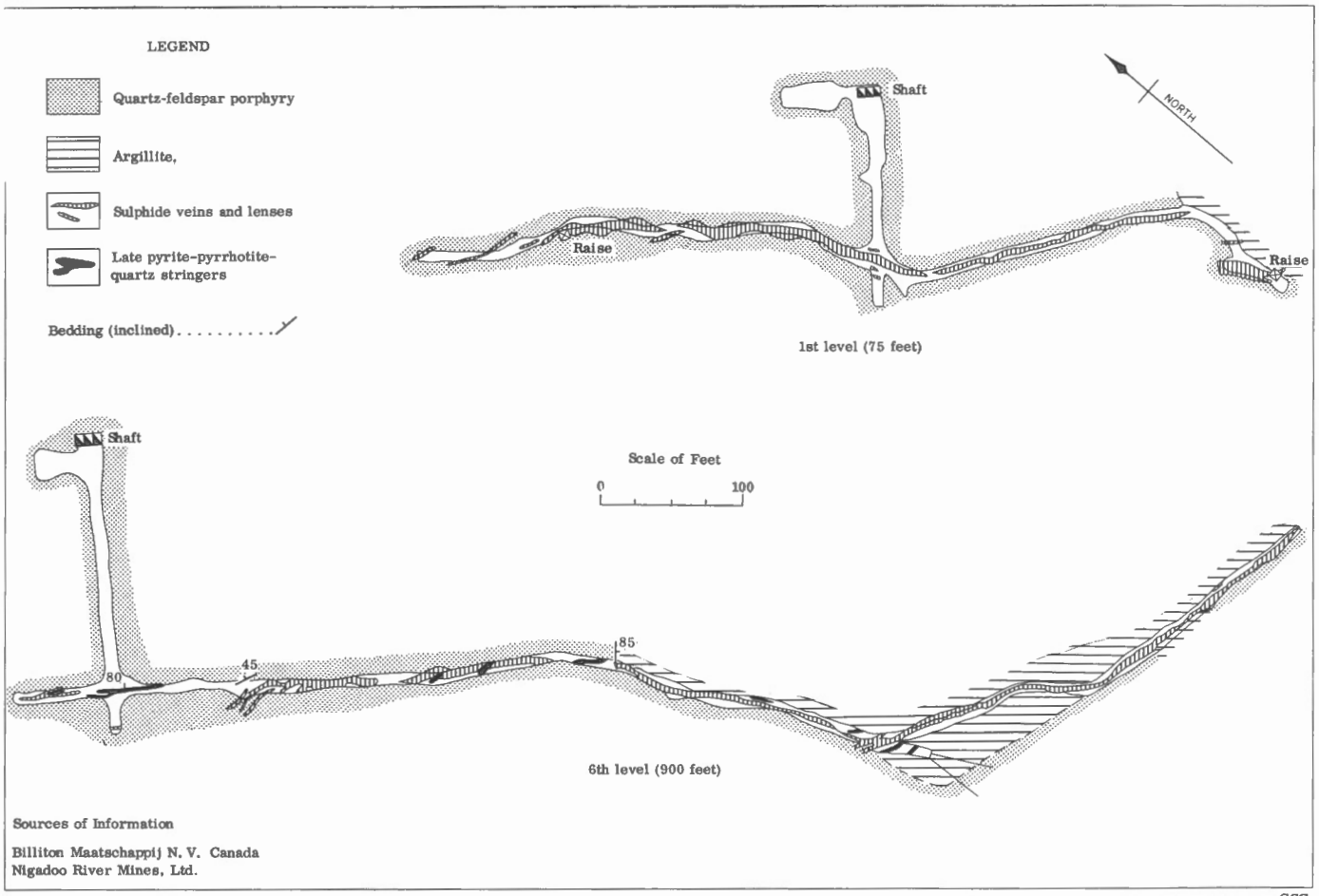

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Figure 7. Geological plans of 1st and 6th levels, Nigadoo Mine

and horizontally as shown on Figure 7. The zone enclosing the principal sulphide lenses is 3,400 feet long and contains 1,390,000 tons of ore to a depth of 1,000 feet, grading 4.36 oz silver, 2.97 per cent lead, 2.77 per cent zinc, and 0.34 per cent copper across an average width of 6.8 feet. In addition, cadmium, and probably also bismuth and tin, can be recovered as by-products from the ores.

The form, mineralogy, and paragenesis of the Nigadoo sulphide veins and lenses have been described by Aleva (1960), Kalliokoski (1961), and Roy (1961).

The following primary minerals have been identified in the deposits: pyrite, marcasite, pyrrhotite (hexagonal and orthorhombic forms), arsenopyrite, sphalerite, galena, cassiterite, loellingite, chalcopyrite, native bismuth, stannite, and tetrahedrite. The gangue minerals are mainly carbonates with minor quartz. The sulphide minerals are medium to coarse grained, and hypogene replacement relationship among the primary minerals are common. Exsolution exists between chalcopyrite and tetrahedrite, and between sphalerite and chalcopyrite. Colloform textures have been noted in the pyrite.

Secondary minerals in the shallow gossan developed in places on the sulphide lenses in the main fault include limonite, anglesite, calcite, and beudantite.

Kalliokoski (1961) thought that the deposit is 'telescoped' because the mineralogy shows both high and low temperature characteristics. The principal minerals are appropriate for the hypothermal class, but the late carbonate veins suggest lower temperatures.

Aleva (personal communication) has grouped the sulphide veins and lenses into the following categories:

(1) Massive pyrrhotite veins containing pyrrhotite, sphalerite, galena, and chalcopyrite accompanied by minor pyrite, arsenopyrite, cassiterite, stannite, and native bismuth.

(2) Foliated marcasite-pyrite veins composed of marcasite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, and stannite.

(3) Narrow crosscutting veins containing sphalerite with arsenopyrite, pyrite, chalcopyrite, galena, carbonate, and quartz.

(4) Arsenopyrite-rich veins containing arsenopyrite, chalcopyrite, sphalerite, galena, and charbonate.

(5) Late pyrite-pyrrhotite veins composed of pyrite, pyrrhotite, and carbonate.

On the basis of metallographic studies and examination of the vein system in the underground workings Aleva advocates two main periods of mineralization. The two periods are associated with vein types (1) and (2).

Most of the sulphides were introduced during the late stages of phase 3 of the structural history as outlined earlier. Movement continued along the main northwest-striking faults during and after mineralization as witnessed by the brecciation of the late carbonate minerals.

Geochemistry of the Deposit

Studies of all of the facets of the geochemistry of the sulphide deposits and their enclosing rocks have not yet been completed. However, a trace element study of the quartz-feldspar porphyry, a sulphur isotope investigation of the sulphides, a wall-rock alteration study, and other features are sufficiently advanced to report the results.

