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A HISTORY OF COPPER-NICKEL AND TITANIUM OXIDE TEST PITS, BULK SAMPLES, AND RELATED METALLURGICAL TESTING IN THE KEWEENAWAN DULUTH COMPLEX, NORTHEASTERN MINNESOTA

By

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Cover Photo
Teck Cominco bulk sample site at the Babbitt copper-nickel deposit, spring, 2001; looking northeast.

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ABSTRACT

This project describes the bulk samples (test pit and some drill hole composites) taken from various locations in the Duluth Complex since the 1960s, with minor background information on earlier work. Included are: 1) descriptions of sample areas; 2) local geology and expected grade of samples; 3) rationale for sample location; 4) review of the metallurgical results; and 5) an index of where the complete data (mostly metallurgical) can be found. Historical (Native American and early settlers) native copper, native silver, accidental iron ore prospects, and any other test pits are not covered in this report.

The copper-nickel and iron-titanium-oxide deposits associated with rocks of the Duluth Complex have had a number of large bulk samples removed for metallurgical testing since the 1960s. There are at least six bulk sample sites in the South Kawishiwi intrusion (SKI) and about fourteen bulk sample sites in the Partridge River intrusion (PRI; Table 1.) Common to most of these bulk samples have been erratic grades, relative to what had been outlined by prior drilling, and difficulty in defining and producing an “average” or “typical” mineralized sample. Our research experience has led us to believe that the mineralization is borderline chaotic over short distances within the mineralized zones of these deposits. Thus, in many instances, it may not be possible to obtain an “average” mineralized bulk sample with samples of small size (depending on how one defines “average”). It is important to note that once a bulk sample site was chosen by a mining company, based on limited on-site drilling, no detailed drilling or mapping was conducted prior to collecting the sample.

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INTRODUCTION

This paper is a narrative review of the modern bulk sample history for the Duluth Complex (Complex; Fig. 1). The bulk samples that were collected consisted of either test pits or composite samples generated from multiple drill holes. We are geologists, not metallurgists. This distinction means that our definition of a "successful" bulk sample is one where the overall grade and mineralogy is what was predicted from assaying, drilling, or outcrop study. Geologists often tend to see these pits as tests of their skill in regards to predicting geologic and assay continuity. A metallurgist may define a successful bulk sample as one that represents, or is typical of, the bulk composition and the mineralogical ratios of the deposit, and therefore, allows reliable conclusions to be drawn from testing certain steps in the beneficiation process.

We set out to concentrate on the geological aspects of these test pits, especially how the grade of the final sample compared to the predicted grade and on the issues of geologic or assay continuity. What metallurgical data we have included is that which we clearly understand. Hopefully the indexing aspects of this paper will allow interested parties to more easily track down the existing metallurgical information when they need it.

We did not find the differences or comparisons between predicted grade and head grade to be well documented.

Note that the bulk samples that are described in this report were collected from the basal contact zone of the Duluth Complex. Test pit and bulk sample work in the Beaver Bay Complex, Logan Sills area of far northeastern Minnesota, or the North Shore Volcanic Group are not covered in this study because no modern documented work is known. There has been historic exploration for native copper and other materials in rocks of the North Shore Volcanic Group by both native Americans and early settlers, as well as exploration for Silver Islet-type native silver mineralization in the Logan Sills, but no effort was made to track down any of these data. There may be more current work on mineralization in the Logan Sills of Ontario that could be applied to the similar geology in Minnesota, but this work is not covered in this report. The Minnesota Department of Natural Resources (MDNR) has released a comprehensive indexing report covering historic test pits, drill holes, and "ore" mineral occurrences in Minnesota as far back as the mid-1800s (Martin, 1983).

PURPOSE

The purpose of this project is to index and consolidate, though not necessarily recreate the data for, a record of bulk samples taken in the Duluth Complex (Fig. 1). This record is intended to act as a starting point for those doing further metallurgical work in the Complex.

FUNDING

This project was funded under the PUTF (Permanent University Trust Fund) program of the University of Minnesota. This research money is generated from iron mining revenues and is granted in keeping with the NRRI mission of encouraging economic development in Minnesota, in this case by providing a narrative and dataset useful in assessing the history of the many development opportunities in copper-nickel-PGE and massive-oxide deposits in the

region. Additional funding came from the NRRI's State Special funding.

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As always, Steve Hauck, Dean Peterson, and Larry Zanko at NRRI have contributed in substantial and various ways to this work.

