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THE POWDERHORN LAKE Ni–Cu SHOWINGS AND THE POTENTIAL FOR MAGMATIC SULPHIDE MINERALIZATION IN CENTRAL NEWFOUNDLAND

A. Kerr
Mineral Deposits Section

ABSTRACT

The recent discovery of Ni–Cu sulphide mineralization near Powderhorn Lake, south of Springdale, defines a new exploration target in a region known mostly for its volcanogenic base-metal sulphides. One showing consists of disseminated to semimassive pyrrhotite-dominated sulphides hosted by an altered gabbroic or dioritic dyke, and displays well-preserved interstitial and droplet sulphide textures typical of magmatic environments. The mineralization contains up to 0.92% Ni and 0.45% Cu, and the sulphides themselves hold from 1% to 4.7% Ni and 0.6% to 3.0% Cu. The host rock does not appear to contain olivine, and may have been a "transport agent", rather than the actual magmatic source of the metals. A second showing, associated with quartz diorite, has lower Ni and Cu contents, and may, in part, involve hydrothermal redistribution of metals from an original magmatic source. Sulphide-bearing metasedimentary rocks, prevalent throughout the area, provide a potential source of sulphur contamination in mafic magmas that intruded them. Although the showings appear to be localized, near-surface, sulphide concentrations, they suggest the potential for similar but perhaps more extensive mineralization in this or nearby areas.

Ni–Cu sulphide mineralization is associated with Silurian mafic intrusions of comparable geological setting in northeastern Maine and adjacent New Brunswick, and locally resulted in a large (but low-grade) deposit. However, this mineralization is associated with more primitive, olivine-bearing rocks that are not presently known in the Powderhorn area. Nevertheless, on a regional scale, poorly known middle Paleozoic intrusions elsewhere in central and western Newfoundland locally include such primitive rocks, and may merit exploration for Ni–Cu mineralization.

INTRODUCTION

In October 1998, Canaco Resources Ltd. released information about Ni–Cu sulphide mineralization discovered near Powderhorn Lake, between Badger and Springdale (Figure 1). This generated public and industry interest, including some newspaper articles that drew comparisons with Voisey's Bay. Five short drillholes completed subsequently did not intersect significant mineralization, but further exploration for Ni–Cu deposits in the area is planned. The mineralization was actually discovered almost two years previously, by prospectors Bill Mercer and Jacob Kennedy, who first brought samples to the Geological Survey in early 1997. After visual and petrographic examination, the mineralization was suggested to be of magmatic origin. Further samples were examined in 1997 and 1998, before and after the optioning of the property. Surface showings and diamond-drill core were examined in November 1998, in conjunction with Canaco geologists.

This brief note outlines the results of initial Survey research on these new showings, and offers comments about the potential for magmatic Ni–Cu mineralization in Paleozoic mafic plutonic rocks of Newfoundland, based on analogues elsewhere in the Appalachians. Exploration of the Powderhorn Lake area is presently only in its early stages, but the recognition of a new type of exploration target in this area is significant in itself.

LOCATION AND GEOLOGICAL SETTING

The Powderhorn Lake area is situated west of the Trans-Canada Highway about 50 km south of Springdale, in a poorly exposed, recently logged, area. It lies within the Exploits Subzone of the Dunnage Zone, in an area previously mapped by Kalliokoski (1955) and Swinden and Sacks (1986, 1996). The area is underlain mainly by metasedimentary rocks, derived from greywackes, siltstones and graphitic shales that are probably metamorphosed equivalents of the "Caradocian shale" sequence of central Newfoundland (Swinden and Sacks, 1986). These are intruded in the east by the gabbroic to dioritic plutonic rocks of the Silurian Twin Lakes diorite intrusion, and to the southwest by medium-grained, leucocratic granite of the