Trace Elements in the Quartz-feldspar Porphyry

The copper, lead, zinc, arsenic, antimony, silver, barium, and strontium contents of samples randomly chosen from the main quartz-feldspar porphyry mass are given in Table 1.

It will be noted that the strontium content is much less than, the copper and barium contents approximately the same as, and the lead, zinc, arsenic, antimony, and silver contents several times the average abundance of these elements in crustal rocks.

Wall-Rock Alteration in the Porphyry Stock

The quartz-feldspar porphyry contains phenocrysts of quartz, sanidine, and plagioclase enclosed in an aphanitic quartzo-feldspathic matrix. The feldspars have been altered to sericite, kaolinite, calcite, and epidote. This alteration is pervasive throughout the porphyry stock, but as the veins are approached the alteration of the feldspars becomes more intense, and the feldspars are progressively destroyed.

Because of the pervasive nature of this alteration, the possibility was discussed earlier in this paper that much of the alteration was a late stage deuteric alteration occurring during or shortly after the period of intrusion. However, because this alteration is more pronounced adjacent to the veins, at least some of it must be associated with the mineralization processes.

TABLE 1

CONTENT OF COPPER, LEAD, ZINC, ARSENIC, ANTIMONY, SILVER, BARIUM, AND STRONTIUM IN THE NIGADOO QUARTZ-FELDSPAR PORPHYRY

Constituent[1]	Cu	Pb	Zn	As	Sb	Ag	Ba	Sr
Average content, ppm	37	351	713	138	4.6	0.95	336	87
Range, ppm	0-160	5-6,000	2-6,000+	0-1,900	0-50	0-19	46-660	10-270
Number of samples analyzed	59	59	59	59	59	41	41	41
Method of analyses	dithizone	dithizone	dithizone	Gutzeit	rhodamine B	emission spectrograph	emission spectrograph	emission spectrograph
Extraction	$KHSO_4$ fusion	$KHSO_4$ fusion	$KHSO_4$ fusion	KOH fusion	$KHSO_4$ fusion			
Average abundance crustal rocks, ppm[2]	45	15	65	2	0.2	0.1	400	400

(1) Analyses of Cu, Pb, Zn, As, and Sb by G. Mihailov, Geological Survey of Canada; Analyses of Ag, Ba, and Sr by W.F. White, Geological Survey of Canada.

(2) Average crustal abundances from Mason (1958)

Interestingly, severe water problems were encountered during underground development. The porphyry was found to be very permeable and water poured out everywhere. When the mine pumps were shut off, the mine flooded within twenty-four hours. Some of the pervasive alteration of the feldspars may, therefore, have been due to the action of meteoric water.

Summarizing, it can be said that a large part of the pervasive alteration in the porphyry stock is probably the result of deuteric processes later augmented by the action of groundwaters. The intense alteration adjacent to and in the vicinity of the veins represents another phase and is related to the mineralization processes.

Three types of alteration associated with the veins can be distinguished in the porphyry - an abundant light greenish yellow type, a reddish brown alteration, and a grey alteration. In thin sections the light greenish yellow type contains mainly sericite, saussurite, and quartz; the reddish brown type owes its coloration to the oxidation of pyrite and other sulphides in the porphyry and to the addition of ferric iron in the form of disseminated oxides, mainly hematite; the grey type exhibits a characteristic development of chamosite and limonite.

Analyses of the three types of alteration are given in Table 2 together with an analysis of a composite sample of the relatively fresh porphyry. Comparison of the altered rocks with the relatively fresh porphyry reveals the following: The silica, alumina, soda, and potash contents of the altered rocks are generally less than these of the fresh porphyry. There is a slight increase in magnesia, and a marked increase of calcium, iron, total water, sulphur, and carbon dioxide in the altered equivalents of the porphyry. Exceptions to these generalizations occur in the reddish brown type of alteration where there is a small increase in alumina and potash and a decrease in calcium and carbon dioxide.

These chemical changes can be correlated with the observed alteration of the minerals in the altered parts of the porphyry. Quartz has remained virtually unaltered. Sanidine is altered in part to sericite, kaolinite, and quartz resulting in an addition of H_2O and a loss in K_2O. The plagioclase is most vulnerable; it is replaced by sericite, kaolinite, calcite, epidote, and chlorite, representing a gain in H_2O, CaO, Fe_2O_3, and CO_2 and a loss in Na_2O. The alteration associated with the mineralization processes is thus mainly a combination of sericitization, kaolinization, saussuritization, and chloritization with minor carbonitization. Considerable iron metasomatism was responsible for the formation of the grey type of alteration. This type, it should be emphasized, is relatively sparse.

TABLE 2

CHEMICAL CHANGES PRODUCED BY ALTERATION OF THE NIGADOO QUARTZ-FELDSPAR PORPHYRY

Constituent	BH 7122[1] %	BH 7119[2] %	Adjusted[5] %	Gains and losses in constituents	Percentage gains and losses	BH 7122 %	BH 7123[3] %	Adjusted[5] %	Gains and losses in constituents	Percentage gains and losses	BH 7122 %	BH 7121[4] %	Adjusted[5] %	Gains and losses in constituents	Percentage gains and losses
SiO_2	75.3	71.1	71.7	-3.6	-4.8	75.3	74.9	75.2	-0.1	-0.1	75.3	68.5	73.0	-2.3	-3.1
Al_2O_3	12.6	12.0	12.1	-0.5	-4.0	12.6	12.7	12.8	+0.2	+1.6	12.6	11.1	11.8	-0.8	-6.3
Fe_2O_3	0.17	0.34	0.34	+0.17	+100.0	0.17	0.87	0.88	+0.71	+417.6	0.17	1.0	1.1	+0.9	+529.4
FeO	0.69	1.37	1.38	+0.69	+100.0	0.69	1.06	1.07	+0.38	+55.1	0.69	10.75	11.45	+10.76	+1559.4
CaO	0.80	3.3	3.3	+2.5	+312.5	0.80	0.56	0.56	-0.24	-30.0	0.80	1.5	1.6	+0.8	+100.0
MgO	0.47	0.52	0.52	+0.05	+10.6	0.47	0.70	0.70	+0.23	+48.9	0.47	0.49	0.52	+0.05	+10.6
Na_2O	2.4	0.08	0.08	-2.3	-95.8	2.4	0.18	0.18	-2.2	-91.7	2.4	0.01	0.01	-2.4	-100.0
K_2O	5.7	5.4	5.4	-0.3	-5.2	5.7	6.9	6.9	+1.2	+21.1	5.7	1.8	1.9	-3.8	-66.7
H_2O+															
H_2O-	0.89	1.9	1.9	+1.0	+112.4	0.89	1.5	1.5	+0.6	+67.4	0.89	3.6	3.8	+2.9	+325.8
TiO_2	0.13	0.13	0.13	0.00	0.00	0.13	0.14	0.14	+0.01	+7.7	0.13	0.11	0.12	-0.01	-7.7
P_2O_5	0.04	0.05	0.05	+0.01	+25.0	0.04	0.10	0.10	+0.06	+150.0	0.04	0.11	0.12	+0.08	+200.0
MnO	0.00	0.08	0.08	+0.08	--	0.00	0.03	0.03	+0.03	--	0.00	0.01	0.01	+0.01	--
CO_2	0.50	3.2	3.2	+2.7	+540.0	0.50	0.34	0.34	-0.16	-32.0	0.50	1.0	1.1	+0.6	+120.0
S	0.06	0.18	0.18	+0.12	+200	0.06	trace	--	--	--	0.06	0.40	0.43	+0.37	+616.7
Total	99.75	99.65				99.75	99.98				99.75	100.38			
Less O≡S	0.02	0.07				0.02	--				0.02	0.15			
Net total	99.7	99.6				99.7	99.98				99.7	100.2			
Specific gravity	2.637	2.659				2.637	2.655				2.637	2.810			
Analyst	K. Hoops	K. Hoops				K. Hoops	K. Hoops				K. Hoops	K. Hoops			

