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By

Penelope Morton* and
Steven A. Hauck

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Technical Report
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Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth, MN 55811-1442

***Geology Department**
University of Minnesota Duluth
Duluth MN 55812

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Natural Resources Research Institute
University of Minnesota, Duluth
5013 Miller Trunk Highway
Duluth, MN 55811-1442
Telephone: 218-720-4272
Fax: 218-720-4329
e-mail: shauck@nrri.umn.edu

Web site: http://www.nrri.umn.edu/egg

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ABSTRACT

Large resources of Cu-Ni sulfides are found in troctolitic and gabbroic rocks at the base of the Duluth Complex in St. Louis and Lake Counties of northeastern Minnesota. Analysis of unpublished mining company data shows that there is a substantial reserve of PGE, Au and Ag associated with these sulfides. Weighted averages for combined Pt and Pd values vary as follows: 105 ppb in Water Hen, 278 ppb in Dunka Pit, 378 ppb in Minnamax, 570 ppb in Maturi, 651 ppb in Spruce Road to a high of 1259 ppb in Dunka Road. Au values vary from a low of 63 ppb in the Water Hen to a high of 137 ppb in the Spruce Road. Ag values vary from 1.22 ppm in Dunka Road to 3.8 ppm in the Minnamax deposit. Because recovery of PGE in copper-nickel flotation concentrates is very poor (usually less than 50%), these values add less than $5.00 to the ore.

Even though these PGE and Au values are associated with the Cu-Ni sulfides, it appears that absolute values cannot be correlated with Cu, Ni and/or S contents. If sulfide values are below 0.2 wt %, then there are no appreciable PGE values. This is true for all deposits. However, if Pt+Pd/S is plotted against Cu/S, all samples with high PGE contents appear to be related to samples with high Cu/S contents. Ag values, on the other hand, show a good correlation with absolute Cu content: r=+0.75 for all deposits and r=+0.86 for Minnamax data.

The largest data base comes from the Minnamax deposit where metal values are further separated into Basal and Cloud zones. Basal zone sulfides are those that occur in the lowest 300 feet of the Duluth Complex. Cloud zone sulfides occur several hundred feet above the base of the Complex. In general, Basal zone sulfides consist of both massive and

disseminated types, whereas Cloud zone sulfides are disseminated. At Minnamax, the weighted average sulfur content is 0.38% in the Cloud zone versus 2.78% in the Basal zone. The corresponding combined Pt and Pd values are, respectively, 192 and 396 ppb. Even though the absolute content in the Cloud zone is less, there is a higher metal to sulfur ratio than in the Basal zone, indicating an enrichment in PGE. This is also true for Cu and Ni contents. Ag contents, on the other hand, do not show this relationship. They are related to the absolute Cu content of the ore at Minnamax.

Detailed studies of two anomalous samples, one from Water Hen and the other from Dunka Road, have identified some interesting minerals. PGE bearing minerals were only identified at Dunka Road. At Water Hen the following minerals were identified by using a reflecting microscope as well as a scanning electron microscope equipped with an EDS system: bornite, chalcopyrite, pentlandite (Ni rich), maucherite, sphalerite (pure ZnS) as inclusions in bornite, native Ag as a cross-cutting veinlet in maucherite, niccolite, parkerite ($Ni_3Bi_2S_2$), native Bi, and tentatively tetradymite (Bi_2Te_2S). Previous work by U.S. Steel identified the following minerals in the anomalous zone at Dunka Road: pyrrhotite, chalcopyrite, pentlandite, violarite, froodite ($PdBi_2$), michenerite (PdTeBi), native Gold (Au,Ag), native Bi, and an unknown mineral composed of Pd, Sb and Bi. Textures within both of the samples indicate that pentlandite is being replaced by chalcopyrite and bornite at Water Hen and by violarite, chalcopyrite and the Au and Pd minerals at Dunka Road. These minerals appear to have been concentrated by later secondary copper rich fluids and are not part of the initial formation of Cu-Ni sulfides.

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BACKGROUND

During the last few years, there has been a worldwide increase in demand for Platinum Group Elements (PGE) in the autocatalyst and electronics industries, for investment, and for jewelry. This increased demand pushed prices of Pt, Pd, Rh to values greater than $600.00/oz for Pt, $140/oz for Pd, and $1400.00/oz for Rh in September of 1986. During 1987, prices for Pt and Pd have been maintained at greater than $500.00 and $120.00 per ounce respectively (Figure 1). According to Johnson Matthey (1987), the supply and demand for Pt and Pd in 1986 was as follows:

		Pt		Pd	
		1000 oz	%	1000 oz	%
SUPPLY					
	S. Africa	2350	83	1020	34
	Canada	150	5.3	200	7
	USSR	290	10.2	1660	56
	Others	40	1.4	90	3
	Total	2830		2970	
DEMAND					
	W. Europe	480	17	540	18
	Japan	1010	35	1270	43
	N.A.	1190	42	960	32.4
	Others	170	6	190	6.4
	Total	2850		2960	

This high demand for PGE is met primarily by S. Africa and the U.S.S.R. The United States has relied almost virtually on imports (approximately 7% of PGE are recycled) and until 1987 there was no producer of PGE (Stillwater was brought into production in early 1987 and the first refined metal will be available in August, 1987).

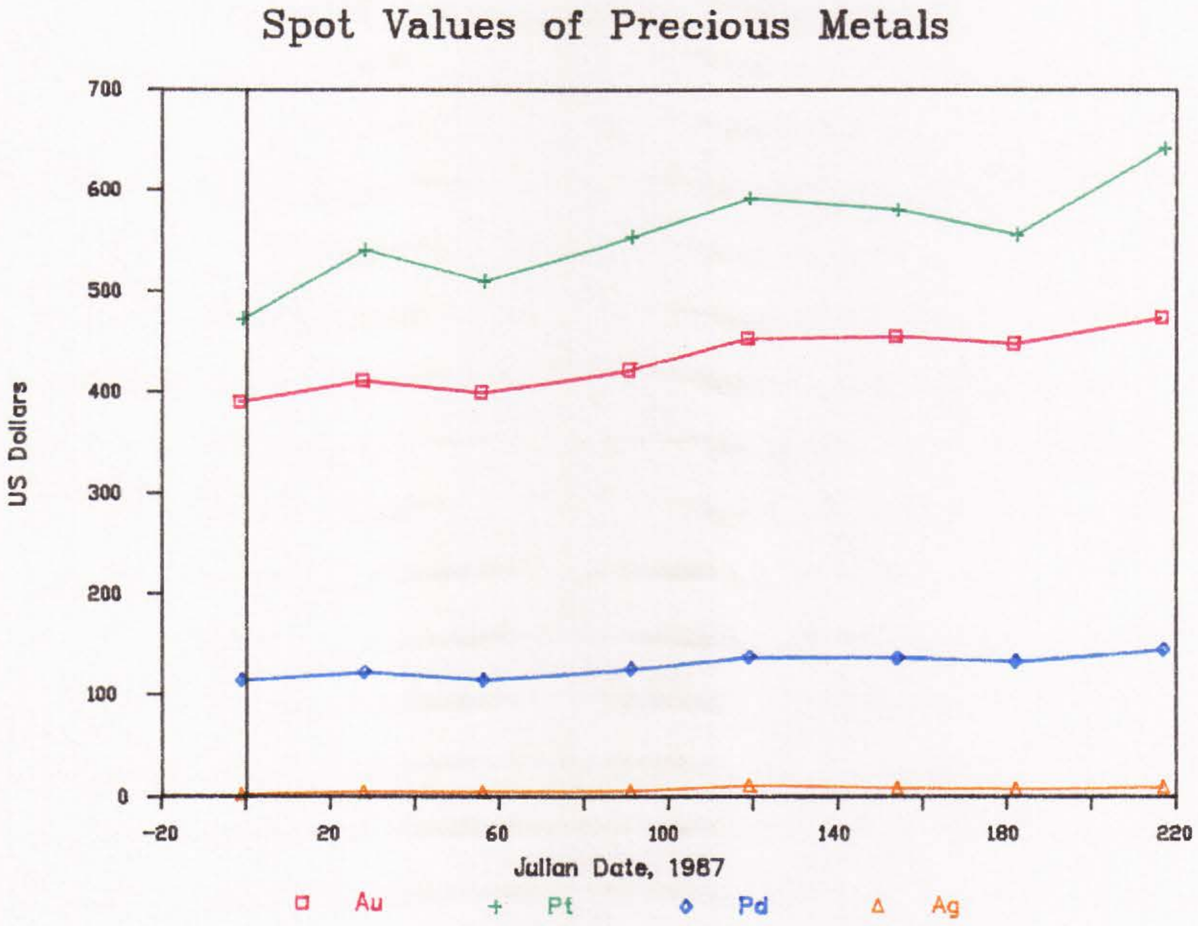

Figure 1: Spot Values of Precious Metals

Because of the upward trend in prices of PGE as well as the need for finding domestic sources of these metals, the NRRI undertook a review and compilation of the existing data on PGE, Au, and Ag, and Co values in the Cu-Ni sulfide bodies that are located toward the base of the Duluth Complex in St. Louis and Lake Counties of NE Minnesota (Listerud and Meineke, 1977). It was hoped that these data would provide a sound base for either renewed exploration for PGE associated with Cu-Ni sulfides or, lead to the actual selection of smaller, higher grade, economically mineable Cu-Ni deposits. As the first phase of this on-going project, active and inactive companies were approached for permission to access their private files so that their data could be compiled and published in a technical report. This report would then serve as a data base for all companies interested in this area. Samples and drill hole intersections with anomalous PGE values are currently being investigated by relogging core, sampling and reassay. This report, the first in a series on this project, represents both a review of the geology of the deposits as well as a compilation of company data. Preliminary results on the mineralogy of anomalous samples are also presented.

ACKNOWLEDGEMENTS

We would like to thank the following companies for access to their data. They are as follows: Kennecott BP Minerals for data from the Minnamax deposit, U.S. Steel for the Dunka Road and Wyman Creek deposits, Hanna Mining for the Maturi Deposit, and Westmont Mining and American Shield for the Water Hen deposit. The Minnesota DNR in Hibbing was also very helpful in locating open file reports on these deposits.

GEOLOGICAL BACKGROUND

The Duluth Complex consists of dominantly mafic igneous rocks of Keweenawan Age (1.1 b.y.) that are exposed in an arcuate body extending from Duluth north toward Ely, and from there north-eastward toward Hovland, Mn. (Figure 2). In the west from Duluth to Hoyt Lakes, the base of the Complex is in sharp contact with Middle Precambrian (1.7 b.y.) slates and greywackes of the Thomson and Virginia Formations and, in some cases, the Biwabik Iron Formation. From Ely northeastward, the footwall rocks of the Complex are Archean (2.7 b.y.) greenstones and granitic rocks. The northernmost basal contact is with Middle Precambrian slates and greywackes of the Rove Formation. The upper contact of the Complex, though not well defined, is with medium to fine-grained, extrusive rocks of the North Shore Volcanic Group. Rock types in the upper part of the Complex appear to be gradational to the volcanics, and therefore, the "upper contact" of the complex appears to be arbitrary in places and subject to revision (Weiblen and Morey, 1975).

In general, rocks of the Duluth Complex are divided into an older anorthositic series and a younger troctolitic series (after Taylor, 1964; Weiblen and Morey, 1980). From Duluth to Ely troctolitic rocks are found at the base of the Complex with anorthositic rocks exposed to the east and northeast (Bonnichsen, 1972a). The troctolitic series consists of troctolite, augite troctolite and troctolitic gabbro (Figure A1). Olivine and plagioclase appear to be contemporaneous and earlier than pyroxene and oxides. Anorthositic series rocks, however, are composed dominantly of gabbroic anorthosite and troctolitic anorthosite (Figure A1). In general, the mafic minerals in these rocks are later than the plagioclase (Bonnichsen, 1972a).

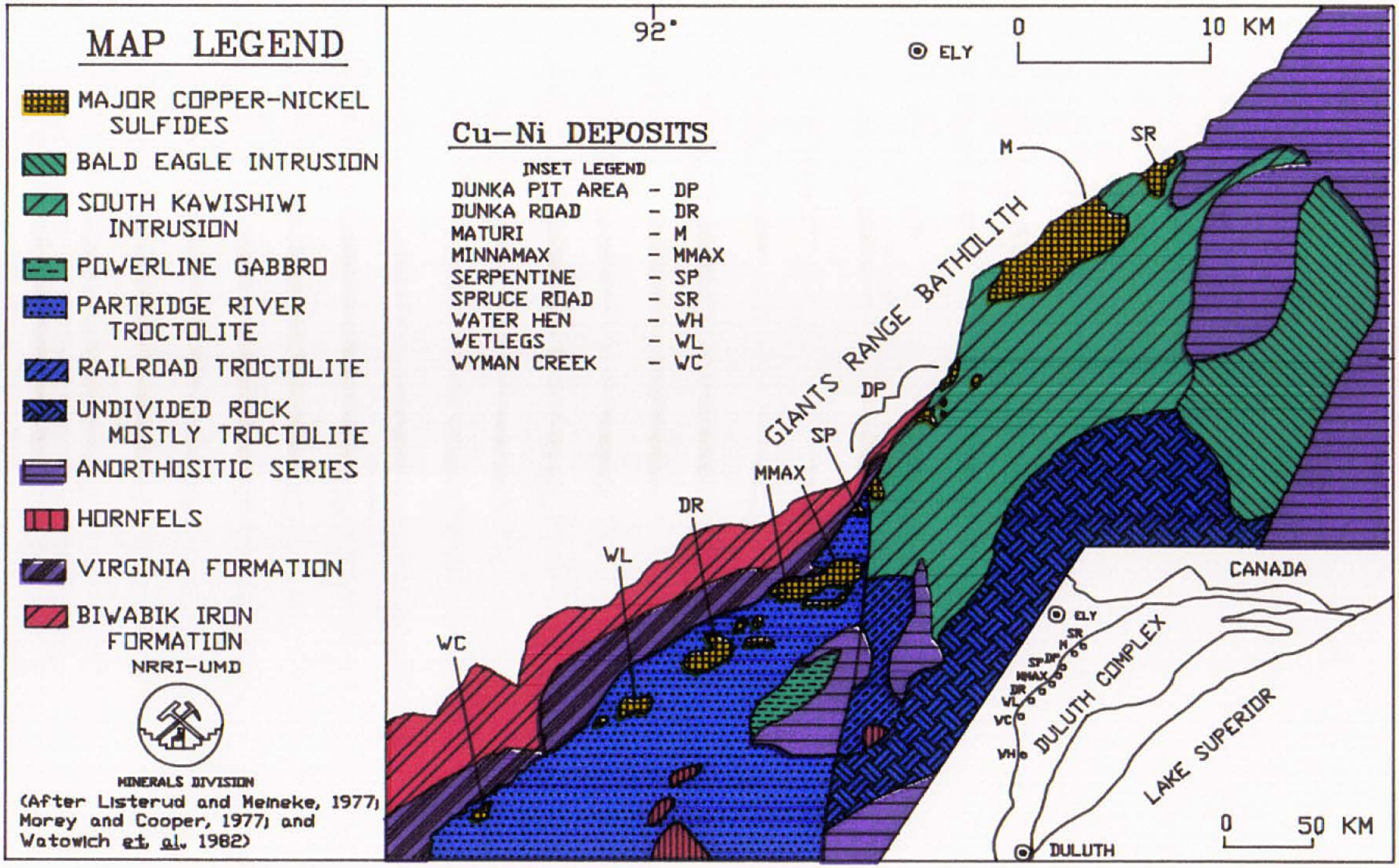

Figure 2. Location of Cu–Ni Deposits in the Duluth Complex, N.E. Minnesota.

Within the troctolitic series rocks exposed at the base of the Duluth Complex are numerous segregations of Cu-Ni sulfides. These Cu-Ni sulfides occur in what is known as the "basal zone" (lowermost several hundred feet) of the Duluth Complex. The vast majority of the sulfide is disseminated but massive and semi-massive ore is locally present (Listerud and Meineke, 1977). The sulfide minerals occur in several large deposits in the Hoyt Lakes--Kawishiwi Lakes area (Figure 2) and from north to south these deposits are: Spruce Road, Maturi, Dunka Pit, Minnamax (also known as Babbitt (Ripley and Alawi, 1986), Dunka Road, and Wyman Creek. There are also Cu-Ni sulfides associated with the Water Hen Intrusion located between Hoyt Lakes and Duluth.

GEOLOGY OF THE HOYT LAKES — KAWISHIWI AREA

Bedrock geology of the Hoyt Lakes-Kawishiwi area (Figure 2) has been described by Weiblen and Cooper (1977) and Morey and Cooper (1977). Most of the rocks exposed in the area belong to the troctolitic series and have been divided by various workers into the Bald Eagle intrusion (Weiblen, 1965), the South Kawishiwi intrusion (Green et al., 1966; Phinney, 1969), the Railroad troctolite, the Powerline Gabbro and Partridge River troctolite (Bonnichsen, 1974). Other troctolitic rocks are unsubdivided.

All of the sulfide deposits occur in the basal zone of the S. Kawishiwi intrusion, the Partridge River troctolite, undivided troctolite and/or the Water Hen intrusion (Mainwaring, 1975). These intrusions are described separately.

South Kawishiwi Intrusion (SKI)

According to Foose and Weiblen (1986), the SKI is composed mostly of plagioclase-olivine cumulates containing minor (less than 10%) interstitial augite, oxides or biotite. Modal layering is not common and generally not traceable for more than 300 feet. From drill hole analysis, three major lithologic zones are recognized: 1) older granitic footwall rocks, 2) basal zone sulfide-bearing rocks and 3) generally sulfide-free troctolite with interlayered anorthosite. The sulfide free rocks consist of sequences of troctolite and anorthosite which form cyclic units in which the crystallization of plagioclase is followed by plagioclase and olivine. It is thought that the crystallization of these rocks occurred in a magma chamber that was continuously being replenished by compositionally similar liquids. The sulfide-bearing zone, however, consists of a mixture of troctolite, picrite, dunite, anorthosite, oxides and hornfels throughout which sulfides are disseminated.

Partridge River Troctolite (PRT)

Bonnichsen (1974) used the term PRT to designate troctolitic rocks exposed near Hoyt Lakes and south of the Reserve Mining Company. Because of extensive glacial deposits, exposures are limited and much of the following description comes from workers studying drill core (e.g., Boucher, 1975; Molling, 1979; Tyson and Chang, 1984; Al-Alawi, 1985; Chalokwu, 1985; Chalokwu and Grant, 1987; Mills, in prep). Rock types present in the core are olivine gabbro, augite troctolite, troctolite and anorthositic troctolite. Anorthosites are rare. There does not seem to be a sulfide bearing and a sulfide free unit as mapped in the SKI. Rather sulfide mineralization is concentrated in the lower 300 feet of the basal zone just above the footwall Virginia Formation, and at about 600 feet above the base of the intrusion (Cloud zone sulfides after Watowich, 1978). It is also disseminated (< 0.5 volume %) in the upper parts of the intrusion (Ripley and Alawi, 1986).

The intrusion itself has been divided into various units by different authors. Grant and Molling (1981) have divided the intrusion into three major units based on trace element and petrochemical differences. Tyson and Chang (1984) studied four drill cores from the Minnamax deposit and described five units based on textural and modal analyses. Ripley and Alawi (1986) divide the intrusion into 3 units on the basis of sulfide content, whereas Chalokwu and Grant (1987) divide it into 4 units on the basis of mineral and rock geochemistry. At present, no correlation between authors' works has been made and at best, it can be said that the Partridge River troctolite is heterogeneous.

Water Hen Intrusion

The Water Hen intrusion consists of a small (2 x 1 Mi.) steeply-dipping, somewhat flattened cylindrical body composed of layers of coarse-grained mafic and ultramafic rocks which have intruded the base of the Duluth Complex (Figure 2). Rock types include feldspar-bearing dunite, peridotite, ilmenite-rich (up to 30%) peridotite, melatroctolite, troctolite, gabbro and anorthosite (Mainwaring, 1975; Mainwaring and Naldrett, 1977). Footwall rocks belong to the troctolitic series which may or may not be part of the Partridge River troctolite. Cu-Ni sulfides are concentrated in the basal dunite, at the base of mineral graded units, and as disseminations in peridotite which contains graphite and recrystallized xenoliths of country rock.

DESCRIPTION OF SULFIDE DEPOSITS

Of those deposits listed above, we were able to obtain detailed, composite, and concentrate analyses from Minnamax, Dunka Road and Water Hen; composite analyses from Maturi and Spruce Road; and previously published analyses of Erie's Dunka Pit and concentrate from INCO's Spruce Road deposit (INCO, 1975). A review of the geology and mineralogy of each of the larger deposits is described below.

Spruce Road and Maturi Deposits

Descriptions of these deposits are taken from INCO's 1975 Open File Report to the DNR, Wager et al. (1969), and Foose and Weiblen (1986). According to INCO geologists, the bulk of the sulfide mineralization at the Spruce Road and Maturi deposits is confined to the narrow basal contact zone of the S. Kawishiwi intrusion. Overall there are approximately 2.9 billion short tons of low grade (>0.5% Cu, >0.15% Ni) ore (Listerud and Meineke, 1977) in these two areas (Table 1). The basal zone is characterized by subtle to well-defined layering, considerable local variability in texture and modal mineralogy as well as numerous fine-grained inclusions of hornfels. In detail, the basal contact zone consists of an assemblage of troctolite, olivine gabbro, norite, picrite, and gabbroic and anorthositic pegmatite. In places picrite alternates with normal troctolite causing a conspicuous layering. These layers are not continuous over any appreciable distance.

Inclusions are ubiquitous in the intrusive rocks throughout this basal zone. In order of abundance they are: 1) light to medium grey hornfels

Table 1: Published Cu-Ni grades and tonnages for Cu-Ni deposits in the Duluth Complex

Deposit	Short ton	Grade		Cu/Cu+Ni	Reference
		%Cu	%Ni		
Spruce Road	273 m.t.	0.46	0.17	0.73	Open File Report 1975
" "	700 m.t.	>0.5		0.73	Listerud and Meineke, 1977
Maturi Area	2.2 b.t.	>0.5		0.76	" " "
Minnamax	419 m.t.	0.54	0.13	0.81	Watowich et al., 1981
"	800 m.t.	>0.5		0.80	Listerud and Meineke, 1977
Dunka Road	300 m.t.	>0.5		0.76	" " "

of sedimentary origin, 2) blocks of well-banded Biwabik Iron Formation which appear to have lateral dimensions of several hundred feet and 3) recrystallized olivine-rich gabbro and troctolite. Olivine in the last inclusion type is the dominant mafic mineral and occurs with a granular and/or poikiloblastic texture. At Maturi, inclusions with granular olivine are the most prevalent. Where the percentage of inclusions exceeds 30%, the term Spruce breccia has been used by INCO geologists.

According to Wager et al. (1969), the distribution of sulfides in the basal zone appears to be largely independent of rock type. The principal sulfide minerals in order of abundance are pyrrhotite, chalcopyrite, cubanite, and pentlandite. Minor minerals include violarite, pyrite, bornite, covellite, digenite, chalcocite, tenorite, cuprite, native Cu, mackinawite and sphalerite. These sulfides occur as disseminated interstitial aggregates and, to a minor extent, as inclusions in feldspar, biotite, amphibole and pyroxene. According to Foose and Weiblen (1986), they also occur as sulfide-silicate intergrowths and as fine-grained sulfide veinlets.

Chalcopyrite is the dominant copper sulfide. Cubanite, where present, occurs as lamellae and irregular intergrowths in chalcopyrite. Relative proportions vary but the ratio of chalcopyrite to cubanite is higher at Spruce Road than at Maturi. Pentlandite, the dominant nickel mineral, occurs either as granular areas or as small exsolution blades and flames in pyrrhotite. In some cases, it is altered to violarite. According to Wager et al. (1969), the ratio of pyrrhotite to pentlandite is higher at Spruce Road than at Maturi. The Cu/Cu+Ni ratio is consistently close to 0.75 in the mineralized zone but ratios from 0.67 to 0.87 have been noted in pegmatitic zones. According to Listerud and Meineke (1977), the average Cu/Cu+Ni ratio varies from 0.73 at Spruce Road to 0.76 at Maturi.

Dunka Pit (Dunka River area)

Sulfides occur in the Dunka River area in the north end of the Erie Mining pit and north and east of the pit (Figure 2). These sulfide zones have been penetrated by numerous drill holes from various mining companies. Host rocks belong to the South Kawishiwi intrusion. Footwall rocks in the area consist of Giants Range granite in the northern part of the area and Biwabik Iron Formation in the area of the Erie Pit. Bonnichsen (1972 a,b) looked at four Newmont drill holes as well as as a series of holes drilled just north of the Erie pit. Fukui (1976) concentrated on one of the Newmont holes (NM-5).

Sulfides are confined to the basal unit of the S. Kawishiwi intrusion where they occur as fine disseminations or locally in the footwall contact zone as massive accumulations. Minerals in order of abundance are pyrrhotite, chalcopyrite, pentlandite and cubanite. Sulfide stringers also penetrate the footwall granitic rocks and here the sulfides consist of chalcopyrite and bornite with very little pyrrhotite. Pentlandite is replaced by millerite, and sphalerite is common. From Cu-Ni assays plotted on Figure V-47 of Bonnichsen (1972a), the estimated Cu/Cu+Ni ratio is 0.72. Sulfide mineral percentages were not tabulated in either of these studies.

Minnamax

The Minnamax deposit (also called the Babbitt deposit) consists of approximately 800 m.t. of > 0.5% Cu (Table 1). The deposit is located in the basal rocks of the Partridge River troctolite (Figure 2). According to estimates from mine geologists (Watowich et al., 1981), there were 419 m.t. of reserves for their mining plan. Numerous theses and studies have been concerned with the distribution and genesis of sulfides within the Minnamax deposit (Table 2). The drill holes listed are those on which the main parts of the theses were based (for location see Figure 3). Other workers include (Watowich,1978; Ripley and Al-Jassar, 1987; Ripley and Alawi, 1986; Boucher, 1975; Pasteris, 1984; and Tyson and Chang, 1984). For a good review of the deposit, the reader is referred to Ripley and Alawi (1986).