METHODS

This report is based on a literature search of archival records stored at MDNR and NRRI (Duluth and Coleraine), archives at the Iron Range Research Center in Chisholm, MN, discussion with those listed above, discussion with other various involved parties, and our general knowledge of the exploration and development history of Duluth Complex "ore" deposits. Note that the terms "ore" and "deposit" as used here have no economic connotation. No new sampling was conducted for this project. Some pit locations were field checked and sites photographed (photos on CD in the back pocket of this report).

All tabulated drill hole-derived assay and lithology data were taken in modified format from Patelke (2003), unless otherwise noted. In general, footages were used in the calculations and tables of this report rather than sample counts ("n"), because some data were taken from tables that combined lithology and assay data in a single table; thus, the original sample lengths and counts may be lost. Patelke (2003) is also the source for drill hole locations as shown on maps in this study. PGE assay results used in the report are compiled in Severson and Hauck (2003). All drafting was by the authors. The basal contact of the Duluth Complex shown on many figures is from Miller et al. (2001). Note that the averages of assay values obtained from cored drill holes and blast holes are given as simple arithmetic averages, i.e., they have not been footage weighted. However, for the most part the copper, nickel, and sulfur assays represent core samples about 5-10 feet long, and properly weighting them doesn't change their value by an appreciable amount at these scales of comparison.

READER BACKGROUND ASSUMPTIONS

The Duluth Complex (Fig. 1) is a series of large, mafic to ultramafic intrusions extending from Hovland on the Lake Superior shore, west towards Ely, then curving southwest and south towards Duluth. The overall dip of these units is to the southeast, between 10° and 20°. The most current overall report and source for

Table 1. General records for major bulk samples and test pits in South Kawishiwi and Partridge River intrusions.

Project	*Responsible party*	*Year(s)*	*Tonnage*	*Comment*
SOUTH KAWISHIWI INTRUSION				
Spruce Road	USBM	3 holes drilled in 1953		Lab / bench tests on composite from 3 drill cores.
	INCO	1966-1967	1,150 tons	Source of sample uncertain, test work done uncertain.
	INCO	1974	10,000 tons	Pit along south side of Spruce Road.
Maturi	INCO	1968	700 tons (?)	Shaft and drift at Maturi, sample sent to INCO lab.
Serpentine	Reserve Mining	1980s	Uncertain tonnage	Exposure of massive sulfide assumed to be similar or related to Serpentine deposit as seen in Peter Mitchell Mine.
Dunka Pit	Eire/LTV	1960s1999	14-20 million tons	Stockpiles at Dunka Pit, moved for iron ore mining, and reclaimed.
PARTRIDGE RIVER INTRUSION				
Babbitt (Mesaba)	AMAX B1-341	1978	1,150 ton excavation, 560 tons sent as sample	Surface pit in NE corner of deposit.
	AMAX	1976		Shaft samples listed as "disseminated."
	AMAX	1976		Drift samples listed as "massive" or "semi-massive."
	Arimetco B1-374	1994	200 tons, split to 85 and 115 ton portions	Surface pit. Sample probably in weakly mineralized pegmatitic zone within Unit III.
	Arimetco B1-411	1995-1996	150 tons	Surface pit. Sample in western part of deposit, location in Unit I. Reasonably typical material.
	Teck Cominco B1-321	2001	5,000 tons	Very typical material. Final sample much larger than 500 tons outlined by Severson.
	Teck Cominco B1-321	Future?	50,000 tons	Planned surface pit, at same location as Teck Cominco B1-321. EAW approved by State in 2003.
Dunka Road (NorthMet)	USS Bulk No 1	1971(?)	unknown tonnage	Surface pit near drill hole (26058) with mineralization only in top few feet.
	USS Bulk No 2	1971	300 tons	Surface pit near drill hole 26105. Intended to intercept mineralization seen in that hole.
	USS Bulk No 3	1971	20 tons	Surface pit near drill hole 26105. Re-entry of Bulk No 2 site to get material uncontaminated with hornfels.
	Fleck / Nerco	1990	2 large diameter core holes	Two large diameter holes and two smaller twins. All four holes twin two existing USS drill holes.
	PolyMet Composite	1998-2000	At least 37 tons shipped to testing laboratory	Reverse circulation drilling composite from about 55(?) reverse circulation holes.
Longnose Fe-Ti oxide (OUI)*	American Shield (?)	1984 & 1999	60 tons? for second sample	Surface pits, sample sent to CMRL** for process testing.
Water Hen Fe-Ti Oxide (OUI)	Drill holes SL-27, and SL-28	Drilled in 1975	about 400 ft. of drill core	USBM samples to test reduction processes on Fe-Ti ore; with goal of producing saleable or processable titanium slag product.