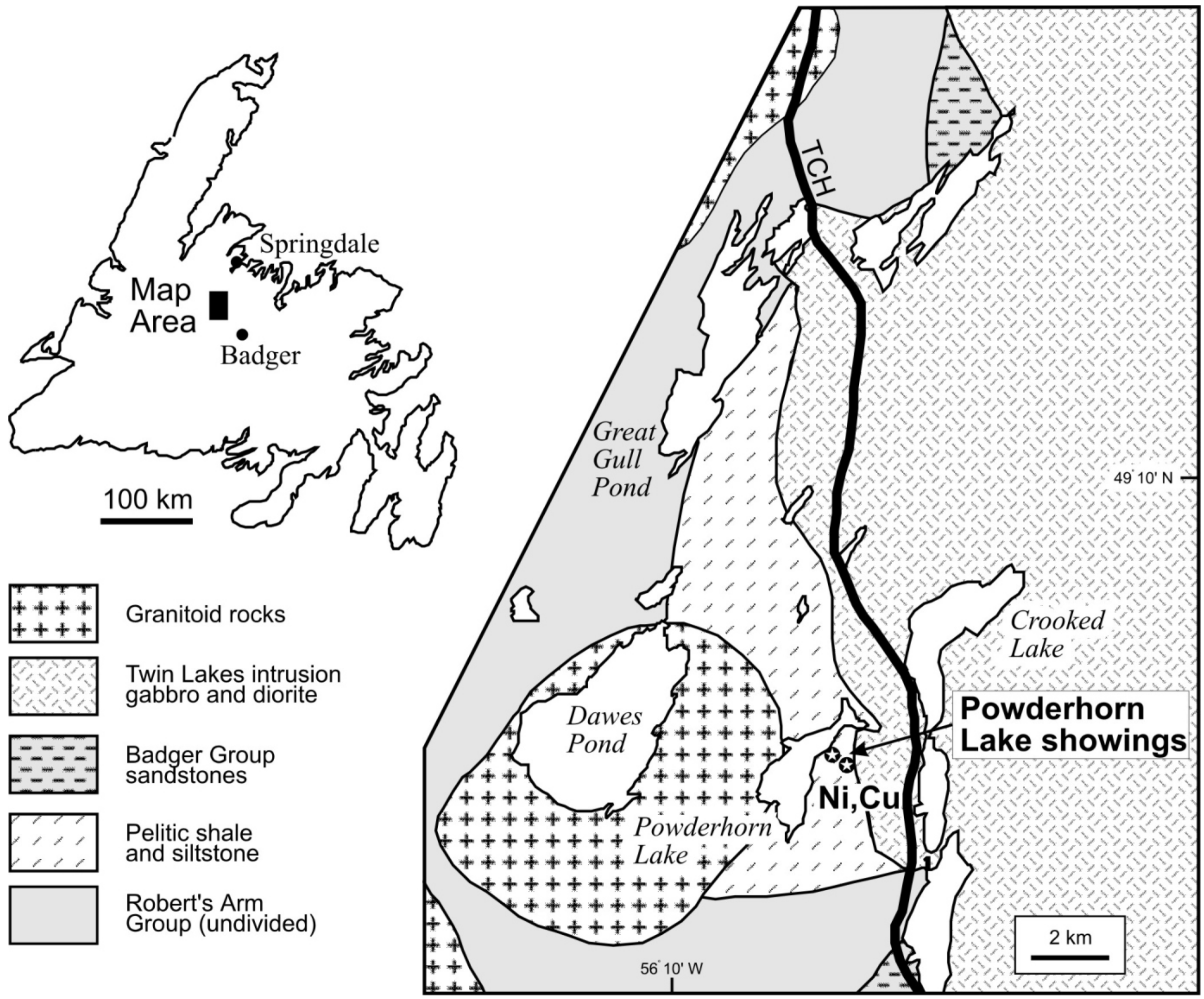

Figure 1. *Location of the Powderhorn Lake area, central Newfoundland, showing the principal geological units, and locations of Ni–Cu showings. (Geology* after *Swinden and Sacks, 1996.)*

Dawes Pond intrusion. The metamorphic overprint in the sedimentary rocks is posttectonic, and may, in part, be a thermal effect from the Twin Lakes diorite and/or the Dawes Pond granite (Kalliokoski, 1955), although regional metamorphism is also present (W. Jacobs, personal communication, 1999). Systematic 1:50 000-scale mapping of the area is planned for 1999, as an extension of the work of Dickson (*this volume*).

The area is poorly exposed, and most exposures were created during logging activity. Detailed mapping has so far been conducted only around the surface showings (W. Jacobs, unpublished work; Figure 2). This confirms that low- to medium-grade metasedimentary rocks, intruded by numerous diabase dykes, are dominant. The metasedimentary rocks are locally rusty-weathering and contain finely disseminated to laminated sulphide (mostly pyrite and pyrrhotite). Three of the five drillholes completed in late 1998 intersected bedded sulphides in the metasedimentary rocks, indicating that these are widespread. Medium- to coarse-grained mafic and intermediate plutonic rocks are present in association with Ni-rich sulphide mineralization, and are also cut by diabase dykes. The mafic to intermediate rocks are assumed to correlate with the nearby Twin Lakes diorite intrusion, but this is not proven. Figure 2 indicates some local geological information (based on information provided by W. Jacobs) and the locations of the surface showings. Canaco Resources Ltd. refers to the showings as the *"Main showing"* and the *"Road showing"*, but the showings are also known as "Birthday Bulge" and "Nickel Point" respectively, names coined by Jacob Kennedy and Bill Mercer.

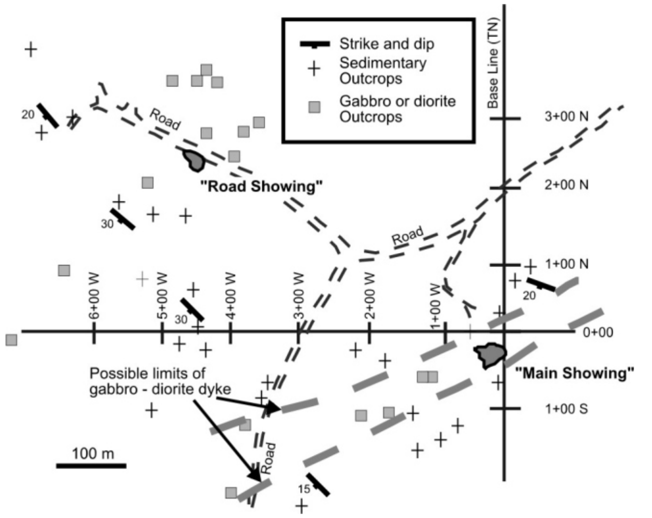

Figure 2. *Sketch map showing locations of surface showings and local distribution of metasedimentary and plutonic rocks. Summarized from work by W. Jacobs on behalf of Canaco Resources.*

MINERALIZATION

"MAIN SHOWING" (OR BIRTHDAY BULGE SHOWING)