(1) BH 7122 - Fresh porphyry - composite sample
(2) BH 7119 - Greenish yellow altered porphyry - composite sample
(3) BH 7123 - Reddish brown altered porphyry - composite sample
(4) BH 7121 - Grey altered porphyry - composite sample
(5) Adjusted % = percentages of BH 7119, 7123, and 7121 multiplied by the factors 2.659/2.637, 2.655/2.637, and 2.810/2.637 respectively, to reduce to a common volume.

Temperature of Formation of the Deposit

A number of ways of estimating the temperature of formation of the minerals of the Nigadoo deposits are possible. These include the sphalerite geothermometer, coexistence of arsenopyrite and pyrite, and pyrrhotite and pyrite, and a study of exsolution textures. Some of these methods have been investigated.

Kalliokoski (1961) investigated the temperature of formation of the Nigadoo deposit using the iron content of sphalerite in the presence of coexisting pyrrhotite. He found temperatures ranging between 595°C and 670°C.

Arsenopyrite and pyrite, and pyrrhotite and pyrite occur throughout the deposit and appear to have formed as coexisting phases. According to Clark (1960) arsenopyrite and pyrite cannot coexist above 491°C±12°, a condition which sets an upper limit for the formation of these two sulphides. Temperatures of formation are estimated by Arnold (personal communication) from coexisting pyrrhotite and pyrite in the deposit at 490°C. Pyrrhotite remote from pyrite gave temperatures some 40°C lower.

Roy (1961) observed exsolution textures between chalcopyrite and tetrahedrite, and between chalcopyrite and sphalerite in the deposits. Edwards (1946) and Buerger (1934) have shown that solid solution between chalcopyrite and tetrahedrite takes place above 500°C and between chalcopyrite and sphalerite above 400°C.

It can be seen from the above that all of the methods yield relatively high temperatures, of the order of 500 degrees or more. Temperatures of formation of this order are difficult to understand as the wall-rocks do not appear to reflect high temperature conditions. The wall-rock alteration in the porphyry is a low grade sericite-chlorite-carbonate-quartz one, and the argillites cut by the veins are of low metamorphic rank. Furthermore there is an apparent anomaly between results from the sphalerite and the data on the maximum for the coexistence of arsenopyrite and pyrite. If the sphalerite formed above 600°C, then it must have been completely precipitated before the arsenopyrite, a feature which seems improbable in the light of normal paragenetic sequences in veins. To date, there is, however, no agreement on the relative paragenesis of sphalerite and arsenopyrite among the investigators who have looked at the problem carefully (Kalliokoski, 1961; Roy, 1961; Aleva, personal communication).

Sulphur Isotope Data

Tupper (1960) has investigated the sulphur isotope ratios of a number of sulphides in the deposit, and the results are given in Table 3.

TABLE 3

SULPHUR ISOTOPE ABUNDANCE DATA FOR THE NIGADOO SULPHIDE VEINS IN THE MAIN NORTHWEST-STRIKING FAULT

No.	Sulphide mineral	Location and depth within deposit	Description	S^{32}/S^{34}	S^{34} $^0/_{00}$[1]
707	Galena	Mine dump	Coarse-grained "granitoid" intergrowth of galena, arsenopyrite, pyrite, and carbonate.	22.14	+3.2
708	Chalco-pyrite	Mine dump	Irregular stringers 2-10 mm wide of chalcopyrite cutting arsenopyrite.	22.17	+1.8
710	Arseno-pyrite	DDH[2] 103 at 727', centre, deep	Coarse-grained pyrite, arsenopyrite and quartz with minor chalcopyrite and carbonate.	22.16	+2.3
712	Sphalerite	DDH 114 at 511', north end, medium depth	Irregular stringers 1-2 cm wide of black sphalerite cutting pyrite.	22.15	+2.7
713	Sphalerite	DDH 38 at 165'	Coarse-grained sphalerite and galena replacing pyrite.	22.19	+1.0
714	Pyrite	DDH 50 at 223'	Pyrite in part replaced by galena and sphalerite.	22.21	0.0
715	Sphalerite	DDH 129 at 1067'	Irregular stringers 1-2 cm wide of black sphalerite cutting pyrite and arsenopyrite.	22.20	+0.6
717 (a)	Pyrite	DDH 122 at 1549'	Coarse-grained pyrrhotite containing 3-5 cm pyrite cubes.	22.22	-0.5
717 (b)	Pyrrhotite	DDH 122 at 1549'	Pyrrhotite in 717 (a).	22.20	+0.6
719	Pyrrhotite	DDH 115 at 931'	Coarse-grained pyrrhotite containing pyrite with blebs and stringers of black sphalerite.	22.21	0.0
721	Pyrrhotite	DDH 108 at 858'	Coarse-grained massive pyrrhotite containing a few blebs of chalcopyrite.	22.22	-0.5
711 (a)	Pyrite	DDH 127 at 1048', south end, deep	Coarse-grained sphalerite and galena replacing pyrite and arsenopyrite.	22.00	+9.5
711 (b)	Galena	DDH 127 at 1048', south end, deep	Sphalerite in 711 (a).	21.90	+14.0
716	Pyrite	DDH 104 at 176', centre, shallow	Coarse-grained massive pyrite.	21.90	+14.0
718	Pyrrhotite	DDH 115 at 931', centre, deep	Coarse-grained pyrrhotite containing 3-5 cm pyrite cubes.	21.91	+13.5

(1) $S^{34}\ ^0/_{00} = \dfrac{(S^{32}/S^{34})\ \text{sample} - (S^{32}S^{34})\ \text{meteoritic sulphur}}{(S^{32}/S^{34})\ \text{meteoritic sulphur}} \times 10^3$

(2) DDH - diamond-drillhole

The Nigadoo deposit has two distinct sets of sulphur isotope ratios. One set, ranging from 21.90 to 22.00, is enriched in S^{34}, the other set, ranging from 22.14 to 22.22, is enriched in S^{32}.