* OUI – Oxide-bearing ultramafic intrusion
** CMRL – Coleraine Mineals Research Laboratory

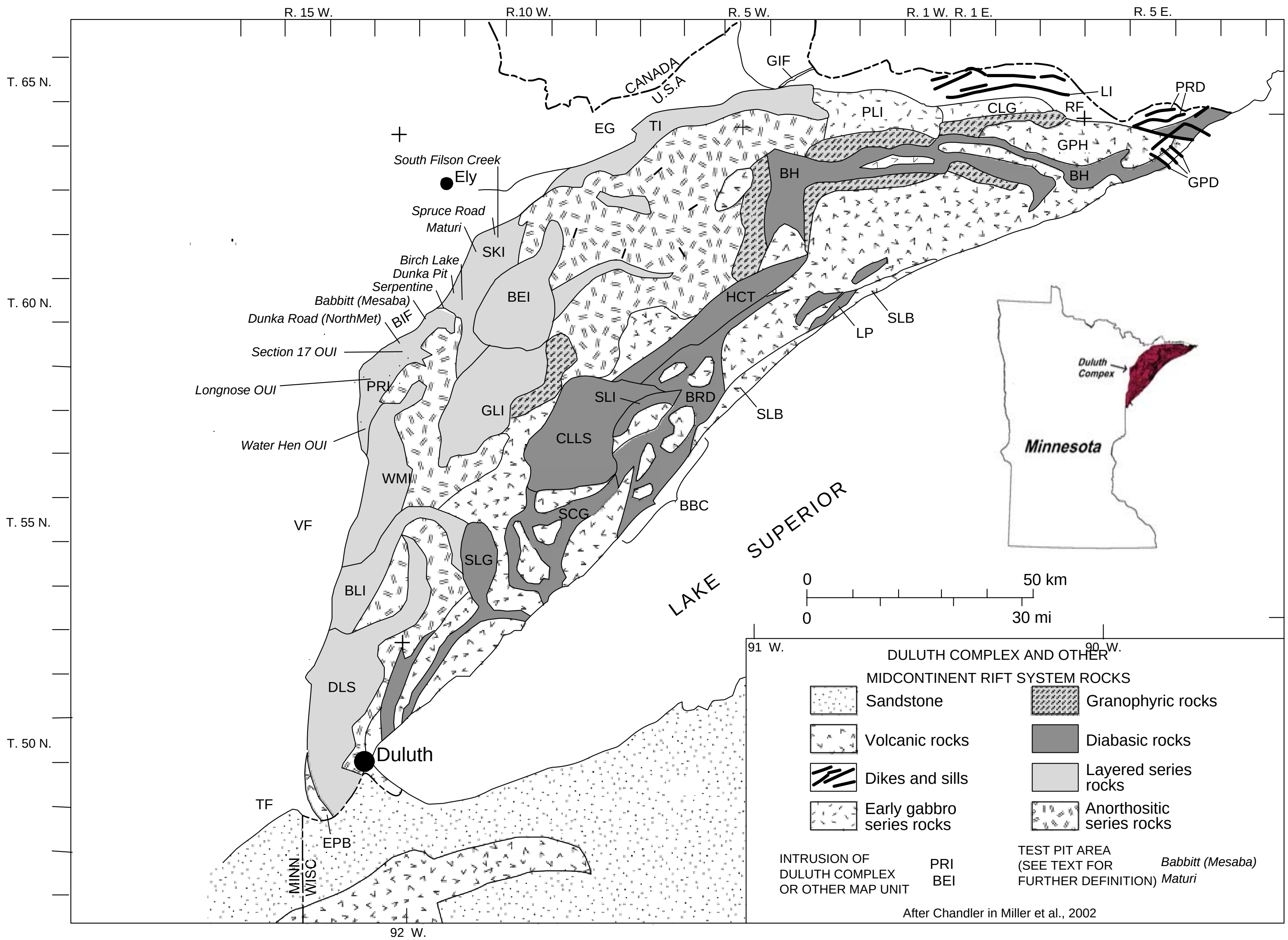

Figure 1. Generalized geologic map of the Duluth Complex and related rocks (from Miller et al., 2002a) showing locations areas where some form of bulk sampling has taken place along the western contact zone. Abbreviations are as follows: EG = Ely Greenstone (Archean); BIF = Biwabik Iron Formation, GIF = Gunflint Iron Formation, VF = Virginia Formation, RF = Rove Formation, TF = Thomson Formation (all five are Paleoproterozoic); LI = Logan intrusions; PLI = Poplar Lake intrusion; DLS = Layered series at Duluth, BLI = Boulder Lake intrusion, WMI = Western Margin intrusion, PRI = Partridge River intrusion, SKI = South Kawishiwi intrusion, GLI = Greenwood Lake intrusion, BEI = Bald Eagle intrusion, TI = Tuscarora intrusion (all 8 are contained within the Duluth Complex); CLG = Crocodile Lake gabbro, SLG = Sawmill Lake gabbro, SCG = Silver Creek gabbro, CLLS = Cloquet Lake layered series, SLI = Sonju Lake intrusion, BBC = Beaver Bay Complex, BRD = Beaver River diabase, HCT = Houghtaling Creek troctolite, BH = Brule Lake and Hovland gabbros, LP = Leveaux porphyritic diorite, EPB = Ely's Peak basalts, SLB = Schroeder-Lutsen basalts, GPH = Grand Portage basalts & Hovland lavas; GPD = Grand Portage dikes, and PRD = Pigeon River diabase.

references on the geology of the Duluth Complex is Minnesota Geological Survey (MGS) Report of Investigations 58, "Geology and Mineral Potential of the Duluth Complex and Associated Rocks" (Miller et al., 2002a), which includes a GIS-based compilation geologic map of the Duluth Complex on CD-ROM. The map is also available as a separate publication (MGS Miscellaneous Map 119, Miller et al., 2001). Report of Investigations 58 (RI-58) with its associated GIS database is available from the Minnesota Geological Survey on-line at http://www.geo.umn.edu/mgs/.

The reader is assumed to have some familiarity with Duluth Complex geology and geography, which is best described in RI-58, and the following reports:

- NRRI report on the South Complex area, from the Mesabi Range to Duluth (Severson, 1995). There are no copper-nickel test pits in this area, but there are good descriptions of Oxide-bearing Ultramafic Intrusions (OUIs) in this report, and more specifically, the Water Hen area;
- NRRI reports on the general igneous stratigraphy of the Partridge River intrusion by Severson and Hauck (1990, 1997);
- Babbitt deposit reports by Severson et al. (1994, 1996); Severson and Barnes, 1991; Patelke, 1994 (which includes assay data and an inventory of drill hole specific data for Babbitt and Serpentine deposits); geologic maps by Severson and Miller (1999) and Miller et al. (2005). Some of these reports have extensive maps and cross-sections included, and all contain geologic descriptions;