This was the second mineralized outcrop to be discovered, but is described first because it contains the best mineralization. It is located a short distance from a logging road, along a skidder track (Figure 2), and consists of some rounded, smooth outcrops, which have been trenched in several places. The sulphide mineralization is locally spectacular, but is of restricted extent (< 40 m^2). It consists of disseminated sulphide, typically as patches 2 to 10 mm in size, within a medium-grained plutonic rock (Plate 1a), and local larger patches of semimassive sulphide. Most of the sulphide is pyrrhotite, but chalcopyrite is locally obvious, particularly on fracture surfaces. No pentlandite is visible to the naked eye. The proportion of sulphides ranges from 10 to 20 percent to a maximum of about 50 percent, and they appear to be interstitial to the silicate minerals (Plate 1b). Locally, mineralization shows a weak banding defined by sulphide abundance variations. The southwestern part of the showing is poorer in sulphides, but contains some interesting textures, including rounded sulphide patches that resemble immiscible droplets (Plate 1c). Two short drillholes completed at the showing in 1997 suggest that the more sulphide-rich section plunges southwest, structurally beneath the zone with sulphide droplets (W. Jacobs, personal communication, 1998). Grab samples from the surface mineralization contained between 0.24 and 0.92% Ni, 0.11 and 0.45% Cu and between 0.05 and 0.09% Co (Canaco Resources Ltd., press releases, 1998). The best field evidence for an orthomagmatic origin comes from sulphide droplets, seen in grab samples and part of the outcrop (Plate 1c). These commonly have chalcopyrite concentrated around their rims, and pyrrhotite in their centres. Drill core from the showing area shows locally well-preserved interstitial sulphide textures, and the sulphides are locally intergrown with slightly coarser grained, late-crystallizing silicate minerals (Plate 1b). Interstitial sulphide textures are clearly visible in thin section in less altered variants, but are blurred and indistinct in retrogressed samples (*see below*). Much of the alteration apparently postdates sulphide mineralization.

The host rock to the sulphides is a medium-grained, equigranular igneous rock dominated by altered plagioclase and several generations of amphibole. Petrographic studies indicate that it originally consisted of clinopyroxene, amphibole and plagioclase, i.e., it was a hydrous gabbro or diorite. Primary pyroxene is locally preserved, but is widely altered to secondary actinolitic amphibole. Primary brown–green amphibole (hornblende), and red biotite, occur in better-preserved samples, but are also altered to secondary amphibole and chlorite respectively. There is no sign that the original rock was olivine-bearing. The most poorly preserved samples are a murky intergrowth of saussuritic plagioclase, fibrous secondary amphibole and chlorite. The distribution of outcrops (Figure 2) suggests that the host rock forms a southwest-trending, dyke-like body about 50 m wide (W. Jacobs, personal communication, 1998). However, the outcrop control is poor, and the dimensions and attitude of the body are poorly constrained. Xenoliths of sedimentary rocks and white, vein-like quartz having dark reaction rims, are present in parts of the outcrop, and there are also inclusions of finer grained mafic and intermediate igneous rocks (W. Jacobs, personal communication, 1998). The gabbro or diorite is cut by numerous grey to black, aphanitic to weakly porphyritic, diabase dykes, which locally show well-preserved chilled margins. Although it is always difficult to be sure in fine-grained rocks, these appear mostly fresh and unaltered. The diabase dykes show no sign of sulphide mineralization, and probably postdate it.

An inclined drillhole (~150 m long) completed beneath the showing in late 1998 confirms all of the geological relationships noted above. The hole intersected an upper section of metasedimentary rocks, a central section dominated by complex plutonic rocks, and a lower metasedimentary section, which showed more evidence of contact metamorphism and/or metasomatism. The distribution of medium-grained gabbro or diorite is consistent with, but not diagnostic of, a steeply dipping, dyke-like, body. However, this rock type is essentially unmineralized in drill core. The adjoining metasedimentary rocks locally contain concordant laminations of sulphide, interpreted as primary syngenetic material. Diabase dykes are abundant, and cut both the

