Current Research (2000) Newfoundland Department of Mines and Energy
Geological Survey, Report 2000-1, pages 311-334

MAGMATIC Ni–Cu SULPHIDE MINERALIZATION IN THE HARP LAKE INTRUSIVE SUITE, CENTRAL LABRADOR

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ABSTRACT

Most sulphide mineralization in the Harp Lake Intrusive Suite (HLIS) consists of disseminated, interstitial sulphides in leucotroctolite to anorthosite, and forms concordant "stratiform" zones of syngenetic aspect. Absolute grades are low, because there is normally <5% sulphide, but the Ni and Cu contents of the sulphides are high, ranging up to 6.5% Ni and 3.15% Cu. In detail, there are two subgroups, which are respectively Ni-dominated and Cu-dominated. A small number of showings consist of discordant semimassive and massive sulphides that appear to have intruded their anorthositic wall rocks. These have low sulphide Ni contents (<0.5% Ni) and variable sulphide Cu contents (0.3% to 5.3% Cu). Disseminated sulphide mineralization hosted by marginal gabbroic rocks of the HLIS has similarly low Ni and Cu contents in sulphides, and low Ni/Cu. The semimassive and massive mineralization is analogous to much of the mineralization seen in Nain Plutonic Suite (NPS) anorthosites, but the stratiform, disseminated mineralization has no clear analogue in the NPS. The differences in the character of the two anorogenic plutonic suites are likely related to their different erosional levels.

Although some HLIS mineralization has sulphide metal contents akin to those seen at Voisey's Bay, there is no indication of significant sulphide accumulation. The magmatic environment, in which sulphides equilibrated with trapped late-stage liquids in near-solid cumulates, may not have been conducive to concentration of sulphides. Nevertheless, some of the principal Ni-dominated sulphide zones in the HLIS may merit further exploration for blind targets using deep-penetrating geophysical methods.

INTRODUCTION

Anorogenic plutonic suites in Labrador were subjected to intense mineral exploration following the Voisey's Bay discovery in late 1994. Most of this activity was concentrated in the Nain Plutonic Suite (NPS) and adjacent gneisses (Figure 1) that were previously unexplored. In contrast, the nearby Harp Lake Intrusive Suite (HLIS) of central Labrador was intermittently explored for base metals and platinum-group elements (PGE) in the 1970s and 1980s, and has long been known to contain magmatic sulphide mineralization, but it received comparatively little exploration attention in the post-Voisey's Bay era. This report summarizes the pre- and post-1995 exploration programs in the HLIS, and integrates these results with more recent field and laboratory investigations conducted as part of the Labrador nickel project. The objective is to provide a concise and current summary of magmatic sulphide mineralization in the HLIS, and to offer some preliminary comparisons with analogous mineralization now known from the NPS.

REGIONAL GEOLOGY

The Harp Lake Intrusive Suite (formal terminology after Wardle, 1993) is one of several undeformed Mesoproterozoic plutonic complexes that sit north of the Grenville Front in Labrador (Figure 1). This region consists of Archean rocks of the Nain Province in the east, and Archean to Paleoproterozoic rocks of the southeastern Churchill Province in the west, which were juxtaposed ca. 1850 Ma, during the formation of the Torngat Orogen. The tectonic boundary between these two structural provinces is a major crustal-scale discontinuity. The dominant country rocks around the HLIS are amphibolite-facies orthogneisses and paragneisses assigned to the southeastern Churchill Province. However, the eastern edge of the HLIS is in contact with Archean orthogneisses of the Hopedale Block of the Nain Province (Figures 1 and 2). Like the NPS to the north, the HLIS straddles the Nain Province–Churchill Province boundary, but most of the intrusion probably lies within the Churchill Province. The southern boundary of the

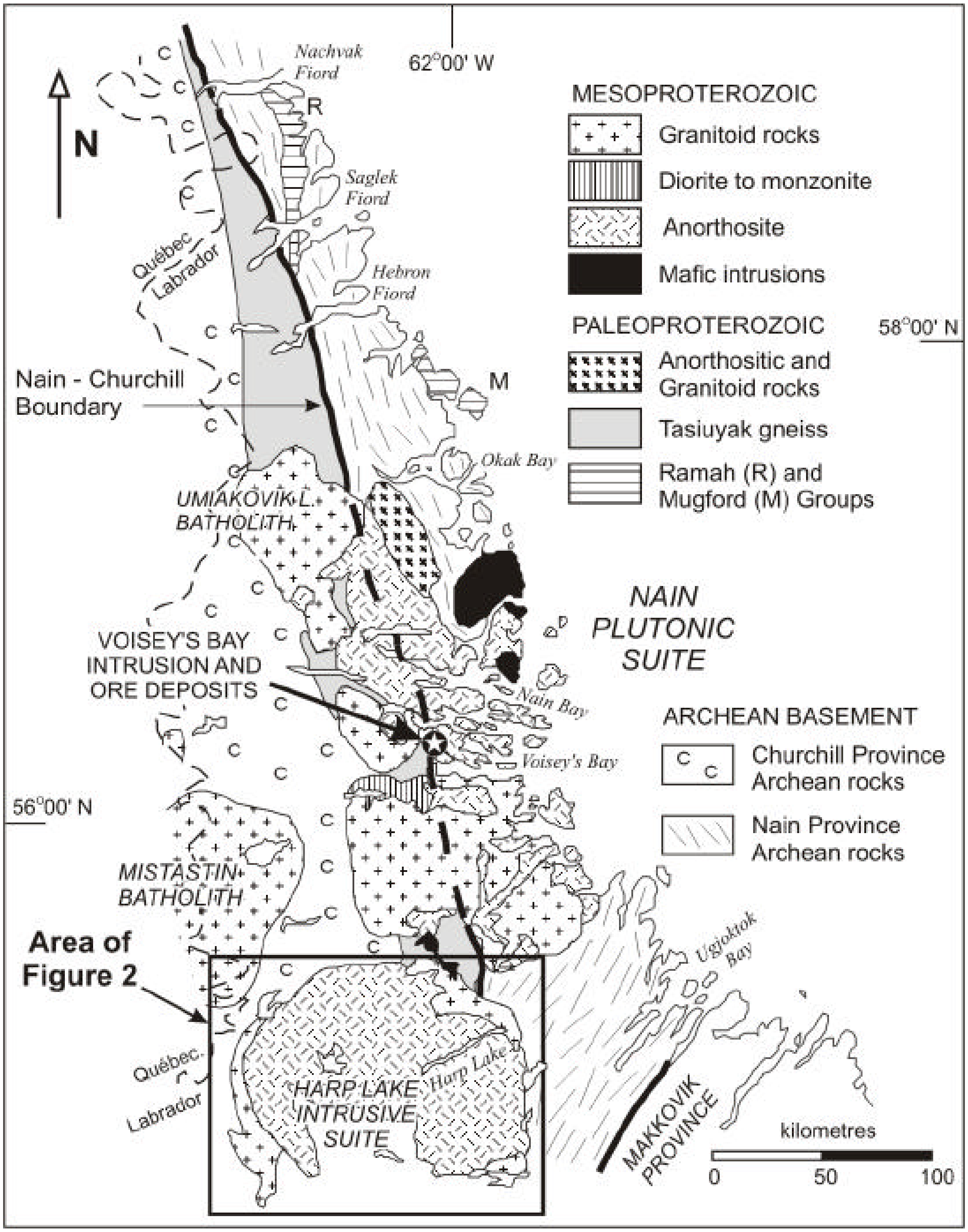

Figure 1. *Simplified geology of central and northern Labrador, showing the locations of the Nain and Churchill structural provinces, their boundary zone, and Mesoproterozoic anorogenic intrusive complexes.*

HLIS is partly defined by flat-lying terrestrial sedimentary (and lesser basaltic) rocks of the 1273 to 1250 Ma Seal Lake Group (Romer *et al.*, 1995) that appear to form a thin veneer sitting above the intrusion (Figure 2). Iridescent (Labradorite) plagioclase fragments in Seal Lake Group conglomerates imply an unconformable relationship (Emslie, 1980). There have been no recent geochronological studies of the HLIS, but Emslie (1980) reports U–Pb ages of ca. 1450 Ma and 1426 Ma from granites near Arc Lake and Snegamook Lake, and a K–Ar (hornblende) age of 1482 ± 45 Ma from gabbroic rocks near Shapio Lake (Figure 2). The K–Ar (hornblende and biotite) ages from gneisses within the contact metamorphic aureole of the intrusion range from 1450 to 1350 Ma (Emslie, 1980). The anorthositic

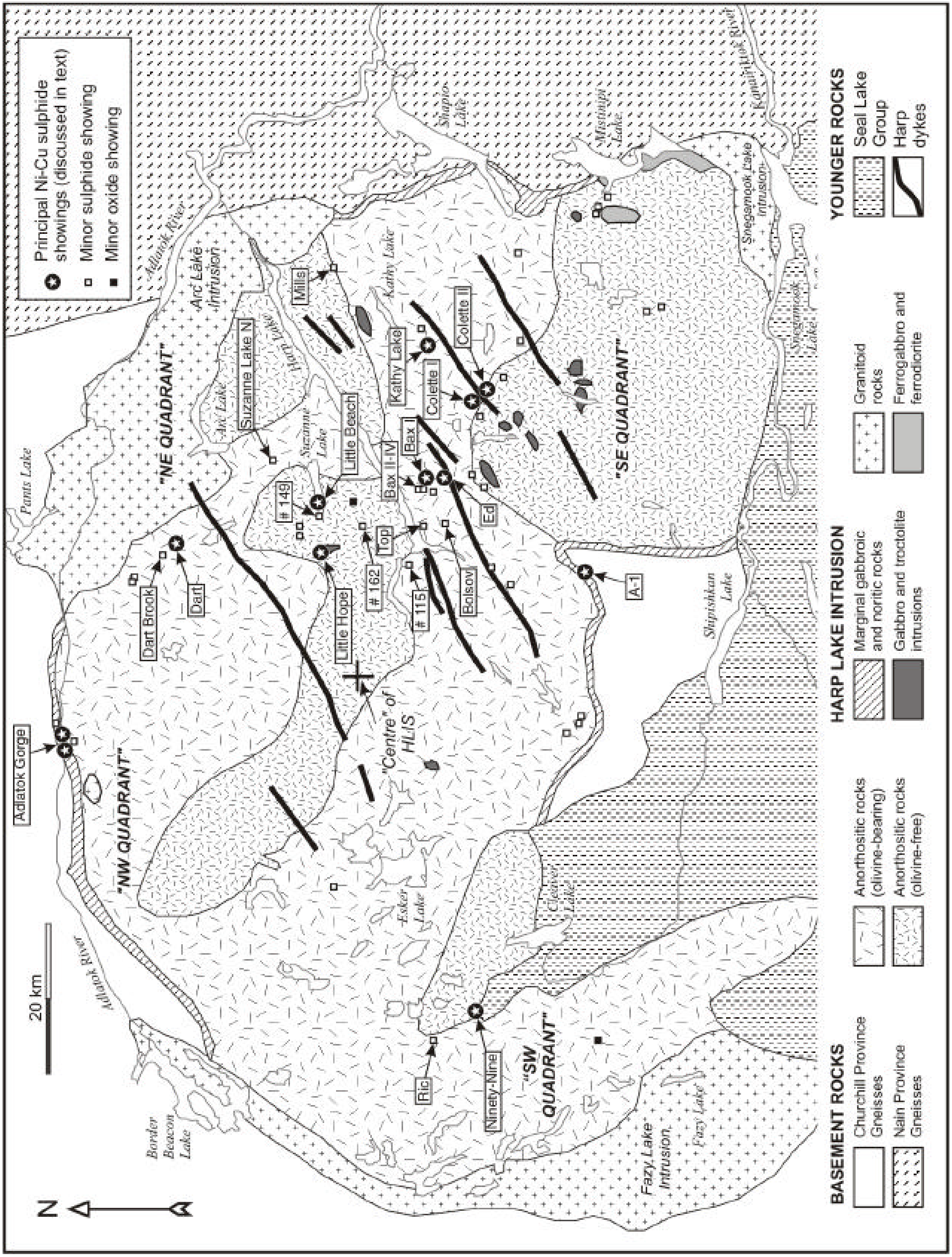

Figure 2. *The geology of the Harp Lake Intrusive Suite (after Emslie, 1980) showing the broad possible compositional subdivisions, and the locations of Ni–Cu sulphide occurrences of various types.*

rocks are cut by an east-northeast-trending swarm of olivine–diabase intrusions (the Harp Dykes) dated at 1274 ± 2 Ma (Cadman *et al.*, 1993). The HLIS thus appears to be at least 100 Ma older than the nearby NPS (1350 to 1290 Ma; Ryan, 1998, and references therein).