The two sets of S^{32}/S^{34} ratios suggest two separate sources and/or phases of mineralization. The set enriched in S^{34} corresponds to the ratios found in the massive sulphide deposits located south of the 'Rocky Brook-Millstream Break', whereas the set enriched in S^{32} corresponds to the ratios found in the fissure deposits along the 'Rocky Brook-Millstream Break' (Tupper, 1960). The two sets of ratios support evidence found by Aleva (personal communication) in metallographic studies for two phases of mineralization. Studies now in progress are investigating the relationship between the heavy and light ratios and specific vein types.

Notwithstanding the presence of two distinct sets of ratios, the narrow range of the sulphur isotope ratios suggests that the sulphides were derived from a relatively homogeneous source.

Metal Ratios

A comparison of the copper, lead, and zinc ratios from the Nigadoo deposit with those from three of the massive sulphide deposits south of the 'Rocky Brook-Millstream Break' are presented in Figure 8.

It is evident that the metal ratios in the Nigadoo deposit differ from those in the massive sulphide deposits. The Pb/Zn ratio is two to three times and the Cu/Zn ratio two to four times greater than those from the massive sulphide deposits. The silver content in the Nigadoo deposit as a whole is also two to three times that of the average of the massive sulphide deposits. These features may reflect a different source for the metals in the two types of deposits, or alternately they may be the result of different processes of concentration. It is not possible at the present stage of the investigation of the district to give an unequivocal answer to this problem.

Geochemical Dispersion of Heavy Metals in Soils

The soils in the Nigadoo area are developed on Pleistocene till. They show a fair profile development and have been studied in detail by Presant (in press).

The dispersion train in the soils of the cold extractable combined heavy metals from the vicinity of the deposit is shown in Figure 9. All

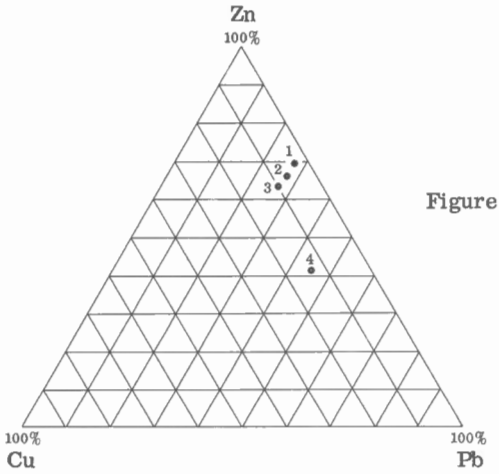


Figure 8. Ternary relations (weight per cent) between copper, lead and zinc in deposits of the Bathurst area

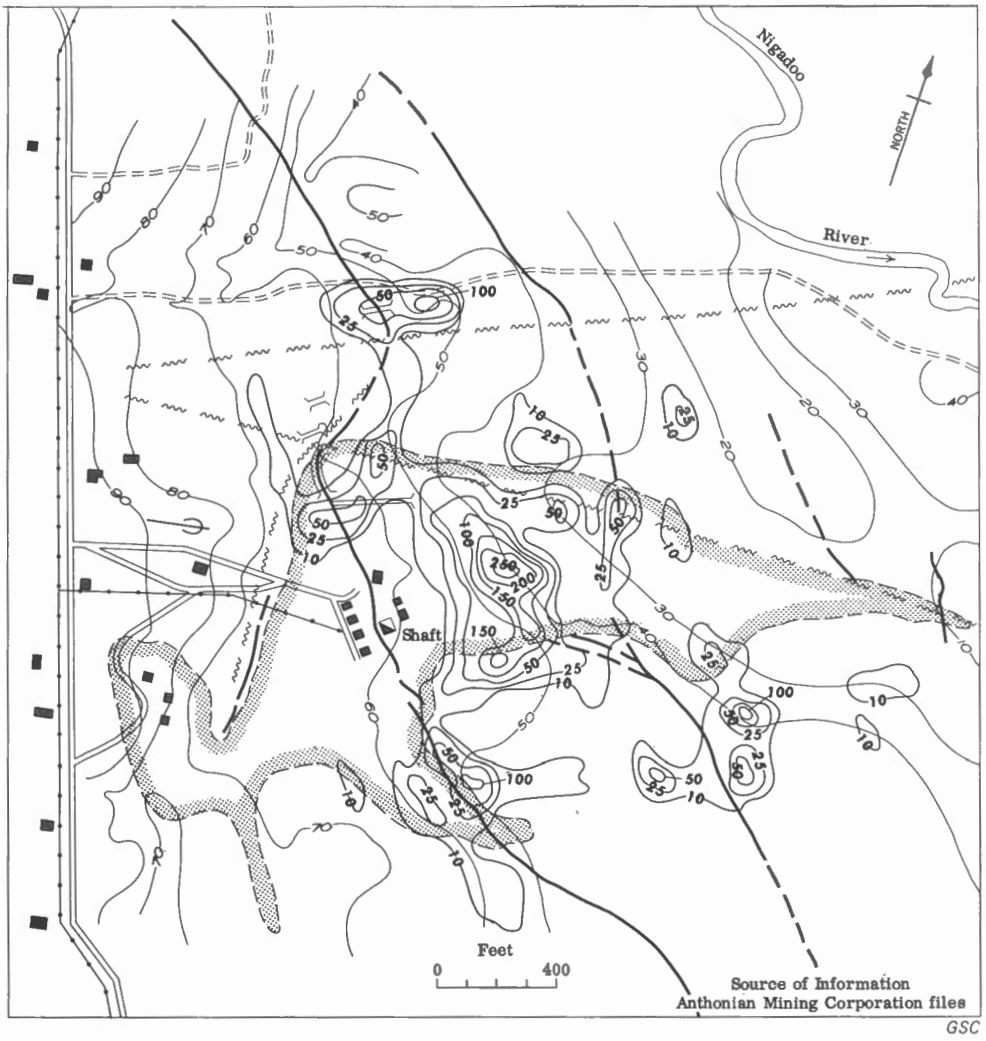
Massive sulphide deposits south of 'Rocky Brook-Millstream Break'

1. Brunswick No. 12
2. Brunswick No. 6
3. Heath Steele

Sulphide vein deposit north of 'Rocky Brook-Millstream Break'

4. Nigadoo

GSC



LEGEND

Quartz-feldspar porphyry . . . . . .
Contours of heavy metal distribution in units from 10 to 250 (one unit = one millilitre of dithizone used in titration of combined cold extractable heavy metal) 10
Sulphide vein . . . . . .
Fault (approximate) . . . . . .
Direction of ice movement known . . . . . .
Trench . . . . . .
Road, all weather . . . . . .
Other roads . . . . . .
Electric power line . . . . . .
Contour, interval 10 feet (from arbitrary datum) 40
Building . . . . . .