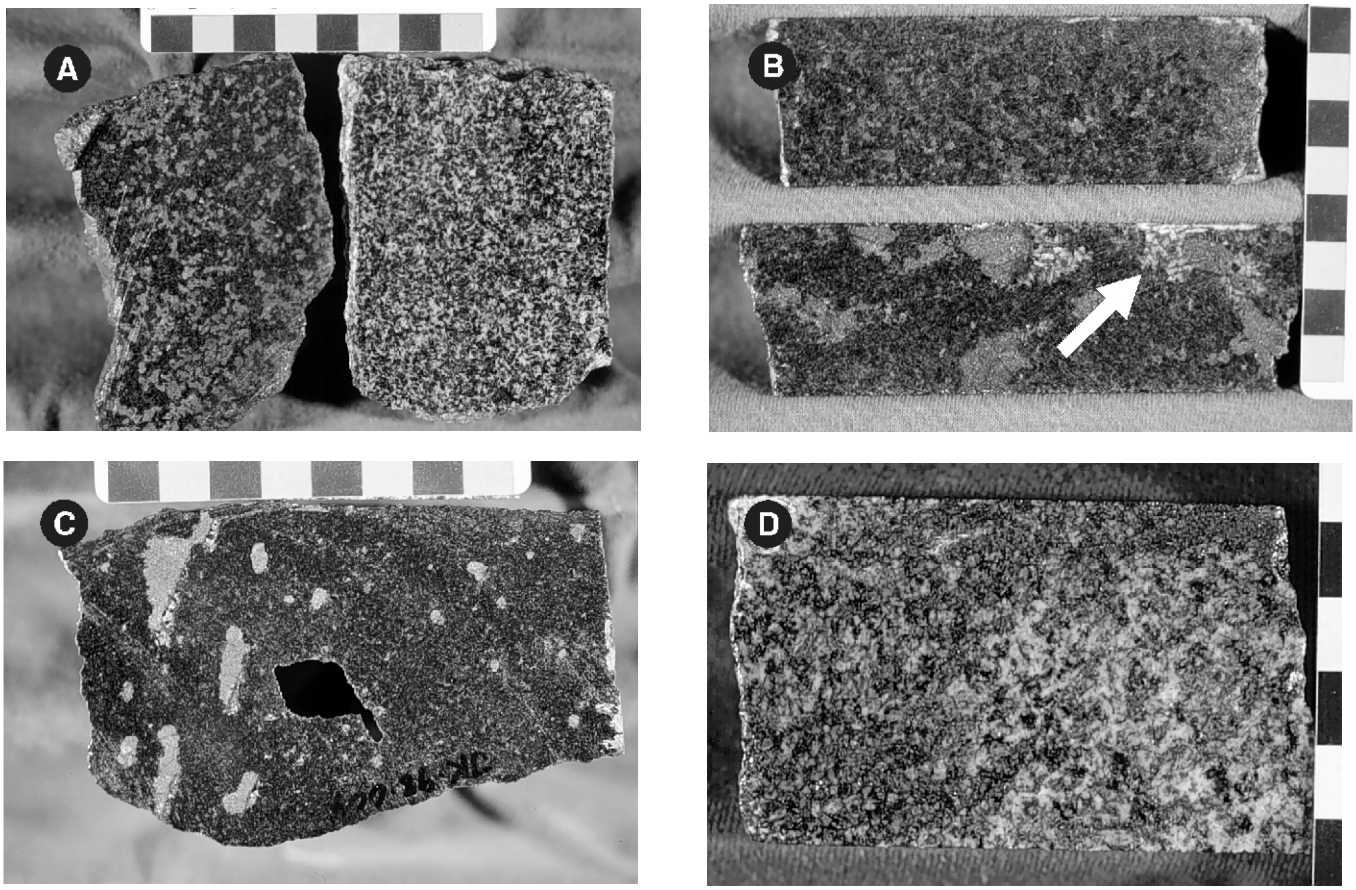

Plate 1. *Features of sulphide mineralization at the Powderhorn Lake showings. (A) Textures of mineralized (left) and essentially unmineralized (right) gabbro or diorite from the "Main showing". Sample at right contains very minor interstitial sulphide. (B) Drill core from the "Main showing". Upper core sample shows typical magmatic interstitial texture, and lower core sample shows coarse patchy sulphides, locally intergrown with coarser silicate material at their edges (denoted by arrow). (C) Cut slab showing well-developed ellipsoidal sulphide droplets, containing over 4% Ni in sulphides, locally associated with coarser silicates. Black area in centre of photo is a hole in the slab. (D) Weakly mineralized diorite or quartz diorite with apparently interstitial sulphide from the "Road showing".*

metasedimentary rocks and the gabbro–diorite. Locally, they contain patches of sulphide, most likely derived from the metasedimentary rocks. Metasedimentary rocks in the lowermost section of the hole contained thin quartz and feldspar-rich veinlets surrounded by diffuse zones of bleaching. These may represent fluid migration and/or anatexis related to contact metamorphism.

Four samples from the showing were analyzed for base metals and sulphur to determine the metal content of the sulphides, using the procedure outlined by Kerr (*this volume*). The results suggest a wide range, from 0.7 to 4.7% Ni, 0.7 to 3.0% Cu and 0.1 to 0.3% Co (Table 1). The highest values are from a very small sample containing clear sulphide droplets (Plate 1c), and are probably not representative of the mineralization as a whole; the Ni/Cu ratios are > 1.0 for all samples.

"ROAD SHOWING" (OR NICKEL POINT SHOWING)

This showing is located some 500 m northwest of the Main showing, and was the first recognized site of Ni–Cu mineralization. It consists of an outcrop adjacent to a logging road, and similar mineralization exposed in several nearby trenches.

The mineralization consists mostly of disseminated pyrrhotite, hosted by a pale grey, medium- grained, quartz-bearing igneous rock that appears more leucocratic than the gabbro or diorite host rock at the Main showing. The host rock is here described as a quartz diorite. This contains numerous irregular patches and zones of white to grey quartz, some of which appear to be vein-like in form, although some may be xenolithic. Clear magmatic textures,

Table 1. Cobalt, nickel and copper concentrations in samples from Powderhorn Lake Ni showings, and calculated metal contents at 100 percent sulphides

Area	"Main Showing"				"Road Showing"	
Sample Number	PH-1	JK-98-003	BB-1	BB-2	PH-2	NP-1
Uncorrected whole-rock geochemical data						
Co (ppm)	130	171	494	65	95	64
Ni (ppm)	814	2753	4863	165	878	690
Cu (ppm)	579	1779	1565	167	234	176
S (%)	2.80	2.04	17.30	0.86	5.42	2.94
Calculated metal contents in sulphide component, not corrected for metal in silicates						
Sulphide %	8.0	5.8	49.4	2.5	15.5	8.4
Co (%)	0.16	0.29	0.10	0.26	0.06	0.08
Ni (%)	1.02	4.72	0.98	0.67	0.57	0.82
Cu (%)	0.72	3.05	0.32	0.68	0.15	0.21

Notes :
1. Calculation of sulphide percentage and metal values at 100 percent sulphide based on S content of 35 wt% in pure sulphide.