At Minnamax, footwall rocks are composed of Virginia Formation. Although xenoliths of iron formation are not uncommon within the Minnamax deposit, the Biwabik Iron Formation is not in direct contact with igneous rocks of the Partridge River troctolite in this area. Two major sulfide zones have been identified: 1) Basal zone mineralization which varies from massive to disseminated in texture occurs at the base of the complex (up to 300 feet thick) and 2) Cloud zone (Watowich, 1978; Ryan, 1984; Mills, in prep.) mineralization which is disseminated and occurs

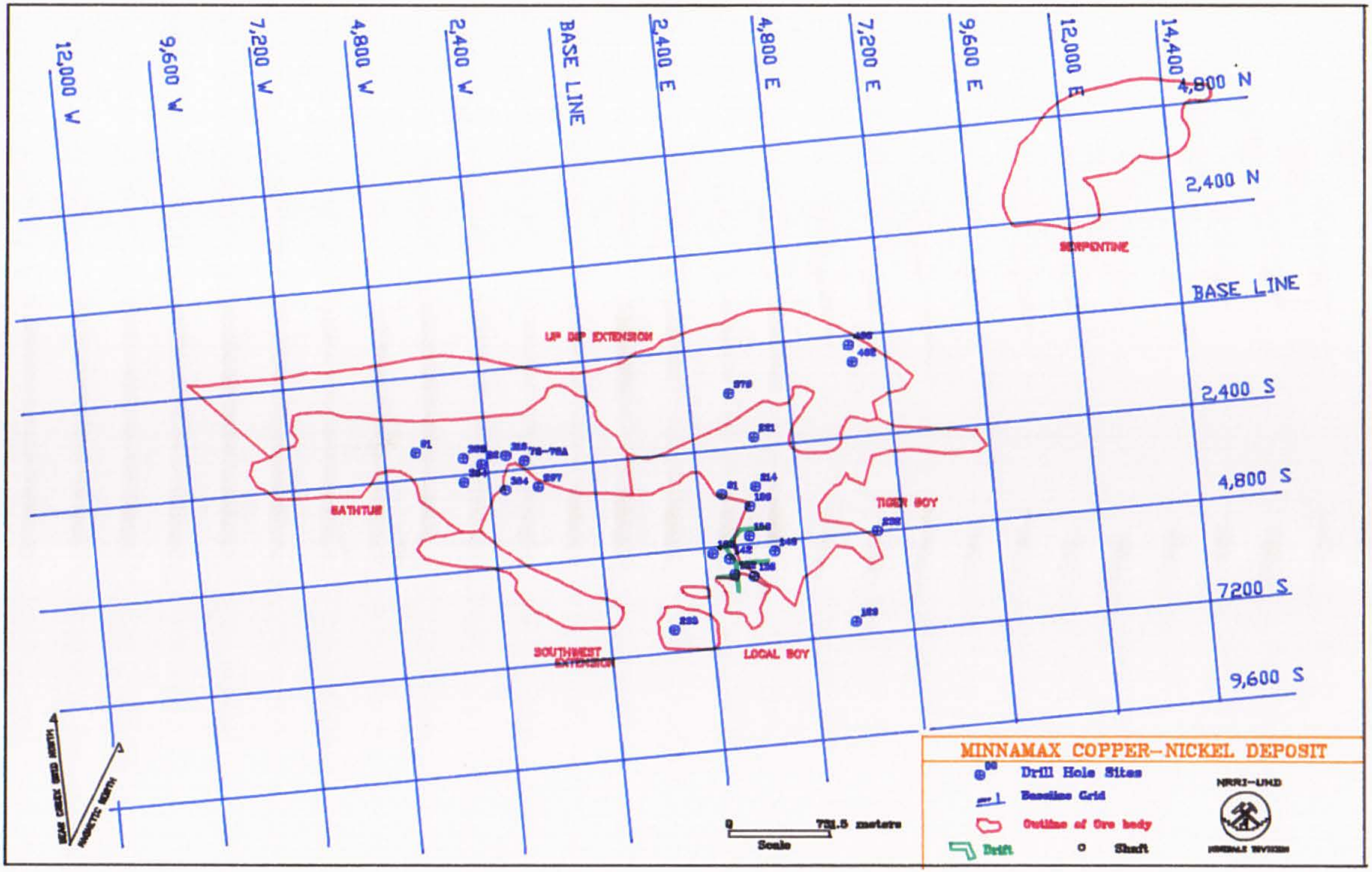

Figure 3: Location of drill holes studied in theses of the Minnamax Deposit

Table 2: List of Theses* Written on the Cu-Ni Sulfides at the Base of the Duluth Complex in St. Louis and Lake Counties

Deposit	Reference	Drill Holes Studied	Degree
Dunka Pit	Fukui, 1976	NM-5 (NM-7, NM-9, NM-11+ 128) 128 from Minnamax	M.S.
Minnamax			
Tiger Boy	Al-Alawi, 1985	136, 156, 189, 379, 146+ underground	Ph.D.
Tiger Boy	Al-Jassar, 1985	136, 146, 156, 189, 214, 221, 379 + underground	Ph.D.
Tiger Boy	Chalukwu, 1985	221	Ph.D.
Tiger Boy + Bathtub	Davidson, 1979	73, 162, 316, 232, 402, 406	M.S.
Tiger Boy	Hardyman, 1969	61	M.S.
Tiger Boy	Fellows, 1976	128	M.S.
Tiger Boy	Matlack, 1980	A, B, C, D, drifts	M.S.
Bathtub	Mills, in prep.	82, 363	M.S.
Tiger Boy	Molling, 1979	295	M.S.
Tiger Boy	Ryan, 1984	132	M.S.
Bathtub	Tyson, 1979	297, 304, 364, 91+ others	Ph.D.
Dunka Road	Ingemansen, 1985	26069	B.S.
	Rao, 1981	26082, 26056, 26081	Ph.D.
Water Hen	Mainwaring, 1975	CN-7, SL-2, CN-11	Ph.D.
Wyman	Churchill, 1978	17700+ samples from Minnamax and INCO	M.S.

* Theses documenting metamorphism of hornfels and country rocks have not been included.

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approximately 500 to 600 feet above the base of the intrusion. In both areas there are a large number of inclusions (Virginia Formation and mafic hornfels).

While the Minnamax deposit was leased by AMAX, their geologists (Watowich, 1978) gave different names to parts of the ore body: Tiger Boy; Local Boy, a rich massive sulfide zone of the Tiger Boy; Up Dip Tiger Boy; Southwest Extension; Bathtub; and Up Dip Bathtub (Figure 3). Cloud zone sulfides are present in all of these areas. Of the theses written, the bulk are concerned with Tiger and Local Boy basal mineralization.

Only Ryan (1984) deals specifically with Cloud zone sulfides, whereas Al-Alawi (1985), Tyson (1979), and Mills (in prep.) deal with both Cloud zone and Basal zone sulfides.

Sulfide mineralization at Minnamax is locally massive to semi-massive. AMAX defined approximately 3 to 6 million tons of 3.0% Cu and 0.6% Ni (Listerud and Meineke, 1977) in the vicinity of the shaft (Figure 3). Here the sulfide minerals in order of abundance are: pyrrhotite=cubanite>> chalcopyrite>pentlandite. The overall Cu/Cu+Ni ratio of the semi-massive zone is 0.83 (Listerud and Meineke, 1977). Other textural types found throughout the Basal zone include disseminated and interstitial, filling interstices between plagioclase laths; connecting veins of sulfides between interstices; copper rich veinlets which cross-cut silicates; and simplectic intergrowths of monomineralic sulfide with silicates.

In the Basal zone mineralization, the overall ratio of cubanite to chalcopyrite is 2:1 (6:1 in semi-massive) and according to Al-Alawi (1985), where the volume per cent of sulfides is greater than 6%, cubanite is the dominant copper sulfide. According to Matlack (1980), in the area of underground Cu-rich ore, the veins that connect interstices are composed dominantly of pyrrhotite and cubanite with minor chalcopyrite and pentlandite whereas veins that cross-cut hornfels of Virginia Formation or in the formation itself are composed of chalcopyrite and cubanite with minor pyrrhotite, pentlandite and bornite. He also documents late stage veins composed of chalcopyrite, bornite, chalcocite, quartz and calcite with rare laumontite.

Tyson (1979) describes the same kinds of sulfide textures and minerals. He also recognized troilite, and valleriite in the Basal zone.

He states that sulfide veinlets are dominantly composed of chalcopyrite. Other minerals that have been recognized by a variety of workers are: talnakhite, native Cu, digenite, mackinawite, sphalerite, violarite, covellite, tenorite, graphite, ilmenite and magnetite.

In comparing the Cloud and Basal zones, even though there are less sulfides in the Cloud zone overall (Ripley and Alawi, 1986), the relative abundance of copper and nickel sulfides is higher than in the Basal zone. Tyson (1979) states that chalcopyrite is the dominant copper sulfide in the Cloud zone, whereas Al-Alawi (1985) says that chalcopyrite equals cubanite in abundance. Electron microprobe analyses of pentlandite and pyrrhotite confirm that they are both richer in Ni within the Cloud zone, suggesting a different magma as a source for the Ni (Al-Alawi, 1985; Ripley and Alawi, 1986). Overall, the average Cu/Cu+Ni ratio of the Cloud zone sulfides from drill hole 132 is 0.77 (Ryan, 1984) compared to 0.8 for the deposit overall and 0.83 for the semi-massive ore.

Dunka Road Deposit

The Dunka Road deposit is owned by U.S. Steel and is situated at the base of the Partridge River troctolite southwest of the Minnamax deposit (Figure 2). According to Listerud and Meineke (1977), there are over 300 m.t. of ore with greater than 0.5% Cu and an overall Cu/Cu+Ni ratio of 0.76. Ripley (1981), however, quotes a Cu/Cu+Ni ratio of greater than 0.86. Descriptions of this deposit come from U.S. Steel reports, Rao (1981), Ripley (1981) and Rao and Ripley (1983).

Footwall rocks within the area are Virginia Formation and xenoliths of sedimentary hornfels are found at the base of the troctolite sequence and are also found higher up in the sequence. Ripley and Rao (1983) suggest that the Virginia Formation was the footwall for a series of troctolitic pulses intruded one below the other. A Cu-Ni sulfide zone exists at the base of each of three possible intrusive pulses.

Rock types within these three intrusions vary from norite at the base to troctolite, anorthositic troctolite, gabbro, olivine gabbro and picrite. Overall, troctolites are the most common with plagioclase and olivine occurring as cumulate grains. Interstitial minerals include ortho- and clinopyroxene, ilmenite, spinel, biotite and locally sulfides. Biotite increases in abundance toward the base of the intrusion.

Sulfides are concentrated in areas of inclusions. The two most common textures for these sulfide minerals are: 1) interstitial between subhedral grains of plagioclase and olivine, and 2) as ragged aggregates in intimate association with biotite and/or ilmenite. According to Ripley (1981), irregular sulfides associated with biotite constitute about 50 to 60 per cent of the sulfide accumulation. In order of abundance the sulfide minerals are pyrrhotite (55%), chalcopyrite (32%), cubanite (10%), pentlandite (3%) and minor bornite (Rao, 1981). In the upper zones of sulfide mineralization, chalcopyrite is the dominant sulfide mineral (much the same as at Minnamax).

Wyman Creek

The Wyman Creek area, owned by U.S. Steel, is located just east of Hoyt Lakes (Figure 2). Footwall rocks are composed of Virginia Formation and the only studies to date on this deposit have been done by U.S. Steel geologists and Churchill (1978). Churchill studied samples from drill hole 17700 which penetrates the base of the contact zone between the Duluth Complex and the Virginia Formation (Figure A3). This drill hole intercepts only 220 feet of the Complex and, therefore, cannot be considered representative of rocks or sulfide mineralization in the area.

From preliminary logging of core by Dean Peterson (this project, August 1987), it appears that the bulk of the Duluth Complex in this area consists of olivine gabbro, pyroxene-bearing troctolite and troctolite. Other rock types include picrite, anorthosite, and anorthositic gabbro. Sulfides are disseminated throughout, usually interstitial and are related to hornfelsic inclusions. Sulfides are also concentrated in pegmatitic portions of the rock types.

In drill hole 26144 there are two sulfide zones: one occurring from 250 to 383 feet in depth and one from 700 to 780 feet at the base of the intrusive rocks. The Cu/Cu+Ni ratio for the upper unit is 0.62 whereas that of the lower is 0.73. This might well suggest at least two pulses of magma: the lower being intruded beneath the other as suggested at Dunka Road by Rao and Ripley (1983).

According to Churchill (1978), sulfides are found in two areas of drill hole 17700: 1) at 28 to 128 feet and 2) from 200 to 222 feet in depth. The latter sits just above the contact with the Virginia Formation. Overall there appears to be about 2 per cent sulfides in these zones. Within the sulfide zones the relative abundance of sulfide minerals is as follows: pyrrhotite (60-80%), cubanite and chalcopyrite (20-40%) , pentlandite (2-12%) and bornite (1%).

Water Hen Cu-Ni-Ti Deposit

The Water Hen Cu-Ni sulfides differ from those deposits described above because they occur within an ilmenite-rich mafic to ultramafic body which has intruded troctolitic series rocks at the base of the Duluth Complex. This deposit has been described by Mainwaring (1975) and Mainwaring and Naldrett (1977). The Water Hen intrusion itself consists of cyclical units of mineral-graded layers varying from dunite at their bases through troctolites to anorthosites at their tops. Xenoliths of underlying Virginia Formation are found in the lower third of the intrusion. The Cu-Ni sulfides occur either as massive and disseminated ores associated with dunites, both at the base of the intrusion and in zones forming the base of individual units, or secondly, as disseminations in peridotite containing graphite and recrystallized xenoliths. Texturally the sulfides fill voids between olivine and ilmenite grains.

Sulfide mineralogy is similar to that found in the Cu-Ni sulfides associated with troctolites. Major minerals are pyrrhotite, pentlandite, cubanite, chalcopyrite, and mackinawite. Minor minerals include arsenopyrite, maucherite, sphalerite and galena. Secondary minerals are bravoite, violarite, and marcasite. The overall Cu/Cu+Ni ratio of the sulfides is 0.66 but the grade is considerably less than 0.5% copper. Sulfides are generally absent in footwall troctolites (Mainwaring,1975) although they do occur in late stage pyroxenite dikes which cross-cut the footwall rocks.

PGE CHARACTERISTICS OF SULFIDE DEPOSITS OF THE DULUTH COMPLEX

Review and Introduction

Magmatic sulfide deposits fall into two main categories with respect to their PGE content: 1) those in which the PGE are the principal products extracted from the ore, and 2) those in which Ni and Cu are the most important products and the PGE are by-products (Naldrett and Duke, 1980). The former includes deposits such as those of the Merensky Reef of the Bushveld Complex and the JM reef of the Stillwater Complex, whereas the latter includes Ni-Cu deposits that are associated with a variety of mafic and ultramafic rock types. Naldrett and Duke (1980) maintain that over 95% of all known Ni-Cu sulfide ores in this latter category fall into one of the following petrotectonic settings:

1. Setting I, noritic rocks associated with an astrobleme. The only known occurrence is the Sudbury Mining Camp in Ontario, Canada.

2. Setting II, intrusive equivalents of flood basalts associated with intracontinental rifting. Noril'sk camp of Siberia, Duluth Complex and the Crystal Lake Gabbro (Postle et al., 1986) are important examples of this deposit type.

3. Setting III, rocks emplaced during early stages of formation of Precambrian greenstone belts. These may be associated with tholeiitic lavas, e.g., Pechanga Ni camp, USSR or komatiitic lavas and intrusions, particularly the more ultramafic variety, e.g., Kambalda camp of Western Australia.

4. Setting IV, Synorogenic tholeiitic intrusions of Phanerozoic belts, e.g., Rana deposit, Norway.

Of these, the Duluth Complex falls within Setting II. Naldrett and Duke (1980) maintain, that any supply of PGE from the Duluth Complex would be tied directly to the mining of Cu and Ni. They estimate a total reserves for the Duluth Complex (based on a reserve of 8 billion kilograms of Ni) to be 544,000 kg Pt and 1,808,000 kg Pd. These are 1/3 the reserves for Noril'sk.

Since the publication of the above paper, there have been several studies about the distribution of PGE within Cu-Ni sulfides of the Duluth Complex (Watowich et al., 1981; Ryan and Weiblen; 1984; Tyson and Bonnichsen, 1986; Ripley and McMahon, 1987, Weiblen et al., 1987; Morton, 1987). Also, there are high PGE values in oxide-rich rocks in drill holes DU-15 and DU-9 of the Birch Lake area in the basal zone of the South Kawishiwi intrusion (Sabelin et al., 1986; Dahlberg and Gladen, 1987). Here the PGE appear to be related to Cr spinels rather than sulfides and their distribution is not considered in this report.

As stated before, this project was undertaken to compile unpublished company data on the distribution of PGE in the hopes of adding to the meager data base and perhaps, delineating PGE rich areas within the Cu-Ni sulfides. The rest of this report deals with company data.

Presentation of Results

All individual data for deposits are listed in separate tables (A1 to A12) within the Appendix. Drill Hole location maps (Figures A2-A5) are also found in the Appendix. These describe locations of holes for which there are assay data. Where known, rock types are included in these tables. Weighted mean and median values for all of the deposits are presented in Tables 3 and 4 and average concentrate values in Table 5. It should be noted that data presented in Tables 3 - 5 come from a very small percentage of available core, usually less than 1%. For purposes of

Table 3: Weighted averages of metals in Cu-Ni sulfide deposits of the Duluth Complex

DEPOSIT	# of samples	Total feet	%Cu	%Ni	%S	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Ag (ppm)	Au (ppb)	Pt+Pd +Au (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd
Dunka Road	30	425.5	0.71	0.24	1.67	256	1003	1259	1.22	125	1385	0.73	0.21
Wyman Creek	16	134	0.71	0.30	2.57	-	-	-	3.52^	-	3835^	0.62	-
Water Hen	42	801.5	0.32	0.15	na	*	*	105	2.59	63	174	0.66	*
Dunka (Erie) Pit	8	40	0.47	0.19	na	107	171	278	na	na	na	0.69	0.33
Minnamax													
All	194	4442	0.98	0.22	2.52	148	277	378	3.82	*	*	0.78	0.30
Cloud	45	445	0.28	0.08	0.38	49	143	192	0.72	na	na	0.71	0.35
Basal	149	3997	1.06	0.23	2.78	157	290	396	4.12	66	489	0.80	0.30
Spruce Road	1	89	0.70	0.25	1.19	342	308	651	na	137	788	0.74	0.53
Maturi	2	425	0.66	0.24	1.21	308	262	570	na	91	661	0.73	0.54

*	not complete
na	not analyzed
^	not reliable

Table 4: Median values of metals in Cu-Ni sulfide deposits of the Duluth Complex

	%Cu	%Ni	%S	%Co	Ag (ppm)	Au (ppb)	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd	Co/ Co+Ni
Minnamax												
All	0.80	0.17	1.22	0.03	3.08	17	50	140	180	0.81	0.26	0.07
Cloud	0.25	0.07	0.31	-	0.60	-	35	90	140	0.77	0.26	-
Pre-1969	1.05	0.20	2.23	0.04	4.79	17	-	-	205	0.83	0.20	0.09
U of T	0.91	0.21	1.98	0.01	-	30	60	110	140	0.81	0.21	0.06
Baseline	0.69	0.16	1.08	-	3.50	-	55	160	215	0.82	0.25	-
Basal	0.90	0.19	1.66	0.03	4.00	17	60	155	200	0.82	0.29	0.07
Water Hen	0.25	0.12	-	0.04	0.17	17	-	-	103	0.65	-	0.15
(Erie) Dunka Pit	0.45	0.17	-	0.02	-	-	120	170	290	0.66	0.28	0.09
Dunka Road	0.83	0.27	1.20	-	0.03	68	342	856	1164	0.76	0.25	-
Wyman	0.45	0.20	2.60	-	4.28	-	-	-	-	0.67	-	-

Table 5: Average metal contents of concentrates

	Cu %	Ni %	Co %	Fe %	S %	Pt (ppb)	Pd (ppb)	Ag (ppm)	Au (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd
Minnamax	13.71	2.56	0.15	33.71	26.73	820	2151	47.5	783	0.84	0.28
Dunka Road	5.11	1.41	0.04		7.89	1176	5245	21*	514	0.78	0.19
Spruce Road	12.5	2.85	0.12	27.6	21.1	1045	4019	41.60	1242	0.81	0.21

* estimate only from heads

simplicity, whenever the term mean is used, it refers to the weighted average. Histograms of data from the deposits as a whole are shown in Figures 4 through 13. Because there is a wealth of data from the Minnamax deposit, a separate section is devoted strictly to distribution of sulfides and PGE in the Minnamax deposit with particular reference to Cloud and Basal zones.

Mean and Median Values

Because the data in Tables 3 and 4 were compiled only from holes that were analyzed for Pt, Pd, Au and/or Ag, it may be that Cu, Ni, Co and S contents are not representative of the whole Cu-Ni sulfide deposit. For example, the Cu-Ni grades might be slightly different from published values. The Cu/Cu+Ni ratios are not very different from previously published values (see previous section) with the exception of the Dunka Road deposit (Figure 4). The Cu/Cu+Ni ratio has a mean of 0.73 and a median value of 0.76 (Tables 3 and 4). This agrees with Listerud and Meineke's (1977) estimate, but not with Ripley's (1981).

Mean values of combined Pt and Pd vary from a low of 105 ppb in the Water Hen to a high of 1259 ppb in the Dunka Road deposit (Table 3). Median values are somewhat lower, 103 and 1164 ppb respectively (Table 4). Because the distribution is highly positively skewed (Figure 5) and highly anomalous samples increase the mean considerably, for purposes of comparison, medians (and histograms) give a better representation of background data. Because analyses from Spruce Road and Maturi (Table 3) are composite, no medians can be calculated for these footages.

The data suggest that the Dunka Road deposit is much richer in Pd and slightly richer in Pt than the other deposits listed in Tables 3 and 4.

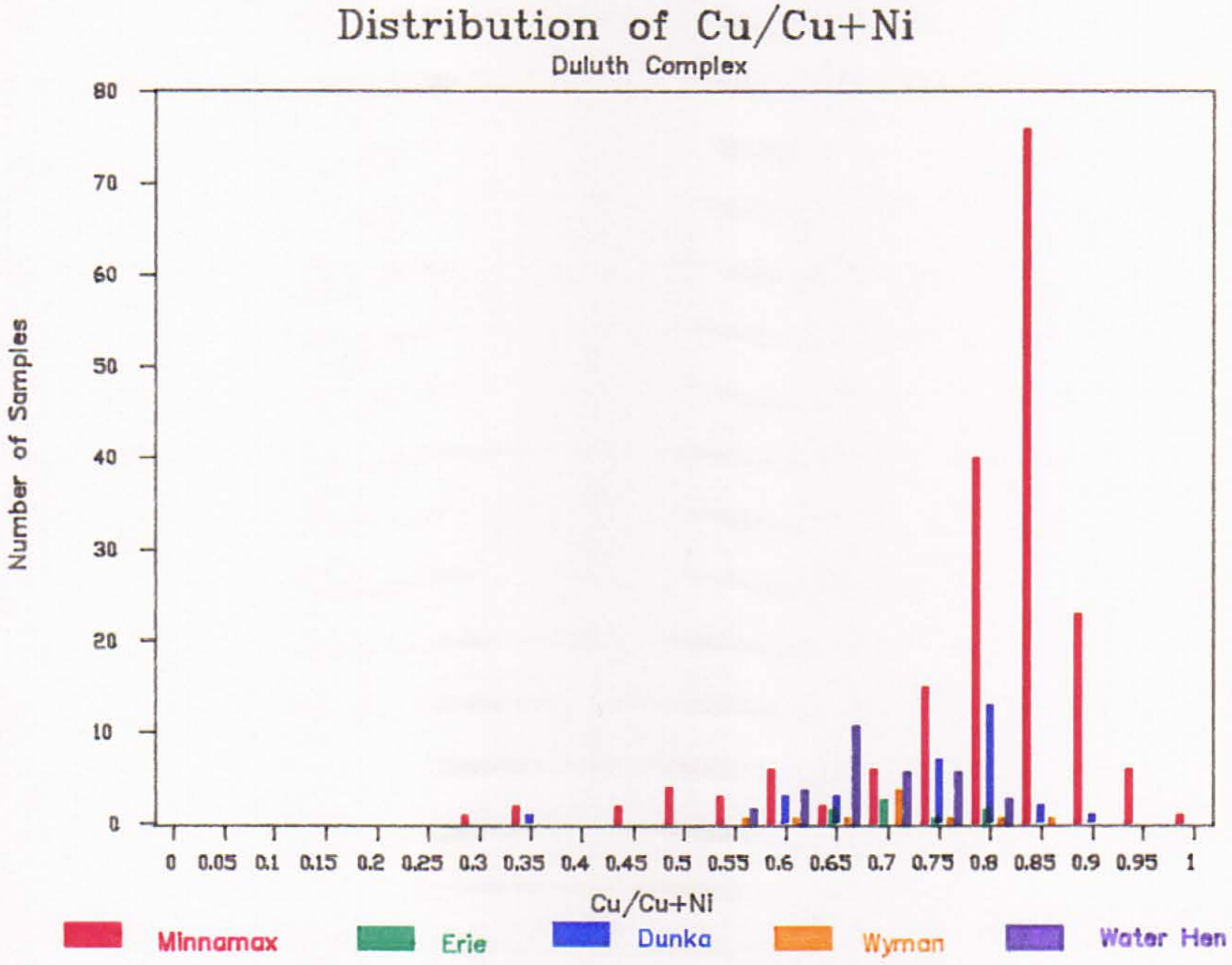

Figure 4: Distribution of Cu/Cu+Ni ratios in Cu–Ni sulfide deposits of the Duluth Complex

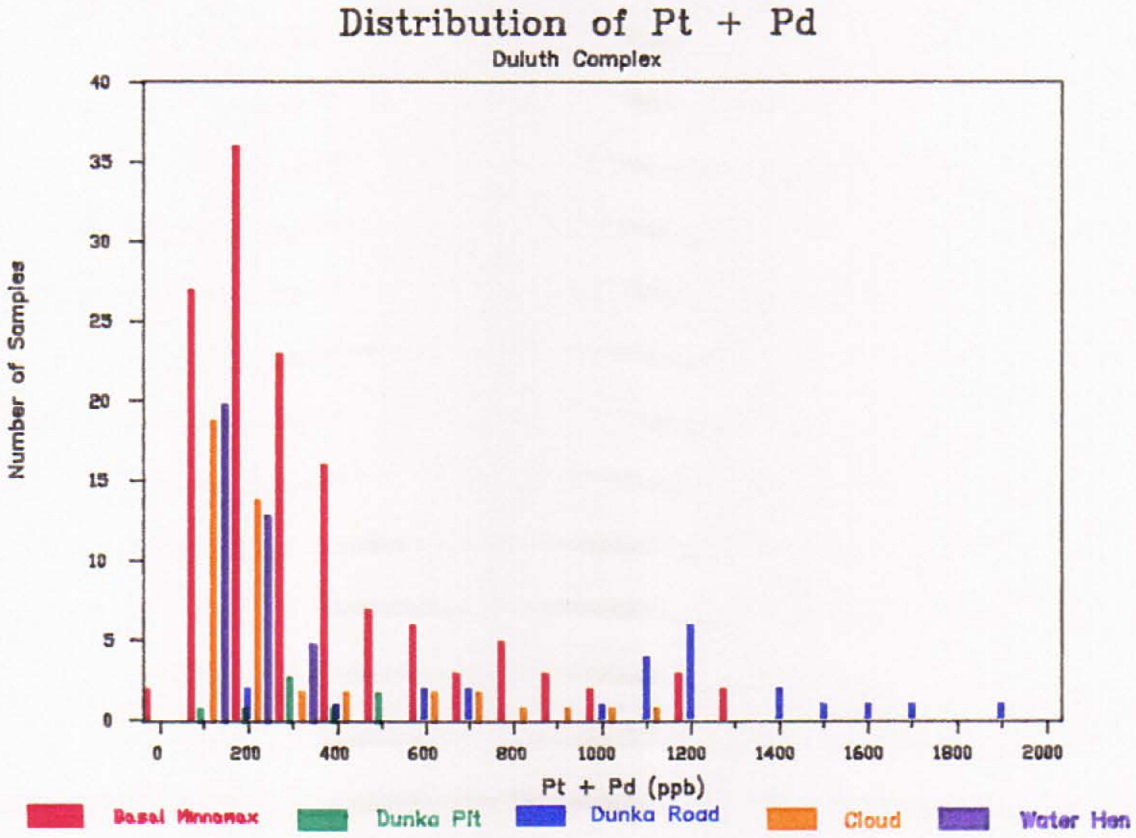

Figure 5: Distribution of Pt+Pd contents in Cu–Ni sulfide deposits of the Duluth Complex

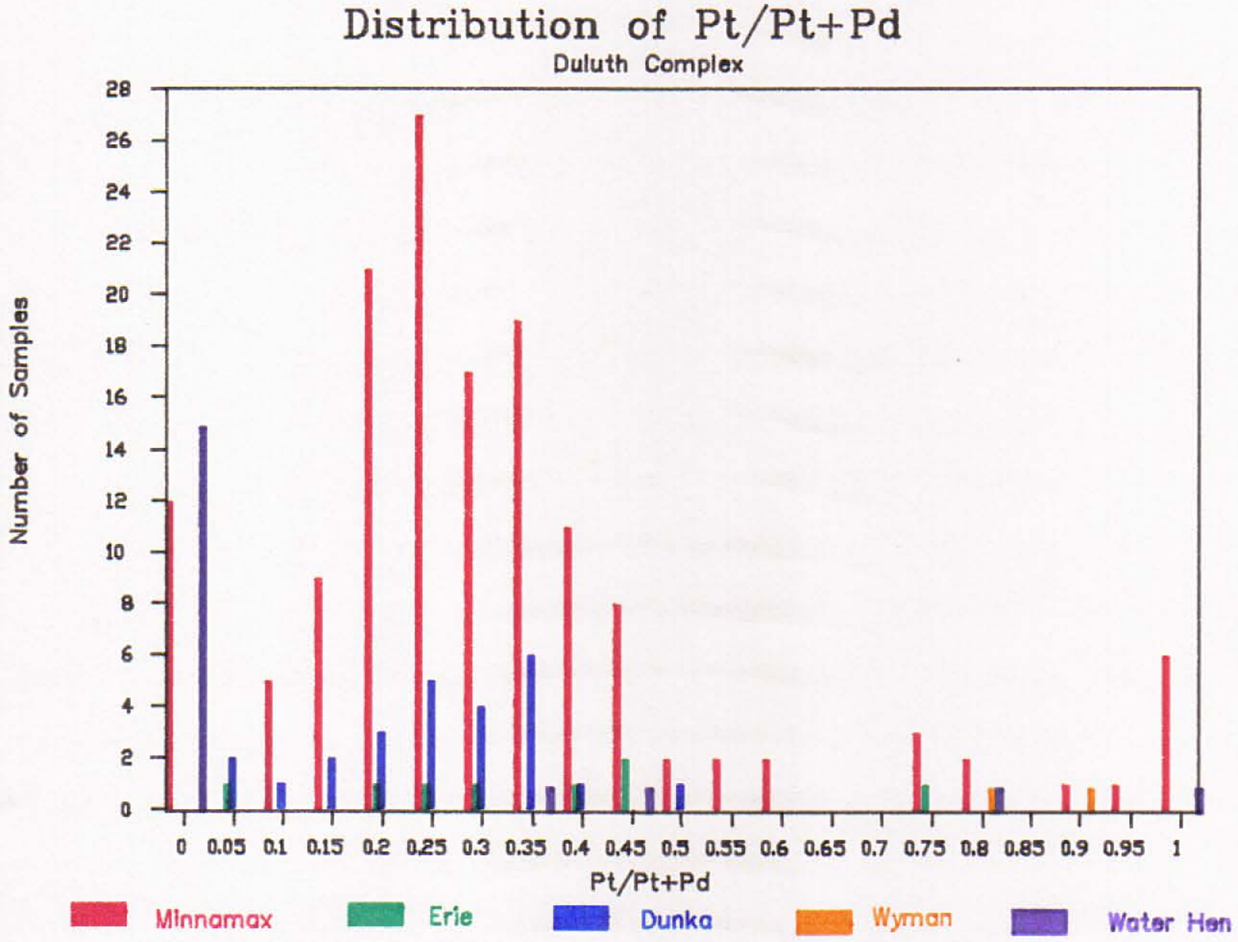

Figure 6: Distribution of Pt/Pt+Pd ratios in Cu–Ni sulfide deposits of the Duluth Complex