Figure 9. Cold extractable heavy metal content in soils, Nigadoo deposit

samples were collected from the B horizon, and the units used in representing the metal values are millilitres of dithizone necessary to titrate the combined extractable metals[1].

Background metal content in the soils is less than 1 unit. The largest anomaly, 300 feet northeast of the shaft, was greater than 250 units. Several other anomalies between 50 and 100 units are present.

The anomalies generally occur downslope from the surface expression of the main vein, and the metal dispersion pattern is thus controlled in large part by the water-table. A series of small springs occur in the vicinity of the largest anomaly. Ice movement during Pleistocene time was also in the same direction and may have contributed to the dispersion pattern. The soils and hence the train are post-Pleistocene in age.

Geophysical Surveys

A self potential and 'Turam' electromagnetic survey were conducted over the Nigadoo mine area by the company. The results are given in Figures 10 and 11. They are self explanatory and require little comment. The main vein is clearly outlined by both surveys and the subsidiary veins are outlined in part by the electromagnetic survey.

Summary

The Nigadoo sulphide deposits are epigenetic vein deposits containing pyrite, marcasite, pyrrhotite, arsenopyrite, sphalerite, galena, chalcopyrite, and carbonates, with minor amounts of native bismuth, stannite, cassiterite, tetrahedrite, and loellingite. These minerals occur in narrow, northwest- and northeast-striking fault zones that are mineralized over lengths of 3,600 feet or more. The fault zones transect northeasterly striking Silurian sedimentary rocks and a small quartz-feldspar porphyry stock.

The sedimentary rocks, consisting of slates, argillites and greywackes, are Upper Silurian in age. The quartz-feldspar porphyry consists of phenocrysts of quartz, sanidine, and plagioclase enclosed in an aphanitic quartzo-feldspathic matrix. The quartz phenocrysts in places have a dipyramidal habit and are highly resorbed. The feldspars are altered to kaolinite, sericite, and epidote. Some alteration may be of deuteric origin, but the greater part is the product of wall-rock alteration processes. A Devonian age is postulated for the porphyry.

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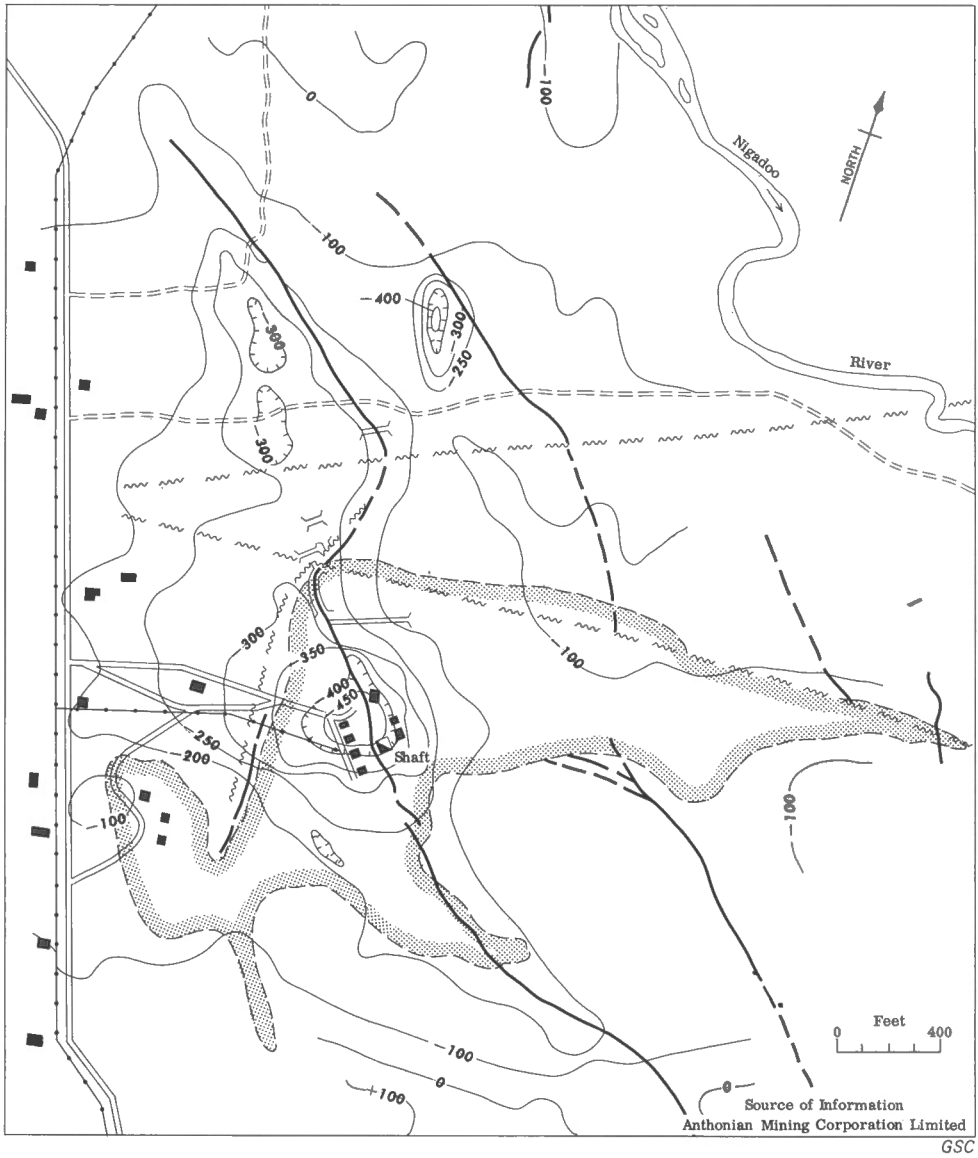
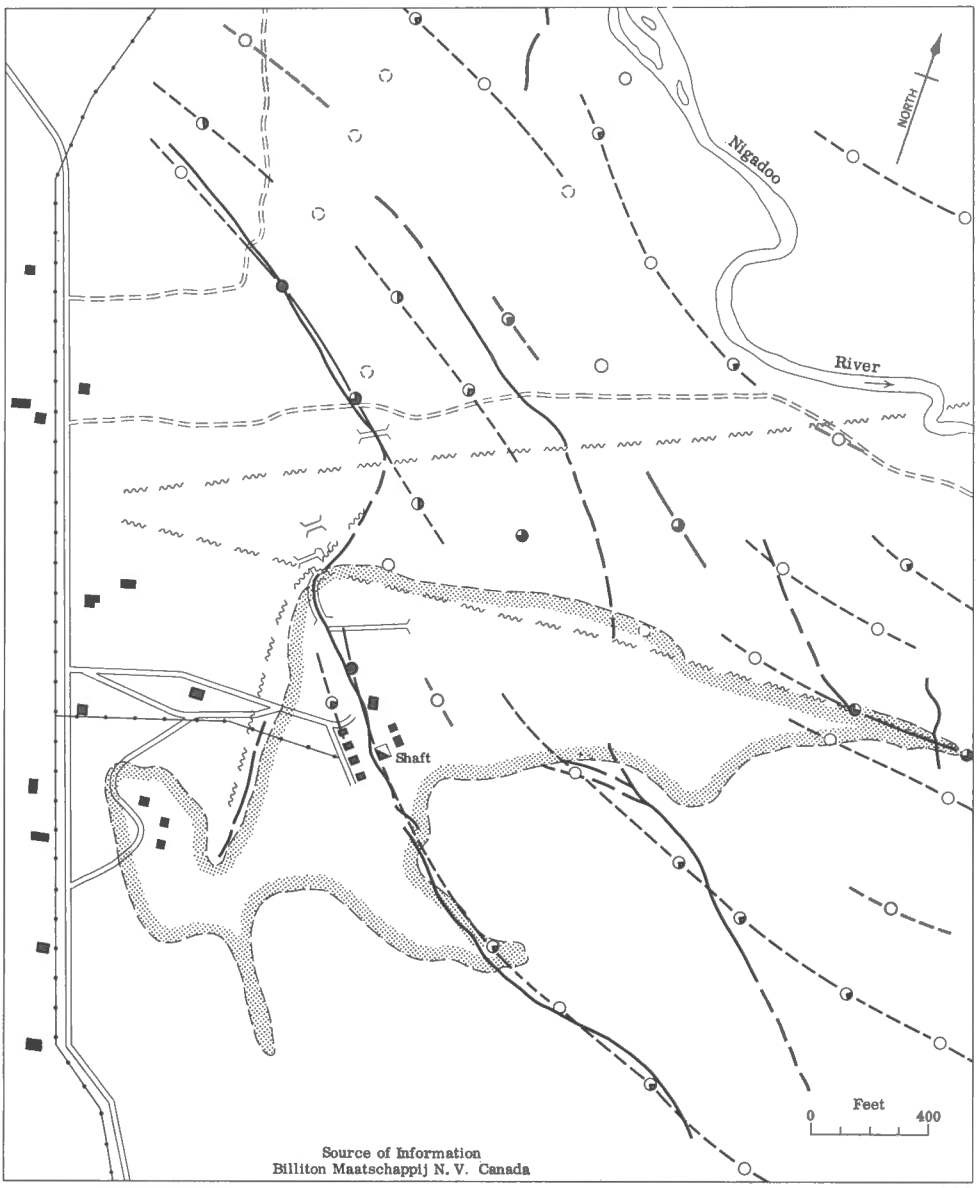
[1] Concentration of dithizone = 0.001 per cent.