2. No correction applied for metals present in silicate phases due to absence of olivine. Effects of correction would be minor, except in samples with low sulphide contents, e.g., BB-2. Also, Co values are particularly sensitive to silicate corrections, due to lower Co values and lower sulphide: magma partition coefficients. For these reasons, recalculated Co values should be treated with some caution.

or sulphide droplets, are not obvious in the surface outcrops, although the sulphides locally appear to be interstitial (Plate 1d). The host rock is cut by a medium-grained, equigranular gabbro or diorite that resembles the host rock at the main showing, and also by numerous diabase dykes. Local outcrops indicate that the quartz diorite occurs for at least 1000 m^2 outside the immediate area of mineralization, and there is no indication that it forms a restricted dyke-like body, as inferred at the Main showing.

In thin section, the host rock is dominated by altered plagioclase and several generations of amphibole, and has a general resemblance to samples from the Main showing. Quartz occurs both as irregular masses (originally interpreted as xenocrysts or xenoliths) and as interstitial material of primary igneous appearance. The latter suggests that the rock had a more differentiated, quartz-rich primary composition than the host rock at the Main showing. Vein-like quartz, locally associated with sulphides, was also noted in thin section. The gabbro or diorite, which seems to cut the quartz diorite, is identical to the better preserved samples from the Main showing, but contains only minor interstitial sulphide associated with biotite–oxide clots. A short drillhole completed in 1997 at the showing contains two main rock types. The grey quartz diorite is cut by diabase, which forms discrete intervals and centimetre-scale veins with chilled margins. Sulphides are associated with the older unit, and have a vein-like form in several areas, associated with quartz-rich intervals. The sulphides are mostly pyrrhotite containing very minor amounts of chalcopyrite. A longer (~150 m) inclined drillhole completed beneath the surface showing in late 1998 consists mostly of plutonic rocks, and subequal amounts of quartz diorite and diabase. The quartz diorite contains minor sulphide mineralization in the upper section. A more homogeneous gabbro or diorite, resembling surface outcrops, is also present. The lowermost 30 m or so consists of foliated metamorphic rocks of uncertain character.

Two samples from the showing were assayed for base metals and sulphur. Results indicate that the sulphides contain 0.6 to 0.8% Ni, 0.15 to 0.2% Cu and minimal Co (Table 1). The metal contents of the sulphides are lower than at the Main showing, and the Ni/Cu ratio is significantly higher.

INTERPRETATION AND DISCUSSION

NATURE OF MINERALIZATION

The two showings in the Powderhorn area have different characteristics, but both represent mineralization in which Ni is an important component. In this respect, they are clearly different from the more common volcanic-associated Cu–Zn sulphide mineralization known from this part of Newfoundland.

The Main showing has several features that indicate an orthomagmatic origin. Although the host rocks are altered and retrogressed, textures in the field, drill core and thin-sections suggest the presence of sulphides in a crystallizing magma. These include interstitial sulphide patches, the development of faint layering, and the rounded sulphide patches that suggest immiscible droplets. Alteration and retrogression have partially blurred the textures, but they remain convincing (Plate 1). Analytical data show that the sulphides have Ni/Cu ratios greater than 1.5, and locally contain up to 4.7% Ni and 3.0% Cu (Table 1). Although these high values are interesting in that they are comparable to sulphide tenors from the Voisey's Bay area, other samples contained more modest Ni contents in sulphide of 0.7 to 1.0% (Table 1).

In contrast, some of the features of the Road showing imply the operation of hydrothermal processes. The sulphide textures are less clearly magmatic, and the Ni contents in sulphides are generally lower. The association of sulphides with vein-like quartz concentrations suggests at least some hydrothermal deposition, but it is not clear if this represents remobilization of existing primary sulphide in the host rocks, or introduction of externally derived material. The high Ni/Cu ratio of the mineralization is atypical of volcanogenic hydrothermal systems, and suggests that the Ni may have come from a magmatic source even if the latter interpretation is correct.

The host rock at the Main showing originally had a relatively evolved, olivine-free, mafic to intermediate composition, and is atypical of igneous rocks generally associated with nickeliferous sulphides. In general, sulphide liquids associated with more evolved mafic magmas have high Cu/Ni, but low absolute values of both metals. The mineralization is certainly anomalous in this regard, and the metal-rich sulphide droplets of sample JK-98-003 are particularly unusual. One possibility is that the mineralization represents a sulphide liquid of magmatic origin that was collected and transported by a temporally associated but genetically unrelated mafic magma. This may also provide an explanation for the strong grade variations noted in the analytical data (Table 1), which may reflect variable loss of metals from the sulphide phase in transit.