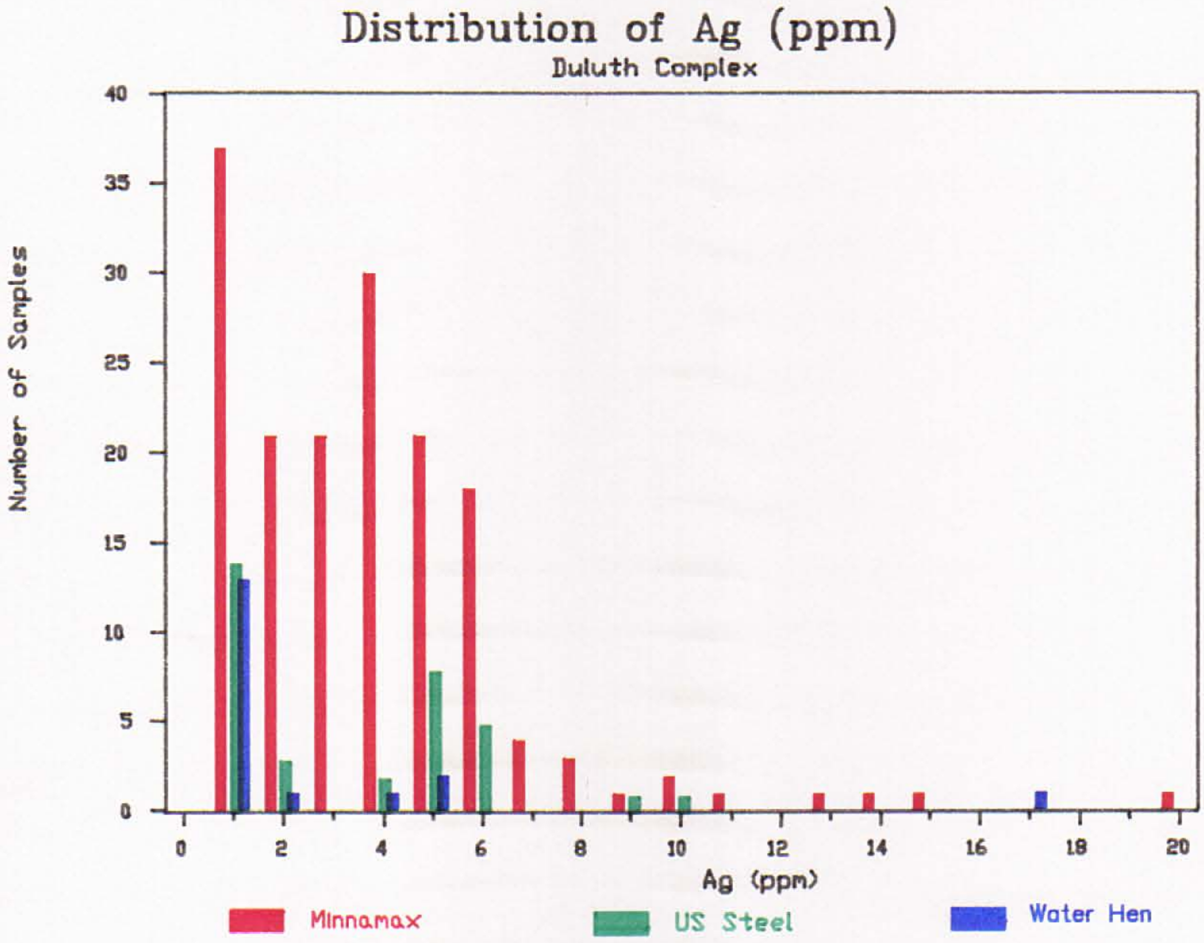

Figure 7: Distribution of Ag contents in Cu–Ni sulfide deposits of the Duluth Complex

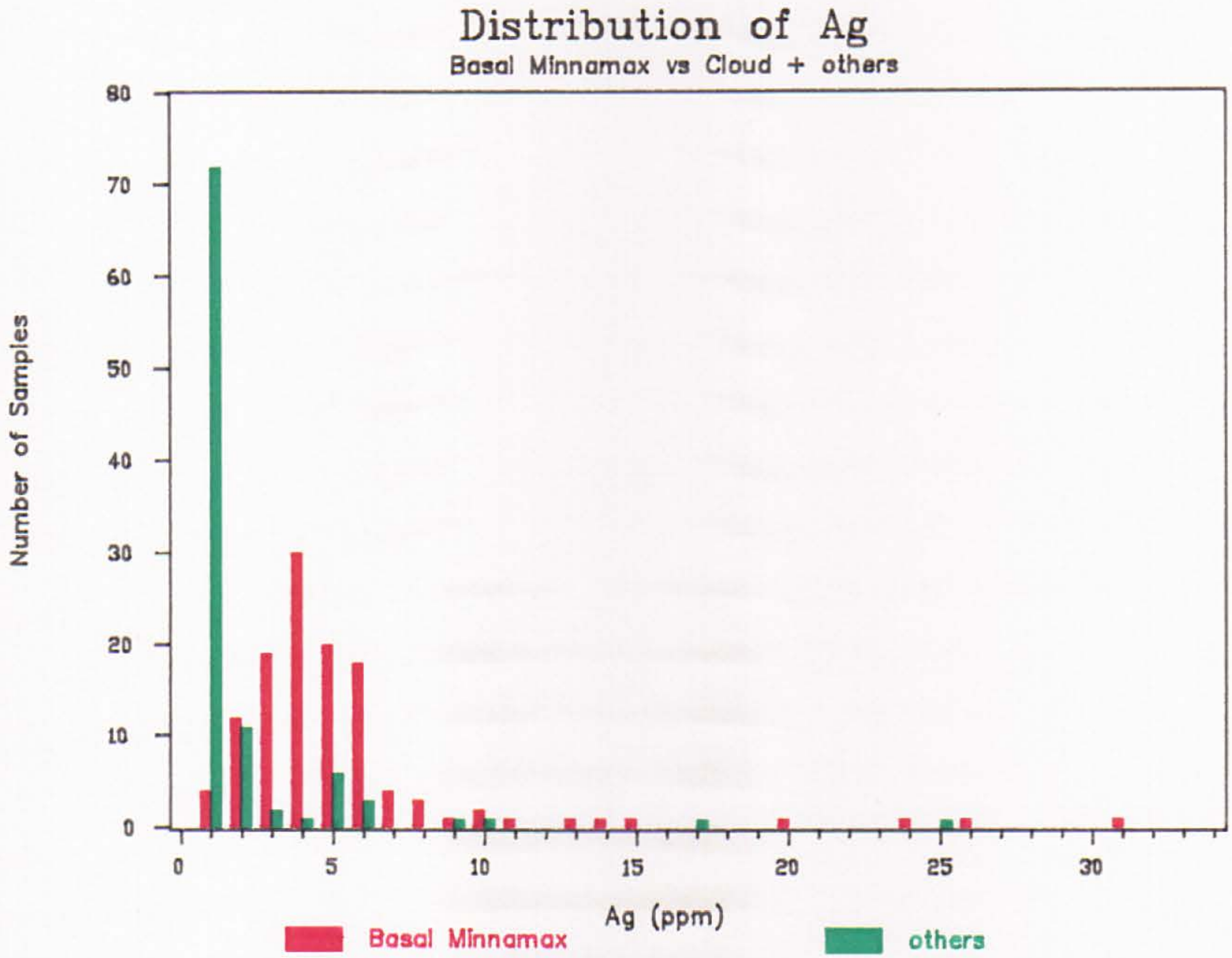

Figure 8: Comparison of Ag contents in Minnamax Basal zone with other Cu–Ni sulfide deposits including the Cloud zone.

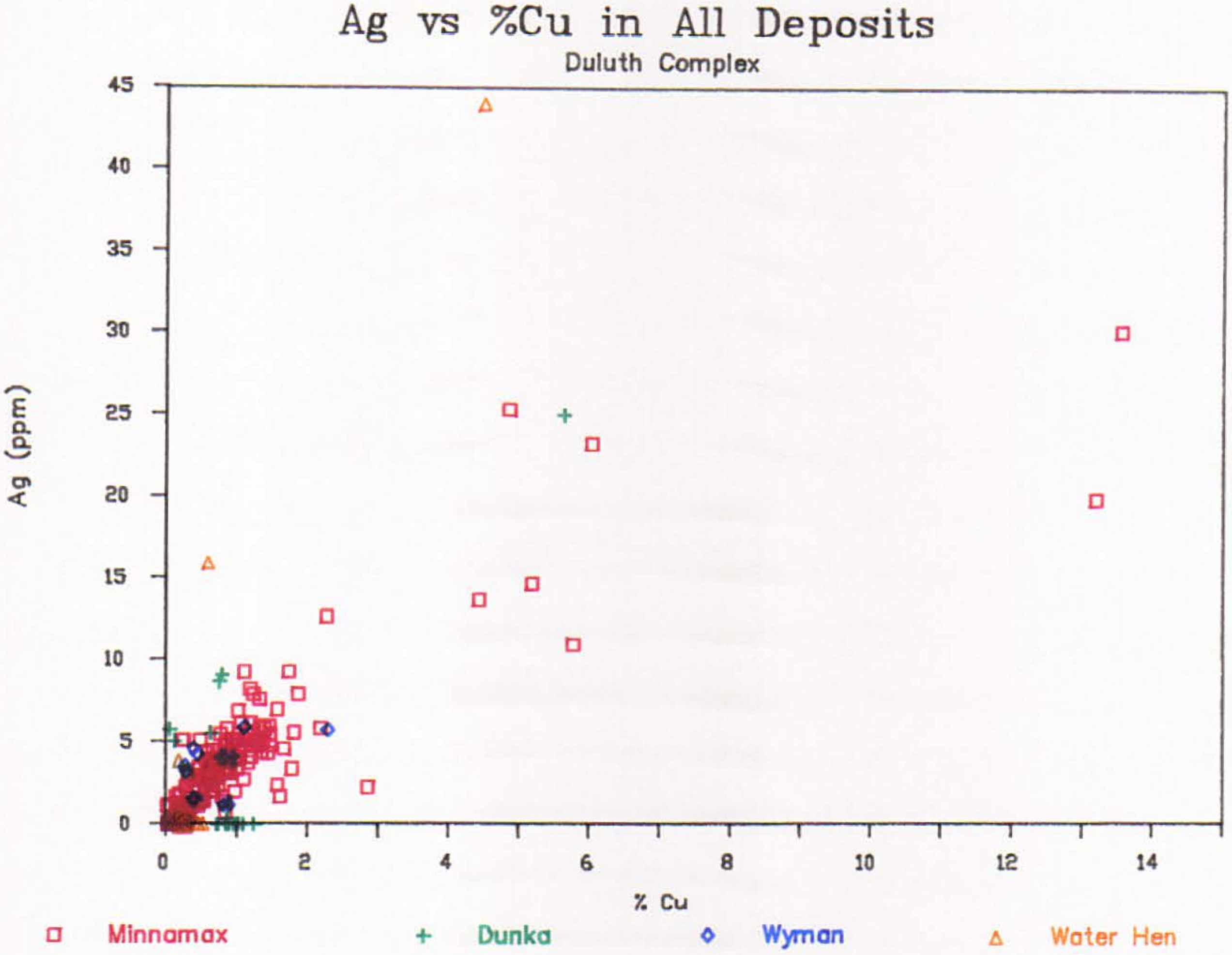

Figure 9: Correlation of Cu and Ag contents for Cu–Ni sulfide deposits

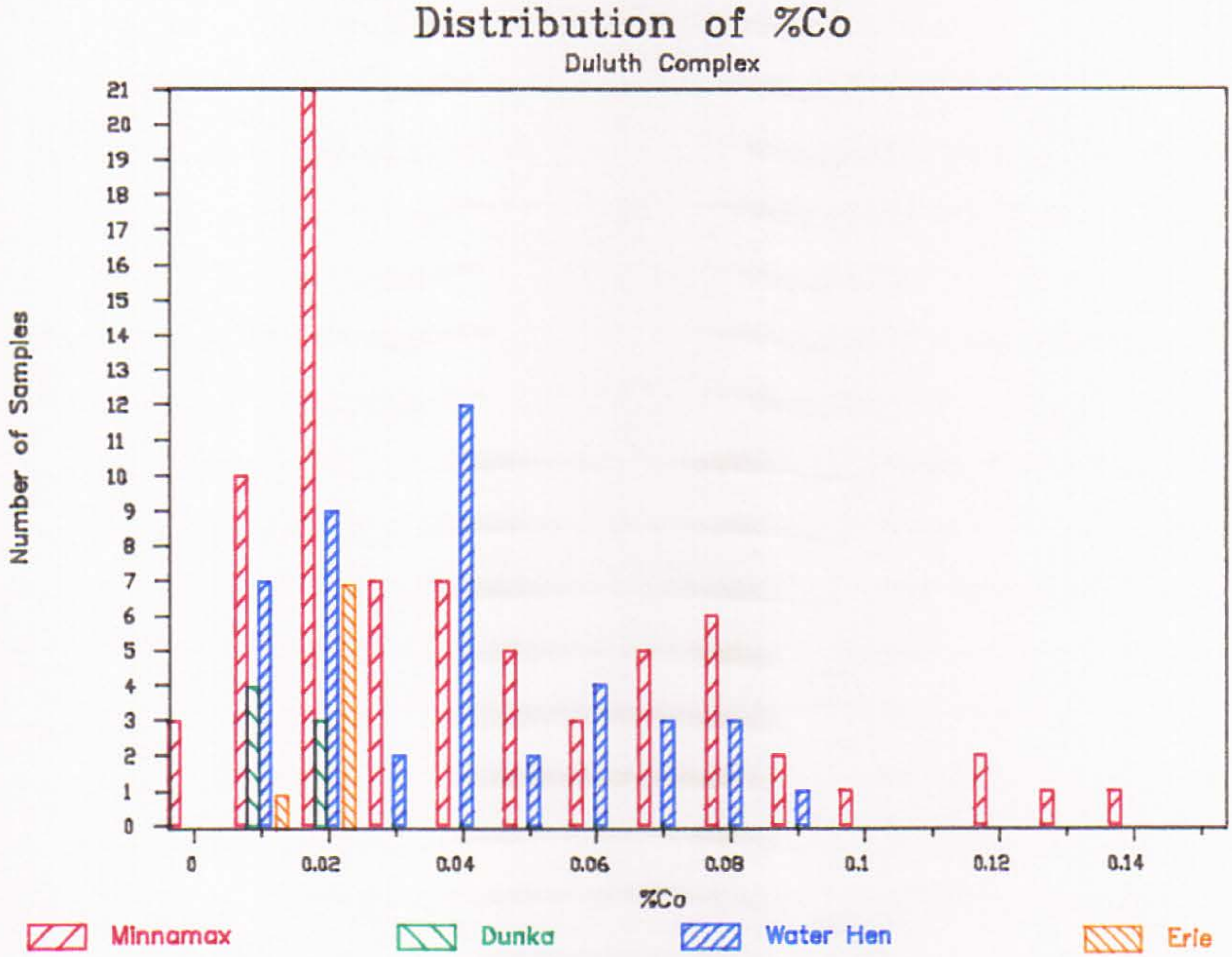

Figure 10: Distribution of Co contents in the Cu−Ni sulfide deposits of the Duluth Complex

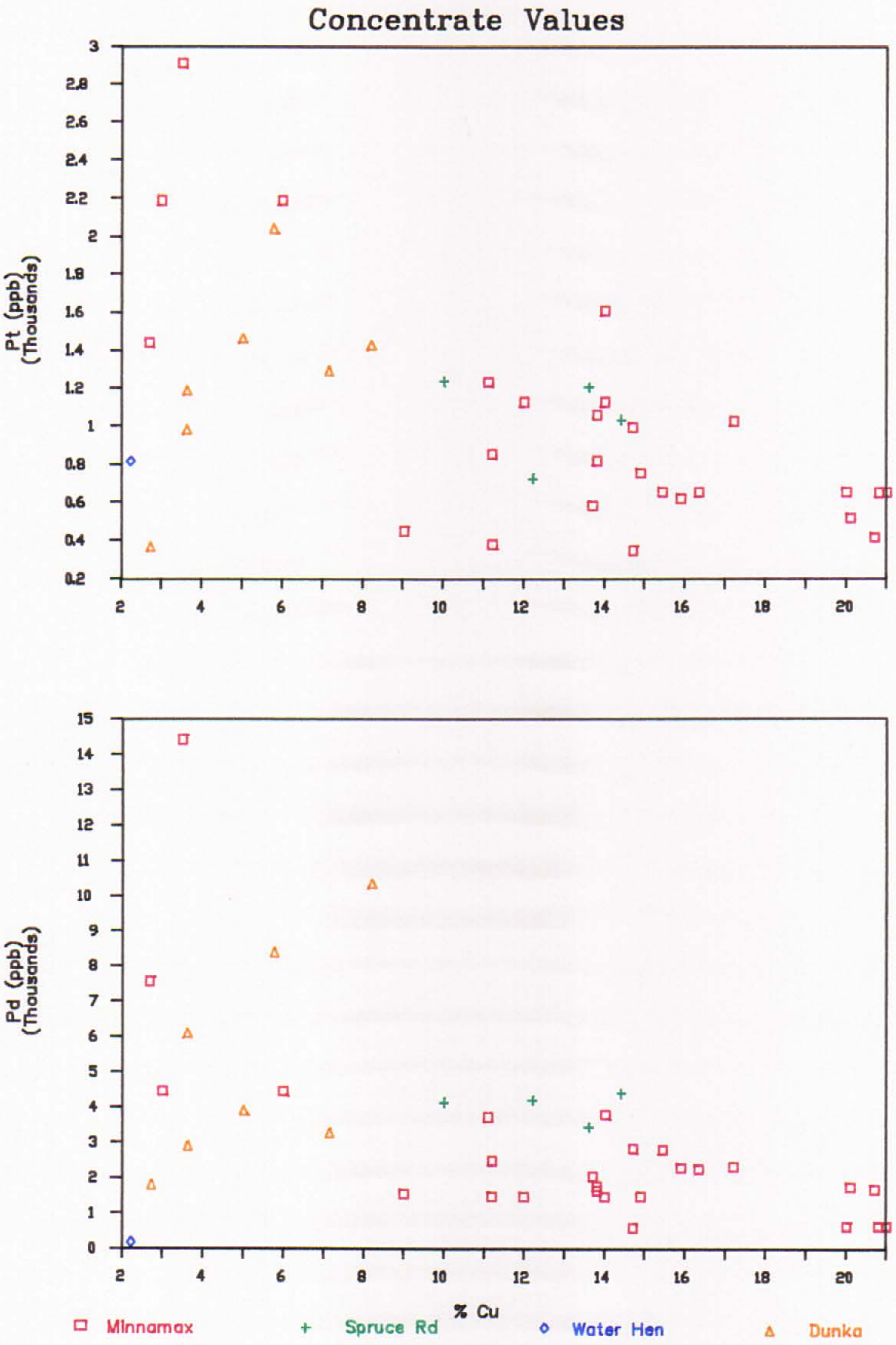

Figure 11: Pt and Pd contents versus %Cu in concentrate

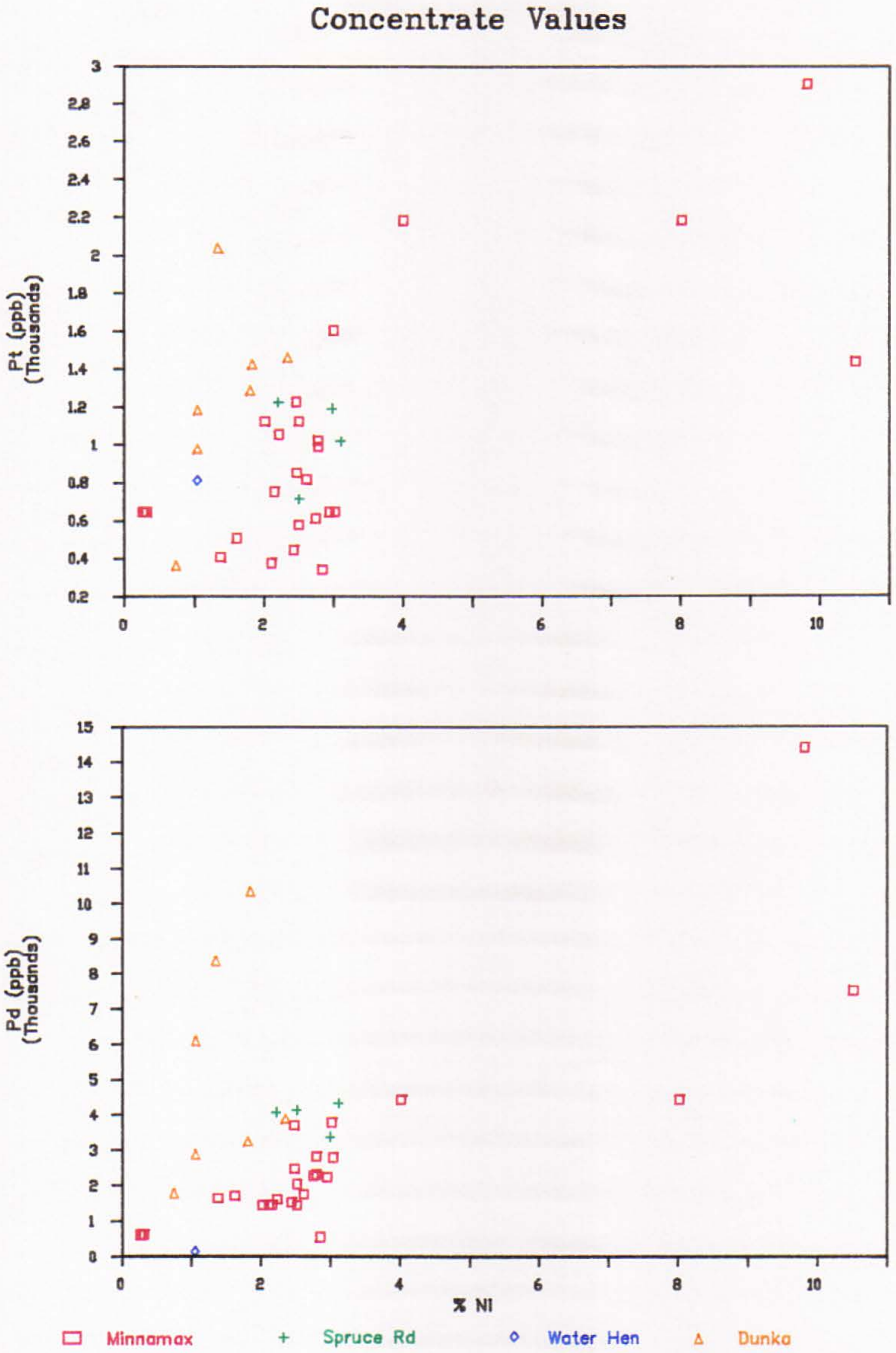

Figure 12: Pt and Pd contents versus %Ni in concentrate

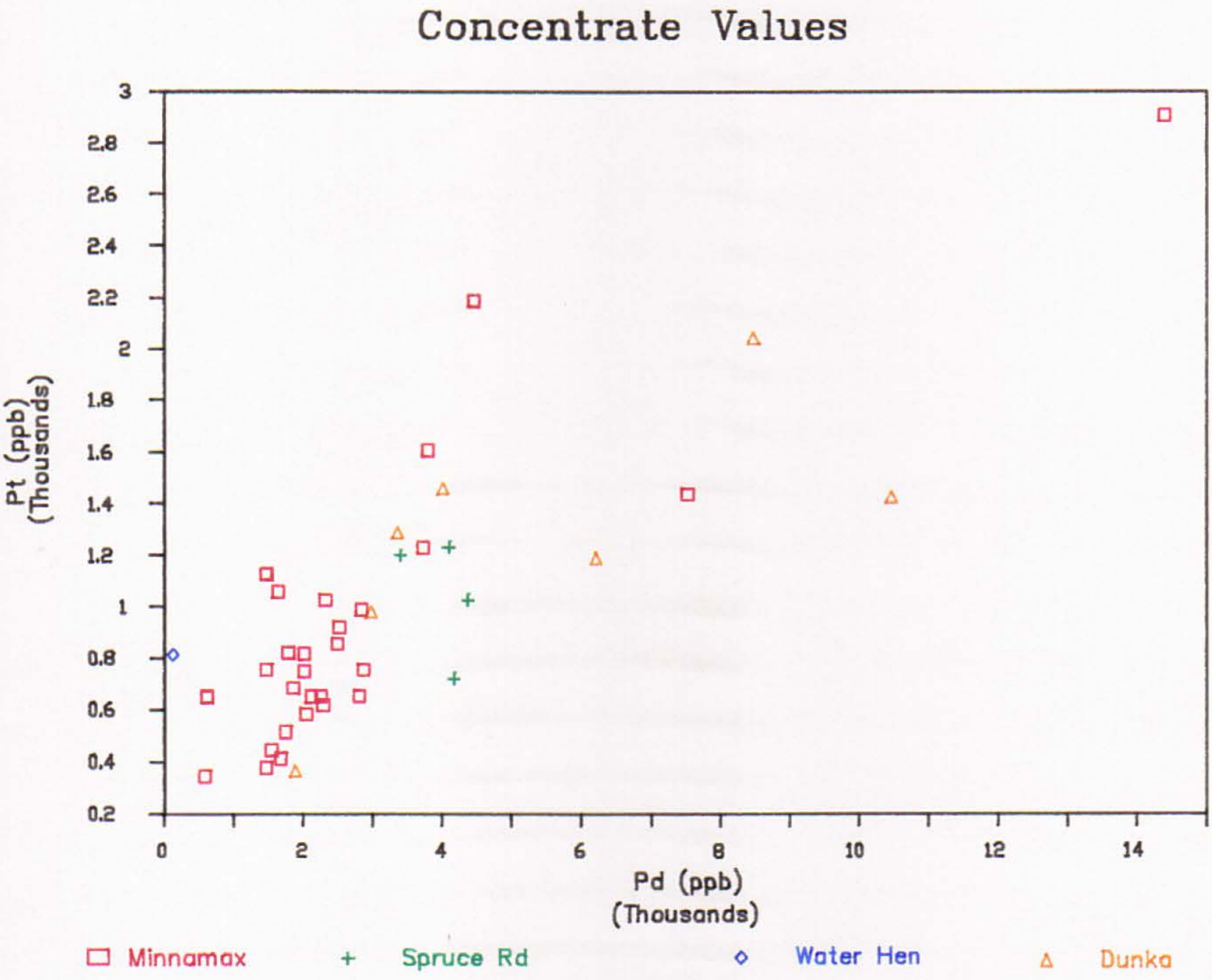

Figure 13: Pt versus Pd contents in concentrate

The majority of these samples (Table A1) come from an area in the Dunka Road deposit (Figure A2) where palladium minerals have been identified (this study and U.S. Steel) and may not be representative of the whole deposit. Ripley and Al-Jassar (1987) state that "copper grades and concentrations of PGE appear to be greater within the Babbitt (Minnamax) deposit" (pg. 88) in comparison to Dunka Raod. Certainly this is born out for Cu but not so by PGE in this study.