GEOLOGY OF THE HARP LAKE INTRUSIVE SUITE

Parts of the HLIS were initially mapped in reconnaissance fashion by the Geological Survey of Canada (Taylor, 1972). Systematic mapping was completed in the early 1970s by the Geological Survey of Canada, and published as a 1:250 000-scale geological map and accompanying bulletin (Emslie, 1980). No subsequent regional mapping has been completed throughout the area, although the northern edge of the HLIS was mapped by Thomas and Morrison (1991). The following account, and the simplified map shown in Figure 2, are summarized from Emslie (1980).

The HLIS is an almost elliptical body underlying some 10 000 km^2, or roughly half the total area covered by the nearby NPS (Figure 1). It includes a wide variety of igneous rocks, but is dominated by anorthosites (*sensu lato*, i.e., including leuconorite, leucogabbro and leucotroctolite) that make up at least 80 percent of its outcrop area (Figures 1 and 2). Granitoid rocks form three discrete bodies (Arc Lake, Fazy Lake and Snegamook Lake intrusions) located around the margins of the main anorthositic mass. Minor amounts of mafic rocks and iron-rich intermediate plutonic rocks ("ferrodiorites") also occur as small masses and dykes cutting the anorthositic rocks. These three compositional groups are familiar from the NPS (e.g., Ryan, 1998), but their relative proportions in the HLIS are distinctly different.

The mafic rocks of the HLIS fall into two groups. Fine- to medium-grained gabbroic rocks mostly occur in marginal areas, and define a near-continuous outer "ring" up to 1 km wide, broken only where granitoid rocks separate anorthosites from country rocks (Figure 2). However, due to lack of outcrop, the continuity of this zone, in part, reflects interpretation and extrapolation. In most cases, the marginal gabbroic rocks grade inward into coarser grained anorthosites, but in some areas, notably around Shapio Lake, marginal gabbros appear to intrude the anorthosites and their country rocks, and are thus later in the intrusive sequence. Small bodies of medium-grained gabbro and troctolite are also present in several locations within the anorthositic rocks, and also appear to be late intrusions. The interior of the HLIS is dominated by coarse-grained, plagioclase-rich, mafic rocks including leucotroctolite, leuconorite and true anorthosite. These were divided simply by Emslie (1980) into olivine-bearing and olivine-free variants. Both units exhibit sporadic mineralogical and textural layering, and variations in the attitudes of such primary features imply that the interior of the body may be a composite mass of separate, yet closely similar, anorthositic intrusions (Emslie, 1980). The details of this internal anatomy, and the exact age relationships between different subunits, remain essentially unknown.

The granitoid rocks of the HLIS are dominated by quartz monzonite and monzogranite ("adamellite") that form massive plutons lacking clear internal structure. Both the Arc Lake and Fazy Lake intrusions appear to locally overlie the anorthositic rocks. Aside from scattered dykes and veins, granitoid rocks are absent from the interior of the HLIS. Ferrodiorites occur as dykes and small masses throughout the complex, and also occur in the areas where anorthosites and granitoid rocks come into contact. The only ferrodioritic pluton visible at the scale of Figure 2 is at Mistinipi Lake, at the southeast margin of the HLIS.

There are several important differences between the HLIS and the larger and better known NPS, which are as follows:

1. The relative proportions and distribution of anorthositic (*s.l.*) and granitoid rocks differ. In the HLIS, granitoid rocks are minor (<20 percent by area) and occur only around the margins of the main anorthosite mass. In the NPS, granitoid rocks are more abundant (>40 percent by area) and have a more complex distribution, in which outcrop patterns imply that they commonly sit above the anorthosites, which are seen through erosional "windows" in the granites (Figures 1 and 3).

2. The HLIS has a near-continuous outer ring of marginal fine- to medium-grained gabbroic rocks, which is not seen within the NPS, although some individual plutons may have similar border zones.

3. Layered "troctolitic" mafic intrusions (such as the Kiglapait Intrusion) are a prominent component of the NPS, but these rocks are virtually absent from the HLIS. Similarly, large sheet-like ferrodiorite bodies known in the NPS (such as the Cabot Lake Intrusion) are absent from the HLIS.

4. Based on the subunits defined by Emslie (1980) and recent petrographic studies, olivine-bearing anorthosite and leucotroctolite are more abundant in the HLIS than in the NPS, which is dominated by leuconoritic compositions.

5. The HLIS has relatively little aeromagnetic expression compared to the NPS, and there are areas, notably in the west, where Churchill Province structural trends appear

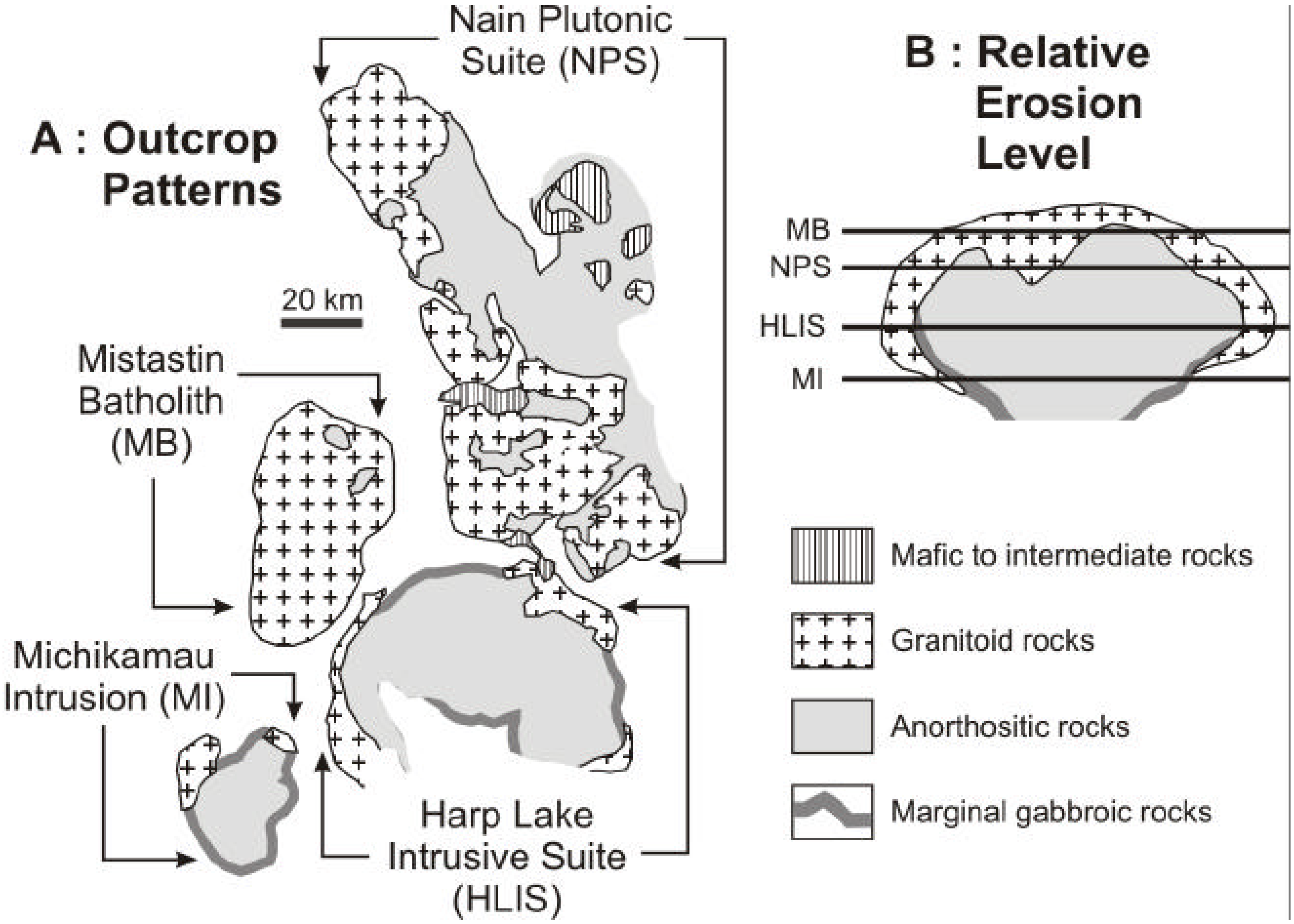

Figure 3. *Simplified map patterns of anorogenic plutonic complexes in Labrador, and their interpretation in terms of differential erosion of composite batholiths in which the granitoid rocks form a sheath above and around mafic and anorthositic rocks. Based on suggestions by Ryan (1991).*

to be visible through the anorthosites, suggesting that they have limited depth extent (R. Wardle, personal communication, 1999).

Following suggestions initially made by Ryan (1991), these differences most likely reflect differential erosion of large plutonic complexes in which the granitoid rocks originally formed a shell or "sheath" around the mafic rocks and the anorthosites (Figure 3). The Mistastin batholith, located northwest of the HLIS (Figures 1 and 3) is probably the least eroded example in Labrador because its anorthosites are visible only in one small area, possibly an uplift associated with the meteorite impact crater. The NPS has been eroded to a greater extent, and parts of its "granitic roof" have been removed, revealing a much greater proportion of anorthosite, and many complex, low-angle intrusive contacts. However, the eastern part of the NPS may represent a deeper erosional level, as it is dominated by anorthositic rocks. The HLIS represents a significantly deeper level of erosion, as most of the granitoid rocks have been removed, except around the edges. The presence of a semicontinuous marginal gabbroic zone in the HLIS implies that these rocks are best developed in the lower regions of such complexes. The Michikamau intrusion (Emslie, 1970; Figure 3) exhibits a similar border zone, and is also poor in intermediate and granitoid rocks, and it may represent a similar (or deeper) erosional level.

HISTORY OF MINERAL EXPLORATION

The HLIS formed part of a large concession held by Kennco Explorations Ltd. in the early 1970s. In 1971 and 1972, reconnaissance work detected numerous "colour anomalies", many of which proved to be sulphide-bearing gossans. A stream-sediment survey was also completed over much of the HLIS, which revealed associated surficial Cu–Ni anomalies. Several prominent gossans were investigated through trenching and detailed sampling, but most gave low-grade assay results, typically less than 0.5% combined Ni and Cu (McAuslan, 1973a). Continued exploration in 1973 led to the detection of additional gossans that were investigated in a similar manner. Induced-polarization (IP) and total-field magnetic surveys were conducted locally with a view toward defining potential drill targets. Massive and semimassive sulphides were discovered at the Dart and Ninety-Nine showings and yielded better, but still subeconomic, Ni and Cu assays (McAuslan, 1973b). In 1974, the A-1 showing, located at the south edge of the HLIS (Figure 2), was examined in more detail and drill-tested, but results were discouraging (Jones, 1974). A B.Sc. thesis project was completed on selected occurrences (Sebastian, 1973), and Emslie (1980) provided the first published petrological descriptions and interpretations of the mineralization, including analyses of the sulphides.

In 1986, Apex Geological Consultants staked the most prominent gossan zones, and optioned the properties to Platinum Exploration Canada Ltd. An extensive rock and stream-sediment sampling program was completed to assess the PGE potential, but the results were not encouraging (Reusch, 1986), and the mineral rights lapsed. Falconbridge Limited subsequently acquired the larger gossans, and completed ground mapping and sampling in 1992, and landsat image interpretation in 1993 (Osmond, 1992; McLean, 1994). The company re-examined the HLIS in 1995, following the Voisey's Bay discovery. Further work around the Ninety-Nine and Dart showings was recommended, and it was also suggested that the more mafic phases of the HLIS be examined in more detail (Olshefsky, 1996). Further exploration work was conducted by the company during the summer of 1999 at (appropriately) the Ninety-Nine showing, but these results remain confidential.

By the summer of 1995, the entire HLIS was covered by claims staked following the Voisey's Bay discovery. Many of these areas were investigated by limited ground prospecting and airborne geophysics in 1995 and 1996, but assessment reports were not submitted for all such properties. Most of these programs resampled minor gossans and "colour anomalies" previously detected by Kennco in the 1970s, and several new sulphide showings were also discovered. Very few properties in the HLIS area proceeded to advanced stages of exploration. Gallery Resources Ltd. identified a gossan zone near Kathy Lake (Figure 2), reported to coincide with strong EM anomalies (French, 1999). Drilling in 1997 intersected some minor sulphide mineralization in anorthositic rocks, but deeper holes drilled in 1998 did not intersect any significant mineralization. The property was inactive during the 1999 season. As of writing, the mineral rights to large sections of the HLIS have lapsed, and the area is open for staking.