In general, the contact region of the Twin Lakes diorite intrusion and sulphide-bearing metasedimentary rocks (Figure 1) represents a potentially favourable environment for the development of magmatic sulphides. Contamination by sulphur-bearing country rocks seems to be a common thread in the development of many types of magmatic Ni–Cu deposits (e.g., Naldrett, 1989). However, economic grades of Ni and Cu in the sulphides are contingent upon a suitable magmatic source – i.e., a magma in which Ni and Cu have *not* been extensively depleted by fractional crystallization. Present information about the Twin Lakes diorite intrusion suggests that much of it is relatively evolved gabbro or diorite, but its internal anatomy is not well-known, and it may include more favourable units (*see below*).

POSSIBLE ANALOGUES IN THE NORTHERN APPALACHIANS

The best-known examples of magmatic Ni–Cu sulphide deposits in the Appalachian Orogen are hosted by middle Paleozoic mafic intrusions in northeastern Maine and adjacent New Brunswick. Although these intrusions are not directly equivalent to those that exist in the Powderhorn area, they provide a possible analogue and exploration model for central Newfoundland, and are briefly reviewed.

Mafic plutonic rocks form two subparallel belts in northeastern Maine, and one of these (situated on the coast) extends into New Brunswick. These plutons intrude metasedimentary and metavolcanic rocks of the Miramichi Subzone and St. Croix Subzone, which broadly correspond with the Gander Zone of the Newfoundland Appalachians (Williams, 1995). Mineralization in the inland belt, specifically the Moxie and Katahdin plutons, is discussed by Thompson and Naldrett (1982), and the Ni deposits of the St. Stephen pluton in the coastal belt are discussed by Paktunc (1986, 1987) and Kooiman (1996). Important Ni mineralization is also associated with mafic and ultramafic rocks at the Harriman deposit, in the coastal belt (e.g., Rainville and Park, 1976), but these are considered to be of Ordovician age.

The Moxie pluton is an elongated, irregularly shaped body about 30 km long, which includes dunite, troctolite, olivine–gabbro, norite and iron-rich gabbro and diorite (Thompson and Naldrett, 1982). Layering is not well developed, but the range of compositions corresponds to those seen in larger layered mafic intrusions. The Katahdin pluton is a small 4.5 by 1.5 km pluton consisting of troctolite, norite and olivine–gabbro (Thompson and Naldrett, 1982). Sulphide mineralization in the Moxie pluton is hosted by olivine-bearing cumulate rocks, and consists of interstitial disseminated sulphides to local semimassive and net-textured sulphides. The sulphide mineralization, which is of limited extent, is localized near the contacts of the pluton, in close proximity to sulphide-bearing sedimentary country rocks. The Katahdin pluton contains one of the largest sulphide deposits in the Appalachians, consisting of over 200 million tonnes of near-massive (>75 percent) magmatic sulphides. Unfortunately, the Ni and Cu grades are low (<0.3 percent combined), and only the limonitic surface gossan of the deposit was mined, as a source of iron ore in the 19th century. All the deposits have a common sulphide mineralogy dominated by pyrrhotite, chalcopyrite and pentlandite. They have all been affected by post-mineralization alteration and retrogression of their host rocks, and local remobilization of sulphides.

The Ni, Cu and Co contents of the sulphides in these deposits are highly variable. The Katahdin sulphides contain only 0.2% Ni and 0.1% Cu, but contain 0.1 to 0.18% Co. The Moxie pluton sulphides contain from 0.44% to 1.87% Ni, 0.32% to 0.72% Cu, and 0.13% to 0.22% Co (all values from Thompson and Naldrett, 1982). The variations in sulphide tenor are attributed to variations in the "R-factor", i.e., the ratio of source silicate magma to the sulphide liquid that extracts metals from it. Thus, smaller occurrences having higher metal grades record relatively high R-factors (but produced limited amounts of sulphide) whereas overabundance of sulphur at the Katahdin deposit resulted in a huge tonnage, but excessive dilution of Ni and Cu (Thompson and Naldrett, 1982). Cobalt is less affected by R-factor variations, as its sulphide/magma partition coefficient is smaller than the equivalent parameters for Ni and Cu (Naldrett, 1989). The Katahdin deposit is a case where there was *too much* sulphide liquid – had the ambient R-factor been an order of magnitude greater, it could have been a 20 MT deposit having potentially economic grades of Ni and Cu. Sulphur isotope and S/Se data summarized by Thompson and Naldrett (1982) show that sulphur derived from metasedimentary country rocks was important in all the deposits, contributing from 31 to 91 percent of the total sulphur.

In New Brunswick, the Silurian St. Stephen intrusion also includes varied mafic rocks, including peridotite, troctolite, olivine gabbro, gabbronorite and anorthosite (Paktunc, 1986, 1987). It contains numerous sulphide occurrences, including three deposits that collectively contain 1 MT of 1.05% Ni and 0.53% Cu (Paktunc, 1987), and were the subject of underground exploration in the late 1950s. A recent study of archived sample material suggested average grades of 0.6 to 0.8% Ni (maximum around 2%), 0.25 to 0.5% Cu (maximum 2.6%) and 0.05 to 0.1% Co (Kooiman, 1996), and the area is presently under active exploration by Cobrun Mining Corporation. Paktunc (1986, 1987) recognized both primary magmatic sulphide mineralization and remobilized sulphide mineralization. Most of the known larger concentrations are of the latter type, and appear to be in part structurally controlled. The metal contents of sulphides in the St. Stephen deposits are not explicitly reported, but are stated to be similar to values obtained from the Moxie pluton in Maine by Thompson and Naldrett (1982). However, much of the Ni is present in solid solution in pyrrhotite, with lesser amounts of pentlandite. The source of the sulphur in the St. Stephen deposits appears to have been Lower Ordovician sulphide-bearing sedimentary rocks, which are intruded by the pluton and also seen as xenoliths within it (Paktunc, 1987).