LEGEND

Quartz-feldspar porphyry
Equipotential contours in millivolts
Sulphide vein
Fault (approximate)
Trench
Road, all weather
Other roads
Electric power line
Building

Figure 10. Self potential survey, Nigadoo Mine area



Quartz-feldspar porphyry
Conductors denoting decreasing strength of e.m. indications (solid circle – strong indication; broken circle – weak indication
Fault (approximate)
Sulphide vein
Trench
Road, all weather
Other roads
Electric power line
Building

Figure 11. 'Turam' electromagnetic survey, Nigadoo Mine area

The competent porphyry mass acted as a locus of discontinuity and caused the localization of the faults and the openings along the ore-bearing fault planes. The fault planes in turn provided an access for the ore and gangue materials and a site of deposition. Movement continued along the faults during and after the period of mineralization.

Five types of veins occur in the deposit: (1) massive pyrrhotite veins; (2) foliated marcasite-pyrite veins; (3) narrow crosscutting sphalerite veins; (4) arsenopyrite-rich veins; and (5) late pyrite-pyrrhotite veins. Metallographic studies suggest two main phases of mineralization.

The wall-rock alteration processes in the porphyry consisted of intense sericitization and argillic alteration, with local chloritization, saussuritization, and carbonatization.

Knowledge of the temperature of formation of the sulphide minerals is uncertain, judging from conflicts in a number of the methods of determining the temperatures of crystallization of the sulphides. The available data suggest a minimum temperature of formation of 490° C, but this is not borne out by geological data such as low grade wall-rock minerals, etc.

The Nigadoo deposit possesses two distinct sets of sulphur isotope ratios. The two sets suggest two separate sources and/or phases of mineralization. The narrow range of the sulphur isotope ratios further suggests that each phase of mineralization was derived from a homogeneous source.

A comparison of the metal ratios in the Nigadoo deposit with those in the massive sulphide deposits in the Bathurst district south of the Rocky Brook-Millstream fault system shows no relationship. The Pb/Zn and Cu/Zn ratios are two to four times higher in the Nigadoo deposit. The silver content of the Nigadoo deposit is double that of the massive sulphide deposits.

A shallow gossan is developed on the main vein in places. The minerals in this gossan include limonite, anglesite, and beudantite.

A pronounced combined heavy metal dispersion train is developed in the soils overlying and downslope from the Nigadoo deposit.

The main vein is marked by both self potential and electromagnetic anomalies.

GEOLOGY OF THE BERESFORD COPPER DEPOSIT

D. J. Bachinski

INTRODUCTION AND HISTORY

This paper contains a short description of the Beresford cupriferous magnetite deposit, located some 8,000 feet east of Nicholas Dénys. The deposit is the most important of a number of magnetite deposits in the southern skarn zone associated with the Nicholas Dénys granitic body (see the contribution to this paper by Davies). Only the geology and mineralogy of the deposit are briefly discussed in this paper. For more detail on these subjects and on the geochemistry of the deposit the reader is referred to a thesis by the writer (Bachinski, 1965).

The cupriferous magnetite deposits in the vicinity of Nicholas Dénys have been known since 1890 and have been subjected to intermittent examination since then. In 1952 detailed drilling by Noranda Exploration Co., Ltd. outlined the Beresford deposit and further drilling was carried out by this company in 1956, 1957, and 1962. Magnetometer, electromagnetic, and self-potential surveys have also been done over the deposit, and in the summer of 1962 a geochemical survey for readily extractable copper in soils and stream sediments was completed. Geological mapping by J. Kruse has given a relatively clear picture of the setting of the deposit. Reports indicate that the deposit contains approximately 200,000 tons of ore with an average tenor of 2 per cent copper.