Within all the deposits there is no correlation between Cu, Ni and/or S contents with total PGE content. It does appear, however, that to get any PGE values, there must be at least 0.2 wt % S in the rocks. But, as the per cent of Cu-Ni sulfides increases, the amount of PGE does not necessarily increase. This is also discussed in the section on the Minnamax deposit.

The mean ratio of Pt/Pt+Pd (Table 3) varies from a low of 0.21 in Dunka Road to highs of 0.53 and 0.54 at Spruce Road and Maturi. Values from Minnamax and Dunka (Erie) Pit average about 0.30. The median values, however, are lower and do not appear to vary significantly among deposits (Figure 6). Not enough data exist from the Spruce Road and Maturi deposits to calculate medians. Data from DDH 34872 in the vicinity of Spruce Road (Dahlberg, 1987) yield an average ratio of 0.21. This is vastly different from the mean of 0.53 reported in Table 3.

Average silver contents vary from less than 1 ppm in the Cloud zone of Minnamax to about 4 ppm in the Minnamax Basal zone and Wyman Creek (Table 3). The distribution of Ag contents is shown in Figure 7. All Minnamax data are combined, as well as data from Wyman Creek and Dunka Road (U.S. Steel). The vast majority of the values are less than 8 ppm. There are some samples that assay greater than 20 ppm Ag: hole 26010 (115.5 -118.5 feet) in the Dunka Road deposit (Table A1), Sl-1 (680-683 feet) in the

Water Hen deposit (Table A4) and drill holes 60 (1731-1735 feet), 105 (1842-1855 feet) and 116 (1680-1698 feet) in the Minnamax deposit (Table A9). Three of these samples are also anomalous in PGE and Au (see Appendix). If Ag contents are grouped into those from the Basal zone at Minnamax and those from all other deposits (including Cloud zone), there appears to be two different distributions of Ag content (Figure 8): one in the Minnamax Basal zone with a median of approximately 4 ppm and a second with a skewed distribution with the bulk of the samples less than or equal to 1 ppm. This may be a reflection of the richer Cu content of the Minnamax Basal zone, because overall, there is a good correlation (r= 0.75) between Cu and Ag contents for all of the deposits (Figure 9), or it may also reflect different initial Ag contents of sulfides and/or magma (see section on Minnamax).

Co content, where analyzed, is low, usually much less than 0.05 wt. % (Table 4). The median Co/Co+Ni ratio varies from 0.07 at Minnamax to 0.15 at Water Hen (0.1 to 0.19 for mean). The distribution of Co is shown on Figure 10. Minnamax exhibits the most variance, probably because it reflects the greatest number of samples. Water Hen does have higher Co contents than other deposits, just as it has a relatively higher Ni concentration.

Concentrate Values

Average values of Pt, Pd, Ag and Au in Cu-Ni concentrates from Minnamax, Dunka Road and Spruce Road are listed in Table 5. Individual analyses from different concentrates are presented in Tables A10, A11, and A12. Those analyses from Minnamax and Dunka Road are from company files whereas those from Spruce Road are from INCO (1975) or from Lawver, et al.

(1975). These values support the contention that Pd (not necessarily Pt) is enriched in the Dunka Road deposit.

The Cu/Cu+Ni ratio of the concentrate is slightly higher than in the heads for each of the deposits because overall recovery is better for Cu than Ni (Watowich et al., 1981 and this study), around 90% for Cu and 70% for Ni. Co recoveries are very low however, about 30 to 35% (Watowich et al., 1981; Table A10 this study). It has been suggested that Co, as well as occurring in pyrrhotite and pentlandite, may also exist in discrete Co-bearing phases that are not separated by the concentrating methods (Ryan and Weiblen, 1984).

Recovery for Pt and Pd is estimated to be 50 to 60% by Watowich et al. (1981) whereas U.S. Steel estimates it to be < 50% (Table A10). Plots of Pt and Pd versus %Cu and %Ni in the concentrates are shown in Figures 11 and 12. The PGE values show a decrease in content with Cu content, and an increase with Ni content, especially in Minnamax ores, suggesting that they may be preferentially concentrated in a Ni concentrate. No correlations of PGE content with %S in the concentrates was observed. Au and Ag content do not correlate with Cu or Ni content.

A plot of Pt versus Pd (Figure 13) indicates that Pt and Pd contents are highly correlated (r=0.78) which shows that at least they appear to occur together in the concentrate. It is interesting to note that the correlation coefficient for Pt vs Pd in the head values and drill core analyses is only 0.17 (0.5 if two very anomalous samples are deleted) which may be a reflection of the overall inhomogeneity of the samples. It may be, however, that Pt and Pd are not necessarily found together in the ore and during the concentrating process, only those PGE found together are liberated. Not enough is understood about the mineralogy of PGE in these deposits to answer this question properly.

Minnamax Deposit

General

By far the largest amount of data listed in the Appendix comes from the Minnamax deposit largely because AMAX geologists (Stan Watowich in particular) were interested in ascertaining whether in fact there might be some anomalous areas with respect to Pt and Pd within the deposit. The data presented in Table 6 have been divided several ways:

1. "All" represents weighted averages of all analyses.
2. "Pre-1969" are all analyses done prior to 1969. They were separated out because: a) it was not known if the data were reliable, and b) they all come from early holes drilled throughout the central part of the deposit (Figure A5)
3. "Cloud" represents analyses only performed on Cloud zone sulfides.
4. "Baseline" represents analyses performed every ten feet through two representative drill holes through the Tiger Boy and Bathtub ore bodies.
5. "U of T core" (University of Toronto) are samples from the Basal zone of Minnamax sent to A. J. Naldrett at the University of Toronto. These are analyses published by Naldrett and Duke (1980). They have further been subdivided into the Tiger Boy, Bathtub, and SW extension ore bodies.
6. "U of T Drift" are samples sent to A. J. Naldrett and are from the more copper rich Local Boy deposit located near the shaft.

All individual data for these divisions are listed in separate tables in the appendix (Tables A5 though A9).

Table 6: Weighted average metal values in the Minnamax Deposit

	# of samples	Total feet	Cu %	Ni %	Co %	S %	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Ag (ppm)	Au (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd
All	194	4441.7	0.98	0.22	0.03	2.52	148	277	378	3.82	66	0.78	0.30
Pre 1969	61	1777.2	1.22	0.26	0.04	3.86	*	*	340	4.61	89	0.80	*
Cloud	45	445	0.28	0.08	na	0.38	49	143	192	0.72	na	0.71	0.35
Baseline	63	630	0.79	0.17	na	1.28	81	196	276	3.76	na	0.80	0.28
Bathtub 296	44	440	0.68	0.16	na	1.07	89	193	282	3.40	na	0.80	0.32
Tiger Boy 254	19	190	1.07	0.20	na	1.77	61	202	263	4.59	na	0.82	0.18
U of T core	16	1589.5	1.00	0.22	0.01	2.22	193	304	497	na	60	0.81	0.29
Bathtub	5	531	1.14	0.24	0.01	1.97	326	186	512	na	61	0.82	0.34
Tiger Boy	7	662	0.98	0.22	0.01	2.55	72	175	247	na	46	0.82	0.30
SW extension	4	397	0.86	0.20	0.01	2.01	118	579	696	na	75	0.81	0.17
U of T drift	9	+	4.16	1.11	0.07	14.77	155	239	394	na	180	0.76	0.42

+ grab samples only
na not analyzed
* not available

Baseline values for combined Pt and Pd for the Minnamax ore bodies are 282 ppb for Bathtub and 263 ppb for Tiger Boy. These numbers compare favorably with that of Ripley and McMahon's (1987) value of 244 ppb. Values from the pre-1969 and U of T's data are slightly higher (340 to 497 ppb). When the medians are compared (Table 4), these numbers decrease to 205 ppb for pre-1969 and 140 ppb for U of T. It appears, therefore, that these higher weighted means are due to a few anomalous samples. Indeed one sample from drill hole 60 (Table A9) has 14,000 ppb combined Pt and Pd.

As a check on the validity of some of the old analyses, it is of interest to note that Dahlberg (1987) reanalyzed some intersections from the B1-AMAX drill hole (Tables 7 and A9). The mean from Dahlberg's data is 602 ppb versus 805 ppb for the pre-1969. Considering there is a difference in the amount of core analyzed over the section, this is in remarkable agreement.

Table 7: Comparison of pre-1969 data with that of Dahlberg, 1987

	%Cu	%Ni	%Co	%S	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Au (ppb)	Ag (ppm)	Cu/ Cu+Ni	Pt/ Pt+Pd	Co/ Co+Ni
BA-1	0.56	0.07	0.01	0.76	130	640	770	76	<5	0.89	0.17	0.13
	0.4	0.028	0.007	0.39	100	480	580	52	<5	0.93	0.17	0.20
	0.63	0.043	0.009	0.67	90	430	520	52	<5	0.94	0.17	0.17
	0.42	0.024	0.008	0.71	100	350	450	48	<5	0.95	0.22	0.25
	0.51	0.058	0.01	0.94	120	430	550	72	<5	0.90	0.22	0.15
	0.44	0.051	0.01	0.94	80	350	430	38	<5	0.90	0.19	0.16
	0.46	0.052	0.009	0.84	80	760	840	49	<5	0.90	0.10	0.15
	0.47	0.09	0.01	1.04	170	750	920	83	<5	0.84	0.18	0.10
	0.41	0.053	0.01	0.79	70	330	400	22	<5	0.89	0.18	0.16
	0.46	0.086	0.014	1.41	100	460	560	42	5	0.84	0.18	0.14
average 2635-2726	0.48	0.06	0.010	0.85	104	498	602	53	1	0.90	0.18	0.16
pre-1969												
2590-2660	0.23	0.09		0.38			596	48	5	0.73		
2660-2720	0.48	0.15		0.56			1048	55	5	0.77		

In comparing the samples analyzed by the University of Toronto, it can be shown that the more Cu and S rich samples from the drifts are not higher in PGE contents (Table 6). However, Au content is higher in the massive sulfide from the drifts and this is due to one anomalous sample. Similarly, the mean value of 326 ppb Pt in Bathtub is due to one sample with 1,900 ppb Pt (Table A6). If one compares the baseline values with those from U of T, it seems that Tiger Boy compares favorably (263 ppb vs 247 ppb Pt+Pd respectively), whereas Bathtub does not. If we disregard the one anomalous Pt value in Bathtub, the weighted average for combined Pt+Pd drops to 212 ppb (vs. 512 ppb in Table 6). This is not that different from the 282 ppb reported for baseline Bathtub. Samples taken from SW Extension are slightly higher in PGE (mean of 696 ppb combined Pt and Pd versus 247 ppb in Tiger Boy and 282 ppb in Bathtub). This has yet to be documented by further analysis.

If the basal Minnamax data are used in one data base (not including Cloud zone data) and a log normal distribution for combined Pt and Pd contents in the Cu-Ni sulfides is assumed, the threshold value for anomalous samples can be calculated. From these data, the log mean is 215 ppb (very close to the median of 200 ppb, Table 4) and the threshold value is 1,155 ppb at the 95% confidence interval. This means that any samples listed in Tables A6, A8, and A9 with Pt+Pd values > 1,155 ppb are considered anomalous. If Cloud zone data are included in this analysis, then the threshold is increased to 1,253 ppb.

Comparison of Basal and Cloud Zone Sulfides

The Cu/Cu+Ni ratio of sulfide from the Cloud zone has a mean of 0.71 and median of 0.77 (Tables 3 and 4). This indicates that it has a negatively skewed distribution as shown in Figure 14. The median value is a better estimate of the background. The corresponding Cu/Cu+Ni ratio of sulfides from the Basal zone is 0.82 (Table 4). This may well indicate that sulfides from the Cloud zone separated from a magma of slightly different composition than those from the Basal zone (Rajamani and Naldrett, 1978). The Pt/Pt+Pd ratio is approximately the same for each of the data sets (0.25, Figure 15).

Weighted means for Cu, Ni and S contents of Basal and Cloud zone sulfides in the Minnamax deposit are considerably higher within the Basal zone (Table 3). The same can be said for Pt, Pd and Ag contents (no Au values are available for Cloud zone). Therefore, to compare metal contents between the two zones, the individual metal value has been divided by its corresponding S content and these are plotted in histograms and scattergrams for comparison (Figures 16-23).