MAGMATIC SULPHIDE MINERALIZATION

There are more than 100 gossan zones within the HLIS, most of which contain sulphides. Mineral occurrences shown on geological maps of the area (e.g., Wardle, 1993) are largely plotted from the Kennco results, but not all localities are shown, and the positions of many are imprecise, due to the small scales of the original maps, and the relatively large symbols used to denote occurrences. Compilation of pre- and post-1995 exploration work has been in progress since 1997 in order to update the MODS database for Labrador (e.g., Stapleton and Smith, 1999). Many of the previously known sulphide occurrences were visited during the 1998 season to obtain precise coordinates and gather additional geological information, and several new showings were examined. Most were sampled, and subsequent petrological and geochemical studies are now partially complete. These efforts permit a more detailed assessment of the character of sulphide mineralization in the HLIS, and also comparisons with results now reported from sulphide mineralization in the NPS (Kerr, 1998, 1999; Kerr and Ryan, *in press;* Piercey and Wilton, 1999; Hinchey *et al.*, 1999). However, comparisons of this type are hindered by the lack of diamond drilling in the HLIS compared to the NPS. Fresh drill core provides invaluable 3-D geological information about many NPS sulphide showings, which would be difficult to obtain from surface geology alone. Although some HLIS showings have been trenched and yield fresh samples, many consist of little more than piles of friable, oxidized rubble, and the original geological relationships are very difficult to discern.

For the purposes of description, magmatic sulphide mineralization in the HLIS is subdivided here on a purely geographical basis, rather than by character or immediate host rock-type. The position 55°05'N – 63°20'W is arbitrarily labelled as the "centre" of the HLIS (Figure 2), and used to define four quadrants (NE, SE, SW and NW). Mineralization is most widespread in the southeast quadrant, notably in the area south of Harp Lake itself. Most known mineralized localities are indicated in Figure 2 (a few minor examples are omitted due to scale problems), but only those actually discussed in this report are labelled. The UTM coordinates for the principal sulphide occurrences discussed in this report are shown in Table 2. The locations of some smaller showings documented in the 1970s remain approximate because they have not been revisited.

SOUTHEAST QUADRANT

The southeast quadrant of the HLIS contains some of its most significant mineralized localities, including the A-1, Colette I, Colette II, Ed and Bax showings discovered by

Kennco, and new showings discovered by Gallery Resources (Figure 2). The southeast quadrant corresponds generally (but not exactly) with NTS map areas 13K/11, 12, 13 and 14, together with the eastern part of NTS map area 13L/16, and the southern part of NTS map area 13N/04.

Plate 1. *Intrusive rocks and mineralization at the A-1 showing. (a) Homogenous, coarse-grained leucotroctolite containing interstitial olivine and minor orthopyroxene; (b) localized concentration of interstitial sulphides in leucotroctolite.*

A-1 Showing

The A-1 showing (also known as gossan 37) is located near the southern boundary of the HLIS, north of Shipiskan Lake, close to the external contact of the HLIS and Churchill Province orthogneisses (Figure 2). It is one of only two localities in the HLIS that have been drilled. The local geology is described by McAuslan (1973b) and Jones (1974). The intrusive contact is well defined in the area of the showing, but is not actually exposed. According to McAuslan (1973b), fabric orientations in the gneisses are subparallel to the contact itself, and the attitude of the contact may have been controlled by pre-existing folds in the gneisses. The contact is estimated to dip steeply (50 to 75°) northward. Adjacent to the contact, there is a thin zone of poorly exposed fine- to medium-grained "streaky" gabbro, locally transitional into pyroxenite, which probably represents the marginal (chilled?) zone of the HLIS. This rock is generally unmineralized, although minor sulphides do occur in one pyroxenitic outcrop. Further from the contact, this gives way to medium- to coarse-grained olivine–norite to leucotroctolite, which hosts most of the sulphide mineralization. This rock exhibits a well-defined igneous texture in which the mafic minerals are clearly interstitial to plagioclase laths (Plate 1a). It shows wide variation in grain size, with many coarse "pegmatitic" patches, and also contains finer grained mafic inclusions. McAuslan (1973b) noted "intrusive breccias" in several localities, and matched these inclusions to the rock types seen adjacent to the contact, suggesting that the chilled contact facies was intruded by the leucotroctolite. The mineralized unit in turn grades inward into a similar but unmineralized, coarse-grained, leucotroctolite, which is distinguished mainly by its greater homogeneity. Mineralogically and texturally, this rock type is similar to the mineralized unit.

Sulphide mineralization has a patchy distribution (Plate 1b), and was suggested by Jones (1974) to be preferentially hosted by coarser, pegmatitic zones. This was not evident in the field but may have been more obvious in diamond-drill core. Fresh material from several small trenches contains interstitial patches of pyrrhotite and lesser chalcopyrite, and the sulphides are clearly part of the primary igneous mineral assemblage. However, the proportion of sulphide is small, commonly less than 5%, based on calculations derived from analyses of sulphur content (Table 1; *see* below for further explanation). In thin section, the host rocks are fresh leucotroctolite to olivine–leuconorite, consisting of plagioclase, fresh olivine, variable amounts of orthopyroxene (commonly mantling olivine) and minor biotite. Orthopyroxene has a well-developed interstitial (intercumulus) habit, but olivine is present both as interstitial material and rounded grains, locally enclosed in plagioclase. The host rock was probably an olivine–plagioclase cumulate. Minor interstitial sulphide also occurs in medium-grained pyroxenite, dominated by orthopyroxene containing extensive exsolved clinopyroxene. Two mineralized leucotroctolite

Table 1. Ni, Cu and Co contents of magmatic sulphide showings in the Harp Lake Intrusive Suite, and uncorrected and corrected Ni and Cu contents in sulphides

	WHOLE-ROCK ANALYTICAL DATA						UNCORRECTED SULPHIDE METAL CONTENTS			CORRECTED SULPHIDE METAL CONTENTS	
Sample Number	Co (ppm)	Ni (ppm)	Cu (ppm)	Ni/Cu Ratio	S (wt%)	Sulphide (%)	Co (wt%)	Ni (wt%)	Cu (wt%)	Ni (wt%)	Cu (wt%)
COLETTE II SHOWING											
AK98099	48	1232	946	1.30	0.89	2.5	0.19	4.84	3.72	4.27	3.15
AK98100	73	1435	1602	0.90	1.30	3.7	0.20	3.86	4.31	3.47	3.92
AK98101	48	1562	972	1.61	0.92	2.6	0.18	5.94	3.70	5.39	3.14
AK98103	89	2871	1345	2.13	1.68	4.8	0.19	5.98	2.80	5.68	2.50
COLETTE I SHOWING											
AK98104	90	2516	1488	1.69	1.81	5.2	0.17	4.87	2.88	4.59	2.60
ED SHOWING											
AK98106	70	1641	1236	1.33	1.31	3.7	0.19	4.38	3.30	4.00	2.9
BAX I SHOWING											
AK98109	95	2634	1279	2.06	1.34	3.8	0.25	6.88	3.34	6.50	2.96
GALLERY RESOURCES KATHY LAKE SHOWING											
AK98182	68	575	724	0.79	1.00	2.9	0.24	2.01	2.53	1.67	2.19
AKC1197	96	895	879	1.02	1.30	3.7	0.26	2.41	2.37	2.15	2.11
AKC1198	76	710	904	0.79	1.06	3.0	0.25	2.34	2.98	2.02	2.66
A-1 SHOWING											
AK98087	138	854	1214	0.70	0.87	2.5	0.56	3.44	4.88	2.85	4.30
AK98088	100	974	1324	0.74	1.14	3.3	0.31	2.99	4.06	2.54	3.62
GOSSAN 149 SHOWING											
AK98118	61	483	575	0.84	0.84	2.4	0.25	2.01	2.40	1.40	1.79
NINETY-NINE SHOWING											
AK98090B	1492	3944	2668	1.48	29.2	83.4	0.18	0.47	0.32	0.47	0.32
AK98090C	261	694	10948	0.06	7.2	20.6	0.13	0.34	5.32	0.28	5.26
AK98091	1792	4768	5621	0.85	34.62	98.9	0.18	0.48	0.57	0.48	0.57
DART SHOWING											
AK98141A	1826	5259	2044	2.57	31.07	88.8	0.21	0.59	0.23	0.59	0.23
AK98141B	112	329	1944	0.17	2.47	7.1	0.16	0.47	2.75	0.27	2.56
DART NORTHEAST SHOWING											
AK98143	301	661	812	0.81	4.46	12.7	0.24	0.52	0.64	0.42	0.53
ADLATOK GORGE SHOWINGS											
AK98176B	183	606	721	0.84	3.63	10.4	0.18	0.58	0.70	0.50	0.61
AK98177	74	343	372	0.92	0.97	2.8	0.27	1.24	1.34	0.89	0.99
AK98179B	69	256	794	0.32	1.6	4.6	0.15	0.56	1.74	0.35	1.53

Notes: 1) Analyses by Inductively-Coupled Plasma Emission Spectroscopy at Department of Mines and Energy Laboratory, with detection limit of 5 ppm. 2) Sulphide metal content calculation based on massive sulphide (pyrrhotite, chalcopyrite and pentlandite) containing 35 wt% S, and non-sulphide minerals containing 50 ppm Co, 150 ppm Ni and 150 ppm Cu. In all cases, these values exceed those recorded for unmineralized rocks of equivalent composition at these localities. Corrected sulphide metal contents are thus conservative estimates.

samples average 914 ppm Ni, 1269 ppm Cu and 114 ppm Co, and the mineralized pyroxenite contains 252 ppm Ni and 542 ppm Cu (*see* also Table 1). Kennco assays from surface samples were reported to average "0.12% Cu and 0.13% Ni" (McAuslan, 1973b).

The area of the A-1 showing contains diffuse IP anomalies that were interpreted to indicate more extensive subsurface disseminated mineralization (McAuslan, 1973b). However, a ground EM survey in 1974 did not detect any strong conductors indicative of massive sulphide mineralization. Four diamond-drill holes were eventually completed in 1974, in the face of some typically Labradorian logistical headaches (see Jones, 1974, for an interesting discussion). Three holes intersected the mineralized unit, but the assay results were disappointing, with most sections containing <0.1% combined Ni and Cu. A hole placed directly beneath the showing included a 1.3 m section averaging 0.17% Ni and 0.14% Cu, which was the best result (Jones, 1974). All the sulphide mineralization was contained within medium- to coarse-grained leucotroctolite, and not within the marginal rocks. A single hole penetrated the contact between the HLIS and the gneisses but this proved to be unmineralized. A small amount of unmineralized drill core remains at the site, but the location of the remaining core is unknown.

Colette II Showing

The Colette II showing (also known as gossan 44), is located southeast of Harp Lake, within a prominent cluster of showings (Figure 2). It is probably the largest single sulphide-bearing gossan in the HLIS, with a strike length of about 1.4 km. It forms a generally east–west-trending zone, within which there are several discrete deeply weathered rusty zones (Plate 2a). The local geology, as established by the Kennco exploration program, is described by McAuslan (1973b).

The showing sits within an area of massive anorthositic rocks that show gently south-dipping (15 to 20°) primary fabrics (plagioclase alignment, and rare layering), and it has a general correspondence to a boundary defined by Emslie (1980) between noritic anorthosites to the south and olivine-bearing anorthosite to leucotroctolite to the north (Figure 2). In the field, a distinctive anorthosite containing large orthopyroxene clots (Plate 2b; labelled "the blob rock" by Kennco) invariably outcrops south of (above ?) the gossan zone, but is separated from it by a thin zone of pale anorthosite. The mineralization is contained within dark-grey pyroxene-bearing anorthosite that is essentially indistinguishable from unmineralized anorthosite to the north of (below ?) the gossan zone. There are some structural complexities created by small faults in the area, around which there is significant retrogression. The mineralized zone is also cut by a large Harp Dyke, which clearly postdates the mineralization. The link between the gossans and changes in rock composition and texture strongly suggests that the sulphides are part of a broadly stratiform zone. However, the mineralized anorthosites contain pyroxene, rather than olivine, as do the rocks north of the gossan. Thus, there is not an exact correspondence between the mineralization and the boundary noted by Emslie (1980).