Nickel mineralization is associated with feldspathic peridotite and gabbro–diorite of the Harriman and Warren intrusions located near Augusta, Maine. The Warren deposit contains about 10 MT of 1% Ni and 0.5% Cu (Rainville and Park, 1976), including 1.5 MT of potential open-pit reserves grading 1.6% Ni, 0.8% Cu and 0.13% Co, and came close to a production decision in the early 1990s (Whiteway, 1990). However, land-use issues connected to its location in a populated area have delayed development or further exploration of the deposit (H. Berry, personal communication, 1998). Mineralization is related to mafic–ultramafic intrusions emplaced into high-grade gneisses including graphitic, sulphide-bearing rocks, and is contained as interstitial sulphides in an olivine-rich phase. Although the host rocks are generally considered to be Ordovician, their ages are not well constrained (H. Berry, personal communication, 1998).

POTENTIAL TARGET MAFIC INTRUSIONS IN NEWFOUNDLAND

The Maine and New Brunswick examples discussed above are all associated with intrusions that include relatively primitive olivine-bearing mafic rocks such as dunite, troctolite and olivine gabbro. These primitive host rocks cannot be equated directly to the olivine-free gabbro or diorite that host Ni–Cu mineralization near Powderhorn Lake. However, on a regional scale, central and western Newfoundland contain several mafic to intermediate plutonic complexes of known or inferred Silurian age (Figure 3). Some of these mafic plutons are poorly known, and all have traditionally been perceived to have little potential for metallic mineralization. This article concludes with a brief review of their main features.

Mount Peyton Gabbro

The Mount Peyton Intrusion is one of the largest in central Newfoundland, and about 60 to 70 percent of it consists of gabbro and diorite, which intrude sedimentary and volcanic rocks of the Botwood Group. It is currently exploited as a source of high-quality dimension and monument stone. Descriptions of the mafic rocks (Dickson, 1992, 1993, 1994) indicate that they are dominated by homogeneous gabbro, composed of plagioclase, clinopyroxene, primary hornblende and biotite. However, some parts of the intrusion,

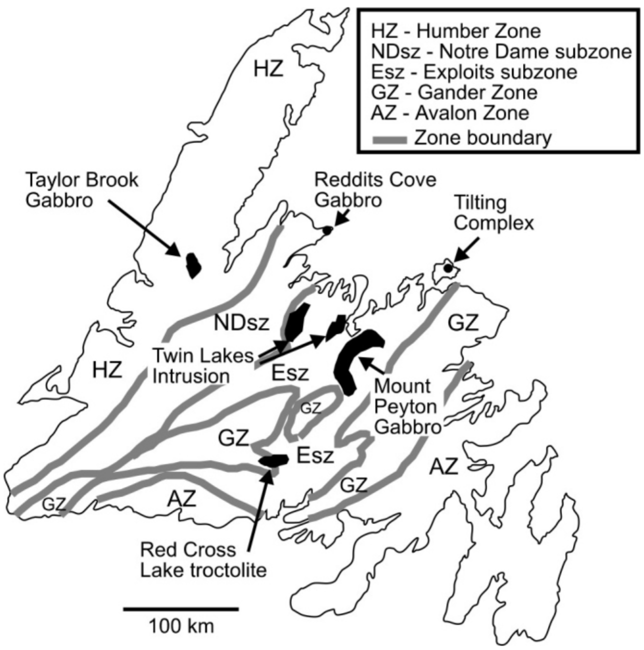

Figure 3. *Location of middle Paleozoic mafic intrusions in central and western Newfoundland that may merit some exploration effort for magmatic Ni–Cu mineralization.*

particularly in the south, exhibit well-developed layering and include peridotite, olivine gabbro and troctolite. Dickson (1992) reports "extremely friable and rusty gossan" developed on some gabbro outcrops, which is a common characteristic of olivine-bearing rocks. Sulphide-bearing Ordovician sedimentary rocks occur in the general area of these more mafic variants. A more detailed study of this area by Eckstrand and Cogulu (1993) defined two discrete layered olivine gabbro sequences, and a "schleiric troctolite". No sulphides were reported, and analyses of samples did not indicate any enrichment in platinum group elements (PGEs). However, depletion in PGEs by no means precludes potential for base metals.

Tilting Complex, Fogo Island

Mafic and intermediate rocks on Fogo Island are dominated by hornblende-rich gabbro and diorite, commonly mingled with spatially associated granitoid rocks. However, layered mafic rocks, termed the Tilting Complex, occur at the northeastern corner of the island. The Tilting Complex includes pyroxenitic, gabbroic and noritic rocks that are locally olivine-bearing, and were in part directly derived from the mantle (Cawthorn, 1978). However, olivine is not an abundant phase, and most of the rocks contain abundant primary hornblende. Tabular xenoliths of arenaceous sedimentary rocks are common in the mafic rocks, implying possible assimilation and contamination by Botwood Group country rocks. Limited exploration work was conducted in the area by Newfoundland and Labrador Corporation (NALCO) in 1954 (reported by Baird, 1958), but there has been no recent attention. Eckstrand and Cogulu (1992) report low PGE values, and mention disseminated magmatic sulphides in pyroxenites. A sulphide-bearing sample from the Tilting area given to the author by prospector Gary Lewis contained 6% sulphides, 663 ppm Ni and 1026 ppm Cu. Normalized to 100% sulphide, these indicate sulphide metal contents of about 1% Ni and 1.7% Cu.