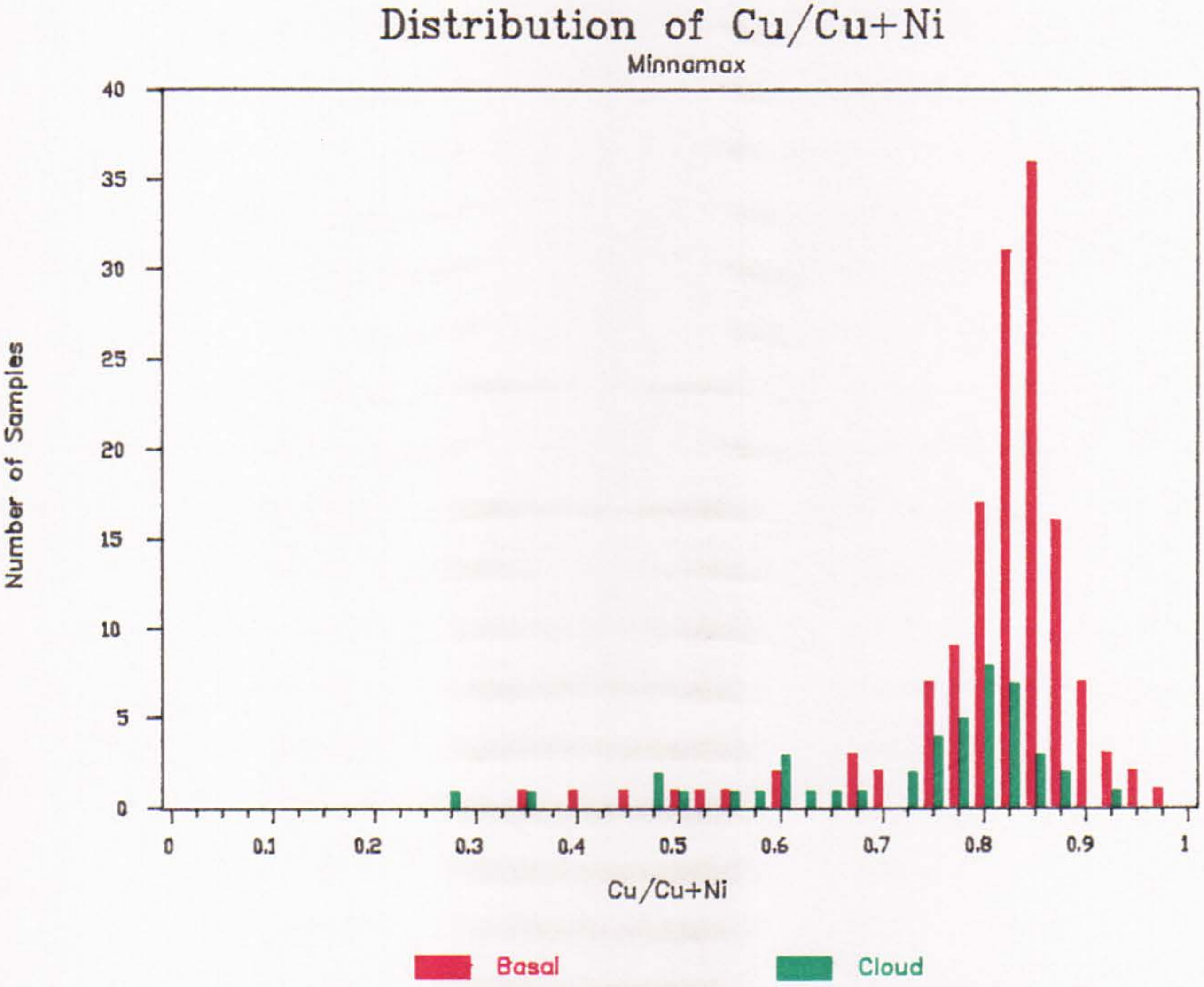

Figure 14: Distribution of the Cu/Cu+Ni ratio at Minnamax

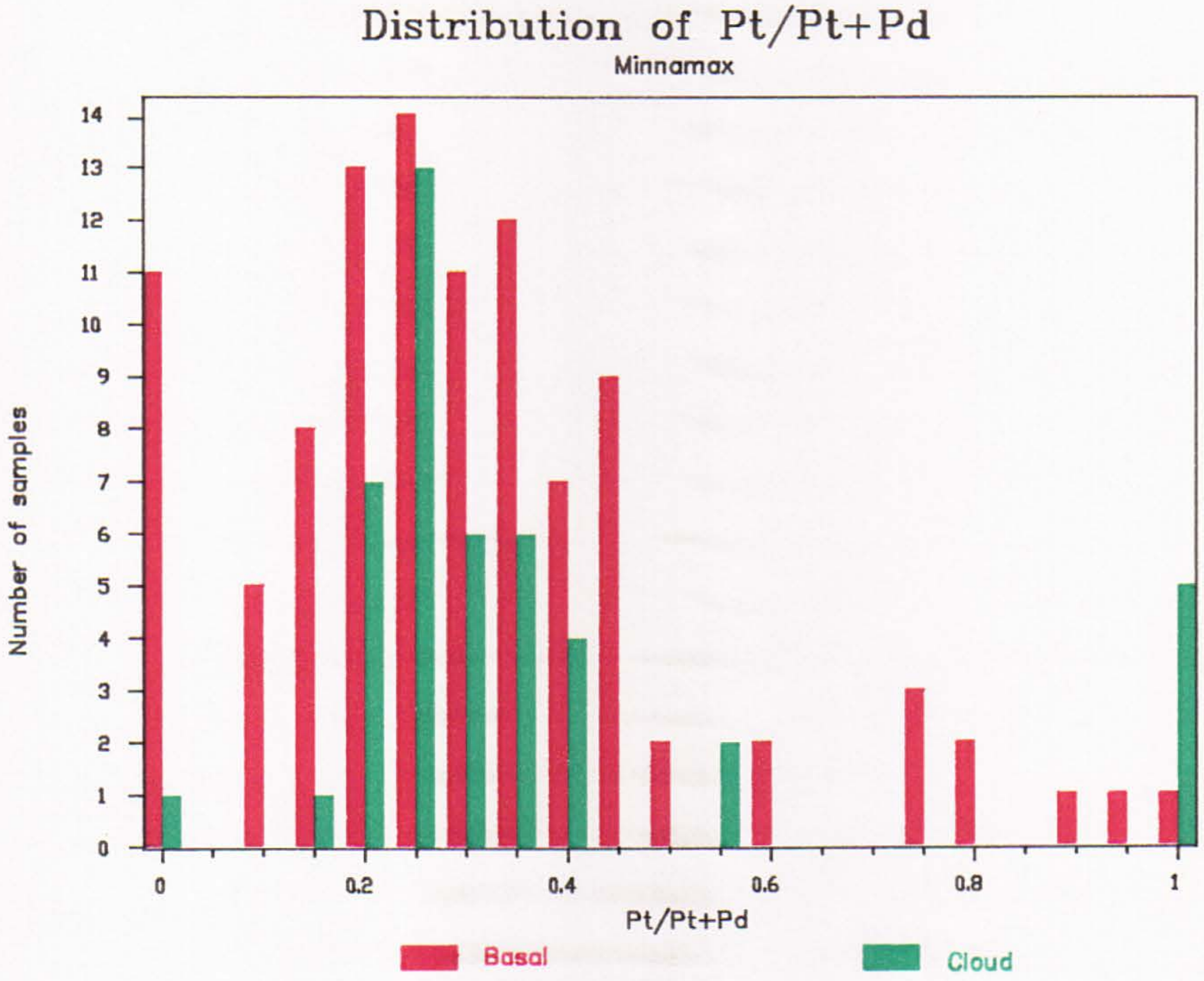

Figure 15: Distribution of the Pt/Pt+Pd ratio at Minnamax

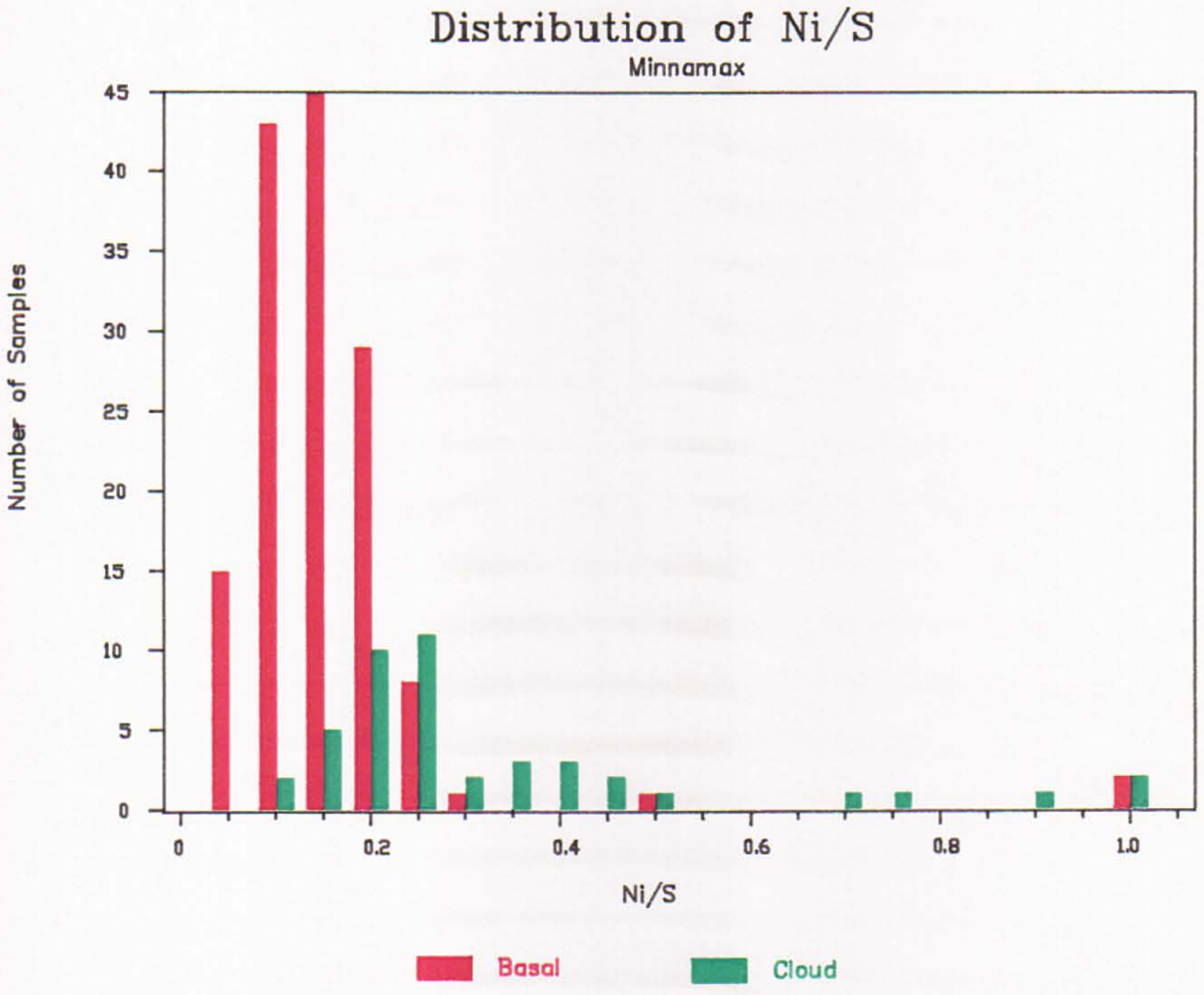

Figure 16: Distribution of Ni/S at Minnamax

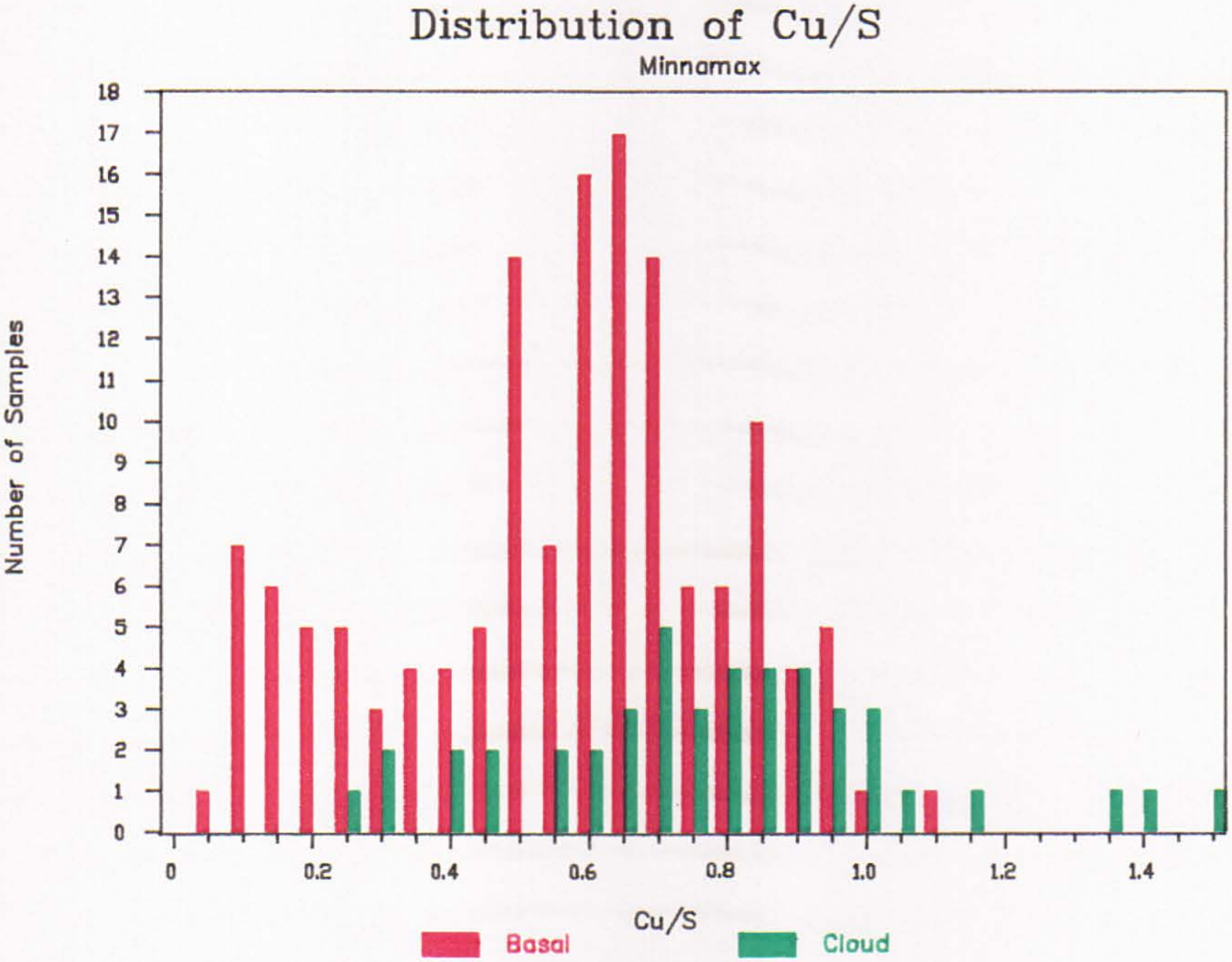

Figure 17: Distribution of Cu/S at Minnamax

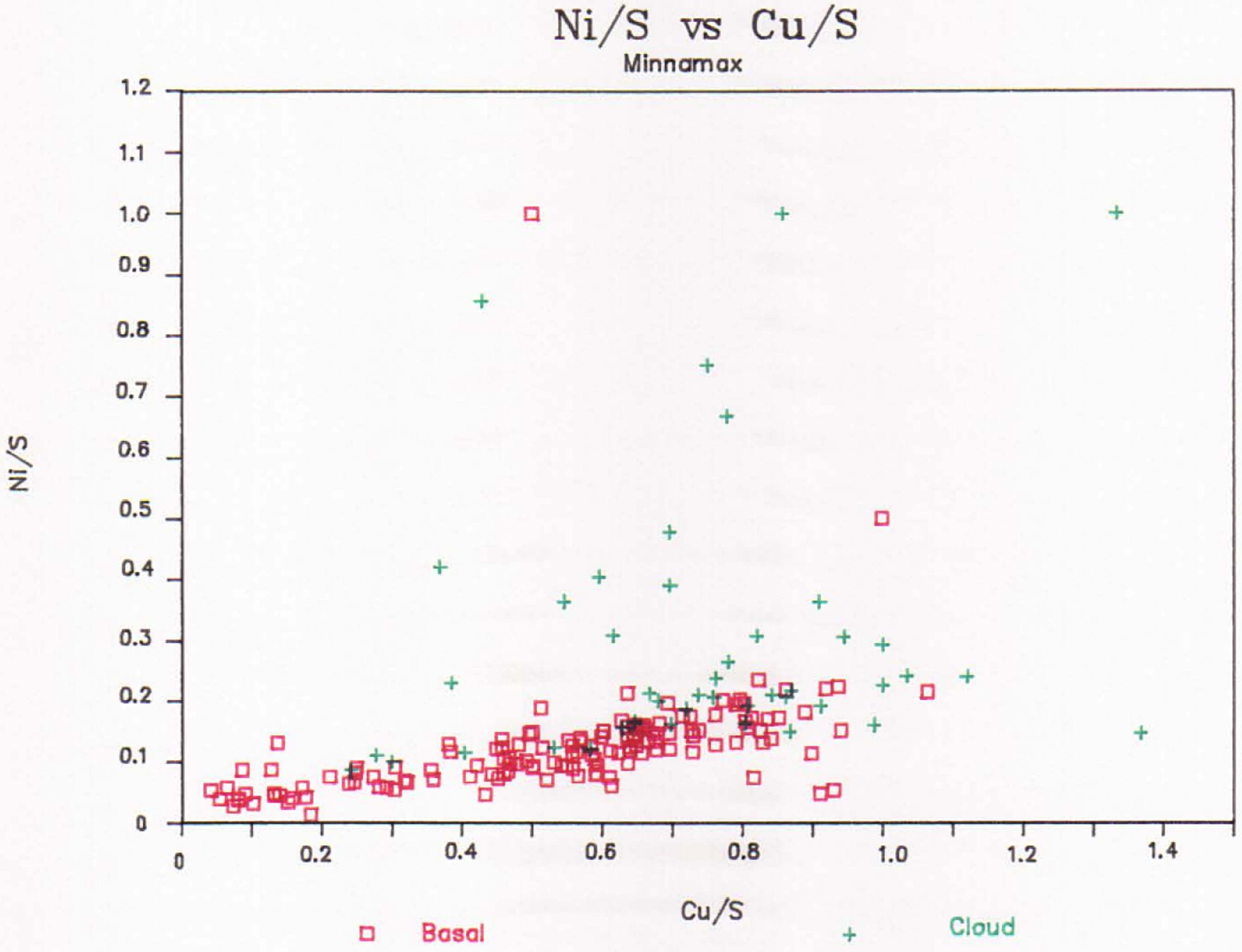

Figure 18: Ni/S versus Cu/S for Basal and Cloud zones

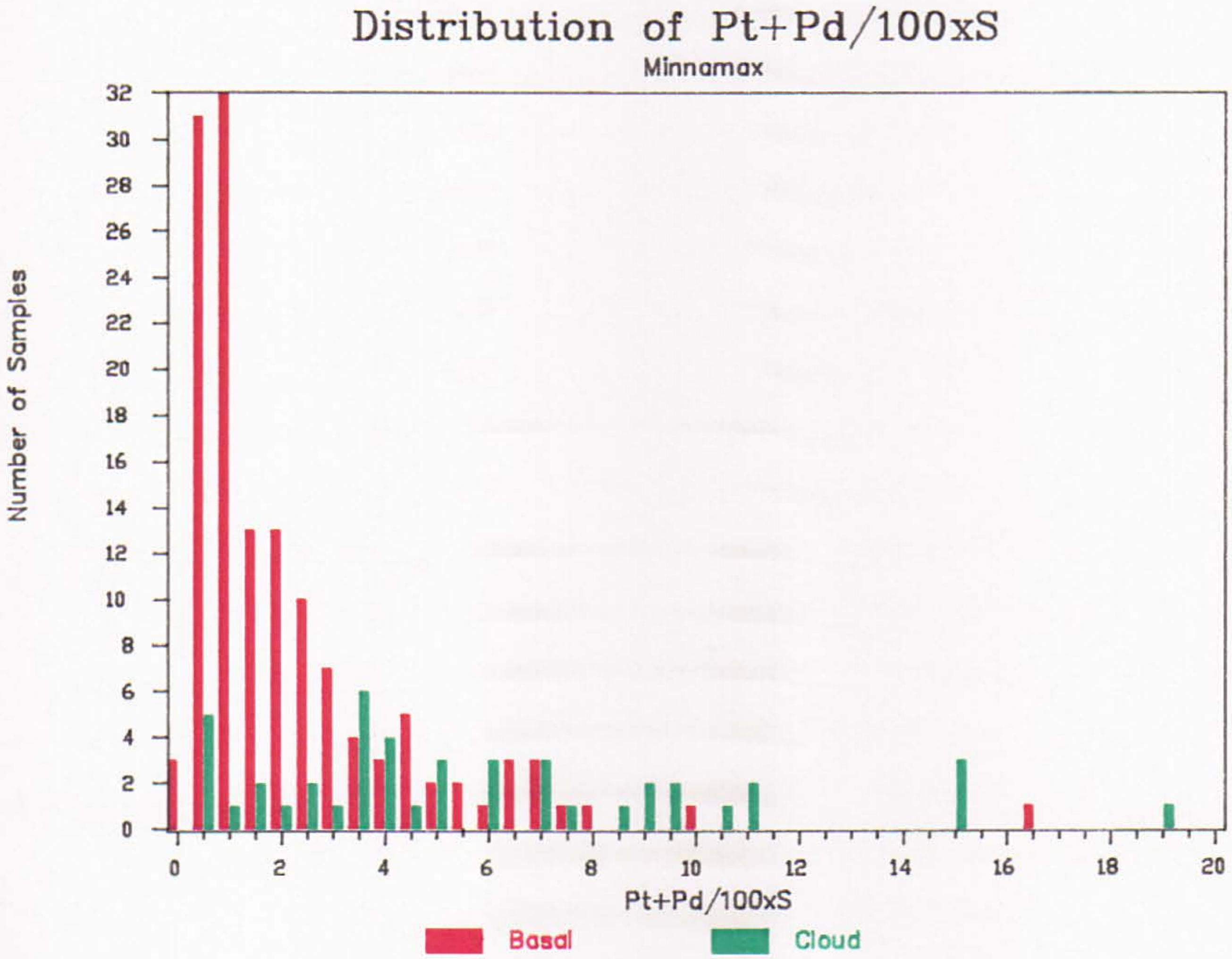

Figure 19: Distribution of Pt+Pd/100xS at Minnamax

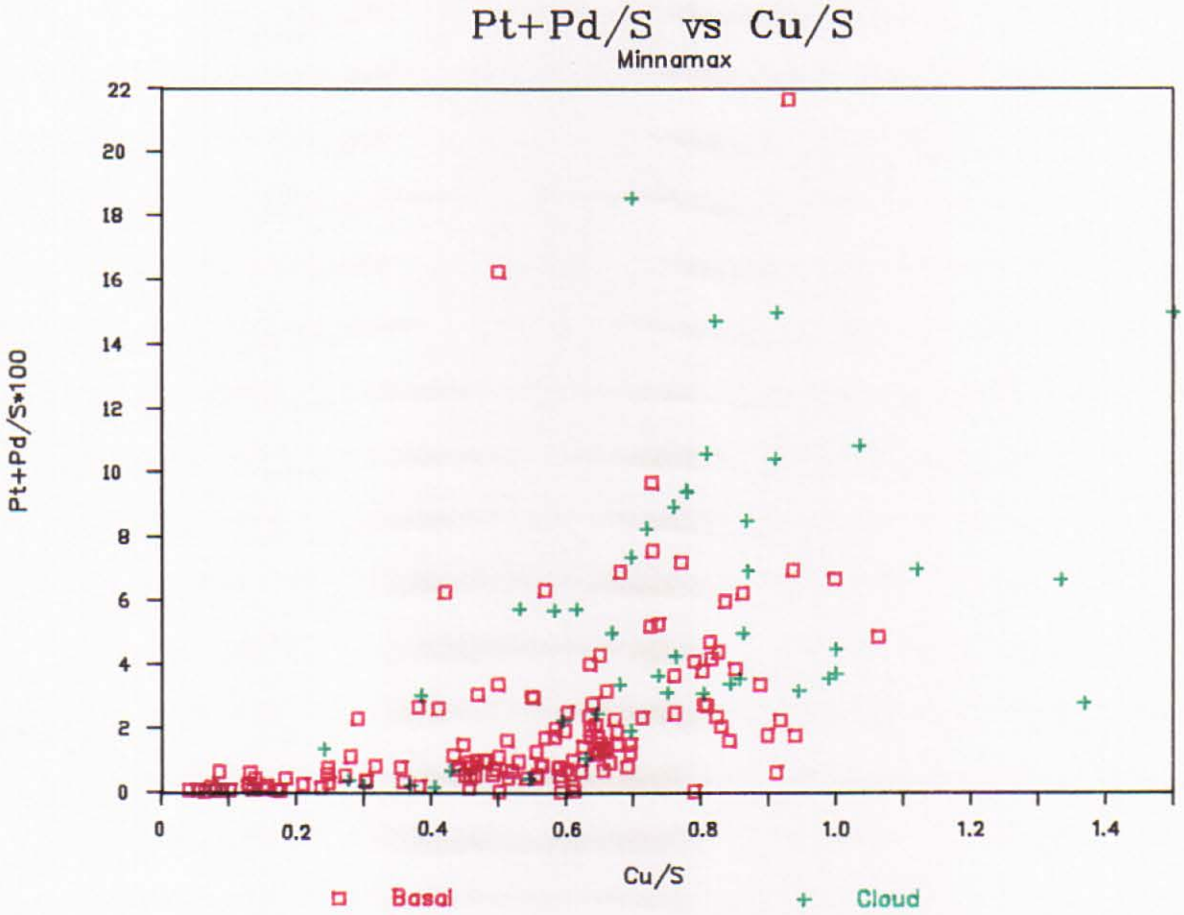

Figure 20: Pt+Pd/S versus Cu/S for Basal and Cloud zones

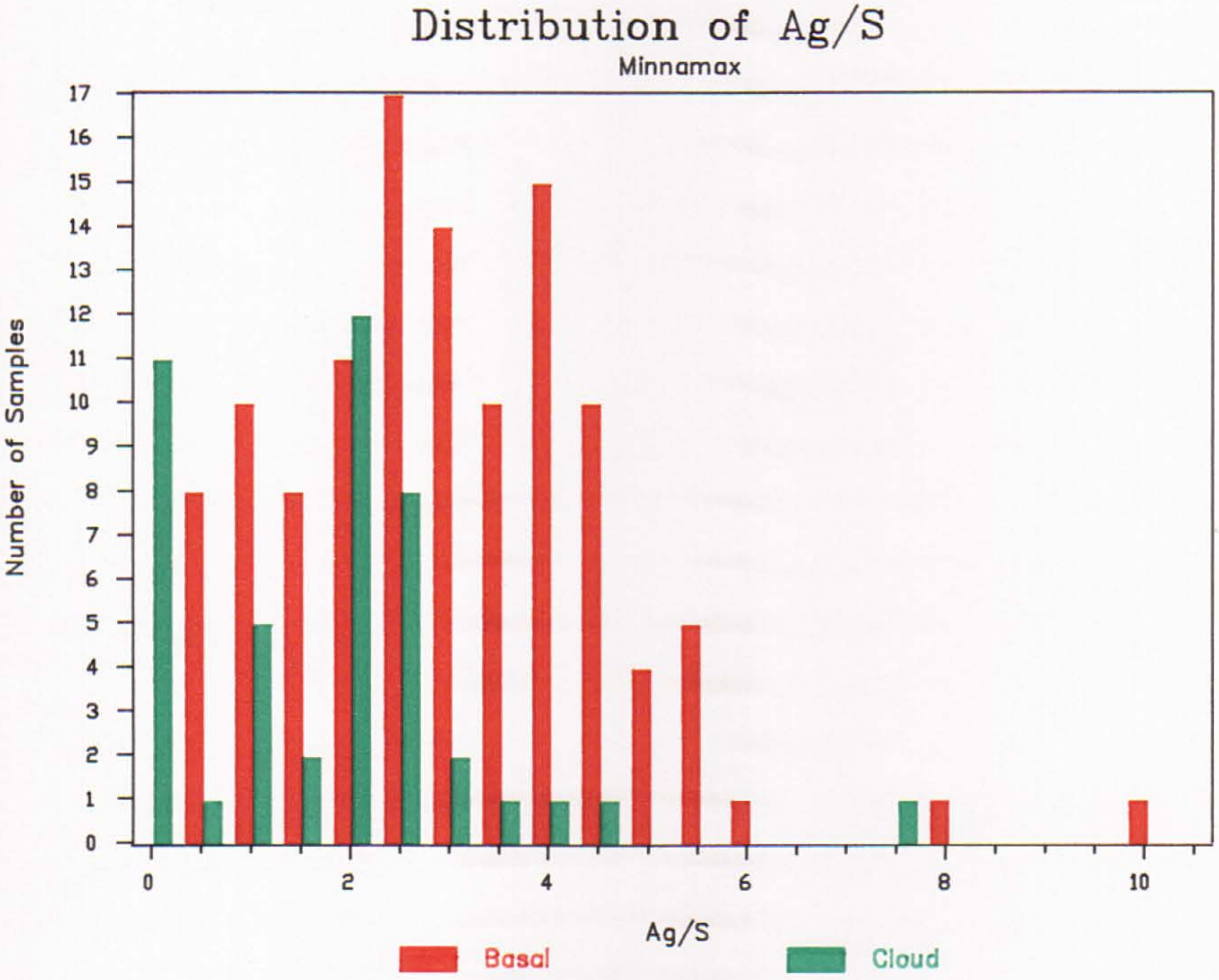

Figure 21: Distribution of Ag/S at Minnamax

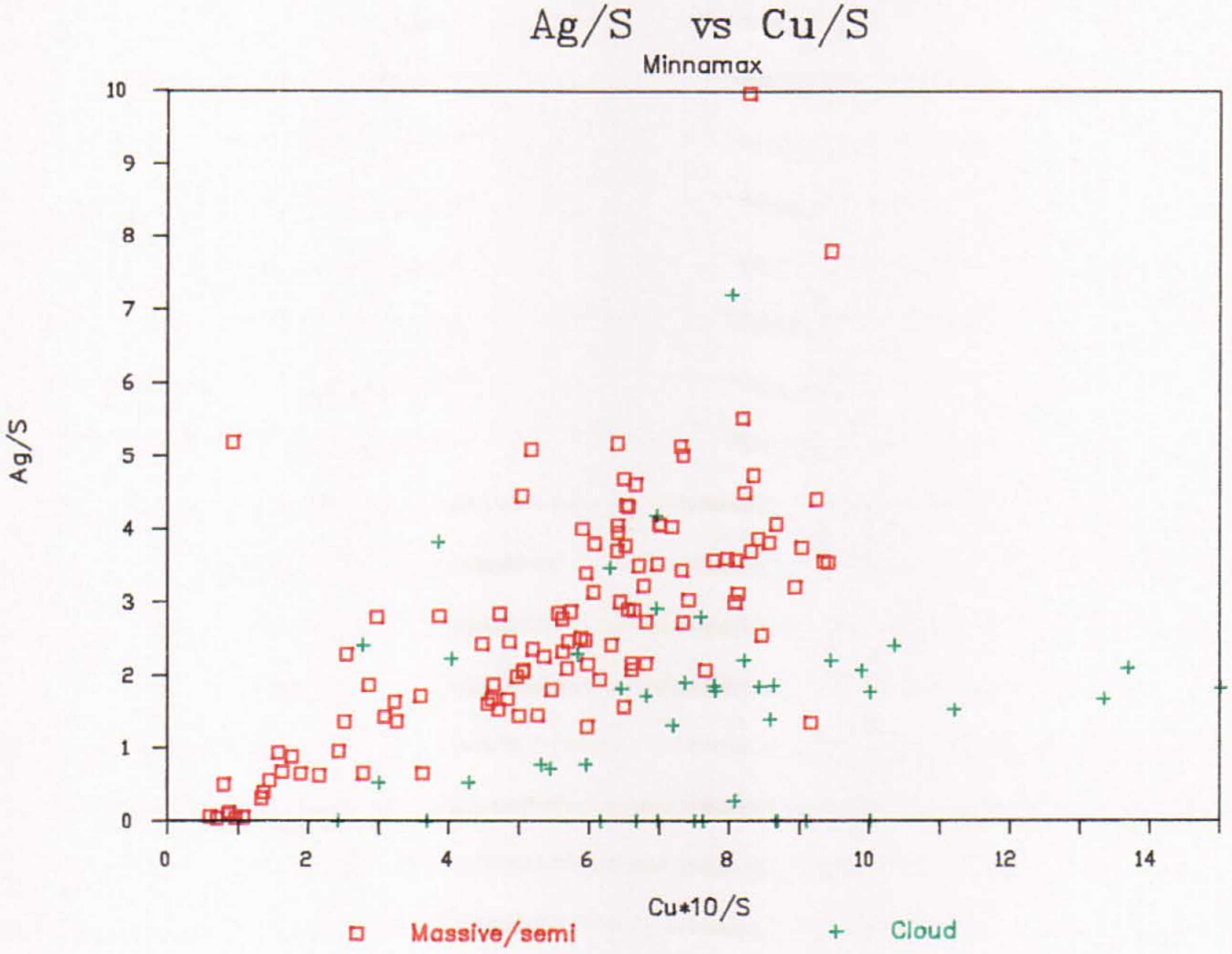

Figure 22: Ag/S versus Cu/S for Basal and Cloud zones

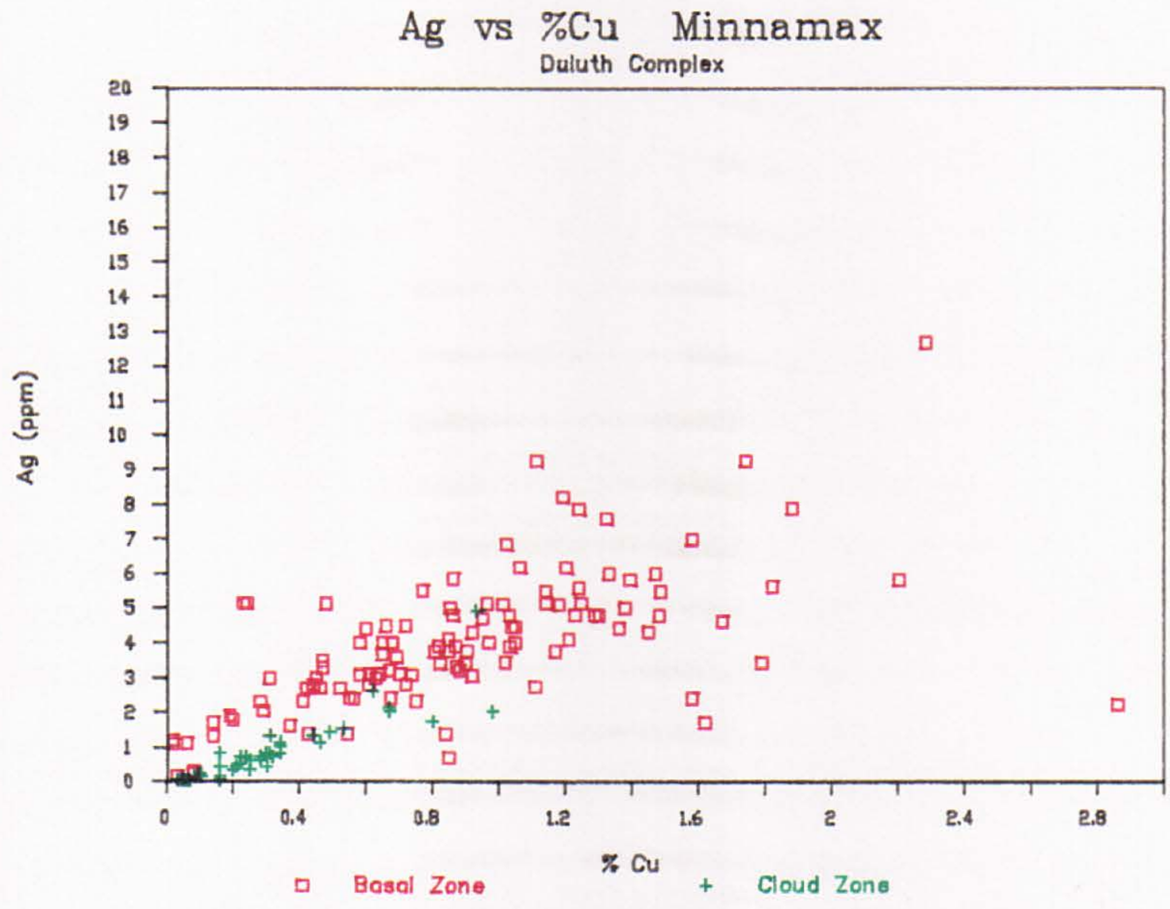

Figure 23: Ag versus %Cu for Basal and Cloud zones

The distributions of Ni/S and Cu/S are shown in Figures 16 and 17. From these diagrams it can be seen that the relative amounts of Ni and Cu are much higher in the Cloud zone sulfides compared to the Basal zone sulfides. Ni/S versus Cu/S content is plotted in Figure 18. For Basal zone sulfides, there is a good correlation between Ni/S and Cu/S contents. For the Cloud zone, however, the Ni/S ratio does not seem to vary in any systematic manner with the Cu/S ratio. This does not argue well for Cloud zone sulfides having separated from a single magma. For if this were the case, we would expect a more consistent variation between Cu and Ni (Rajamani and Naldrett, 1978).

The distribution of the ratio of combined Pt+Pd/(100 x %S) is shown on Figure 19. Even though the median value of combined Pt+Pd is 140 ppb for Cloud zone versus 200 ppb for the Basal zone (Table 4), it can be seen that the ratio of Pt+Pd/S is much higher and much more variable in Cloud zone sulfides than in the Basal zone of Minnamax. This was also noted by Tyson and Bonnichsen (1986). Pt+Pd/S versus Cu/S is plotted on Figure 20 for both Basal and Cloud zone sulfides. There appears to be a relative increase in Pt+Pd/S with Cu/S for those samples that have a high Cu/S ratio, even for those from the Basal zone. With more data, this might make a useful tool for estimating PGE content of Cu-Ni sulfides.

It was initially believed that Ag contents were also enriched in the Cloud zone relative to sulfide content (Morton, 1987). However, upon further inspection (Figures 21-23), it can be seen that when Ag/S contents are plotted, Ag is depleted in the Cloud zone relative to the Basal zone (Figure 21). A plot of Ag/S versus Cu/S (Figure 22) shows that with an increase in Cu/S, there is no increase in Ag content for the Cloud zone. Ag content appears to be directly related to the absolute Cu content

(Figure 23; r=0.85 for the Basal zone data and 0.89 for the Cloud zone data) and not to the overall sulfide content or the metal/sulfide ratio.

ANOMALOUS SAMPLES

Geochemistry and Reassaying

As a part of the first phase of this project, the decision was made to reassay, where possible, any samples having anomalous PGE contents. Samples were also reassayed to determine whether or not there was a geochemical "pathfinder" suite of elements that might indicate the presence of PGE mineralization. Platinum group minerals consist of sulfides, arsenides, bismuthenides, tellurides and native elements or alloys. As, Bi and Te plus Sb, Pb, Se, Sn contents have been found enriched over background in samples with high PGE content from the following areas: a) the Bushveld Complex, b) Noril'sk copper-nickel deposit, c) the Stillwater Complex, and d) the Sudbury copper-nickel deposits (Cabri and LaFlamme, 1976; Genkin and Evstigneeva, 1986; Stumpfl and Tarkian, 1976). In all cases, these elements, along with Cu, Ni, Ag, Au and PGE content seem to indicate secondary enrichments in a fluid or residual phase. In addition, chlorine may also be enriched as an indicator of fluid movement (Ballhaus and Stumpfl, 1986). The chlorine can be an indicator of alteration and may indicate areas within the sulfide deposits where there has been remobilization of sulfides and, perhaps, concentration of PGE content. Similarly, the presence of graphite may be an indication of the deposition of platinum group elements (Ballhaus and Stumpfl, 1985).

Because few data exist on the distribution of this "pathfinder" suite of elements in the Cu-Ni sulfide deposits of the Duluth Complex, and that Pt-Ni arsenides have been reported by Ryan and Weiblen (1984) in the Minnamax deposit, this reassaying program was designed to be a pilot study to determine the presence and concentration of As, Sb, Bi, C, Cl, Pb, Se, Sn and Te associated with PGE, Au, and Ag concentrations. The data in Tables 8 and 9 illustrate the increased concentration of some of these elements with PGEs, Au, and Ag, as well as other metals, e.g., increased Mo with high C (see Table 9). The next phase of this study will be a more systematic examination of the distribution of these elements.

Of all the samples previously analyzed by the companies (Tables A1 to A9), only three samples were highly anomalous with respect to PGE: one each from the Water Hen, Dunka Road and Minnamax deposits. (There was also a highly anomalous sample taken from the Local Boy, Minnamax deposit and analyzed by INCO that contained greater than 14 ppm combined Pt and Pd. No specific location can be given for this sample.) Similarly, several samples from the Wyman Creek deposit had preliminary fire assay analyses that looked promising. Upon reanalysis of some samples from Wyman Creek, it was determined that the preliminary results were misleading at best. Follow up work to date has concentrated on the Water Hen and Dunka Road deposits with preliminary logging and sampling of Wyman Creek core (August, 1987). No Minnamax core was sampled and/or reassayed. Analyses of samples from the Water Hen, Wyman Creek and one sample from the Dunka Road deposit are presented in Tables 8 and 9. One sample from Wyman Creek has 8 ppm Ag and also has the highest Au, Pd, As, Te and Bi values. However, due to the analytical uncertainties cited above, these results will not be discussed further.