Fresh material from trenches shows well-developed interstitial pyrrhotite–chalcopyrite patches of primary, syngenetic appearance, but the proportion of sulphide is low (<5% in most areas). The host rocks are anorthosites, with interstitial orthopyroxene and clinopyroxene, both of which

Plate 2. *The Colette II showing. (a) Aerial view of gossan zone, which trends from lower left to top right; (b) homogeneous leuconorite containing poikilitic orthopyroxene, nicknamed "the blob rock" by Kennco, believed to consistently overlie the sulphide-bearing zone.*

are variably retrogressed to amphibole. Olivine may be present in relict form in one sample. Sampling by Falconbridge (Osmond, 1992) gave assays of 725 to 1030 ppm Ni and 1250 to 1360 ppm Cu, but previous work by Kennco gave values up to 0.3% Ni (= 3000 ppm) and significantly higher Ni/Cu. McLean (1994) and Olshefsky (1996) resampled the showing, and obtained values of 800 to 3000 ppm Ni and 600 to 3000 ppm Cu, with Ni > Cu for most samples. McLean (1994) makes reference to "a sample collected by Noranda" which reputedly contained 3.4% Ni, but no other written record of this exceptional result could be located. Samples collected in 1998 contained 2.5 to 4.8 % sulphide, 1232 to 2871 ppm Ni and 946 to 1345 ppm Cu (*see* Table 1). Our Ni and Cu analyses resemble those obtained by McLean (1994), but S analyses suggest that the zone probably contains <5% sulphide, rather than the 10 to 25% previously suggested on the basis of visual estimates (McLean, 1994).

Plate 3. *General view of sulphide-bearing gossans at the Ed showing, which appear to be flat lying.*

Colette I Showing

The Colette I showing (also known as gossan 43) lies about 2 km northwest of the Colette II showing, and is hosted by olivine-bearing anorthosites (Figure 2). It was investigated briefly by Kennco, but considered to be of little interest as it contained less than 0.1% Ni (McAuslan, 1973a). Colette I is an extensive zone about 250 m long, but it trends generally north–south, rather than east–west. The mineralization closely resembles that seen at Colette II, and consists of interstitial pyrrhotite and chalcopyrite in dark-coloured anorthosite. The mineralization appears to be primary and syngenetic. The zone also appears to be flat lying or gently dipping, but its precise attitude and trend are difficult to establish. There is no sign of the distinctive anorthosite unit containing poikilitic orthopyroxene noted at Colette II, and this is probably a different sulphide-bearing horizon. The host rock is an anorthosite, and the mafic phase appears to be serpentinized olivine. A single sample collected from a trench at the showing contained 5.2% sulphide, 2516 ppm Ni and 1488 ppm Cu (*see* Table 1). These results are considerably better than those obtained by Kennco, and resemble values from Colette II samples having equivalent sulphide contents.

Ed Showing

The Ed showing (also known as gossan 29) is located about 5 km south of Harp Lake (Figure 2), south of the nearby Bax showings (*see below*). The zone was initially discovered by Kennco (McAuslan, 1973a, b) and later investigated by Falconbridge (Osmond, 1992; Olshefsky, 1996). It consists of at least three partially discrete sulphide-bearing gossans hosted by massive anorthosite, within which primary fabrics dip gently (10 to 20°) southward. The gossan zone covers a strike length of 250 to 300 m (Plate 3), and is similar in general appearance to the Colette I and Colette II zones. McAuslan (1973b) suggested that the sulphides were contained within trough-like depressions, but this is difficult to verify in the field. Magnetic surveys did not yield useful results, and there is no record of any IP or EM surveys over the zone. Mineralized material recovered from trenches consists of dark anorthosite with interstitial pyrrhotite and chalcopyrite, and is essentially indistinguishable from material found at the Colette I and II showings. The host rock is an anorthosite containing small amounts of both olivine and pyroxene. Kennco assays gave maximum values of 0.14% Ni (McAuslan, 1973a), and similar values were reported by Falconbridge (Osmond, 1992). A single sample collected in 1998 contained 3.7% sulphide, 1641 ppm Ni and 1236 ppm Cu (*see* Table 1).

Bax I Showing and Nearby Occurrences

The Bax I showing (also known as gossan 49) is the largest of four mineral occurrences that lie 1 to 2 km north of the Ed showing (Figure 2). The others are Bax II (gossan 50), Bax III (gossan 75) and Bax IV (gossan 103). All were initially identified by Kennco and described by McAuslan (1973a); Bax I was also investigated later by Falconbridge. There is no record of any geophysical surveys in the area.

The Bax I showing is located about 3 km south of Harp Lake, and consists of several small gossans within a crumbly weathering leucotroctolite, just below the summit of a hill. The showing preserves some interesting geological relationships because the hilltop itself consists of layered anorthosite that overlies the leucotroctolite unit. One outcrop, noted also by McLean (1994), preserves the contact between the upper anorthosite and the underlying mineralized zone, which is clearly parallel to primary layering defined by mineralogical and grain-size variations in the anorthosite (Plate 4a). Layers of monomineralic anorthosite show well-developed plagioclase laminations (Plate 4b), and all the layering elements indicate a gentle (10 to 20°) dip to the northeast. Rusty-weathering rocks also occur above the upper anorthosite unit, suggesting that there is more than one mineralized zone. Mineralization at Bax I consists of interstitial sulphides in fresh, homogeneous leucotroctolite, reported to contain up to 0.32% Ni and 0.20% Cu (McAuslan, 1973a; Osmond, 1992). A single sample collected in 1998 contained 3.8% sulphide, 2634 ppm Ni and 1279 ppm Cu (*see* Table 1).

The other Bax showings were not visited in 1998, but all are reported to be small gossans containing similar minor disseminated sulphide (McAuslan, 1973a). It is possible that the Bax I, II and III showings, and the Ed showing represent a single discontinuously mineralized horizon that dips gently to the northeast. However, location data and accuracy of preliminary topographic maps for the area do not permit a rigorous geometric analysis of this idea.

Kathy Lake Showings

This name is applied here to the showings identified by Gallery Resources in 1997. The company refers to the project area as "Harp Lake 2", but this name could lead to confusion if applied to the locality itself. The larger showing is located about 2 km southwest of the western end of Kathy Lake, on a steep hillside. There is no record of

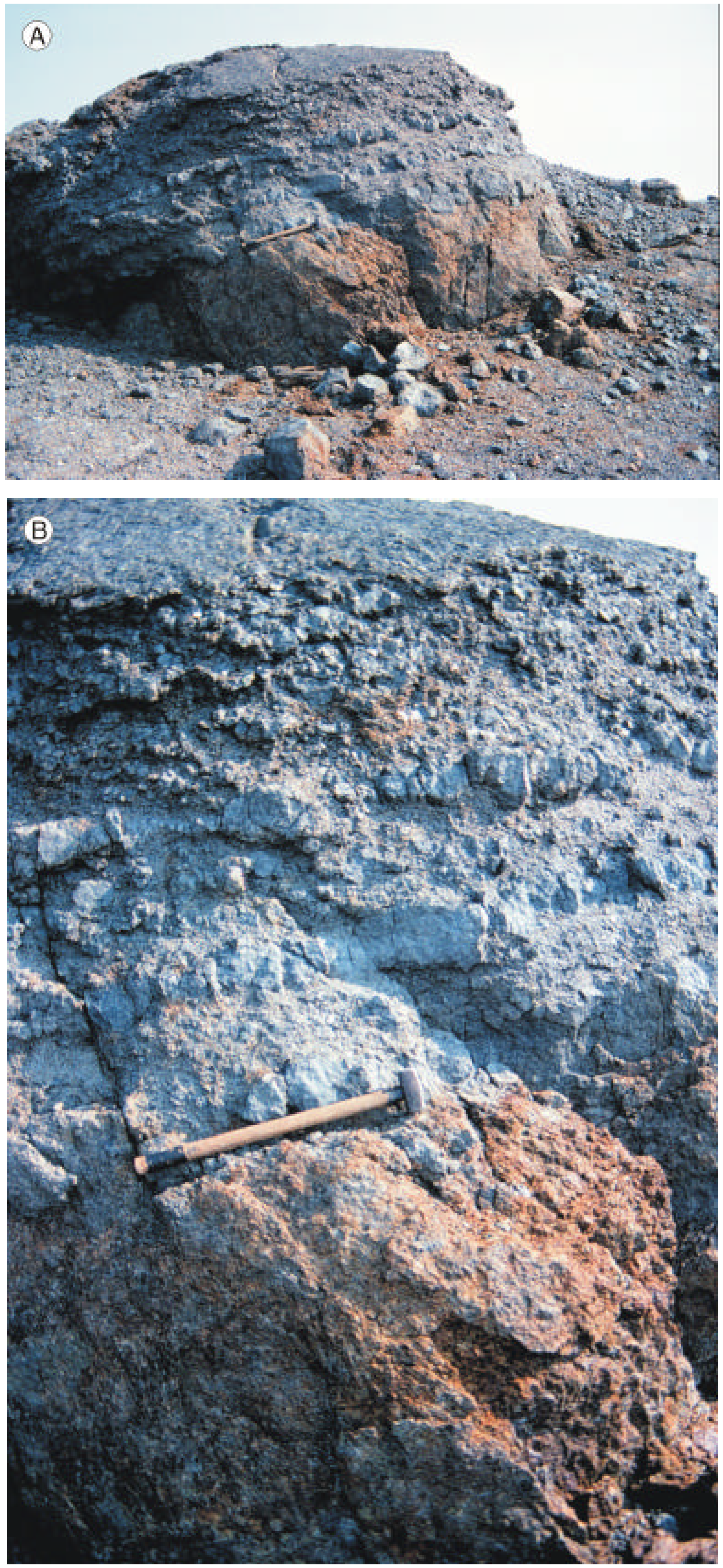

Plate 4. *Geological relationships at the Bax I showing. (a) Key outcrop showing well-developed magmatic layering in anorthositic rocks, defined by mineral proportions and plagioclase laminations, and the upper contact of the stratiform sulphide-bearing zone; (b) close-up of upper contact of sulphide-bearing zone.*

investigation by Kennco, although it lies within a few hundred metres of the plotted location of their "colour anomaly 139", and the two may be the same feature. The Kathy Lake showing is the only site in the interior of the HLIS that has been investigated by diamond drilling. The exploration work carried out at the property is detailed by French (1999), and summarized below.

The principal rationale for advanced exploration at this property is the presence of an EM anomaly, initially detected as a weak airborne EM response in 1996. Following the recognition of surface mineralization, ground EM (Horizontal Loop) and magnetometer surveys indicated a strong conductor with associated positive magnetic anomalies, interpreted to indicate a sulphide-rich source. Drilling in 1997 did not explain these responses, but low-grade disseminated mineralization was intersected beneath the surface showing. Geophysical surveys were repeated in 1998, and the anomaly was confirmed, although the overall response was not as strong as initially recorded. Three more holes were completed in late 1998, but these did not intersect any significant mineralization. The EM anomaly remains unexplained.

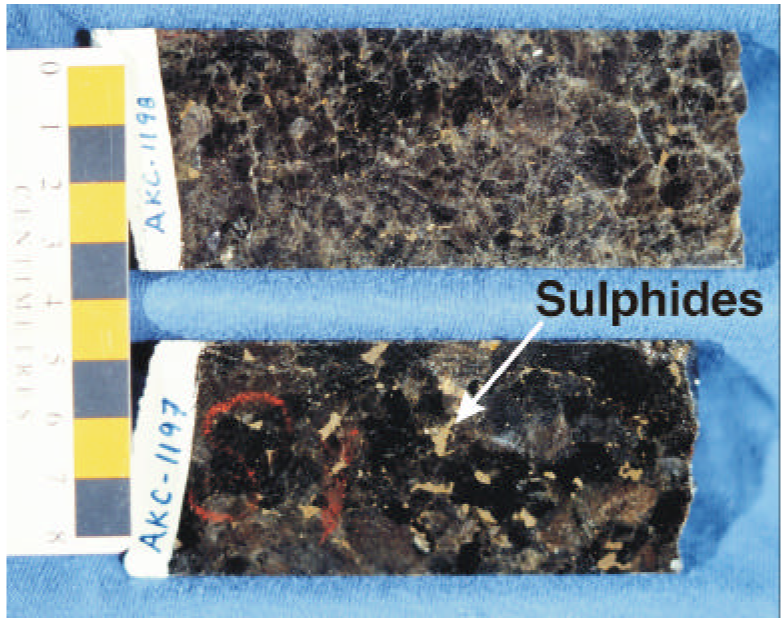

Plate 5. *Drill core from the Gallery Resources Kathy Lake showings, illustrating the interstitial habit of the sulphides.*

The surface mineralization is of restricted extent (50 by 50 m), and resembles other HLIS occurrences, i.e., it consists of deeply weathered sulphides disseminated in coarse-grained anorthosite. A few larger patches of sulphide, up to 3 cm across, were observed, but these are rare. Drill core from the 1997 program consists of dark-grey to black pyroxene-bearing anorthosite containing well-preserved (but minor) interstitial pyrrhotite and lesser chalcopyrite (Plate 5). This was the only rock type observed in the upper parts of the holes (directly beneath the showing), but the deeper parts of the holes were not examined. The amount of sulphide is low, generally less than 5%, and the material resembles fresh mineralized anorthosites sampled in trenches elsewhere in the HLIS . A surface sample contained 2.9% sulphide, 575 ppm Ni and 724 ppm Cu. The company reported assays up to 0.6% Ni and 0.65% Cu, presumably from local concentrations. Samples of mineralized drill core collected in 1998 contained 710 to 895 ppm Ni and 704 to 879 ppm Cu, with similar amounts of sulphide (*see* Table 1).