Twin Lakes Intrusion

The Twin Lakes diorite intrusion is the mafic intrusion closest to the Powderhorn property, and is a large and complex body that includes numerous discrete phases. The dyke hosting Ni–Cu sulphide mineralization at the Main showing may be related to it, but there is no proof of such a link. Although commonly grouped with other Silurian bimodal intrusions such as the Mount Peyton Intrusion, the mafic rocks of the Twin Lakes body are far more heterogeneous and varied. The internal anatomy of the intrusion, and its petrological variability, are presently known only in a general sense, but the area is currently part of a mapping project (Dickson, *this volume*). Existing information suggests that gabbroic to dioritic rocks containing primary mafic mineral assemblages dominated by clinopyroxene and hornblende are dominant. However, pyroxenitic rocks have been recognized in places (W.L. Dickson, personal communication, 1998), suggesting that some primitive compositions occur.

Red Cross Lake Troctolite

This is a 20-km-long, poorly exposed, mafic intrusion located southeast of Meelpaeg Lake (Figure 3), where it intrudes migmatitic paragneisses assigned to the Gander Zone, and structurally overlying sedimentary rocks assigned to the Exploits Subzone. It is described by Kean (1977) and by Colman-Sadd (1987), and was known previously as the "Rodeross Lake troctolite" due to the misreading of the informal name of the lake on a hand-drawn map. It was originally viewed as Jurassic, but is now generally considered to be Silurian or Devonian. The western end of the intrusion (Kean, 1977) includes peridotite, troctolite, gabbro and diorite, and shows well-developed magmatic layering. The eastern section (Colman-Sadd, 1987) is dominated by massive grey gabbro, which is reported to contain xenoliths of granitoid gneiss, quartzite and pelitic metasedimentary rocks. The country rocks to the intrusion include sulphide-bearing black shales. A pyroxenitic body bearing disseminated sulphides was described by Colman-Sadd (1987), who suggested that the intrusion merited some exploration effort. Interstitial magmatic sulphides are reported in peridotites and troctolites by Eckstrand and Cogulu (1992) but no analytical data were reported. A smaller intrusion to the north-east, termed the Round Pond gabbronorite, includes some similar rock types. The area was reportedly investigated by ASARCO in the 1960s, but has seen no recent attention.

Reddits Cove Gabbro

The Reddits Cove gabbro is located at the northeastern tip of the Baie Verte Peninsula, and is described by DeGrace *et al*. (1976), who grouped it genetically with spatially associated granitic rocks. The Reddits Cove gabbro is dominated by medium-grained clinopyroxene-rich gabbro containing variable amounts of relict olivine, and exhibits well-developed cumulate layering, locally including ilmenite-rich layers.

Taylor Brook Gabbro

The Taylor Brook gabbro (Owen, 1991) is a large mafic intrusion within the Grenville Province inlier of the Humber Zone. Based on regional gravity data, it may also be present widely in the subsurface, beneath Precambrian gneisses (Owen, 1991). It was originally classed as Precambrian, but recent geochronology now indicates a 429 Ma (Silurian) age (Heaman *et al.*, 1996). The mafic rocks of the intrusion are dominated by olivine-bearing gabbronorite, in which olivine compositions are relatively magnesian (Fo_{70}), and the complex shows a concentric layering pattern (Owen, 1991). The area has seen only limited exploration activity.

CONCLUSIONS

The new Ni–Cu showings in the Powderhorn Lake area are significant in that they represent a new type of exploration target in this region of the province. Preliminary information from field, petrographic and geochemical studies indicates that at least one represents magmatic sulphide mineralization of the type commonly associated with mafic–ultramafic intrusions. The other showing may involve hydrothermal processes, but Ni and Cu may have been derived from an original magmatic sulphide source. Although one of the samples contains sulphides having a metal content similar to those seen at Voisey's Bay, it may not be representative of the mineralization as a whole. The extent of mineralization at the showings presently appears to be limited to near-surface outcrops, although neither has yet been fully tested by drilling. The genetic relationship between the mineralization and the host gabbro or diorite at the main showing is unclear, but the host is unlikely to have been a source magma for the Ni and Cu. However, the presence of Ni-rich sulphide mineralization, locally with high-metal tenors, implies that suitable source magmas did exist, and raises the possibility that larger or richer sulphide concentrations may occur in this or nearby areas.

Ni–Cu mineralization associated with middle Paleozoic mafic intrusions in Maine and New Brunswick provides a possible exploration model, and the Katahdin deposit indicates that relatively small intrusions can potentially generate large massive sulphide accumulations. As in most other magmatic sulphide deposits, assimilation of sulphur from sulphide-bearing metasedimentary country rocks appears to have been an important factor in development of sulphide liquids. However, the Maine and New Brunswick deposits are mostly associated with more primitive, olivine-bearing rocks, which are not presently known to exist in the Powderhorn area or in the adjacent Twin Lakes intrusion, although the latter remains poorly known. Other middle Paleozoic mafic intrusions in Newfoundland are known to contain at least some of these rock types, but to date have received little exploration attention.

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