Table 8: Analyses of samples from the Water Hen Deposit

Hole	Footage	Analyst	%Cu	%Ni	%S	Ag ppm	As ppm	Au ppb	Bi ppm
SL-11	696-704	Chemex	0.4	0.28	6.48	0.5	59	40	0.2
SL-11	729-737	Chemex	0.68	0.26	2.83	2.8	700	100	4.2
SL-26	953	Chemex	0.38	0.13	1.75	3.5	90	105	4.7
SL-13	1101-1102	Bondar-Clegg	>2%	0.24	4.55	12.1	27	240	16

Hole	Footage	Analyst	%C	Cd ppm	Cl ppm	Co ppm	Cr ppm	Mo ppm	Pb ppm
SL-11	696-704	Chemex	0.04		<80	275			2
SL-11	729-737	Chemex	0.02		<80	157			13
SL-26	953	Chemex	0.14		<80	78			13
SL-13	1101-1102	Bondar-Clegg	0.09	15	426	156	285	2	57

Hole	Footage	Analyst	Pd ppb	Pt ppb	Sb ppm	Se ppm	Te ppm	Rock Type
SL-11	696-704	Chemex	130	40	0.4		<0.05	opx
SL-11	729-737	Chemex	360	160	28		0.13	opx
SL-26	953	Chemex	204	80	1.8		0.25	opx
SL-13	1101-1102	Bondar-Clegg	300	240	6	14	2.2	opx

Table 9: Analyses of Samples from Wyman Creek and Dunka Road Deposits

		WYMAN CREEK												DUNKA ROAD
ELEMENT	ASSAY LAB	(1) DH#26133 905'-911'	(2) DH#26144 315'-325'	(3) DH#26144 762'-770'	(4) DH#26144 770'-777'	(5) DH#26126 1204'-1214'	(6) DH#26132 47'-57'	(7) DH#26132 57'-67'	(8) DH#26136 62'-72'	(9) DH#26136 72'-82'	(10) DH#26144 309'-315'	(11) DH#26144 325'-336'	(12) DH#26144 741'-751'	(1) DH#26010 115.5'-118.
	USS		0.28	2.30	1.12									5.64
Wt.% Cu	Chemex	0.08	0.30	2.33	1.06	0.39	0.23	0.40	0.31	0.36	0.40	0.23	1.00	
	Bon-Clegg	0.0894	0.3061	>2.0000	1.0697									>2.0000
	USS		0.12	0.47	0.85									0.64
Wt.% Ni	Chemex	0.06	0.09	0.40	0.71	0.09	0.09	0.13	0.11	0.11	0.21	0.10	0.16	
	Bon-Clegg	0.0751	0.1162	0.4250	0.6861									0.5036
	USS		2.13	2.61	6.56									11.99
Wt.% S	Chemex	0.194	2.320	6.770	9.250	1.200	0.293	0.580	1.310	1.500	6.100	2.270	1.890	
	Bon-Clegg	0.18	2.15	7.65	10.52									12.15
PPM Ag	Chemex	0.1	0.1	7.4	3.4	1.2	0.5	1.4	1.0	1.2	0.3	0.5	4.5	
	Bon-Clegg	0.5	1.0	8.3	4.0									15.0
PPB Au	Chemex	12	24	100	44	44	20	60	70	20	14	4	60	
	Bon-Clegg	2	6	85	31									1350
PPB Pt	Chemex	30	60	50	50	40	10	80	45	25	<5	50	130	
	Bon-Clegg	<15	<15	<15	<15									150
PPB Pd	Chemex	82	88	208	128	96	80	132	94	62	42	46	112	
	Bon-Clegg	4	10	190	140									8800
	USS													0.325
OZ.	Chemex	0.004	0.005	0.010	0.006	0.005	0.003	0.008	0.006	0.003	0.002	0.003	0.009	
Pt+Pd+Au	Bon-Cl.			0.008	0.005									0.300
Wt.% C	Chemex	0.07	0.06	1.97	2.71	0.05	0.14	0.16	0.07	0.05	0.06	0.07	0.09	
	Bon-Clegg	0.06	0.06	2.15	3.02									0.32
PPM Co	Chemex	113	132	196	273	84	80	101	148	111	240	129	87	
	Bon-Clegg	137	162	246	397									336
PPM As	Chemex	1	5	35	38	1	1	1	1	3	3	2	10	
	Bon-Clegg	<2	15	33	66									250
PPM Sb	Chemex	1.8	0.2	0.6	0.4	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.4	
	Bon-Clegg	<5	7	11	<5									22
PPM Bi	Chemex	0.1	0.2	1.2	0.5	0.4	0.1	0.1	0.3	0.3	0.1	0.1	1.2	
	Bon-Clegg	<2	<2	<2	<2									12
PPM Pb	Chemex	12	2	29	21	5	1	1	3	4	1	1	5	
	Bon-Clegg	17	8	39	26									247
PPM Sn	Chemex	1	1	4	2	1	1	1	1	1	1	1	1	
	Bon-Clegg	<5	<5	<5	<5									16
PPM Cl	Chemex	5390	<100	<200	<200	650	<200	280	1160	580	<60	<60	<60	
	Bon-Clegg	536	241	<200	<200									<200
PPM Te	Chemex	<0.05	0.13	0.63	<0.05	0.13	<0.05	<0.05	<0.05	0.13	<0.05	<0.06	0.13	
	Bon-Clegg	0.03	0.06	0.70	0.15									1.70
PPM Mo	Bon-Clegg	<1	<1	22	50									7
PPM Se	Bon-Clegg	<5	28	14	21									25
PPM Zn	Bon-Clegg	91	106	170	186									285
	USS	1300												
PPM Cr	Bon-Clegg	178	48	72	84									31
PPM Mn	Bon-Clegg	1031	862	434	360									522
PPM Cd	Bon-Clegg	5	6	9	8									21
PPM Tl	Bon-Clegg	2	2	1	<1									<1
PPM V	Bon-Clegg	180	41	73	87									9
	USS	27.1	19.3	23.4	25.9									
Wt%Fe	Bon-Clegg	9.19	9.47	>10.00	>10.00									>10.00
Wt.% Ti	USS	22.1												

Water Hen

Sample SL-1 (680-683) was taken from a late-stage orthopyroxenite dike that cross-cuts Virginia Formation toward the base of the Water Hen intrusion. It contains greater than 3 ppm combined Au, Pt and Pd and up to 44 ppm Ag along with 4.44% Cu and 0.69% Ni (Table A4). The Cu and Ni values are considerably higher than any other assays in Water Hen rocks (Bill Ulland, personal communication, 1987). This sample has subsequently been reanalyzed by American Shield (personal communication) and has been confirmed.

To see if any other pyroxenite dikes as well as sulfur and oxide rich peridotites were anomalous in PGE, four samples were sent in for analysis and analyses are presented in Table 8. Of these SL-11 (729-737) and SL-13 (1101-1102) both have combined Pt+Pd values greater than 500 ppb. Even though these contents are not "ore grade", they are considerably higher than background values at Water Hen. Both samples are from pyroxenite dikes. The former sample is from coarse rejects and represents both dike material and peridotite, whereas the latter is just dike material. Within the sample from SL-13, other elements that are anomalous are: Ag, Au, Bi, Cl, Se and Te.

Mineralogy of Water Hen Samples

In hand specimen, the main copper minerals in the anomalous section of SL-1 were primarily bornite and chalcopyrite, and several polished sections are made of a sample from 681 feet. Preliminary analyses were made of the minerals using a scanning electron microscope (SEM) equipped with a Tracor Northern 2000 energy dispersive system (EDS) and using a semi-quantitative analysis (SSQ) computer program. Analyses were done by C. A. Beckman at NRRI's Coleraine Laboratory. The sample contains approximately 8% interstitial sulfides and arsenides. The sulfide (and arsenide) minerals in order of abundance are chalcopyrite (4%), bornite (2-3%), maucherite (0.5-1%), and pentlandite (0.5%). Other minor minerals include sphalerite (pure ZnS); native Ag, as a cross-cutting veinlet through maucherite; niccolite; parkerite (an anisotropic white mineral that contains Bi, Ni and S); and tentatively, tetradymite (soft, anisotropic yellow mineral which contains Bi, Te and S) as an inclusion in parkerite. No Pt or Pd minerals were identified.

Chalcopyrite and bornite are commonly intergrown, showing exsolution textures. They occur as 0.5 to 1 mm composite grains filling the spaces between fine-grained (1mm) subhedral orthopyroxene (Fs_{71}). Pentlandite occurs as inclusions in chalcopyrite and shows replacement by chalcopyrite along cleavage traces. Maucherite occurs as separate interstitial grains filling voids between orthopyroxene. Parkerite occurs with maucherite, generally at grain boundaries. It is easily recognizable by its color, anisotropism, twinning and Bi spectra. Sphalerite usually occurs as small inclusions in bornite.

After identification of the above minerals, several other dikes were sampled for polished section analysis. After looking at sections from five different pyroxenite dikes, two periods of sulfide mineralization have been recognized: the first is composed of pyrrhotite, chalcopyrite, cubanite and some pentlandite which is the basic mineralization in the Water Hen deposit; the second consists of late stage chalcopyrite (shows cross-cutting relationships with other oxides, sulfides and silicates), bornite, maucherite, native bismuth, niccolite, parkerite, native Ag and tetradymite. The later stage is generally enriched in Cu, Ni, As, Bi, Ag and Te. This petrographic work is on-going and core is presently being logged and sampled for both petrographic and chemical analysis.

Dunka Road Deposit

Reports from U.S. Steel indicated that a sample from DDH 26010 (115.5 to 118.5 feet) was highly anomalous in Pd, Au and Ag (Table A1). This analysis has subsequently been confirmed (Table 9). The sample comes from a zone with approximately 50% sulfides that is associated with a gabbroic pegmatite composed of 25% plagioclase, 20% pyroxene, 5% oxides and 50% sulfides (this study, 1987). The upper contact is gradational with white, highly altered, medium to coarse-grained gabbro. Alteration minerals include kaolinite(?) and sericite after plagioclase, chlorite after pyroxene and numerous cross-cutting veins of natrolite and analcime. The latter two zeolites were identified by X-ray diffraction (this study, 1987). The lower contact is gradational with a medium-grained, pyroxene-bearing troctolite that is locally altered to chlorite.

Previous work by Pete Niles of U.S. Steel (now with NRRI) has identified numerous unusual minerals as well as chalcopyrite, pentlandite, violarite and pyrrhotite within the sulfide zone. They are: froodite ($PdBi_2$), michenerite (PdTeBi), gold (Au, Ag), native Bi, and an unknown mineral composed of Pd, Sb and Bi. Textures in the ore minerals indicate that pentlandite is being replaced by violarite, chalcopyrite and the Au, Ag, Pd-bearing minerals which may indicate that these concentrations of PGE are due to later mineralizing fluids. Certainly the amount of alteration in the rocks warrants further research. Work will be focussed on samples from this area during the coming year.

CONCLUSIONS

Large tonnages of Cu-Ni sulfides are located at the base of the Duluth Complex from the Hoyt-Lakes to Kawishiwi Lakes area of northeastern Minnesota. These large resources have background PGE contents associated with them that, if mined for Cu-Ni, would add a few dollars to the value of the ore. Background values for combined Pt and Pd vary from a low of 105 ppb in the Water Hen to a high of 1,259 ppb in the Dunka Road deposit (103 ppb to 1,164 ppb for median). The Pt/Pt+Pd ratio of these deposits average around 0.21 for Dunka to 0.30 for Minnamax. Data for Spruce Road and Maturi are too meager to make a real estimate of the ratio. Recovery of PGE in copper-nickel flotation concentration tests has been consistently below 50% at Spruce Road (INCO), Minnamax and at Dunka Road. This means the added dollar value at today's prices would be as follows: Dunka Road, $4.55; Spruce Road, $4.65; Minnamax, $2.89 and Waterhen, $1.16. Even though there are large resources of PGE, they are not economically viable by themselves, and do not add much to the value of the Cu-Ni ore. However, smaller tonnage, higher grade Cu-Ni-PGE-Au-Ag-Co ore bodies could be economical.

The number of anomalous samples is very low. Even though core have not consistently been analyzed for enriched PGE, one might expect a few more anomalous samples than three, each one being in a different deposit. It does not look promising to find a large area within the Cu-Ni sulfide deposits that could be mined for PGE alone. On the other hand, a smaller Cu-Ni-PGE-Au-Ag-Co deposit could be successfully mined.

Because a few anomalous samples have been found, the best course of action is to study both their geological setting and their mineralogy, not only to their relation to the Cu-Ni sulfide deposits, but perhaps to structure, alteration, and rock types as well. Two of the samples appear to be the result of secondary Cu, PGE enrichment and, therefore, if localized areas of alteration (such as around the anomalous sample at Dunka Road) can be delineated and shown to be related to PGE mineralization, then there is a much better chance of locating other areas of PGE enrichment. These local enriched PGE areas would add additional metal value to a smaller tonnage, higher grade Cu-Ni ore body. One of the goals of this program is to identify smaller Cu-Ni-PGE-Au-Ag ore deposits/zones that would be economical to mine due to the increase in the total metal value per ton of ore.

The data collected for this report suggest that samples with high Cu/S ratios are apt to have higher Pt+Pd/S ratios than background. If Cu/S ratios for the existing Cu-Ni sulfide deposits were delineated and samples taken from those areas with high Cu/S (even if %Cu is not too high) and assayed, more anomalous samples might be found.

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APPENDIX

Additional Tables and Figures

Table A1: Data Collected From U.S. Steel's Dunka Road Deposit

DUNKA ROAD

DDH	From	To	Feet	%Cu	%Ni	%S	%Co	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Au (ppb)	Ag (ppm)	Cu/ Cu+Ni	Pt/ Pt+Pd	%Po
26030	686	726	40	0.64	0.19	1.47	0.017	205	719	925	68		0.77	0.22	1.78
26033	960	980	20	0.83	0.23	1.11	0.012	274	1404	1678	68		0.78	0.16	0.16
26044	67	122	55	0.47	0.17	0.90	0.010	171	1027	1199	68		0.73	0.14	0.74
26044	67	122	55	0.47	0.17	0.90	0.009	171	1027	1199	68		0.73	0.14	0.74
26044	107	117	10	0.64	0.20	1.00	0.009	205	959	1164	68		0.76	0.18	0.46
26045	7	24.5	17.5	0.49	0.15	0.57	0.009	411	1062	1473	68		0.77	0.28	-0.17
26047	518	558	40	0.55	0.35	0.77	0.017	342	1507	1849	103		0.61	0.19	-0.30
26010	115.5	118.5	3	5.64	0.64	11.99		514	8904	9418	1712	25.00	0.90	0.05	15.66
26010	280	282	2	1.00	0.65	14.44		171	342	514	3	0.03	0.61	0.33	35.21
26011	115	123	8	0.72	0.29	7.80		3	171	175	3	0.03	0.71	0.02	18.68
26011	127	133	6	0.85	0.57	21.68		3	171	175	3	0.03	0.60	0.02	55.70
26015	351	361	10	0.80	0.19	0.90		342	1027	1370	342	4.11	0.81	0.25	-0.23
26015	361	371	10	0.87	0.25	0.96		171	514	685	171	0.34	0.78	0.25	-0.41
26017	715	725	10	1.10	0.34	1.34		342	856	1199	3	0.03	0.76	0.29	-0.24
26017	725	735	10	1.04	0.28	1.43		342	685	1027	342	0.03	0.79	0.33	0.33
26018	398	401	3	0.83	0.56	7.04		171	171	342	342	4.11	0.60	0.50	15.60
26021	384	394	10	0.90	0.27	1.27		342	685	1027	342	0.03	0.77	0.33	0.31
26021	394	404	10	0.97	0.28	1.56		342	856	1199	3	0.03	0.78	0.29	0.88
26026	315	325	10	1.02	0.21	1.20		514	856	1370	171	0.03	0.83	0.38	-0.07
26026	325	335	10	0.98	0.33	1.46		342	856	1199	171	0.03	0.75	0.29	0.45
26026	495	505	10	0.95	0.24	1.55		171	514	685	171	4.11	0.80	0.25	1.01
26030	686	696	10	0.87	0.24	1.16		342	685	1027	342	0.03	0.78	0.33	0.16
26031	826	829	3	1.25	0.69	7.29		171	342	514	3	0.03	0.64	0.33	14.79
26033	960	970	10	1.00	0.27	1.09		342	1199	1541	3	0.03	0.79	0.22	-0.47
26033	970	980	10	0.73	0.22	0.92		342	685	1027	342	0.03	0.77	0.33	-0.06
26121	1580	1590	10	0.64	0.25	0.88						5.58	0.72		0.01
26121	1590	1600	10	0.76	0.31	1.11						8.70	0.71		0.15
26121	1600	1607	7	0.80	0.28	1.20						9.11	0.74		0.36
26121	1607	1615	8	0.06	0.12	0.12						5.82	0.33		-0.14
26121	1615	1623	8	0.13	0.10	0.27						5.10	0.57		0.13
	Sum		425.5												
	Average		14.18	0.93	0.30	3.18	0.012	270	1089	1359	200	2.12	0.72	0.24	5.37
	Wt avg			0.71	0.24	1.67	0.007	256	1003	1259	125	1.22	0.73	0.21	
	Std			0.91	0.16	4.87	0.003	128	1633	1701	334	5.75	0.10	0.11	12.30
	Wt std			0.49	0.20	1.78	0.016	217	1146	1342	103	2.52	0.71	0.16	

%Po (pyrrhotite) is estimated by assuming that all sulfur is present only in chalcopyrite, pentlandite and pyrrhotite.

Table A2: Data Collected From the Wyman Creek Deposit, U.S. Steel

DDH	From	To	Feet	%Cu	%Ni	%S	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Ag (ppm)	Cu/ Cu+Ni	Pt/ Pt+Pd	%Po
26126	842	852	10				120	31	151			0.80	
26126	852	860	8				188	24	212			0.89	
26133	855	865	10										
26133	875	885	10							4.38			
26133	905	911	6							4.08			
26133	911	919	8							4.93			
26144	294	299	5	0.90	0.48	3.84				1.13	0.65		6.82
26144	299	304	5	0.82	0.41	3.80				1.13	0.67		7.11
26144	304	309	5	0.45	0.39	3.45				4.28	0.54		7.23
26144	309	315	6	0.33	0.20	2.60					0.62		5.71
26144	315	325	10	0.28	0.12	2.13				3.25	0.70		4.77
26144	751	762	11	0.27	0.07	0.53				3.56	0.79		0.53
26144	762	770	8	2.30	0.47	2.61				5.72	0.83		-0.40
26144	770	777	7	1.12	0.85	6.56				5.92	0.57		12.74
26144	777	782	5	0.40	0.14	0.91				4.59	0.74		1.03
26145	108	118	10	0.40	0.19	1.52				1.54	0.68		2.58
			Average	0.73	0.33	2.80	154	27	182	3.71	0.68	0.84	4.81
			Std	0.59	0.23	1.66	34	3	31	1.59	0.09	0.05	3.79
			Wt. av	0.71	0.30	2.57				3.52	0.69		
			Std	0.66	0.21	1.48				1.86	0.28		

Table A3: Data From the Dunka Pit Area

PICKANDS MATHER

Hole	From	To	Feet	%Cu	%Ni	%Co	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd	Co/ Co+Ni	Rock Type
D-9	935	940	5	0.50	0.15	0.02	240	85	325	0.77	0.74	0.09	F.G. Melatroctolite
D-10	390	395	5	0.69	0.35	0.01	100	155	255	0.66	0.39		F.G. Melatroctolite
D-11	538	543	5	0.18	0.09	0.01	200	260	460	0.66	0.43	0.12	F.G. Melatroctolite
D-12	632	637	5	0.95	0.24	0.02	120	305	425	0.80	0.28	0.06	Melatroctolite to feldspathic dunite
D-12	686	691	5	0.32	0.19	0.02	70	225	295	0.63	0.24	0.09	Melatroctolite to feldspathic dunite
D-12	907	912	5	0.59	0.27	0.02	120	170	290	0.69	0.41	0.07	F.G. Melatroctolite with minor inclusions
D-12	1189	1194	5	0.40	0.17	0.02	1	165	166	0.70	0.01	0.09	F.G. Troctolite with inclusions common
D-13	266	271	5	0.10	0.06	0.01	1	5	6	0.61	0.17	0.12	Hornfels
AVERAGE				0.47	0.19	0.01	107	171	278	0.69	0.33	0.09	
STD				0.26	0.09	0.00	80	89	134	0.06	0.20	0.02	

Table A4: Data Collected From the Water Hen Deposit

DOH	From	To	Feet	%Cu	%Ni	%Co	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Au (ppb)	Ag (ppm)	Pt+Pd+Au (ppb)	Cu/ Cu+Ni	Co/ Co+Ni	Rock Type
CN-1	395	425	30	0.24	0.09	0.04			17	342	1.03	360	0.74	0.32	Banded Dunite
CN-1	425	455	30	0.18	0.09	0.04			17	17	0.17	34	0.67	0.31	Oxide Dunite
CN-1	455	486	31	0.21	0.08	0.04			17	17	0.17	34	0.71	0.32	Oxide Dunite
CN-1	486	515	29	0.27	0.09	0.04			103	17	0.17	120	0.75	0.31	Oxide Dunite
CN-1	515	545	30	0.23	0.10	0.04			171	17	0.17	188	0.70	0.29	Oxide Dunite
CN-1	545	575	30	0.41	0.14	0.04			274	17	0.17	291	0.75	0.22	Oxide Dunite
CN-1	635	665	30	0.19	0.11	0.05			68	17	0.17	86	0.63	0.31	Massive Sulfide
CN-1	665	695	30	0.26	0.14	0.06			68	17	0.17	86	0.64	0.29	Massive Sulfide
CN-1	695	730	35	0.14	0.16	0.03			17	17	1.00	34	0.47	0.16	Hornfels and Troctolite
CN-1	730	765	35	0.12	0.18	0.02			17	17	0.17	34	0.40	0.10	Troctolite
CN-1	765	785	20	0.19	0.11	0.04			17	1	1.00	18	0.63	0.27	Troctolite
CN-1	785	805	20	0.42	0.24	0.06			103	17	0.17	120	0.64	0.20	Troctolite
CN-1	805	845	40	0.27	0.16	0.05			68	17	0.17	86	0.63	0.24	Troctolite
CN-2	40.5	50	9.5	0.14	0.12	0.04	0	0	17	17	0.17	34	0.54	0.25	Saprolite
CN-2	50	70	20	0.48	0.22	0.07	0	0	103	17	0.17	120	0.69	0.24	Ox Br Po Dunite
CN-2	70	90	20	0.25	0.09	0.03			17	17	0.01	34	0.74	0.26	Gabbro Hornfels 67-80 Po-Ox-Dunite
CN-2	90	115	25	0.05	0.03	0.01			1	1	0.17	2	0.64	0.26	Hornfels
CN-2	115	150	35	0.14	0.05	0.02			17	1	0.01	18	0.73	0.28	Hnfs + Pd
CN-2	150	185	35	0.13	0.04	0.01			17	1	0.17	18	0.76	0.20	Hornfels
CN-3	80	105	25			0.07			103	17	0.68	120			Dunite
CN-3	105	130	25			0.08			205	17	1.03	223			Dunite
CN-3	130	155	25			0.02			68	17	0.68	86			Troctolite
CN-3	155	190	35			0.04			17	17	0.17	34			Troctolite
CN-3	190	220	30			0.02			68	17	0.17	86			Troctolite
CN-3	220	260	40			0.01			103	17	0.17	120			Hornfels
CN-3	260	300	40			0.01			17	17	0.34	34			Troctolite
CN-3	300	325	25			0.02			137	17	0.17	154			Dunite
CN-7	1145	1168	23				<30	<20	1			1			Ox Dunite + Troc Anorthos
SL-5	330	340	10	N.A.	N.A.	0.02						0			Troctolite
SL-1	370	450	80	0.60	0.24	0.03	0	205	205	342	4.08	548	0.71	0.12	Ox Pd and Ox Dunite
SL-1	680	683	3	4.44	0.69	0.08	1027	1370	2397	1027	44.18	3425	0.87	0.10	Mafic dike
SL-10	530	580	50	0.13	0.07	0.03	0	205	205	17	4.08	223	0.65	0.31	Oxide Dunite
SL-11	485	515	30	0.26	0.16	0.09	0	137	137	1	3.42	138	0.62	0.35	Troctolite + Massive Po
SL-11	696	737	41	0.54	0.30	0.05	0	103	103	17	16.10	120	0.64	0.15	Oxide Po Peridotite
SL-11	710	715	5	0.54	0.38	0.06	0	0	1				0.59	0.14	
SL-11	715	720	5	0.74	0.51	0.07	0	103	103				0.59	0.12	
SL-11	720	725	5	0.69	0.53	0.07	0	205	205				0.57	0.12	
SL-11	725	730	5	0.55	0.25	0.04	137	274	411				0.69	0.13	
SL-11	730	737	7	0.53	0.16	0.01	0	205	205				0.77	0.07	
SL-11	737	745	8	0.10	0.06	0.01	0	0	1				0.63	0.10	Troctolite/Gabbro
SL-11	745	750	5	0.18	0.10	0.01	0	0	1				0.64	0.07	Troctolite/Gabbro
SL-11	750	755	5	0.31	0.11	0.01	0	0	1				0.74	0.09	Mixed Troc/Gabbro
SL-11	755	765	10	0.19	0.08	0.01	0	0	1				0.70	0.12	Mixed Troc/Gabbro
SL-11	765	775	10	0.36	0.12	0.01	68	0	68				0.75	0.07	Mixed Troc/Gabbro
SL-13	400	410	10	0.42	0.13		0	103	103				0.76		Hornfels
SL-13	480	490	10	0.18	0.14		0	68	68				0.56		Peridotite
SL-13	490	500	10	0.20	0.11		0	103	103				0.65		Pyroxenite
SL-13	500	510	10	0.17	0.14		0	103	103				0.54		Pyroxenite
SL-13	520	530	10	0.24	0.12		0	103	103				0.67		Peridotite
SL-13	530	540	10	0.25	0.12		0	68	68				0.68		Peridotite
SL-13	540	550	10	0.48	0.24		0	137	137				0.67		Dunite
SL-13	550	560	10	0.50	0.27		0	103	103				0.65		Dunite
SL-13	560	570	10	0.33	0.21		342	103	445				0.61		Sulfide Rich Peridotite
SL-13	570	580	10	0.16	0.10		0	0	1				0.62		Pegmatitic Troctolite
SL-13	580	590	10	0.19	0.10		0	0	1				0.66		Troctolite
	Average			0.38	0.17	0.04	54	128	132	67	2.52	207	0.66	0.20	
	Std			0.63	0.13	0.02	196	248	325	190	8.02	671	0.08	0.09	
	Wt Average			0.30	0.15	0.04			95	54	2	150			
	Std			0.34	0.15	0.03			134	228	5.92	346			

Table A5: List of Holes for Which There Are Precious Metal Data at Minnamax

MINNAMAX

DDH	N-S	E-W	DEPOSIT	ELEMENTS	LABORATORY	# of Samples	DATE
1	233S	1599W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	3	1959
3	417N	3196E	UPDIP TIGERBOY	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1958
5	200S	4400E	TIGERBOY	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1958
6	646S	802E	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
7	902S	4398E	UPDIP TIGERBOY	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	5	1959
17	900S	0.0E	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	3	1959
22	895S	2400W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
23	897S	1598W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	4	1959
24	1695.5S	1597W	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
25	202S	4407W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
26	95S	3203W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
29	1695S	3181W	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	3	1959
33	1712S	4803E	TIGERBOY	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	2	1960
34	2397S	5633W	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	3	1960
35	203S	4801E	UPDIP TIGERBOY	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1959
39	2510S	3201W	BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	2	1960
40	900S	4012W	UPDIP BATHTUB	AG,AU,CO,PGMTOT	SUDBURY ASSAY OFFICE	1	1960
40			CLOUD	PT,PD,AG	BONDAR CLEGG	2	1979
57	2127S	7532W	BATHTUB	AG,AU,PT,PD,CO	SWASTIKA	1	1967
58	3596S	3047W	SW EXTENSION	AG,AU,PT,PD,CO	SWASTIKA	2	1967
60	3647S	87E	OUTSIDE AREA	AG,AU,PT,PD,CO	SWASTIKA	1	1967
78	2100S	3207W	CLOUD	PT,PD,AG	BONDAR CLEGG	1	1979
82	2100S	2414W	CLOUD	PT,PD,AG	BONDAR CLEGG	4	1979
85	2477S	1657W	OUTSIDE AREA	ZN,PB,AG,AS	KENNECOTT	5	1971
90	1710S	2401W	CLOUD	PT,PD,AG	BONDAR CLEGG	5	1979
91	1705S	4037W	CLOUD	PT,PD,AG	BONDAR CLEGG	4	1979
92	2523S	2420W	CLOUD	PT,PD,AG	BONDAR CLEGG	3	1979
96	3693S	1725W	CLOUD	PT,PD,AG	BONDAR CLEGG	4	1979
100	2499S	107E	BATHTUB	CO,SULNI	KENNECOTT		1971
103	1668S	4817W	CLOUD	PT,PD,AG	BONDAR CLEGG	2	1979
105	5625S	3228E	LOCAL BOY	ZN,PB,AG,AS	KENNECOTT	4	1971
				AU,AG,PT,PD,CO	SWASTIKA	3	1968
				AU,AG,PT,PD,CO	KENNECOTT	3	1968
116	5540S	3047E	LOCAL BOY	AG,AU,PT,PD,CO	SWASTIKA	4	1968
117	4730S	1490E	OUTSIDE AREA	ZN,PB,AG,AS,SULNI	KENNECOTT	1	1971
119	5589S	4800E	LOCAL BOY	AG,AU,PT,PD,CO	SWASTIKA	3	1969
122	5628S	5575E	OUTSIDE AREA	ZN,PB,AG,AS	KENNECOTT	1	1971
130	5609S	2425E	LOCAL BOY	AG,AU,PT,PD,CO	SWASTIKA	3	1969
133	5210.7S	2424.3E	LOCAL BOY	ZN,PB,AG,AS	KENNECOTT	1	1971
136	5199S	3621E	TIGER BOY	ZN,PB,AG,AS	KENNECOTT	1	1971
216	2891.5S	804W	CLOUD	PT,PD,AG	BONDAR CLEGG	1	1979
222	4596S	4799E	TIGERBOY	ALL PGM + AU	U OF T	1	1979
231	3448S	2470E	TIGERBOY	ALL PGM + AU	U OF T	1	1979
254	2894.5S	4414.9E	TIGERBOY	ALL PGM + AU	U OF T	1	1979
254	2894.5S	4414.9E	TIGERBOY	PT,PD,AG	BONDAR CLEGG	18	1976
263	1228.6S	2014.4W	CLOUD P	PT,PD,AG	BONDAR CLEGG	3	1979
268	3600.1S	4003.8E	TIGERBOY	ALL PGM + AU	U OF T	1	1979
289	1299.2S	3201.2W	CLOUD P	PT,PD,AG	BONDAR CLEGG	3	1979
295	6403.5S	1584.2E	SW EXTENSION	ALL PGM + AU	U OF T	2	1979
296	2419.8S	358.7W	BATHTUB	ALL PGM + AU	U OF T	2	1979
296	2419.8S	358.7W	BATHTUB	PT,PD,AG	BONDAR CLEGG	42	1979
304	2844.5S	2024.2W	CLOUD	PT,PD,AG	BONDAR CLEGG	1	1979
307	2406.5S	2001.2W	CLOUD	PT,PD,AG	BONDAR CLEGG	3	1979
316	1998.4S	2001.3W	CLOUD	PT,PD,AG	BONDAR CLEGG	4	1979
333	244.6S	3607.4E	TIGERBOY	ALL PGM + AU	U OF T	1	1979
356	4802.8S	2403.1W	SW EXTENSION	ALL PGM + AU	U OF T	1	1979
361	6015.2S	814W	SW EXTENSION	ALL PGM + AU	U OF T	1	1979
363	1992.6S	2798W	CLOUD	PT,PD,AG	BONDAR CLEGG	3	1979
364	2395.7S	2791.1W	BATHTUB	ALL PGM + AU	U OF T	1	1979
366	302.3S	2798.8W	BATHTUB	ALL PGM + AU	U OF T	1	1979
369	1631.2S	2000.4W	BATHTUB	ALL PGM + AU	U OF T	1	1979
372	1181.5S	2799.2W	CLOUD	PT,PD,AG	BONDAR CLEGG	2	1979
381	1191S	2814.1E	TIGER BOY	ALL PGM + AU	U OF T	1	1979
390	1210.2S	5205.7E	TIGER BOY	ALL PGM + AU	U OF T	1	1979
BI AMAX			OUTSIDE AREA	AU,AG,PT,PD	SWASTIKA	3	1967
					KENNECOTT	3	1967
					OCHS AND GOLDEN	3	1967
66225	650S	6100W	UPDIP BATHTUB	AG,AU,PT,PD,CO	SWASTIKA	1	1967
DRIFT			TIGER BOY	ALL PGM + AU	U OF T	9	1979