About 1 km east of the main showing, Gallery Resources identified minor disseminated sulphide in rusty anorthosite, but the amount of sulphide is very low and our samples returned only background values of Ni and Cu. The outcrop does, however, contain some very small massive sulphide patches, reported to contain up to 0.78% Ni and 0.43% Cu (French, 1999). It is further reported that two shallow drillholes intersected some narrow (15 to 30 cm) sulphide zones containing up to 0.95% combined Ni and Cu near this locality (French, 1999). Drill core from the 1998 program has not been examined.

Other Mineral Occurrences

There are many other mineral occurrences in the southeast quadrant of the HLIS (Figure 2), but these were examined only very briefly, or not at all. Localities close to Harp Lake (e.g., the "Bolsov" and "Top" showings) consist of deeply weathered disseminated sulphide in anorthosite (*s.l.*) and are akin to those described above. Gossans previously identified by Kennco in a rugged area west of the head of Harp Lake were later explored by Goldnev Resources (Mitchell and Tallman, 1996). This program revealed some more interesting results, with assays up to 1.67% Ni (Kennco gossan 162) and 1.98% Cu (Kennco gossan 115), but this higher grade mineralization was reported to be of restricted extent. These areas were not examined in 1998. Showings in the Mistinipi and Snegamook lakes area were described by McAuslan (1973a, b) as "of no further interest", but some were reexamined by junior exploration companies. No noteworthy results were obtained, and most of these gossans contain less than 1000 ppm combined Ni and Cu.

SOUTHWEST QUADRANT

The southwest quadrant of the HLIS contains very few known mineral occurrences and the Ninety-Nine showing (Figure 2) is the only location to have received continued

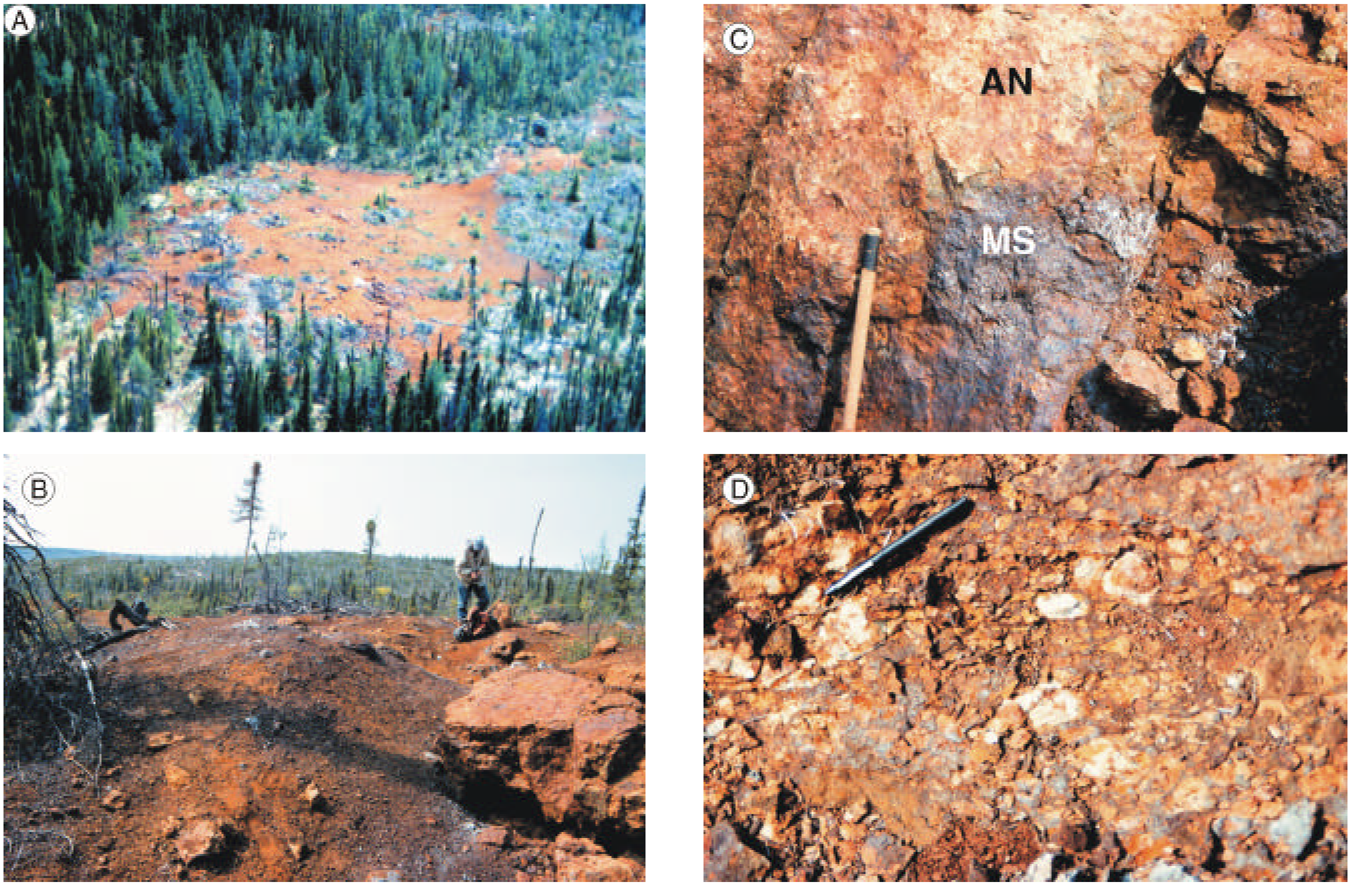

Plate 6. *Geological relationships and mineralization at the Ninety-Nine showing. (a) Aerial view of gossan zone, showing its extent and intensity of weathering; (b) weathered massive sulphide outcrop, showing characteristic jarosite (white areas) alteration; (c) contacts between massive sulphide (purple) and unmineralized anorthosite in exploration trench; (d) weathered outcrop of sulphide zone containing numerous rounded plagioclase inclusions (white areas). MS = massive sulphide; AN = anorthosite.*

exploration attention. The southwest quadrant corresponds generally (but not exactly) with NTS map areas 13L/14, 15 and the west part of 13L/16.

Ninety-Nine Showing

The Ninety-Nine showing, which takes its name from "gossan 99", is located close to the limit of exposure of the HLIS in a remote area northwest of Cleaver Lake (Figure 2). The edge of the HLIS here is defined only by the Seal Lake Group unconformity, and mafic rocks likely continue for some distance to the south; thus, there is likely no relationship between the mineralization and the margin of the HLIS. The showing was outlined in 1973, when massive sulphide mineralization was uncovered, and was found to be accompanied by IP anomalies and positive magnetic anomalies (McAuslan, 1973b). It was further investigated by Falconbridge (Osmond, 1992; Olshefsky, 1996) and was the subject of additional work in 1999. It is distinctly different from the disseminated sulphide zones described from the southeast quadrant of the HLIS. The geology is described in general terms by McAuslan (1973b) and Olshefsky (1996).

Ninety-Nine is easily the most spectacular sulphide gossan in the HLIS. It covers an area of greater than 150 by 150 m, and exhibits the intense red-brown colour typical of massive sulphide gossans (Plate 6a), and also their characteristic white jarosite (Fe-sulphate) alteration products. Several exploration trenches reveal massive pyrrhotite–chalcopyrite material, and weathered massive sulphide outcrops abundantly (Plate 6b). The rock surrounding the mineralization is a fresh, leucocratic, monomineralic anorthosite, which is unmineralized. It displays variable recrystallization, but shows little sign of alteration in thin section. Contacts between massive sulphide and sulphide-free anorthosite are visible in trenched areas, and are sharp (Plate 6c). The anorthosite is commonly cut by thin sulphide veinlets, and areas that appear to contain "disseminated" sulphide probably represent "pseudonetwork" textures of the type described by Kerr (1998), developed by percolation of hot sulphide liquid along grain boundaries. The massive sulphides are dominated by pyrrhotite, within which chalcopyrite forms irregular patches and some discrete vein-like segregations. Weathered massive sulphides in one part of the gossan contain numerous rounded plagioclase inclusions (Plate 6d).

There is clearly more than one individual massive sulphide zone at the Ninety-Nine showing, but the attitudes of such zones are difficult to establish, although there does not seem to be any obvious consistency of geometry or orientation. Descriptions by McAuslan (1973b) imply that the sulphides are lenses, oriented concordantly with primary structures in the surrounding rocks, but the field relationships are more easily explained if there are several irregular sulphide veins or "shoots" that actually cut through the anorthosites. In general, the relationships closely resemble examples of anorthosite-hosted massive sulphide mineralization in the NPS, particularly in the area north of Nain (Kerr, 1998; Kerr and Ryan, *in press*).

Despite the massive nature of the sulphides, the nickel content of the mineralization is low. Kennco obtained values up to 0.44% Ni and 0.62% Cu (McAuslan, 1973b) and Falconbridge found massive material with up to 0.51% Ni and 1.27% Cu (Osmond, 1992; Olshefsky, 1996). Samples collected in 1998 gave broadly similar results, and a "disseminated" sulphide sample proved to be very Cu-rich, containing 1.1% Cu in a sample that had only 21% sulphide (Table 1). Cobalt contents are also generally high, ranging up to 0.18% (1800 ppm) in massive material. Results are akin to those reported from many anorthosite-hosted showings in the NPS (e.g., Kerr and Smith, 1997).

Other Mineral Occurrences

Ric's showing (also known as gossan 3) (Figure 2) is a small zone of disseminated sulphide in anorthosite, located on bluffs above the south Shipiskan River. It is described as a gently dipping layer by McAuslan (1973a). A sample collected in 1998 contained 600 ppm Cu but only 150 ppm Ni (Table 1). Other small gossans in the area northwest of Esker Lake (Figure 2) are reported to be similar, low-grade, disseminated sulphides in anorthosite (McAuslan, 1973a). Minor gossans were also reported by Kennco about 20 km west of the A-1 showing, but these were not visited in the field, and their locations remain uncertain. Emslie (1980) also reports some Fe–Ti oxide occurrences in this region, of which only one small example was visited.

NORTHWEST QUADRANT

The northwest quadrant of the HLIS contains few known mineral occurrences, and the only significant examples occur in the Adlatok River Valley (Figure 2). The northwest quadrant corresponds generally (but not exactly) with NTS map areas 13M/02, 03 and 09, and the western edges of 13M/01 and 04.

Adlatok Gorge Showings

Along the north side of the HLIS, the Adlatok River has incised a deep valley, which locally becomes a spectacular canyon. The course of the river parallels the north margin of the HLIS, and mostly lies within Churchill Province gneisses, but it includes a 17 km transect through the edge of the HLIS (Figure 2). Most of this is unmineralized anorthosite, but several rusty zones are present in a 1-km-long section through the marginal gabbros at its western end. These were initially noted by Kennco, who referred to them as gossans 70 to 73 inclusive, and were reported to contain up to 0.5% Ni and 0.3% Cu (McAuslan, 1973b). However, sampling by Falconbridge (Osmond, 1982; Olshefsky, 1996) produced much lower values. Two showings on the south side of the valley, visited in 1998, consist of disseminated sulphides (pyrrhotite and minor chalcopyrite) in medium-grained, homogeneous gabbro and gabbronorite. Due to the steep topography of the valley walls, it is difficult to establish any geological relationships, but the surrounding outcrops consist of similar (but unmineralized) gabbro and gabbronorite. The host rocks are olivine-free, and locally have a recrystallized appearance. Falconbridge also investigated a gossan on the north side of the valley, which they described as disseminated sulphide "hosted by a possible dyke or steeply-dipping layer of gabbro to norite composition" (Olshefsky, 1996). This locality was not visited in 1998, but descriptions suggest that the host rock is similar. A separate showing (previously unreported), located several hundred metres south of the canyon lip, consists of disseminated sulphide in a coarse-grained leucotroctolite typical of the interior regions of the HLIS. The locations of the showings indicated by Kennco and Falconbridge in the valley walls do not match, and do not correspond exactly to coordinates recorded for localities visited in 1998. These problems reflect the difficulty of precise navigation on the very steep slopes of the canyon, and possibly problems with GPS systems in this rugged topographic setting. Coordinates indicated in Table 2 are derived from the maps of Olshefsky (1996).