ACKNOWLEDGMENTS

The writer thanks the Noranda Exploration Co., Ltd. and particularly Mr. Paul Sawyer for making available all data pertaining to the Beresford deposit. He wishes also to thank Dr. A.B. Baldwin of M.J. Boylen Engineering Ltd., for a variety of data used in the study of the deposit and associated skarn, and Dr. Paul Dean Proctor of the University of Missouri at Rolla for assistance during the final stages of the preparation of the thesis on which this paper is based.

GEOLOGY OF THE DEPOSIT

The deposit occurs on Lavigne Brook some 2,500 feet southeast of the contact of the Nicholas Dénys granitic body with sediments of the Chaleur Bay Group. It consists of three or more lenses, one faulted, in a band of skarn that strikes north 70 degrees east and has been traced by Davies northeast as far as Stephens Brook and southwest to Anne's Creek. The deposit is the largest and most important of a number of magnetite deposits that occur

along this band. It is similar geologically and mineralogically to the Millstream Iron deposit described earlier in this paper by Davies.

The detailed geological setting of the Beresford deposit is shown on the plan and sections in Figure 13 (in pocket). The wall-rocks of the deposit are serpentinite, conglomerate, argillite, skarn and hornfels. The serpentinite and skarn are the most characteristic rocks in this sequence and deserve brief descriptions.

The serpentinite was apparently originally a peridotite sill that partly occupies the axial plane of a very tight anticline from Stephens Brook in the east to Bradley Brook in the west. It is bounded by fault planes associated with the Main fault and is extensively sheared, brecciated, and altered. On weathered surfaces it is bluish to greenish black, commonly with a mesh of anastomosing calcite stringers, ubiquitous hematite staining, and seams of greenish serpentine. Along Stephens Brook, the serpentinite is highly brecciated by late north-striking faults; elsewhere the rock is more compact but is soft and somewhat friable and moderately sheared in a direction parallel to the Main fault.

As seen in thin sections the serpentinite contains essentially antigorite, magnetite, some talc, minor calcite and magnesite, and rare serpophite. Magnetite constitutes about 10 per cent of most samples, and where the rock is relatively undisturbed, forms discontinuous rims which presumably outline original ferromagnesian minerals, probably olivine from their shape. The magnetite was probably exsolved from the ferromagnesian minerals and has accreted along the grain boundaries. In places magnetite and associated hematite are localized along distinctive partings in serpentinized grains suggestive of the former presence of diallage. Crudely oriented massive magnetite veinlets commonly occur in zones which are otherwise devoid of iron oxides. In some places imperfectly developed chrysotile veinlets occur, but these are erratic in their distribution. Slip surfaces are invariably coated with green serpentine and less commonly with pyrrhotite and/or pyrite films and blebs. Pyrite is common in late calcite stringers and in the adjacent rock.

Silicification of the serpentinite is of local importance and has given rise to irregular quartz aggregates. A late talcose and carbonate alteration generally obliterates all vestiges of the original rock except residual clots of serpentine. These altered zones are lacking in iron oxides, although the residual serpentine is veined with magnetite in places. Pyrite stringers transect magnetite and serpentine in these altered zones, and late, scattered calcite veinlets carry some pyrite and lesser amounts of hematite.

The skarn rocks are developed mainly from impure limestone, limy argillites, and siliceous limestone. Transitions from these original sedimentary rocks to impure crystalline limestones and skarn are common.

In hand specimens the skarn is extremely variable. In many occurrences it is a fine grained, porcellaneous compact rock. Other variants are medium grained with a granular fabric. Beige, yellow, and greenish brown to green are the common colorations. Some skarns are massive, other varieties are finely bedded or crudely banded. Still others present a micro-boudinage structure.

The principal minerals in the skarn as seen in thin sections include garnet, diopside, hornblende, actinolite, muscovite, epidote, albite, chlorite, rare green to dark brownish green biotite, calcite, magnetite, pyrite, and chalcopyrite. Granular skarns are characterized by pale orange andradite which when intergrown with sulphides and iron oxides, exhibits excellent dodecahedral forms. The crystals are commonly zoned and attain a maximum diameter of about 5 millimetres and average 1 millimetre to 2 millimetres. In addition to garnet there are also variable amounts of diopside, hornblende, actinolite, muscovite, biotite, albite, epidote, calcite, magnetite, and chalcopyrite in the granular skarns. The fine-grained compact and banded skarn contains all of the above minerals in a dense intergrown mosaic. Some garnetiferous skarns are extremely fine grained and in thin section are essentially isotropic under crossed nicols. Fractures in the skarns are ubiquitous; these contain mainly calcite and pyrite with minor amounts of calc-silicate minerals locally.

The Beresford deposit consists of irregular lenticular bodies that conform in a general way with the strike and dip of the skarn band that encloses them. The lenses strike northeast, dip steeply north to vertical, and plunge eastward at about 50 degrees. They extend along the strike for at least 800 feet and have been found by drilling to a depth of more than 450 feet. Northwest-trending faults cut the skarn band in a number of places as shown in Figure 13. These may have had some part in localizing the mineralized bodies.

MINERALOGY

The primary metallic minerals in the lenses, as identified megascopically and in polished sections, include magnetite, chalcopyrite, pyrite, sphalerite, pyrrhotite, arsenopyrite, marcasite, and molybdenite, in about that order of abundance. The gangue is largely composed of garnet, diopside, epidote, calcite, small amounts of hornblende and actinolite, and minor amounts of quartz. A thin residual gossan caps the lenses. In the gossan predominant minerals are limonite and hematite, with minor amounts of malachite and chalcocite.

The primary metallic minerals commonly exhibit a crude banding alternating with the calc-silicates of the skarn. There are distinct chalcopyrite, chalcopyrite-magnetite, and magnetite lenses in the deposit.

The following is a brief description of the minerals as seen in hand specimens and polished sections.

Magnetite is the most abundant of the minerals in the lenses and occurs as hypidiomorphic to allotriomorphic granular aggregates or interstitially among the euhedral calc-silicate skarn minerals, especially garnet. Individual grains of magnetite seldom exceed 1 millimetre in diameter. The textures developed suggest that magnetite formed later than the calc-silicate minerals. Magnetite grains are fractured locally; the fractures are filled with pyrite, pyrrhotite, chalcopyrite, marcasite, and calcite. The magnetite embedded in chalcopyrite is generally ragged or anhedral.