NOTE: CLOUD ARE BATHTUB EXCEPT MARKED WITH P

Table A6: PGE Data from Minnamax Analyzed at University of Toronto

Area	Hole	From	To	Feet	#of samp. in interval	%Cu	%Ni	%Co	%S	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Rh (ppb)	Ru (ppb)	Ir (ppb)	Os (ppb)	Au (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd	Co/ Co+Ni	%Po
Bathtub	366	245	305	60	3.6	0.76	0.12	0.01	1.36	20	40	60	2.4	0.6	0.8	0	13	0.86	0.33	0.10	1.32
Bathtub	364	1525	1606	81	4.8	1.45	0.32	0.02	3.44	1900	260	2160	12	5	4	2	110	0.82	0.88	0.05	4.61
Bathtub	369	1305	1445	140	8.4	1.75	0.34	0.02	2.86	20	41	61	2.5	6	0.7	0.2	11	0.84	0.33	0.05	2.14
Bathtub	296	1287	1457	170	10	0.77	0.18	0.01	1.01	60	310	370	7.9	5	3	0	110	0.81	0.16	0.06	0.18
Bathtub	296	1517	1597	80	4.8	0.84	0.20	0.01	1.40	60	210	270	6.9	8	2	0	34	0.81	0.22	0.06	1.01
Tigerboy	231	1754	1884	130	7.8	0.80	0.14		1.58									0.85			1.76
Tigerboy	268	1955	2045	90	5.4	0.89	0.24	0.02	1.98	60	230	290	4.5	0.3	1.7	2	23	0.79	0.21	0.06	2.36
Tigerboy	222	1793.4	1865	71.6	2.1	0.96	0.35		7.27									0.73			16.40
Tigerboy	254	1773	1923	150	9	1.31	0.24		2.10									0.85			1.52
Tigerboy	381	325	375	50	3	0.99	0.20	0.01	0.93	200	250	450	10	10	6	6	80	0.83	0.44	0.05	0.00
Tigerboy	333	545	615	70	4.2	0.80	0.14	0.01	1.74	25	110	135	2.5	0	0.8	0	30	0.83	0.19	0.08	2.20
Tigerboy	390	1235	1335	100	4.8	0.91	0.27	0.02	2.99	25	67	92	6	5	2	0	42	0.77	0.27	0.07	5.00
S.W. Ex	356	1400	1545	145	8.7	0.98	0.21	0.01	1.56	160	830	990	19	20	4	0	80	0.81	0.16	0.05	1.28
S.W. Ex	361	2054	2105.9	51.9	1.5	1.16	0.38	0.01	4.67	50	310	360	25	20	3	1	42	0.75	0.14	0.03	8.64
S.W. Ex	295	1375	1435	60	3.6	0.75	0.18	0.01	1.10	140	620	760	1.4	6	3	7	100	0.81	0.18	0.06	0.48
S.W. Ex	295	2095	2235	140	8.4	0.77	0.14	0.01	1.87	90	400	490	1.1	7	3	3	72	0.85	0.18	0.07	2.64
Drift A	260			+		2.48	2.38	0.13	18.04	60	80	140	45	42	16	0	35	0.51	0.43	0.05	36.58
Drift A	375			+		3.45	0.78	0.14	19.40	5	54	59	20	67	11	11	23	0.82	0.08	0.15	41.71
Drift A	1174			+		1.42	0.24	0.02	2.58	250	520	770	8	6	4	0	120	0.86	0.32	0.06	2.54
Drift B	925			+		1.00	0.21	0.02	2.13	360	290	650	10	0	2	2	62	0.83	0.55	0.08	2.54
Drift B	1110			+		1.45	1.82	0.08	34.59	100	130	230	110	72	40	10	17	0.44	0.43	0.04	86.29
Drift B	1267			+		0.53	0.16	0.01	1.16	60	49	109	3	2	1	0.1	4	0.77	0.55	0.07	1.31
Drift C	260			+		8.00	2.45	0.12	20.86	100	260	360	27	21	15	0	51	0.77	0.28	0.05	28.86
Drift D	310			+		14.80	1.45	0.07	24.12	60	21	81	31	2	6	0	4	0.91	0.74	0.05	21.52
Drift D	345			+		4.35	0.46	0.03	10.02	400	750	1150	7	0	4	7	1300	0.90	0.35	0.05	14.28
				Mean		2.13	0.54	0.04	6.83	191	265	456	16	14	6	2	107	0.79	0.34	0.06	11.49
				Std		3.02	0.68	0.04	8.93	387	228	482	23	20	8	3	263	0.10	0.20	0.02	19.14
			Mean	Bathtub		1.11	0.23	0.01	2.01	412	172	584	6	5	2	0	56	0.83	0.39	0.06	1.85
			Std	Bathtub		0.41	0.08	0.00	0.96	744	112	797	4	2	1	1	45	0.02	0.26	0.02	1.52
			Mean	Tigerboy		0.95	0.23	0.01	2.66	78	164	242	6	4	3	2	44	0.81	0.28	0.06	4.18
			Std	Tigerboy		0.16	0.07	0.00	1.97	72	78	141	3	4	2	2	22	0.04	0.10	0.01	5.18
			Mean	SW Ext		0.89	0.23	0.01	2.30	110	540	650	12	13	3	3	74	0.80	0.17	0.05	3.26
			Std	SW Ext		0.16	0.09	0.00	1.40	43	202	244	11	7	0	3	21	0.03	0.02	0.02	3.20
			Mean	Drift		4.16	1.11	0.07	14.77	155	239	394	29	24	11	3	180	0.76	0.42	0.07	26.18
			Std	Drift		4.34	0.88	0.05	10.88	136	235	359	31	28	11	4	398	0.16	0.18	0.03	25.54
		Sum	1589.5	Wt Avg		1.00	0.22	0.011	2.22	193	304	497					60	0.814	0.28	0.061	
				Wt Std		0.55	0.11	0.006	1.24	398	314	523					51				

+ grab samples only

Table A7: Pt, Pd, Cr, and Ag Contents of the Cloud Zone Sulfides

Hole	From	To	Feet	%Cu	%Ni	%S	Cr (ppm)	Ag (ppm)	Pt (ppb)	Pd (ppb)	Pd+Pt (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd	%Po
91	131	136	5	0.62	0.13	0.68	3300	2.6	270	750	1020	0.83	0.26	-0.18
91	136	149	13	0.05	0.03	0.13	700	0.0	10	30	40	0.63	0.25	0.14
91	157	167	10	0.10	0.04	0.11	2400	0.2	45	70	115	0.71	0.39	-0.08
91	425	435	10	0.03	0.08	0.02	300	0.0	10	20	30	0.27	0.33	-0.23
304	498	508	10	0.07	0.08	0.19	200	0.0	5	0	5	0.47	1.00	0.12
316	45	55	10	0.16	0.05	0.21	1800	0.4	20	70	90	0.76	0.22	0.01
316	175	185	10	0.28	0.08	0.38	900	0.7	45	95	140	0.78	0.32	0.06
316	205	215	10	0.16	0.04	0.19	400	0.1	15	50	65	0.80	0.23	-0.02
316	215	225	10	0.03	0.06	0.07	400	0.0	5	0	5	0.33	1.00	-0.04
307	224	239	15	0.08	0.04	0.13	400	0.1	30	45	75	0.67	0.40	0.03
307	411	420	9	0.25	0.17	0.42	1200	0.3	15	80	95	0.60	0.16	0.03
307	735	745	10	0.06	0.04	0.11	500	0.0	5	0	5	0.60	1.00	0.03
263	55	65	10	0.28	0.10	1.16	400	0.6	85	75	160	0.74	0.53	2.15
263	75	85	10	0.06	0.02	0.20	200	0.0	5	0	5	0.75	1.00	0.33
263	115	125	10	0.22	0.07	0.33	900	0.5	35	130	165	0.76	0.21	0.12
96	108	115	7	0.28	0.06	0.25	500	0.7	25	150	175	0.82	0.14	-0.24
96	125	135	10	0.22	0.06	0.29	100	0.7	60	200	260	0.79	0.23	0.03
96	135	139	4	0.10	0.04	0.36	300	0.1	0	15	15	0.71	0.00	0.61
96	139	145	6	0.67	0.16	0.83	700	2.0	155	725	880	0.81	0.18	0.01
92	118	125	7	0.30	0.07	0.29	500	0.4	70	245	315	0.81	0.22	-0.21
92	381	396	15	0.06	0.07	0.07	1400	0.0	10	15	25	0.46	0.40	-0.15
92	634	640	6	0.30	0.07	0.43	900	0.8	230	570	800	0.81	0.29	0.17
90	98	112	14	0.07	0.06	0.09	700	0.0	20	65	85	0.54	0.24	-0.10
90	488	502	14	0.06	0.06	0.08	500	0.0	5	20	25	0.50	0.20	-0.10
90	511	514	3	0.98	0.17	1.13	900	2.0	195	770	965	0.85	0.20	-0.05
90	514	518	4	0.24	0.07	0.24	1400	0.7	30	60	90	0.77	0.33	-0.18
90	535	541	6	0.16	0.11	0.23	700	0.0	45	125	170	0.59	0.26	-0.09
82	237	248	11	0.31	0.07	0.31	400	0.0	50	90	140	0.82	0.36	-0.19
82	525	539	14	0.16	0.09	0.23	600	0.8	10	35	45	0.64	0.22	-0.04
82	595	607	12	0.44	0.11	0.70	500	1.3	15	60	75	0.80	0.20	0.42
82	655	665	10	0.25	0.06	0.29	400	0.6	25	120	145	0.81	0.17	-0.05
363	205.5	218	12.5	0.80	0.13	0.81	2700	1.7	90	200	290	0.86	0.31	-0.32
363	298	310	12	0.93	0.10	0.68	400	4.9	50	140	190	0.90	0.26	-0.96
363	310	319	9	0.49	0.10	0.61	2200	1.4	60	130	190	0.83	0.32	0.06
372	119	134	15	0.67	0.14	1.15	2100	2.1	155	505	660	0.83	0.23	0.94
372	651	662	11	0.31	0.08	0.48	2100	0.8	65	55	120	0.79	0.54	0.26
78	381	390	9	0.04	0.03	0.03	1600	0.0	5	15	20	0.57	0.25	-0.10
289	215	225	10	0.20	0.05	0.23	300	0.3	35	125	160	0.80	0.22	-0.05
289	225	235	10	0.46	0.12	0.64	600	1.1	85	445	530	0.79	0.16	0.18
289	745	755	10	0.34	0.10	0.50	200	1.1	50	120	170	0.77	0.29	0.18
103	115	119	4	0.32	0.12	0.39	300	0.7	175	400	575	0.73	0.30	-0.12
103	119	128	9	0.53	0.18	0.68	800	1.5	175	465	640	0.75	0.27	-0.06
216	355	369	14	0.34	0.11	0.36	400	0.8	25	90	115	0.76	0.22	-0.23
40	44	52.5	8.5	0.21	0.06	0.52	2500	0.4	10	0	10	0.78	1.00	0.69
40	90	106	16	0.34	0.08	0.64	1300	1.0	70	300	370	0.81	0.19	0.61
		Total	445											
		Average		0.29	0.08	0.40	933	0.74	58	170	228	0.72	0.35	0.07
		Std		0.23	0.04	0.29	776	0.91	65	209	270	0.14	0.25	0.43
		Wt. Avg.		0.28	0.08	0.38		0.72	49	143	192	0.71	0.35	

Table A8: Baseline Data From the Tiger Boy and Bathtub Deposits, Minnamax

Hole	From	To	Feet	%Cu	%Ni	%S	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Ag (ppm)	Cu/ Cu+Ni	Pt/ Pt+Pd	%Po
Tiger Boy													
254	1753	1763	10	0.20	0.06	0.40	0	135	135	1.8	0.769	0.000	0.39
254	1763	1773	10	0.19	0.07	0.37	0	60	60	1.9	0.731	0.000	0.31
254	1773	1783	10	0.88	0.18	0.99	135	195	330	3.2	0.830	0.409	-0.18
254	1783	1793	10	1.88	0.24	2.09	90	275	365	7.9	0.887	0.247	-0.08
254	1793	1803	10	1.24	0.23	1.50	90	570	660	5.6	0.844	0.136	0.10
254	1803	1813	10	1.82	0.30	2.16	125	220	345	5.6	0.858	0.362	0.00
254	1813	1823	10	1.67	0.28	2.19	170	370	540	4.6	0.856	0.315	0.00
254	1823	1833	10	1.32	0.21	1.59	30	295	325	7.6	0.863	0.092	0.17
254	1833	1843	10	1.47	0.26	2.17	170	240	410	6.0	0.850	0.415	1.22
254	1843	1853	10	1.23	0.33	1.96	75	200	275	4.8	0.788	0.273	0.00
254	1853	1863	10	1.14	0.19	1.44					0.857		0.31
254	1863	1873	10	1.01	0.23	1.81	35	195	230	5.1	0.815	0.152	1.59
254	1873	1883	10	0.87	0.18	1.54	15	115	130	3.3	0.829	0.115	1.36
254	1883	1893	10	1.18	0.22	2.22	25	190	215	5.1	0.843	0.116	2.27
254	1893	1903	10	1.58	0.21	2.79	25	205	230	7.0	0.883	0.109	2.75
254	1903	1913	10	1.38	0.22	3.05	25	135	160	5.0	0.863	0.156	3.99
254	1913	1923	10	0.97	0.26	4.06	0	60	60	4.0	0.789	0.000	7.80
254	1923	1933	10	0.31	0.06	1.06	90	155	245	3.0	0.838	0.367	1.90
254	1933	1943	10	0.02	0.02	0.23	0	15	15	1.2	0.500	0.000	0.53
Bathtub													
296	1267	1277	10	0.02	0.04	0.04	0	65	65	1.1	0.333	0.000	-0.05
296	1277	1287	10	0.06	0.03	0.06	0	40	40	1.1	0.667	0.000	-0.08
296	1287	1297	10	0.66	0.14	0.81	95	285	380	4.5	0.825	0.250	0.04
296	1297	1307	10	0.63	0.16	0.79					0.797		0.02
296	1307	1317	10	0.92	0.24	1.19	180	675	855	4.3	0.793	0.211	0.11
296	1317	1327	10	1.05	0.25	1.12	170	610	780	4.0	0.808	0.218	-0.47
296	1327	1337	10	0.63	0.16	0.73	180	275	455	3.0	0.797	0.396	-0.15
296	1337	1347	10	1.03	0.21	1.23	290	445	735	4.8	0.831	0.395	-0.01
296	1347	1357	10	0.90	0.22	1.12	140	285	425	3.4	0.804	0.329	0.02
296	1357	1367	10	0.61	0.15	0.77	75	240	315	2.8	0.803	0.238	0.04
296	1367	1377	10	0.87	0.18	1.08	80	215	295	3.9	0.829	0.271	0.10
296	1377	1387	10	1.33	0.27	1.56	80	520	600	6.0	0.831	0.133	-0.09
296	1387	1397	10	0.72	0.14	0.89	80	160	240	2.8	0.837	0.333	0.09
296	1397	1407	10	0.82	0.17	1.11	135	445	580	3.4	0.828	0.233	0.34
296	1407	1417	10	0.65	0.16	0.91	40	170	210	3.7	0.802	0.190	0.29
296	1417	1427	10	0.85	0.18	1.22	75	105	180	5.0	0.825	0.417	0.54
296	1427	1437	10	0.46	0.08	0.66	15	65	80	2.7	0.852	0.188	0.33
296	1437	1447	10	0.82	0.16	1.28	20	335	355	3.9	0.837	0.056	0.84
296	1447	1457	10	1.36	0.27	2.01	50	245	295	4.4	0.834	0.169	1.06
296	1457	1467	10	0.47	0.11	0.71	30	195	225	3.3	0.810	0.133	0.37
296	1467	1477	10	0.14	0.04	0.17	30	10	40	1.7	0.778	0.750	-0.02
296	1477	1487	10	0.55	0.12	0.94	35	125	160	2.4	0.821	0.219	0.75
296	1487	1497	10	0.47	0.16	1.23	145	180	325	3.5	0.746	0.446	1.67
296	1497	1507	10	0.68	0.17	1.05	40	140	180	4.0	0.800	0.222	0.57
296	1507	1517	10	0.45	0.11	0.69	40	65	105	3.0	0.804	0.381	0.37
296	1517	1527	10	0.70	0.17	1.06	50	95	145	3.1	0.805	0.345	0.54
296	1527	1537	10	0.69	0.17	1.25	175	195	370	3.6	0.802	0.473	1.09
296	1537	1547	10	0.61	0.15	1.07	70	110	180	3.1	0.803	0.389	0.00
296	1547	1557	10	0.68	0.17	1.07	75	180	255	4.0	0.800	0.294	0.62
296	1557	1567	10	0.60	0.13	0.93	75	120	195	4.4	0.822	0.385	0.56
296	1567	1577	10	0.67	0.14	0.92	705	185	890	3.2	0.827	0.792	0.00
296	1577	1587	10	0.65	0.15	1.39	30	105	135	4.0	0.813	0.222	1.63
296	1587	1597	10	0.64	0.14	0.95	55	160	215	3.1	0.821	0.256	0.48
296	1597	1607	10	0.44	0.11	0.73	30	150	180	2.8	0.800	0.167	0.51
296	1607	1617	10	0.72	0.11	1.13	55	140	195	4.5	0.867	0.282	0.83
296	1617	1627	10	0.42	0.14	0.66	70	195	265	2.7	0.750	0.264	0.00
296	1627	1637	10	0.28	0.06	0.44	25	60	85	2.3	0.824	0.294	0.28
296	1637	1647	10	0.58	0.11	0.99	65	130	195	4.0	0.841	0.333	0.83
296	1647	1657	10	1.45	0.43	2.92	55	145	200	4.3	0.771	0.275	0.00
296	1657	1667	10	1.40	0.26	2.19					0.843		1.47
296	1667	1677	10	0.95	0.23	2.67	45	155	200	4.7	0.805	0.225	0.00
296	1677	1687	10	0.52	0.14	1.08	80	25	105	2.7	0.788	0.762	0.00
296	1687	1697	10	0.41	0.11	1.66	30	65	95	2.3	0.788	0.316	3.14
296	1697	1707	10	0.14	0.05	0.56	15	0	15	1.3	0.737	1.000	1.02
Mean	296			0.68	0.16	1.07	89	193	282	3.40	0.80	0.32	0.45
S.D.	296			0.322	0.072	0.559	113	151	217	1.046	0.078	0.199	0.635
Mean	254			1.07	0.20	1.77	61	202	263	4.59	0.82	0.18	1.29
S.D.	254			0.539	0.084	0.927	57	123	162	1.879	0.084	0.142	1.895
Mean	254 & 296			.79	0.17	1.28	81	196	276	3.76	0.80	0.28	0.70
S.D.	254 & 296			0.440	0.078	0.762	100	143	202	1.458	0.080	0.193	1.230

Table A9: Pt, Pd, Au and Ag Data Collected Pre 1969 at Minnamax

Hole	From	To	Feet	%Cu	%Ni	%S	%Co	Pt+Pd (ppb)	Au (ppb)	Ag (ppm)	Cu/ Cu+Ni	Pt/ Pt+Pd	Co/ Co+Ni	Po wt%
1	110	135	25	0.43	0.14	3.22	0.02	68	17	1.37	0.75		0.12	7.29
1	135	160	25	0.56	0.18	4.02	0.03	171	17	2.40	0.76		0.14	9.02
1	160	195	35	0.86	0.18	3.05	0.04	342	17	5.82	0.83		0.18	5.53
3	230	245	15	1.06	0.14	1.79	0.00	137	342	6.16	0.88		0.00	1.63
5	410	445	35	2.28	0.21	2.79	0.00	1164	685	12.67	0.92		0.00	0.82
6	245	260	15	1.29	0.35	2.82	0.04	34	342	4.79	0.79		0.10	3.28
7	735	775	40	0.54	0.15	1.98	0.05	103	17	1.37	0.78		0.25	3.55
7	775	815	40	0.67	0.14	1.41	0.09	137	17	2.40	0.83		0.40	1.64
7	815	855	40	0.92	0.17	1.97	0.08	103	17	3.08	0.85		0.32	2.43
7	855	895	40	0.74	0.17	1.61	0.08	68	17	3.08	0.81		0.32	1.94
7	895	935	40	0.29	0.10	3.91	0.04	68	17	2.05	0.74		0.28	9.66
17	130	150	20	1.14	0.28	1.75	0.03	753	685	5.14	0.80		0.10	0.93
17	460	485	25	1.05	0.21	1.88	0.06	103	17	4.45	0.83		0.22	1.72
17	485	510	25	1.04	0.19	1.76	0.04	137	17	4.45	0.85		0.18	1.48
22	985	995	10	1.24	0.27	8.08	0.07	68	17	7.88	0.82		0.21	18.07
23	650	670	20	0.85	0.20	0.92	0.05	205	17	4.11	0.81		0.20	-0.34
23	670	685	15	1.74	0.36	2.61	0.06	240	17	9.25	0.83		0.14	1.44
23	685	705	20	0.58	0.15	0.97	0.05	68	17	3.08	0.80		0.25	0.67
23	894	920	26	0.86	0.16	1.94	0.05	137	17	4.79	0.85		0.24	2.55
24	1300	1340	40	1.20	0.34	1.73	0.01	137	17	6.16	0.78		0.03	0.56
25	370	405	35	1.48	0.18	2.42	0.01	240	17	4.79	0.89		0.05	2.08
26	235	260	25	1.21	0.21	2.23	0.02	103	17	4.11	0.85		0.09	2.23
29	1420	1450	30	1.02	0.24	1.55	0.02	103	17	3.42	0.81		0.08	0.82
29	1480	1500	20	1.11	0.25	1.72	0.02	205	171	2.74	0.82		0.07	1.01
29	1600	1630	30	1.17	0.20	1.78	0.01	240	171	3.77	0.85		0.05	1.13
33	490	505	15	1.19	0.19	1.63	0.01	1233	171	8.22	0.86		0.05	0.69
33	1525	1550	25	0.96	0.32	5.58	0.03	34	17	5.14	0.75		0.09	11.83
34	1730	1755	25	0.81	0.20	1.57	0.01	68	17	3.77	0.81		0.05	1.56
34	1755	1775	20	1.25	0.26	2.53	0.00	137	171	5.14	0.83		0.00	2.83
34	1775	1810	35	0.85	0.22	5.36	0.01	103	17	3.77	0.80		0.04	11.81
35	310	340	30	0.84	0.59	15.27	0.07	68	17	1.37	0.59		0.11	38.08
39	1540	1560	20	0.91	0.17	1.80	0.03	0	17	3.77	0.84		0.15	2.01
39	1560	1580	20	1.49	0.24	2.50	0.04	0	17	5.48	0.86		0.14	2.14
40	690	710	20	0.77	0.19	1.06	0.01	548	171	5.48	0.81		0.05	-0.30
57	741.7	761	19.3	1.79	0.85	22.03	0.09	137	0	3.42	0.68	0.00	0.10	53.35
58	1373	1389	16	1.14	0.20	3.75	0.02	137	0	5.48	0.85	0.00	0.09	6.63
58	1433	1440.9	7.9	2.20	1.49	17.08	0.07	342	171	5.82	0.60	0.10	0.04	36.99
60	1731.4	1735.4	4	6.04	0.34	6.49	0.04	14041	685	23.29	0.95	0.90	0.11	0.21
66225	1028	1065	37	1.02	0.20	1.57	0.01	205	0	6.85	0.84	0.00	0.05	0.97
130	1686	1688.5	2.5	2.86	0.85	27.88	0.07	137	0	2.23	0.77	0.25	0.08	66.44
130	1703.5	1710	6.5	5.78	1.13	16.07	0.05	514	171	10.96	0.84	0.13	0.04	25.22
130	1710	1717	7	4.44	1.57	21.04	0.07	479	171	13.70	0.74	0.07	0.04	41.45
85	1550	1610	60	0.37	0.08	1.15				1.60	0.83			1.94
85	1394	1460	66	1.03	0.20	1.41				3.90	0.83			0.50
85	1321	1365	44	0.08	0.04	0.24				0.28	0.65			0.33
85	620	720	100	0.03	0.04	0.05				0.14	0.39			-0.06
85	330	400	70	0.09	0.03	0.09				0.23	0.78			-0.05
105	1773	1793	20	5.19	0.70	9.94	0.03	651	342	14.73	0.88	0.21	0.04	11.13
105	1793	1842	49	1.39	0.25	2.77	0.02	308	171	5.82	0.85	0.44	0.07	3.12
105	1842	1855	13	4.86	1.04	15.25	0.06	1267	171	25.34	0.82	0.70	0.05	25.75
105	1803	1834	31	0.75	0.12	1.84			0	2.3	0.86			2.66
116	1650	1660	10	1.11	0.18	1.18	0.01	205	171	9.25	0.86	0.33	0.05	-0.29
116	1660	1680	20	13.19	0.68	14.46	0.04	856	514	19.86	0.95	0.20	0.06	1.43
116	1680	1698.3	18.3	13.55	1.83	22.85	0.08	1164	171	30.14	0.88	0.26	0.04	20.53
116	1698.3	1715	16.7	1.30	0.08	7.04	0.03	308	0	4.79	0.94	0.33	0.27	15.52
119	1853	1885	32	1.58	0.70	19.27	0.10	68	0	2.40	0.69	0.50	0.13	46.73
119	1885	1919	34	1.62	1.40	24.78	0.12	34	0	1.71	0.54	0.00	0.08	59.96
119	1919	1931	12	0.85	0.44	9.30	0.08	34	0	0.68	0.66	0.00	0.15	22.05
BI-AMA	2590	2660	70	0.23	0.09	0.38		548	48	5.14	0.73	0.31		0.17
BI-AMA	2660	2720	60	0.48	0.15	0.56		993	55	5.14	0.77	0.17		-0.16
BI-AMA	2740	2790	50	0.24	0.08	0.43		428	34	5.14	0.74	0.20		0.30
	Total	1777												
	Average			1.76	0.37	5.67	0.04	549	111	6.00	0.80	0.24	0.12	9.76
	Std			2.49	0.40	7.08	0.03	1866	174	5.86	0.10	0.23	0.09	15.87
	Wt. Avg.			1.22	0.26	3.86	0.04	340	89	4.61				
	Std			1.53	0.26	5.12	0.03	437	133	3.82				