Samples collected in 1998 have low Ni and Cu contents, and low Ni/Cu ratios (Table 1) that are consistent with the values reported by Falconbridge from both sides of the valley. Although the Ni and Cu contents of the showings are low, these occurrences are interesting because they are the only clear examples of mineralization hosted in the marginal gabbroic rocks of the HLIS. The A-1 showing has been previously described as such (Sebastian, 1973; Jones, 1974) but its host rocks are more typical of the interior of the HLIS.

NORTHEAST QUADRANT

The northeast quadrant of the HLIS contains many mineral occurrences, of which the best known are the Dart showings (Figure 2). Most of these were initially discovered and investigated by Kennco, but several new showings were identified during post-1995 activity by junior exploration companies. The northeast quadrant corresponds generally with NTS map areas 13N/04 and 05, and the eastern sections of NTS map areas 13M/01 and 08.

Table 2. NTS map sheets and UTM coordinates of the main Ni–Cu sulphide showings in the Harp Lake Intrusive Suite discussed in this report. Coordinates are based on field work and GPS measurements, and carry an uncertainty of ± 100 m in most cases

Name and Object Located	NTS Map	Easting	Northing
SOUTHEAST QUADRANT			
A-1 showing, main gossan	13L/16	554980	6073885
Colette II showing, centre of gossan	13K/13	577355	6086420
Colette I showing, north end of gossan	13K/13	576310	6089190
Ed showing, east section of gossan	13K/13	566730	6092740
Bax I showing, gossan zone	13K/13	566450	6094735
Kathy Lake showing, gossan zone	13N/04	584245	6096025
Bolsov showing, centre of gossan	13K/13	566870	6091675
Gossan 115 (+)	13M/01	553610	6097445
Gossan 162 (+)	13M/01	561225	6099825
SOUTHWEST QUADRANT			
Ninety-Nine showing, main gossan	13L/14	498035	6087985
Ric's showing	13L/14	494785	6094780
NORTHWEST QUADRANT			
Adlatok Gorge (gossan 72) (*)	13M/08	533180	6141725
Adlatok Gorge (gossan 73) (*)	13M/08	534075	6142075
NORTHEAST QUADRANT			
Dart showing	13M/08	556025	6127290
Dart North showing (*)	13M/08	555725	6127895
Dart Northeast showing	13M/08	555050	6127730
Dart Brook showing	13M/08	553350	6127775
Little Beach showing	13N/04	564419	6108530
Gossan 149 showing	13M/01	562470	6108545
Suzanne Lake North # 1 (x)	13M/01	568425	6115475
Little Hope showing, centre of gossan	13M/01	557570	6107570
Mills showing (gossan 41)	13N/04	593955	6105650

Notes: (+) Based on coordinates of Mitchell and Tallman (1996); (*) Based on coordinates of Olshefsky (1996); (x) Based on coordinates of Anderson *et al.* (1996). All other UTM coordinates are based on GPS coordinates and field navigation, with an overall uncertainty of ±100 m, including preliminary topographic map uncertainties.

The Dart Showings

The Dart showings (also known as gossans 17 and 18) are the best known sulphide occurrences in this quadrant. They were located by Kennco (McAuslan, 1973a,b) and found to contain both massive and disseminated sulphides, notably at the main Dart showing (gossan 18). This showing was subsequently re-examined by Falconbridge (Osmond, 1992; Olshefsky, 1996), but the mineralization was considered to be limited in extent and interest. There is no record of any ground geophysical surveys in the area of the showings. The Dart North showing (gossan 17) consists mostly of disseminated mineralization, and was not examined in 1998. Some small, low-grade gossans were also located by Ace Developments east of the main showings (Jacobs, 1996). These have subsequently been explored by Copper Hill Resources, but few results have been released.

Previous descriptions of the main Dart showing suggest that it is a thin massive sulphide layer developed at the base of a thicker unit containing disseminated sulphide mineralization (McAuslan, 1973a,b). The massive sulphides are exposed on a steep, rocky bluff, and additional excavation and natural mass-wasting has now created a ledge along which the contacts of the sulphides and surrounding anorthosites are visible. The contacts are sharp, and at least locally appear to dip steeply (70 to 80°) westward, and are thus discordant to the subhorizontal to gently northeast-dipping primary layering visible higher on the cliff face. The massive and semimassive sulphides appear to strike north–south, but pinch out in either direction; the total length is about 45 m, but the maximum (true) width of sul-

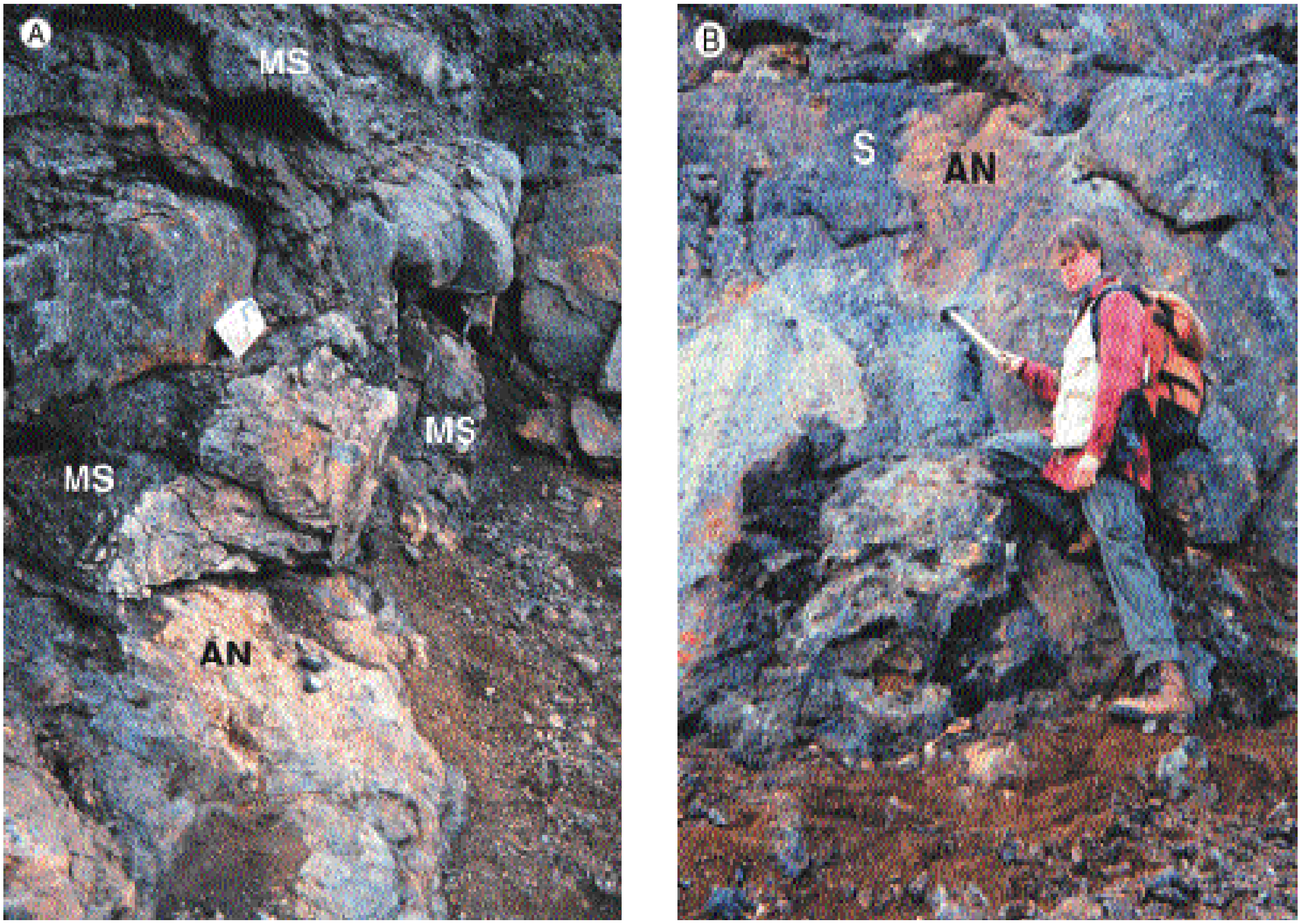

Plate 7. *Geological relationships and mineralization around the Dart showings. (a) Part of main Dart showing, illustrating the sharp contacts of the massive sulphide zone; (b) weathered, vein-like zones of massive sulphide (now mostly oxide) observed in a small cliff-face at the Dart Brook showing. MS = massive sulphide, AN = anorthosite, S = sulphides.*

phides is less than 2 m. In detail, the contacts appear irregular, and they locally protrude in a vein-like fashion into the adjacent unmineralized rocks (Plate 7a). Talus material below the showing contains abundant massive sulphide, in which sulphide–anorthosite contacts are sharp but irregular. The sulphides consist dominantly of massive pyrrhotite, with patches and vein-like stringers of chalcopyrite. "Disseminated" mineralization is also present, notably adjacent to the massive sulphides, but the textural relationships between sulphides and silicates are difficult to discern. The host rocks to the showing were described as gabbro and leucogabbro by Kennco (McAuslan, 1973b) and troctolite by Falconbridge (Olshefsky, 1996). Layering noted adjacent to the sulphides is probably defined by variation in olivine content, based on crumbly weathering characteristics, but the two fresh rock samples collected in 1998 were essentially monomineralic anorthosites. One of these contained irregular sulphide stringers and patches.

The Ni and Cu contents from the Dart showing are similar to those obtained from the Ninety-Nine showing. McAuslan (1973a) reported 0.32% Ni and 0.8% Cu, with some samples containing up to 1.2 % Cu. Some better Ni values (0.6%) were reported by Falconbridge (Osmond, 1992). Pyrrhotite-dominated, nearly massive, material sampled in 1998 contained 0.53% Ni and 0.2% Cu (*see* Table 1). Olshefsky (1996) noted that disseminated mineralization tended to be Cu-dominated, whereas massive mineralization is Cu-deficient.

The overall relationships at the Dart showing suggest that the massive sulphide zone represents an irregular, pod-like or vein-like zone that is discordant to primary layering in the surrounding rocks, rather than a conformable layer. In this respect, the Dart showing closely resembles the Ninety-Nine showing, and also many of the sulphide showings seen in anorthositic rocks of the Nain Plutonic Suite (Kerr, 1998; Kerr and Ryan, *in press*).

Dart Northeast and Dart Brook Showings

The Dart Northeast showing is a small zone of disseminated mineralization in anorthosite, containing small vein-like sulphide zones.

Farther upstream from the Dart and Dart North showings, there is an extensive zone of rusting and staining around the edges of a brook, here termed the Dark Brook showing. The weathering is very intense here, and the sulphides are almost completely oxidized. However, a small cliff face preserves discordant iron-oxide-rich zones, containing some relict sulphides, that are interpreted to represent weathered massive sulphide zones having a vein-like geometry (Plate 7b). These are considered to be similar to the main Dart showing.

Plate 8. *Disseminated sulphide mineralization in part of a small gabbroic intrusion, at the pessimistically named Little Hope showing.*

Little Beach Showings

Two showings in the area around the west end of Suzanne Lake consist of disseminated sulphides in noritic anorthosite, and are typical of many other small sulphide-bearing gossans in the northeast quadrant. The Little Beach showing (gossan 25) was also investigated by Lucero Resources, and described as interstitial sulphide in anorthosite, containing up to 0.12% Cu and 0.09% Ni (Belik, 1995). Gossan 149, a short distance to the west, is closely similar, containing only 483 ppm Ni and 570 ppm Cu (Table 1).