Chalcopyrite is the predominant sulphide and the most important ore mineral. It ranges from 0.1 to 1 millimetre in grain size. In the granular type of skarn, massive chalcopyrite occurs interstitially to euhedral calc-silicate minerals in a manner similar to magnetite. Growth rings in garnet locally contain chalcopyrite fillings, and fractures in the gangue silicates and magnetite are commonly filled with chalcopyrite indicating that both the silicates and magnetite were fractured prior to the deposition of the chalcopyrite. Chalcopyrite also occurs as inclusions or fissure fillings in pyrrhotite. Sphalerite and chalcopyrite commonly display mutual boundaries, and in some cases minute oriented exsolution blebs of sphalerite occur in chalcopyrite. Small amounts of arsenopyrite may occur embedded in chalcopyrite.

Pyrite occurs in cubes from 0.05 to 0.2 millimetre in diameter in chalcopyrite, and small stringers of pyrite may cut chalcopyrite indicating at least two generations of the iron sulphide. The pyrite in surface exposures in places exhibits a colloform banding. This pyrite is associated with limonite, hematite, and chalcocite.

Pyrrhotite, sphalerite, arsenopyrite, and molybdenite are all of minor importance. These sulphides occur as described above under the more abundant sulphides or are disseminated somewhat erratically through the lenses. Pyrrhotite and chalcopyrite show a close association in some places and appear to have been deposited together. The paragenesis of arsenopyrite, marcasite, and molybdenite is uncertain.

The paragenesis of the minerals in the Beresford deposit is shown in Figure 12.

GENESIS OF THE DEPOSIT

The Beresford deposit is a typical contact metamorphic deposit localized in a skarn zone associated with the Nicholas Dénys granitic stock. As determined by spectrographic and mineralogical methods the deposit represents a major enrichment of Fe, Cu, Zn, and S and a minor enrichment

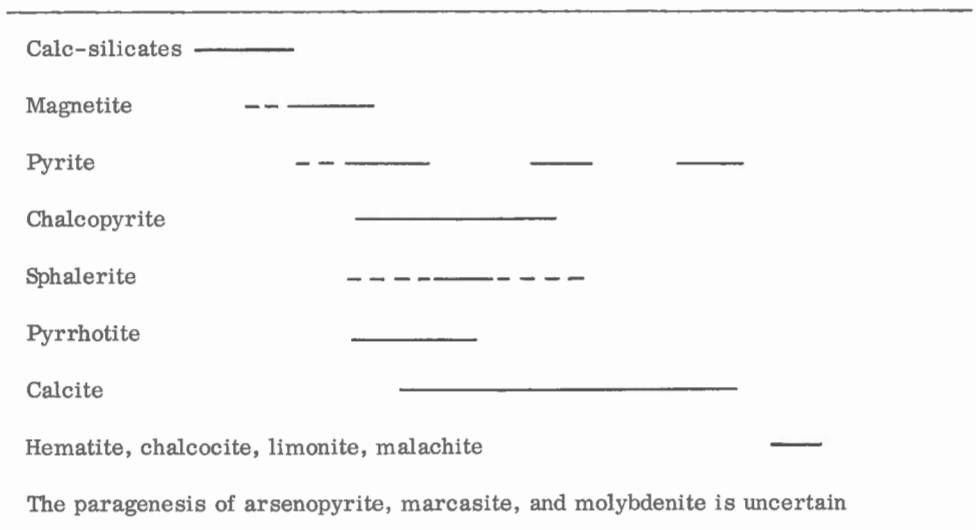


Figure 12. Paragenesis of the Beresford Cupriferous Magnetite Deposit

of Mo, As, Sb, Co, Bi, Ag, and Au. Assuming the deposit was formed by replacement, there are marked depletions of Sr, Ba, CO_2, CaO, and H_2O in the replaced rocks.

The salient features of the deposit are:

(1) The magnetite-sulphide lenses are localized within the thermal aureole of the Nicholas Dénys quartz monzonite-granodiorite stock. A marked temperature gradient existed at the time of emplacement of the stock.

(2) The Beresford deposit and others of the same type in the area are not confined to a single rock type but are associated with a granular, garnetiferous skarn and with a porcellaneous calc-silicate to hornfelsic rock; gross stratigraphic control is evident, however, but this is due to the presence of beds of calcareous rocks which were readily converted to skarn.

(3) The deposits are spatially related to the Main fault of the Rocky Brook-Millstream fault system. This fault is localized along a tight anticline whose core is partly occupied by serpentinite (see contribution to this paper by Davies).

(4) Late, northwest-trending faults are conspiciously developed near the deposits and are considered of importance in the localization of sulphide deposits elsewhere in the district (viz. Nigadoo mine). Marked local

pressure gradients would thus have existed in the vicinity of the deposits and could have served in the conventional sense, as channelways for mobile constituents.

(5) Initial formation of calc-silicate minerals was followed by the deposition of magnetite and subsequently, sulphides.

(6) Concentrations of magnetite and sulphides are coincident in a general sense, but in detail the latter tend to occur to the exclusion of the former in many places in the skarn.

(7) The distribution of the sulphides is discordant.

(8) As outlined elsewhere, Tupper (1960), the sulphur isotopic ratios of the sulphides in the Beresford deposit, and other closely associated deposits, viz. Sturgeon River, Nigadoo (one phase of mineralization), and Keymet are remarkably similar, ranging from 22.18 to 22.21 for the S^{32}/S^{34} ratio. Pyrite from the Nicholas Dénys quartz monzonite-granodiorite had a mean ratio of 22.13. Such data suggest a fairly uniform source for the sulphur or a thorough homogenization of the sulphur prior to its concentration in the deposits.

(9) As discussed elsewhere, Bachinski (1965), the iron in the deposit may have been derived in part from the adjacent magnetite-bearing conglomerate and by the bleaching of argillaceous sediments within the Nicholas Dénys thermal aureole. Chemical traverses across the various rocks in the vicinity of the Beresford deposit to check on the loss of iron in the wall-rocks were, however, inconclusive, but similar traverses at the Millstream Iron deposit did show a minor depletion in iron in the conglomerate adjacent to the deposit. A comparison of normal and bleached hornfels shows that the bleaching is due to loss of iron, and this iron could well be now bound as magnetite in the deposits.

(10) There is no obvious relationship between the base metal content of a particular rock type and the magnetite deposits. Unequivocal evidence to substantiate a lateral secretion hypothesis is lacking from chemical traverses across the rocks in the vicinity of the deposits.

The above features lead to the conclusion that the magnetite was deposited immediately following the development of the skarn. The limy horizons evidently were chemical traps precipitating the iron as magnetite. The iron was probably derived in part from the magnetite-bearing conglomerate and through bleaching of argillaceous sedimentary rocks within the Nicholas Dénys thermal aureole.

Base metals and sulphur, on the basis of the available evidence, appear to be genetically related to the Nicholas Dénys quartz monzonite-granodiorite. Sulphides were deposited later than magnetite and presumably at lower temperatures.

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