Table A10: Analyses of Concentrates, Heads, Tailings and Recovery, Dunka Road

DDH	From	To	Feet	%Cu	%Ni	%S	%Co	Pt (ppb)	Pd (ppb)	Pt+Pd (ppb)	Au (ppb)	Rh (ppb)	Cu/ Cu+Ni	Pt/ Pt+Pd	%Po	Comments
Heads																
26030	686	726	40	0.64	0.19	1.47	0.017	205	719	925	68	7	0.77	0.22	1.78	Med. grade, high FeS, C, alter
26033	960	980	20	0.83	0.23	1.11	0.012	2744	1404	1678	68	10	0.78	0.16	0.16	High grade, low FeS
26044	67	122	55	0.47	0.17	0.90	0.010	171	1027	1199	68	7	0.73	0.14	0.74	Typical sample
26044	67	122	55	0.47	0.17	0.90	0.009	171	1027	1199	68	0	0.73	0.14	0.74	Typical sample
26044	107	117	10	0.64	0.20	1.00	0.009	205	959	1164	68	7	0.76	0.18	0.46	Medium grade, high Mg-olivine
26045	7	25	18	0.49	0.15	0.57	0.009	411	1062	1473	68	10	0.77	0.28	-0.17	Similar to 26044
26047	518	558	40	0.55	0.35	0.77	0.017	342	1507	1849	103	10	0.61	0.19	-0.30	High Ni, low FeS, Mg-olivine
Bulk #2								154	651	805						
Concentrate																
26030	686	726	40	2.67	0.70	6.16	0.046	377	1849	2226	103	21	0.79	0.17	7.73	
26033	960	980	20	8.16	1.80	10.98	0.036	1438	10411	11849	856	123	0.82	0.12	2.95	
26044	67	122	55	3.58	1.01	6.96	0.034	993	2945	3938	171	55	0.78	0.25	6.61	
26044	67	122	55	3.58	1.01	6.96		1199	6164	7363	719	79	0.78	0.16	6.61	Shorter grind--more Pd liberat
26044	107	117	10	7.10	1.77	10.72	0.025	1301	3322	4623	411	55	0.80	0.28	5.25	
26045	7	25	18	5.72	1.30	6.60	0.034	2055	8425	10479	925	110	0.81	0.20	-1.04	
26047	518	558	40	4.97	2.31	6.84	0.036	1473	3973	5445	411	86	0.68	0.27	-0.88	
A-4 composite								925	5308	6233				0.15		
A-2 composite								1644	7260	8904				0.18		
C-4 composite								856	4075	4932				0.17		
C-2 Composite								1164	5753	6918				0.17		
Bulk #2								685	3459	4144				0.17		
Average				5.11	1.41	7.89	0.035	1176	5245	6421	514	75	0.78	0.19	3.89	
Tailings																
26030	686	726	40	0.06	0.05	0.14							0.58		0.09	
26033	960	980	20	0.04	0.06	0.05							0.42		-0.14	
26044	67	122	55	0.04	0.05	0.06							0.43		-0.08	
26044	67	122	55	0.04	0.05	0.06							0.43		-0.08	
26044	107	117	10	0.05	0.06	0.11							0.47		0.03	
26045	7	25	18	0.04	0.05	0.05							0.41		-0.10	
26047	518	558	40	0.03	0.12	0.05							0.19		-0.23	
Recovery																
				%Cu	%Ni	%S	%Co	Pt	Pd		Au	Ru				
26030	686	726	40	92.2	81.1	92.6	47.6	32.2	45.2		26.0	53.0				
26033	960	980	20	95.2	75.6	95.3	29.9	52.4	73.9		125.0	120.0				
26044	67	122	55	92.5	72.1	94.0	27.3	46.6	23.0		20.0	65.0				
26044	67	122	55	92.5	72.1	94.0		45.2	38.7		67.0	74.0				
26044	107	117	10	93.0	74.3	89.9	29.4	66.8	36.4		63.0	84.0				
26045	7	25	18	93.4	69.3	92.7	29.7	39.3	62.3		106.0	84.0				
26047	518	558	40	95.5	69.9	93.8	23.8	48.4	29.8		45.0	97.0				
Average				93.7	72.2	93.3	28.0	49.8	44.0		71.0	87.3				

Table A11: Concentrate Values for Inco's Spruce Road Deposit

Inco Spruce Road

	Tons	%Cu	%Ni	%Co	%Fe	%S	Cu/ Cu+Ni	Metals/Ton Ag (ppm)	Au (ppb)	Pt (ppb)	Pd (ppb)	Rh (ppb)	Pt/ Pt+Pd	Reference
Ore	13440000	0.46	0.17				0.73							
Concentrate	410000	13.26	3.62				0.79	29.5	860	1203	3408		0.26	Open File DNR 1975
Tailings	13030000	0.057	0.061				0.48							
Composite		10	2.2	0.11	26.1	18.3	0.82	37.7	1370	1233	4110	103	0.23	3.4.2.2.2 Aug. 26, 1975 USBM
Composite		14.4	3.1	0.14	29.1	24	0.82	51.4	1370	1027	4384	68	0.19	3.4.2.2.2 Aug. 26, 1975 USBM
Composite		12.2	2.5	0.12	27.5	21.1	0.83	47.9	1370	719	4178	103	0.15	3.4.2.2.2 Aug. 26, 1975 USBM
Average		12.46	2.855	0.123	27.56	21.13	0.814	41.62	1242	1045	4019	91.33	0.207	

Table A12: Values of Metals in Concentrates from Minnamax

Deposit	Composite	Cu	%Ni	%Co	%Fe	%S	%C	Ag (ppm)	Au (ppb)	Pt (ppb)	Pd (ppb)	Rh (ppb)	Ru (ppb)	Cu/ Cu+Ni	Co/ Co+Ni	Pt/ Pt+Pd
Blend	Blend	13.70	2.50	0.16	33.70	26.90	2.10	53.1	205	582	2055	72	137	0.85	0.06	0.22
Blend	Low Po/Cb Diss	16.34	2.94	0.14	33.31	27.46	0.94	60.6	199	651	2260	79	137	0.85	0.04	0.22
Blend	High Po/Cb Diss	9.02	2.42	0.19	34.92	25.00	5.35	29.5	178	445	1541	62	137	0.79	0.07	0.22
Blend	Semi massive	15.44	3.02	0.14	39.70	31.30	3.35	72.3	271	651	2808	123	274	0.84	0.04	0.19
Tiger Boy	Disseminated	13.80	2.60					41.4	925	822	1781			0.84		0.32
Bathtub	Disseminated	17.20	2.78					51.7	1062	1027	2329			0.86		0.31
UP-dip		13.80	2.21					42.5	856	1062	1644			0.86		0.39
Local Boy	Disseminated	11.20	2.46							856	2500			0.82		0.26
Bathtub	Disseminated	14.70	2.78							993	2842			0.84		0.26
Bulk		14.00	3.00					42.1	1473	1610	3801	16		0.82		0.30
Bulk	Minimum	12.00	2.00	0.11	35.00	27.00	3.00	41.8	380	1130	1470			0.86	0.05	0.43
Bulk	Maximum	14.00	2.50	0.11	40.00	30.00	5.00	41.8	380	1130	1470			0.85	0.04	0.43
Bulk	Disseminated	14.90	2.14	0.12	36.27	27.10	1.39	51.4	685	753	1473			0.87	0.05	0.34
Bathtub	Test 317	15.90	2.74	0.11	30.80	24.20	1.46	55.1	1062	616	2295			0.85	0.04	0.21
Partridge	4,5,&6	11.20	2.10	0.14	27.60	21.60	5.73	41.1	479	377	1473			0.84	0.06	0.20
Partridge	4,5,&6							43.8	856	685	1849					0.27
Tiger Boy	No. 2							45.2	959	651	2123					0.23
Bathtub	No. 3							52.1	1164	753	2877					0.21
Local Boy	Disseminated	11.10	2.46		28.50					1233	3733			0.82		0.25
Bathtub	Disseminated	14.70	2.84		31.00					342	582			0.84		0.37
	145			0.20				38.7	410	820	2020					0.29
	152			0.30				58.4	450	920	2530					0.27
	606			0.12				39.7	2880	750	2020					0.27
	Average	13.71	2.56	0.15	33.71	26.73	3.15	47.49	783	820	2151	70.27	171.2	0.84	0.05	0.28
	Std	2.10	0.31	0.05	3.88	2.75	1.73	9.53	616	288	728	34.44	59.32	0.02	0.01	0.07
Cu Conc	Select #8	20.10	1.60							514	1747			0.93		0.23
Ni Conc	Select #8	2.69	10.50							1438	7534			0.20		0.16
Cu Conc	Bulk #8	20.70	1.36					60.3	411	411	1678			0.94		0.20
Ni Conc	Bulk #8	3.50	9.80					76.4	68	2911	14384			0.26		0.17
Cu Conc	Minimum	20.00	0.25	0.03	34.00	32.00	2.00	48.0	600	650	620			0.99	0.09	0.51
Cu Conc	Maximum	21.00	0.30	0.03	37.00	35.00	3.00	48.0	600	650	620			0.99	0.08	0.51
Cu-Ni Conc	Minimum	3.00	4.00	0.40	35.00	30.00	2.00	55.0	720	2190	4460			0.43	0.09	0.33
Cu-Ni Conc	Maximum	6.00	8.00	0.40	39.00	33.00	3.00	55.0	720	2190	4460			0.43	0.05	0.33
Cu Conc	Cu Conc	20.80	0.27	0.03	36.30	32.80	3.00	48	600	650	620			0.99	0.08	0.51
Heads																
Tiger Boy	DDH254	1.31	0.24			2.10		5.1		65	220			0.85	0.00	0.23
Bathtub	DDH296	0.73	0.17			1.16		3.6		80	212			0.81	0.00	0.27
White Metal		62.40	12.90					167.8	5137	6336	15068	68		0.83	0.00	0.30

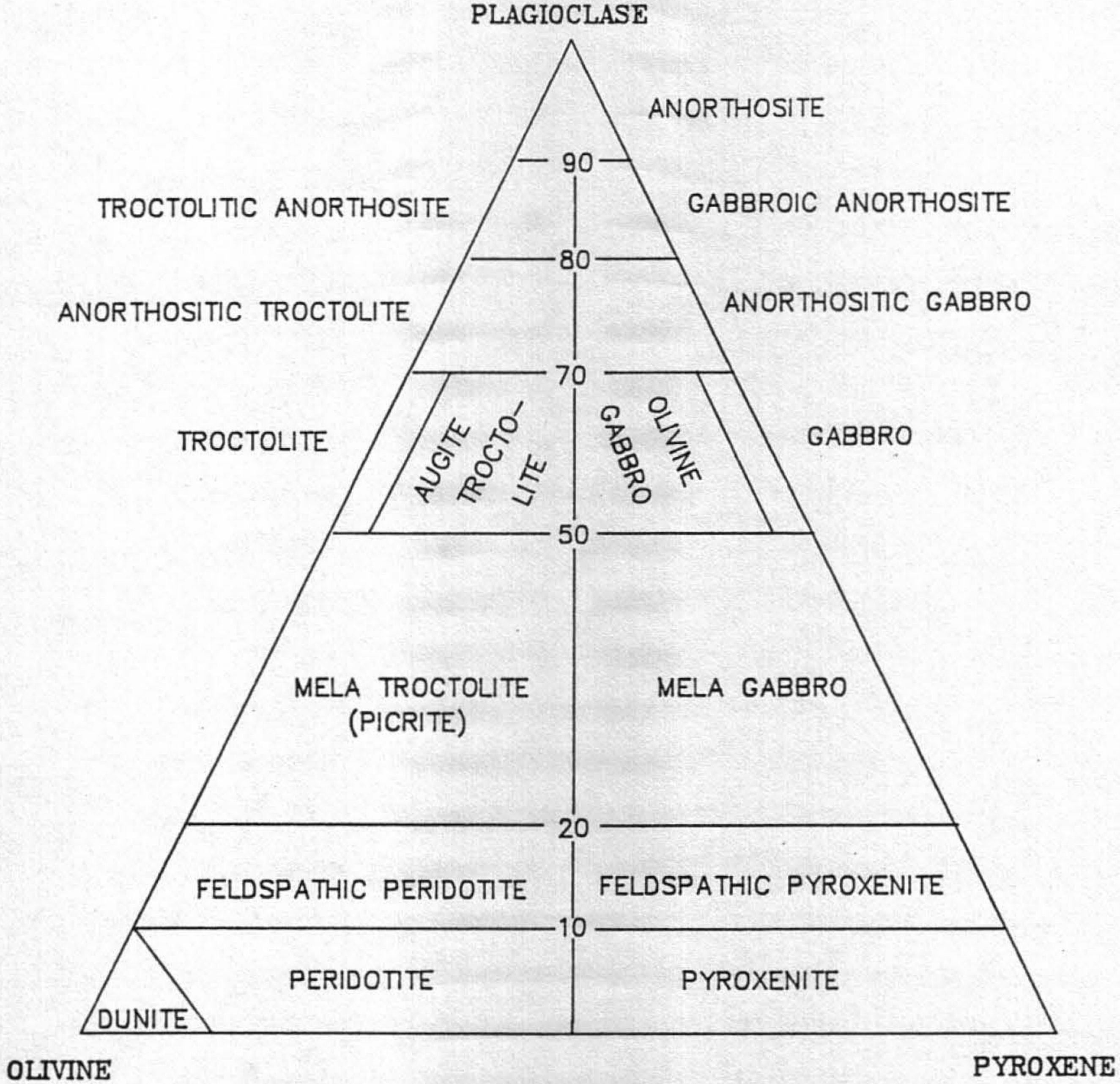
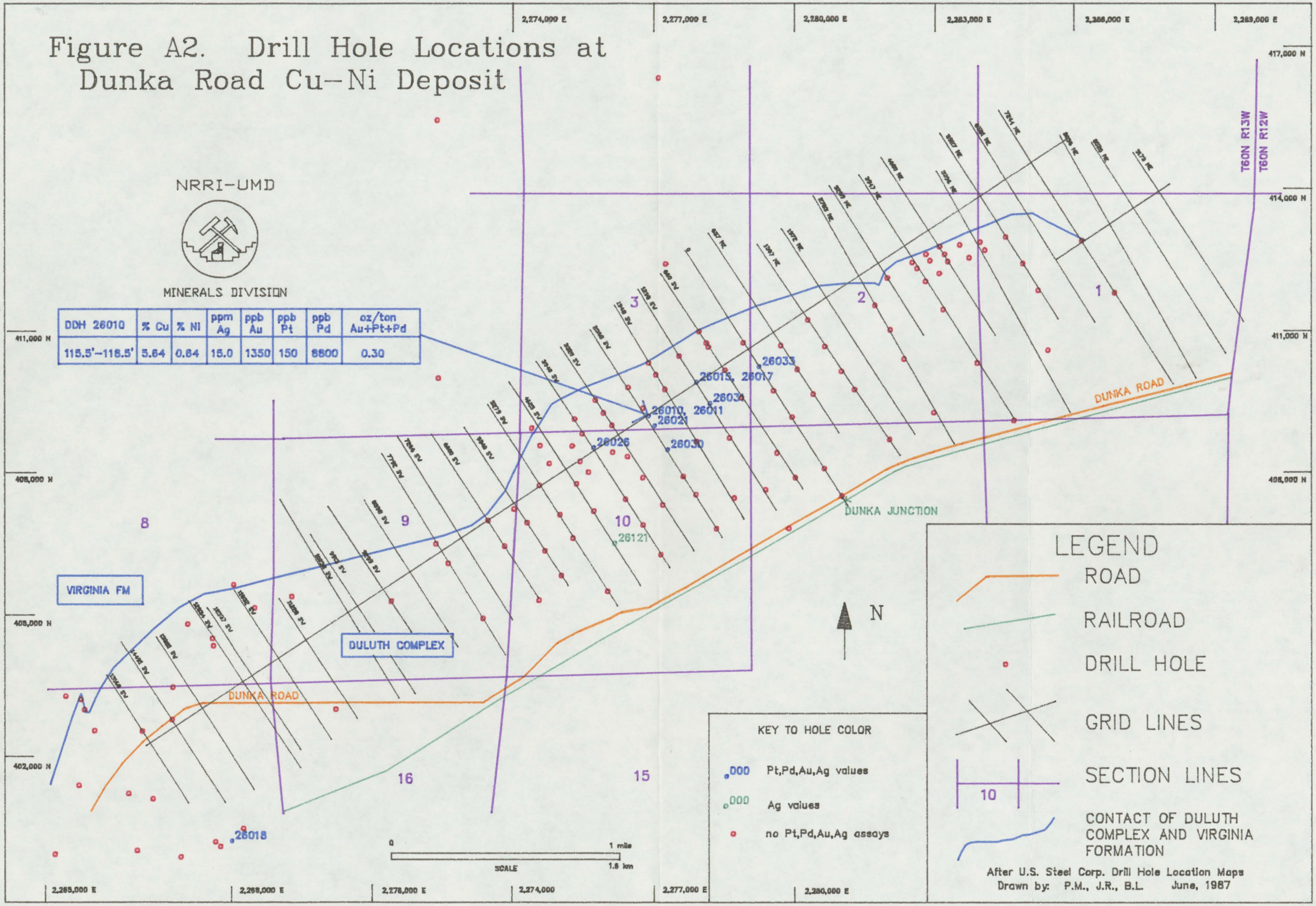


Figure A1. Rock Classification Scheme

Figure A2. Drill Hole Locations at Dunka Road Cu-Ni Deposit



DDH 26010	% Cu	% Ni	ppm Ag	ppb Au	ppb Pt	ppb Pd	oz/ton Au+Pt+Pd
115.5'–118.5'	5.64	0.64	15.0	1350	150	8800	0.30

After U.S. Steel Corp. Drill Hole Location Maps
Drawn by: P.M., J.R., B.L. June, 1987

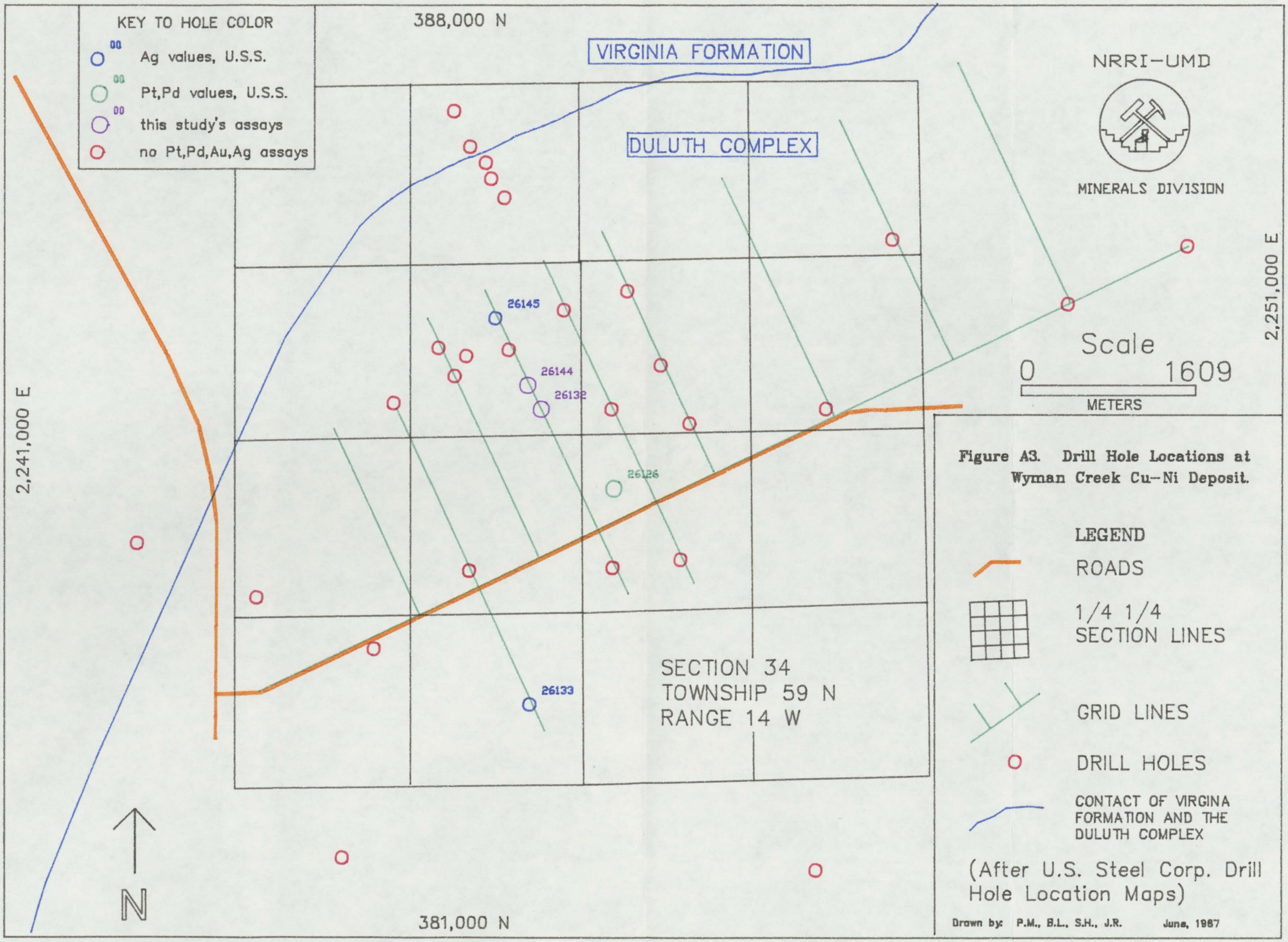


Figure A3. Drill Hole Locations at Wyman Creek Cu-Ni Deposit.

(After U.S. Steel Corp. Drill Hole Location Maps)

Drawn by: P.M., B.L., S.H., J.R. June, 1987

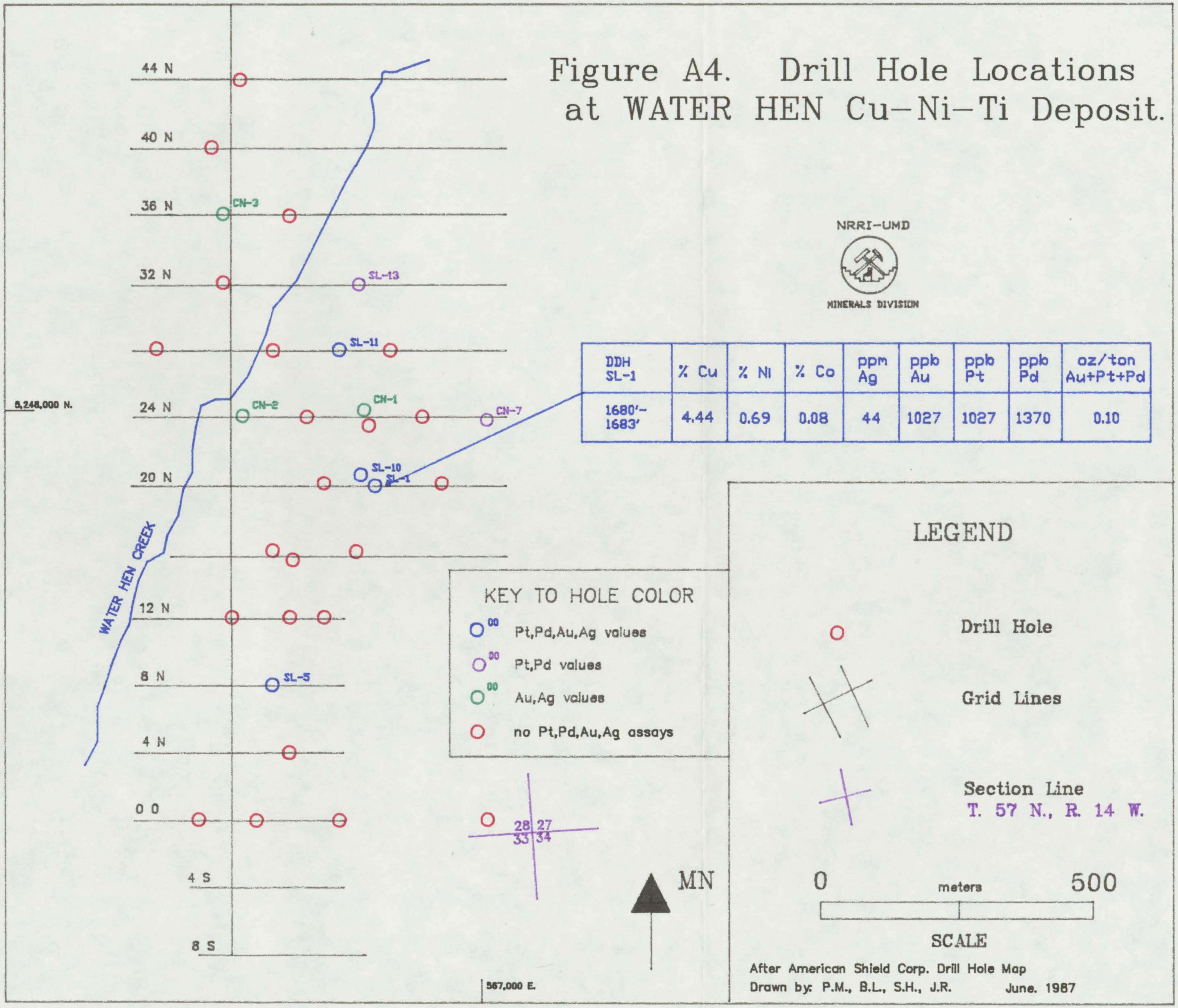


Figure A4. Drill Hole Locations at WATER HEN Cu–Ni–Ti Deposit.

DDH SL-1	% Cu	% Ni	% Co	ppm Ag	ppb Au	ppb Pt	ppb Pd	oz/ton Au+Pt+Pd
1680'–1683'	4.44	0.69	0.08	44	1027	1027	1370	0.10

After American Shield Corp. Drill Hole Map
Drawn by: P.M., B.L., S.H., J.R. June. 1987

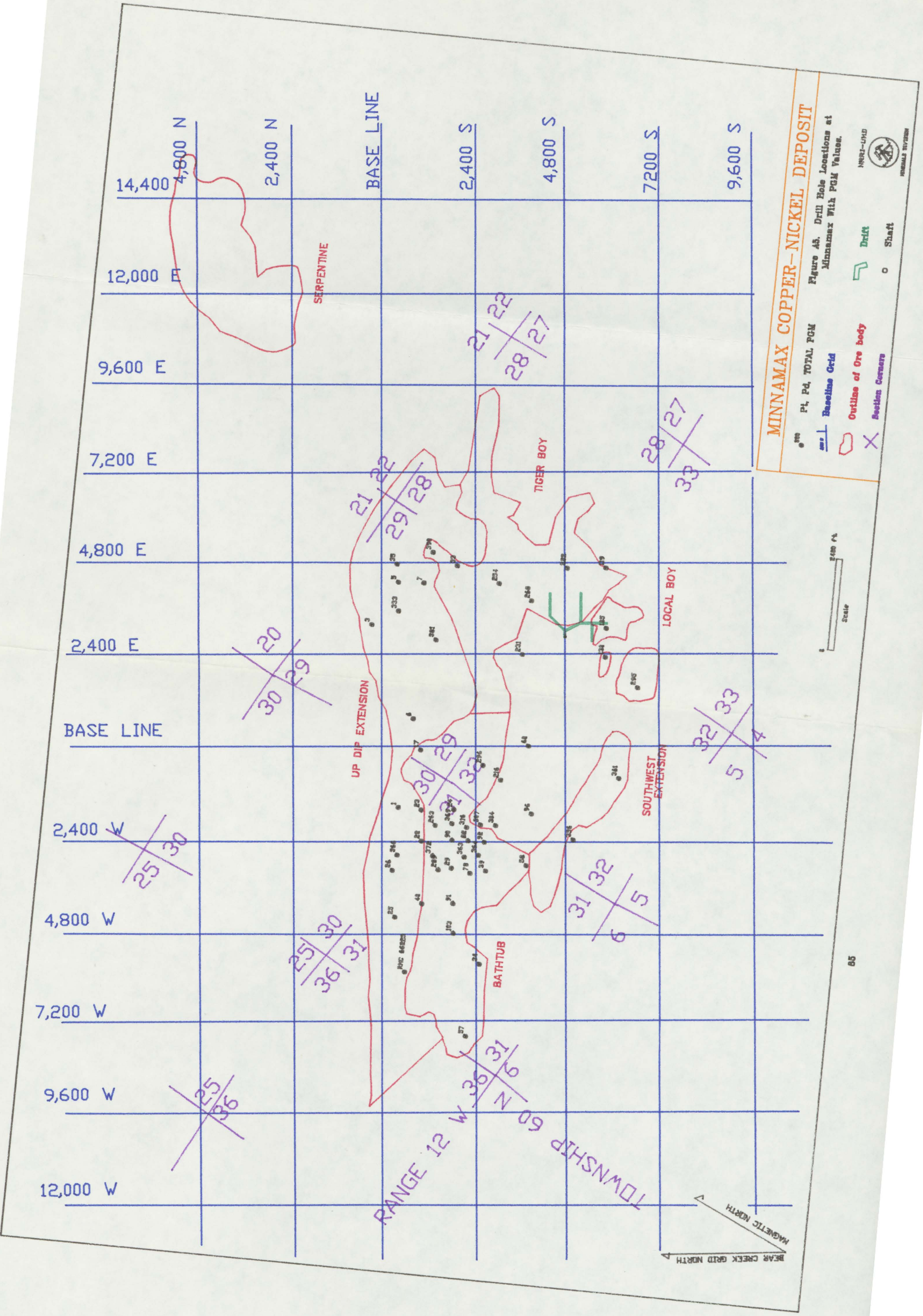


Figure A5. Drill Hole Locations at Minnamax With PGM Values.