Little Hope Showing

This pessimistically named showing is located in the valley of the stream feeding into the west end of Suzanne Lake, and was originally detected by Kennco, who also referred to it as gossan 23 (McAuslan, 1973a). Disseminated sulphide mineralization is present sporadically over 1 km of the stream course (Plate 8). The southern part of the showing was investigated by NDT Ventures (Burns *et al.*, 1996), and the northern part by the Prime Equities Group (Mitchell and Tallman, 1996). The area lies within a small area of medium- to coarse-grained, equigranular gabbro that forms one of several small, "late-stage" intrusions mapped by Emslie (1980) within the HLIS. Examination in 1998 confirmed the presence of these rocks, although in places the grain size approaches that of the surrounding anorthosites and leuconorites, and the differences between them are very subtle. Unfortunately, our mineralized samples were lost during field work. Kennco obtained only background levels of Cu and Ni (100 to 300 ppm), although grab samples collected by NDT Ventures gave values up to 1600 ppm Ni and 3054 ppm Cu, with Cu > Ni (Burns *et al.*, 1996).

Results from this showing clearly do not necessitate a new and more optimistic name, but it is interesting because it is the only clear example of sulphide mineralization hosted by late-stage intrusive rocks in the interior of the HLIS. Other small gabbro and troctolite bodies examined in 1998 contained no signs of mineralization.

Mills Showing

The Mills showing (also known as gossan 41) was described by Kennco as consisting of two lenses of magnetite-sulphide mineralization in leucogabbro having grades of only 0.04% Cu and 0.02% Ni; however, one sample from the showing assayed 185 ppb Pt and 150 ppb Pd (McAuslan, 1973a, b). Reusch (1986) also sampled a showing at this location, but obtained only background PGE values. Attempts to relocate this showing in 1998 proved frustrating, but a small magnetite-rich zone close to the indicated location was examined and sampled. This contained elevated TiO_2 contents (6.7 to 8.5%) but only about 500 ppm Cu and Ni combined; PGE data are presently unavailable. At present, this is assumed to represent the Mills showing, but a more detailed ground search may be required to clarify this uncertainty.

Other Mineral Occurrences

Other mineral occurrences noted by Kennco in this quadrant (Figure 2) are all small gossans containing minor amounts of disseminated sulphide in anorthosite or leuconorite, which gave poor assay results. Re-examination by various junior companies in 1995 and 1996 produced similarly low values. However, some previously unreported gossan zones were also detected, the most significant of which are located about 10 km northwest of Suzanne Lake (Figure 2). These were investigated by Columbia Yukon Resources, and were described as "patches of heavy sulphide mineralization in labradorite-bearing anorthosite enclosing narrow dykes? also carrying significant sulphide enrichments". Channel samples gave values up to 0.63% Ni and 0.13% Cu over 1 m at one of these locations (Anderson *et al.*, 1996). These showings have not been examined, but the descriptions suggest that they are of limited extent.

GEOCHEMISTRY

GENERAL CHARACTERISTICS

Emslie (1980) conducted an extensive whole-rock geochemical study of the HLIS in conjunction with regional mapping. The principal conclusions were that the most primitive mafic rocks within the HLIS were too fractionated to represent primary melts of the mantle, and these magmas must therefore have been produced by fractionation of mafic silicates (olivine, orthopyroxene) from an original tholeiitic magma. The mafic rocks within the HLIS (leucotroctolites, leuconorites and anorthosites) were produced by crystallization and accumulation of plagioclase from these fractionated parental magmas, with olivine, orthopyroxene and clinopyroxene mostly forming as late, interstitial phases. Olivine compositions from HLIS cumulate rocks are moderately magnesian (Fo_{59} to Fo_{68}), and the Ni contents of most mafic rocks are low, ranging from mean values of 16 ppm in anorthosite to 59 ppm in leucotroctolite (Emslie, 1980). Ferrodioritic rocks are late-stage, evolved fractionated magmas characteristic of tholeiitic trends, and show low mean Ni contents of only 6 ppm. The granitoid intrusions of the HLIS are not related by fractionation to either the ferrodiorites or the mafic rocks, and are considered to be mainly formed by melting of older continental crust. Similar observations have been made in many other anorthosite-dominated plutonic suites, and contribute to the genetic models now favoured for them (e.g., Emslie *et al.*, 1994).

Additional geochemical sampling was conducted in 1998 and, in conjunction with the previous data (Emslie, 1980) will be used to investigate geographic variations within the HLIS, and make comparisons with the growing database for the nearby NPS. The only geochemical data discussed in this report relate to the Ni, Cu and Co contents of mineralized rocks and the sulphide minerals that they contain.

CALCULATION OF SULPHIDE METAL CONTENTS

Table 1 lists Ni, Cu and Co values, together with analyses of elemental sulphur (S). As the background values for Ni and Cu in typical sulphide-free HLIS rocks are low, it follows that the bulk of the Ni and Cu in mineralized rocks is hosted by the sulphides. Elemental sulphur analyses permit calculation of the sulphide content of mineralized mafic rocks because all the sulphur is contained within pyrrhotite, chalcopyrite and pentlandite, which all contain about the same amount of sulphur, from 33.3 to 36.5 percent. The sulphide content is given by the ratio between measured sulphur content and the sulphur content of pure sulphide; for simplicity, a value of 35 percent S is here assumed for the latter. Other more sophisticated methods are available (A.J. Naldrett, personal communication, 1998) but offer no great advantage at a reconnaissance level, although they may be better for more detailed petrogenetic studies. Once the sulphide content is known, the measured Ni and Cu contents are easily normalized to 100 percent sulphide, which provides an estimate of the sulphide metal contents. Because some Ni and Cu is contained in silicate minerals (notably Ni in olivine, and to a lesser extent pyroxene), a further correction is sometimes required. The simple method used here is to correct through a mass-balance calculation, using metal values derived from the direct analysis of associated unmineralized host rocks. Unless the Ni and Cu contents of the sulphides are very low, and/or the amount of sulphide in the rock is very small, these corrections are minor. In the case of anorthosites, which contain almost no Ni, the corrections are negligible. The calculation methods are designed to provide consistent but conservative estimates, as discussed by Kerr (1999).

The importance of calculating sulphide metal contents is twofold. First, they provide an indication of the potential grade of sulphide-rich zones, should such exist in association with disseminated mineralization. In practice, semimassive and massive sulphides commonly display lower metal contents than associated disseminated sulphides (e.g., Barnes *et al.*, 1996) so any estimates are generally maximum values. Nevertheless, low contents of Ni in disseminated sulphides provide little encouragement to seek equivalent massive material at a given locality. Second, sulphide metal contents provide a method of comparing the results from scattered localities and placing them on a common scale that is independent of the amount of sulphide in individual samples.

GEOCHEMICAL SUBTYPES OF HLIS SULPHIDE MINERALIZATION

The data from mineralized rocks in the HLIS (Table 1) show considerable variation in terms of their "raw" Ni, Cu and Co contents. The highest Ni, Cu and Co values occur in semimassive and massive sulphide mineralization from the Ninety-Nine and Dart showings, which contain up to 0.48% Ni, 1.1% Cu and 0.18% Co. However, calculated metal con-

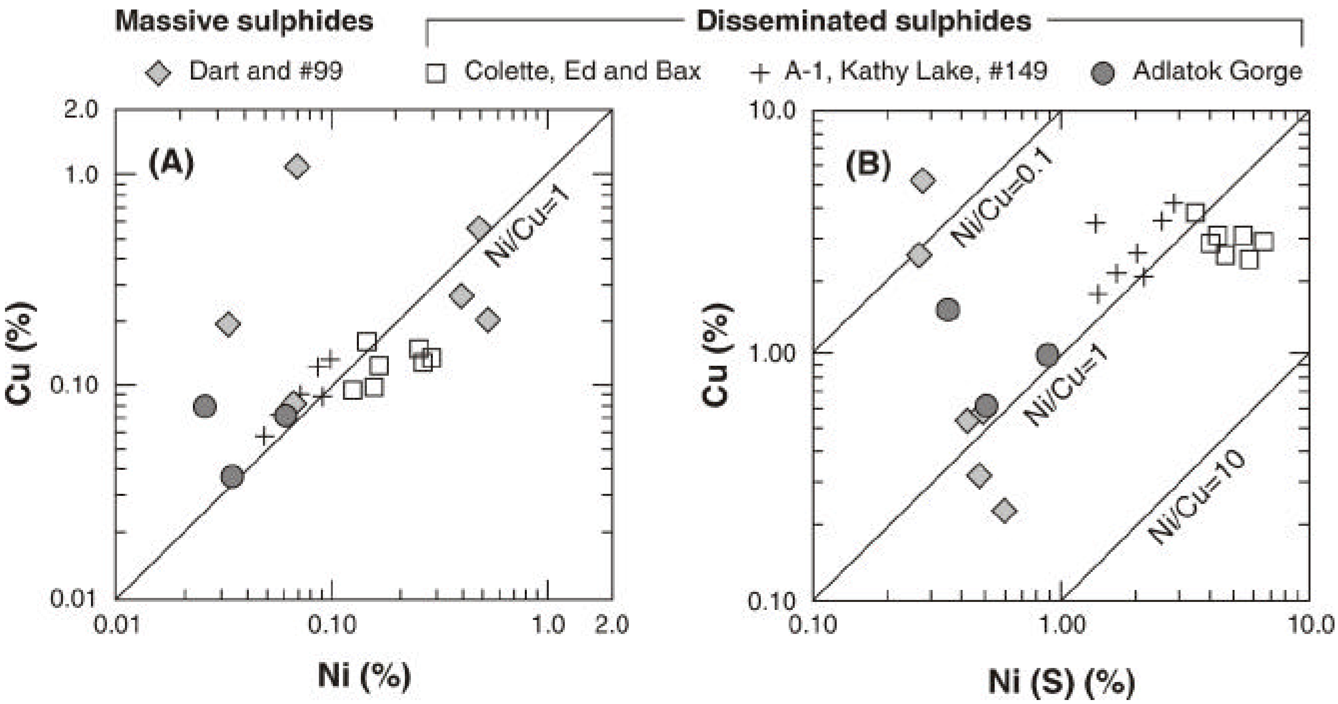

Figure 4. *Ni and Cu contents of magmatic sulphide showings in the Harp Lake Intrusive Suite. (a) raw, uncorrected analytical data; (b) data expressed as corrected metal contents in sulphides; see text for explanation of procedure.*

tents in the sulphides show a very different pattern, indicating the presence of at least three, and possibly more, mineralization subtypes, indicated in Figure 4, and outlined below.

1. Disseminated sulphides from the southeast quadrant of the HLIS, represented by the Colette I, Colette II, Ed and Bax showings, have low sulphide contents (<5%), but these sulphides have high Ni and Cu contents. Corrected values range from 4.0 to 6.5% Ni, and 2.5 to 3.15% Cu; these values are comparable to the metal contents calculated and measured for sulphides at the Voisey's Bay deposit (e.g., Li and Naldrett, 1999). Note that the correction factors used here are conservative (*see* summary of background Ni values above), and that the differences between uncorrected and corrected data are small (<0.5%). For Co, no correction is attempted, because the differences in the Co contents of sulphides and silicates are smaller, and results depend heavily upon assumptions about the latter. These occurrences are also characterized by relatively high Ni/Cu ratios (1.3 to 2.0), and are the only samples in which Ni/Cu is consistently >1.

2. Other disseminated sulphide showings, notably the A-1 and Kathy Lake (Gallery Resources) showings, have more moderate (but still interesting) sulphide metal contents of 1.7 to 2.6% Ni, but are consistently more Cu-rich, containing 2.2 to 4.5% Cu in their sulphides. Inspection of Kennco results from the 1970s, and selected results from several post-1995 exploration programs, suggest that this type of mineralization is probably the most abundant subtype within the HLIS because the reported Ni/Cu ratios of mineralized rocks are most commonly <1.

3. Semimassive and massive sulphides from the Ninety-Nine and Dart showings have uniformly low contents of 0.3 to 0.5% Ni in sulphide, but much more variable contents of 0.32 to 5.26% Cu. Their Ni/Cu ratios are variable, but are largely governed by their Cu content; most of the samples have low Ni/Cu (<1).

4. Disseminated sulphide mineralization from the Adlatok Gorge area, hosted by the marginal gabbroic rocks of the HLIS, is also characterized by low sulphide metal contents of 0.4 to 0.9% Ni, coupled with 1.0 to 1.5% Cu. In general, these results overlap with sulphides from the semimassive and massive sulphide mineralization.

DISCUSSION

CHARACTER OF MAGMATIC SULPHIDE MINERALIZATION

Most disseminated Ni–Cu sulphide occurrences in the HLIS represent syngenetic mineralization, i.e., the sulphides formed in a magmatic environment at the same time as their igneous host rocks. Fresh samples from trenches, and the small amount of drill core available, suggest that sulphides crystallized from a late, residual liquid that was trapped in the interstices of cooling cumulate rocks. The sulphides obviously postdate the euhedral to subhedral cumulus plagioclase, but their relationship to the mafic minerals (olivine and pyroxene) is less clear, because these are also interstitial (e.g., Plate 1a). Thermal corrosion around the sulphide patches is minimal, implying that they were in general equilibrium with coexisting silicates. Many sulphide zones in the HLIS appear to be flat lying or gently dipping, and are locally concordant with primary magmatic fabrics and/or layering in the enclosing rocks. For example, the Colette II showing is everywhere overlain by a distinctive noritic unit containing poikilitic pyroxene that is absent from the underlying leucogabbro and leucotroctolite. The best example of such conformity is the Bax I showing, where magmatic layering above the sulphide zone is clearly parallel to its upper contact (Plates 4a,b). Although such relationships cannot be discerned at every individual sulphide-bearing zone, the broad similarity of disseminated mineralization throughout the HLIS implies that most have similar syngenetic origins.

In contrast, the Ni–Cu sulphide occurrences that contain semimassive to massive sulphides appear to be have different origins. The Ninety-Nine and Dart showings have previously been interpreted as concordant massive sulphide zones developed through gravity settling and coalescence of sulphide liquids (e.g., McAuslan, 1973b; Olshefsky, 1996), but are here reinterpreted as discordant, "epigenetic", vein-like zones of externally derived magmatic sulphides. In other words, the sulphides postdate the crystallization of their wall rocks, although the actual age difference may be small. The field relationships at both zones are consistent with this interpretation, and associated "disseminated" mineralization likely results from the thermal corrosion of the host rocks by low-viscosity sulphide liquids, which percolated along grain boundary regions. These features are familiar from the NPS, where they are well displayed in diamond-drill core (Kerr, 1998; Kerr and Ryan, *in press*).

Consideration of geochemical data for Ni, Cu and Co (Table 1) demonstrates that these two contrasting styles of mineralization are distinct, particularly when the data are converted to sulphide metal contents (Figure 4). The differences between the two groups are extreme, with <0.5 % Ni in massive zones versus 4 to 5% Ni in disseminated sulphides. Such contrasts suggest that the two styles of mineralization are not directly related. In the semimassive and massive mineralization, the strong variations in Ni/Cu, including the presence of Cu-rich, Ni-poor mineralization (Table 1) likely reflects the fractionation and dispersal of the mobile sulphide liquid. In contrast, syngenetic disseminated mineralization is more likely to represent a "closed system" at a sample level, resulting in far more consistent Ni/Cu (Table 1).

The geochemical data (Table 1; Figure 4) also indicate that there are two subgroups of disseminated mineralization that are respectively Cu-dominated and Ni-dominated. The latter, probably of greater exploration interest, are confined to the area south and immediately west of Harp Lake. Disseminated mineralization in marginal rocks of the HLIS in the Adlatok Gorge area is also a distinct subgroup, having low sulphide metal contents that resemble those of the massive sulphide showings.

COMPARISONS WITH NPS MAGMATIC SULPHIDE MINERALIZATION

The apparently discordant semimassive and massive sulphide mineralization at the Ninety-Nine and Dart showings resembles mineralization in anorthositic rocks of the NPS (Kerr, 1998; Kerr and Ryan, *in press*). In many of the NPS occurrences, semimassive and massive sulphides are spatially associated with finer grained mafic veins and segregations (commonly gabbronoritic) that carry disseminated syngenetic sulphides; these are thought to represent the silicate magmas from which the sulphides separated to variable extents (Kerr, 1998; Kerr and Ryan, *in press*). However, equivalent mafic rocks have not so far been recognized in the field at the Ninety-Nine or Dart showings. Gabbroic rocks containing similarly impoverished disseminated sulphides may occur at the Little Hope showing.

The syngenetic, conformable, disseminated sulphide mineralization in the HLIS has no analogue in the NPS. Trivial (<1%) amounts of sulphide are present as a late, interstitial phase in some NPS anorthosites, commonly subordinate to iron oxides, but extensive zones of mineralization containing up to 5% sulphides in anorthosites are unknown. Extensive disseminated sulphide mineralization does occur in some NPS Fe-rich intermediate rocks, notably at the Gallery Resources Okak Project (French, 1999), but this has low sulphide Ni contents and very low Ni/Cu. HLIS disseminated mineralization (notably the Ni-rich subtype) shows much higher sulphide metal contents than any mineralization seen the NPS outside the Voisey's Bay district (Kerr and Ryan, *in press*).

Possible contrasts in the amount of erosion of the NPS and HLIS were noted in an earlier section of this report, and it is logical to suppose that styles of sulphide mineralization may also vary with depth. It appears that discordant, vein-style magmatic sulphide segregations may be more common in the largely leuconoritic upper parts, whereas syngenetic concentrations prevail at depth. However, the reasons for such variations are not clear.

ORIGIN OF METAL-RICH SULPHIDE MINERALIZATION IN THE HLIS

Some disseminated sulphide mineralization in the HLIS is metal-enriched but, due to the small amounts of sulphide, uneconomic. Such high sulphide Ni and Cu contents could, at first sight, be interpreted as positive exploration indicators, but a cautionary discussion is required.

First, the interstitial habit of the sulphides indicates that sulphide liquids were trapped in the interstices of cumulate rocks that were over 90 percent solidified, consolidated and may have had limited permeability. Thus, although the small amount of sulphide liquid developed in the late stages of crystallization contained over 4% Ni, the magmatic environment may not have been conducive to the coalescence and concentration of sulphide liquids. Gravity and fluid-dynamic effects appear to be effective agents in concentrating sulphide liquids in liquid-state magmas, but they would not operate as well within a near-solid cumulate pile. There is no question that massive sulphides equivalent to the disseminated sulphides at the Colette, Ed and Bax showings would be of significant economic interest; however, it is questionable whether such accumulations could form in this particular magmatic environment. However, the report of a sulphide-rich sample containing 3.4% Ni at the Colette II showing (*in* McLean, 1994) is interesting because the analytical data imply that grades of this order are appropriate.

Second, the high metal values found in such disseminated sulphide showings may at least, in part, be a function of their environment, in which sulphide liquids exsolved at the late stages, and equilibrated with trapped, residual silicate liquids developed mainly through plagioclase fractionation. In mafic magmas that are fractionating olivine and pyroxene, Ni behaves as a compatible element, whereas Cu is mildly incompatible or neutral. This accounts for the well-known decrease in the Ni/Cu ratios of mafic rocks and their associated magmatic sulphide deposits from ultramafic to intermediate compositions (e.g., Naldrett, 1989). However, in a mafic magma that is fractionating plagioclase alone, both Ni and Cu are incompatible elements, and their concentration will increase in the residual magma. Thus, trapped liquids in a plagioclase-rich cumulate pile could evolve to higher Ni and Cu contents (although their Ni/Cu ratio would be fixed), and ultimately transfer these elements to any exsolved sulphide liquids. In such a scenario, the two different groups of disseminated sulphide showings could represent discrete parental magma groups that experienced variable amounts of olivine and pyroxene fractionation before switching to plagioclase-dominated fractionation. These two groups would inherit distinct Ni/Cu ratios and (in the case of the Cu-rich group) lower initial levels of Ni. This hypothesis carries clear implications concerning the amount of sulphides that are likely to be formed, as well as their ability to coalesce or accumulate into economic quantities and grades. Thus, although these high values are certainly of significance, they should not be interpreted too simplistically!

ORIGIN OF METAL-POOR SULPHIDE MINERALIZATION IN THE HLIS

The low sulphide Ni contents in semimassive and massive sulphide showings of the HLIS (Table 1) do not augur well for the tenor of any larger sulphide accumulations at these sites. Local Cu-rich sections (e.g., Table 1) are probably of limited extent, as they are fractionated aliquots of the original sulphide liquid. Kerr and Ryan (*in press*) suggest that analogous mineralization in NPS anorthosites is genetically linked to mafic liquids that coalesced and mobilized during the ascent and crystallization of anorthositic crystal mushes. Although no such mafic rocks are recognized at the Ninety-Nine and Dart showings, this does not rule out their existence. In the NPS, mafic rocks containing disseminated sulphides are mostly identified in diamond-drill core, and only rarely seen in surface exposures, presumably because they are recessive-weathering. If the NPS model applies to HLIS examples, these residual mafic liquids must have separated from the anorthositic crystal mushes before protracted plagioclase fractionation acted to concentrate Ni and Cu. The sulphide-bearing gabbroic rocks at the Little Hope showing may represent one example of these associated mafic magmas. Significantly, the fine- to medium-grained marginal mafic rocks of the HLIS, which are presumably closest to "parental" compositions, have only modest Ni contents and contain similar low-grade sulphides associated with gabbronoritic compositions. An integrated model for magmatic sulphide mineralization in anorogenic plutonic suites is beyond the scope of this report, but it is clear that data from the HLIS will be important in refining the initial models suggested by Kerr and Ryan (*in press*).

DISTRIBUTION OF SULPHIDE MINERALIZATION IN THE HLIS

Magmatic sulphide mineralization is not randomly distributed in the HLIS (Figure 2). The concentration of mineral occurrences in the southeast and northeast quadrants cannot represent preferential exploration along the trace of the Nain–Churchill boundary, because most of these gossans were discovered more than 20 years ago, prior to the Voisey's Bay discovery, and any suggestions of its association with this lineament (e.g., Ryan *et al.*, 1995; Naldrett *et al.*, 1996).

All of the sulphide occurrences in the HLIS lie west of the likely position of the Nain–Churchill boundary, and it is unlikely that any are directly linked to it. However, they all lie within the projection of a zone of metasedimentary paragneisses located immediately west of the boundary, which are well documented around the Pants Lake Intrusion (e.g., Kerr, 1999, and references therein). These gneisses contain variable amounts of sulphide and graphite, and are probably the continuation of the Tasiuyak Gneiss of the Voisey's Bay area (Figure 1). The Tasiuyak Gneiss has been implicated as a potential sulphur source for the Voisey's Bay deposits (Li and Naldrett, 1999; Ripley *et al.*, 1999), and also for the Pants Lake Intrusion mineralization (Kerr, 1999; Smith *et al.*, 1999). The distribution of HLIS magmatic sulphide mineralization may indicate that these rocks also exerted their influence here, possibly through contributing to the initial sulphur budget of HLIS magmas in the east, which would increase the probability of a sulphide liquid exsolving at later stages of crystallization.

EXPLORATION OUTLOOK

The Ni and Cu contents of some of the disseminated mineralization in the HLIS indicate the local presence of a metal-rich sulphide liquid, but the amount of sulphide in these showings is too low to provide absolute grades of economic interest. If the high sulphide metal contents do reflect equilibration of sulphide liquids with trapped residual magmas within a cumulate pile, there may be inherent limits on the total amount of such sulphides and their ability to concentrate. On the other hand, most of the exploration of larger gossans in the HLIS took place 25 years ago, and there is no record of ground geophysical surveys (notably deep-penetrating EM methods) that have the capability to detect deeply buried sulphide bodies. Techniques such as audio-magnetotelluric surveys and time-domain EM surveys have proven very effective at Voisey's Bay and in the Sudbury area (e.g., Burrows, 1999), but have never been applied in the HLIS. If the HLIS does indeed represent a more deeply eroded anorogenic plutonic suite, it is possible that more prospective mafic rocks and/or basal regions are present at depth. The area of most interest for further exploration aimed at such blind targets lies south and immediately west of Harp Lake, where showings are Ni-dominated and have the highest sulphide metal contents.

The outlook for massive sulphide occurrences such as the Ninety-Nine and Dart showings is limited, despite their locally spectacular aspect. Although significant variations in the Cu contents of massive sulphides are known from many magmatic sulphide deposits, sulphide Ni contents tend to remain relatively constant within a given system. Results from similar anorthosite-hosted showings in the NPS (Kerr and Ryan, in press) imply that there is little internal variation in sulphide Ni contents, and that zones of this type rarely contain > 1% Ni in 100 percent sulphides.

ACKNOWLEDGEMENTS

Field work in the Harp Lake area was conducted in 1998, based from Hopedale and the Teck Corporation base camp at Pants Lake. The hospitality of Teck Corporation and Donner Minerals Ltd. during part of this work is gratefully acknowledged. Helicopter services from Universal Helicopters (Newfoundland) and Canadian Helicopters allowed us to visit large areas of the HLIS within a short time-frame and in considerable comfort. John Hinchey provided capable and cheerful field assistance. Dick Wardle and Don James are thanked for reading the manuscript and suggesting improvements, and Francois Thibert of Falconbridge Limited is also thanked for his comments.

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