- NRRI reports and UMD thesis on the Dunka Road (NorthMet) deposit (Geerts et al., 1990; Geerts, 1991, 1994). These reports include numerous cross-sections and are the best publicly available work on the Dunka Road (NorthMet) deposit;
- NRRI report on the South Kawishiwi intrusion (Severson, 1994), which includes detailed geology at Birch Lake, Spruce Road, and Maturi (with cross-sections);
- NRRI report (Zanko et al., 1994) on the Serpentine deposit, with cross-sections;
- Dean Peterson's "Project 317," done for the MDNR in 1997, maps much of the copper-nickel assay chemistry across the Complex, and his recent reports for the NRRI refine these concepts and data presentation (Peterson, 1997, 2002). Note that much of the assay and lithologic data in Peterson (1997) is superceded by the Severson and Hauck (2003) and Patelke (2003) reports mentioned below;
- NRRI report (Severson and Hauck, 2003) that reviews the PGE mineralization in the Complex, with a complete listing of all publically available PGE assay related data (over 9,000 assays) for the entire western margin of the Duluth Complex;
- Patelke (2003) is a database of all publically available drill hole-based location, lithologic, and copper-nickel-sulfur assay data for the entire Duluth Complex. The lithological data is from both NRRI and previous mining company work, with NRRI logging taking precedence. The assay data therein is mostly reformatted from previous work;
- Severson and Hauck (in prep.) is a "waste rock characterization" review of mineralogy and chemistry of specific footwall rock units and inclusions.

The Complex contains a large number of sub-intrusions, of which only two of the largest have had documented bulk samples collected. Note that the majority of this report really focuses on four copper-nickel deposits in these two large intrusions. Spruce Road and Maturi in the South Kawishiwi intrusion (SKI), both explored by

INCO; along with Babbitt/Mesaba and Dunka Road/NorthMet in the Partridge River intrusion (PRI). Both deposits in the PRI have had attention from multiple companies, and are on a mix of state, federal, and private land. The INCO projects in the South Kawishiwi are mostly on federal land.

Differences in amount of company attention and in land ownership lead to differences in publically available data density and also affect the "institutional memory" in state agencies about these projects. Simply said, INCO never had to turn in very much material to the state, and had fewer dealings with the people at the state agencies because they were on federal land, but the various companies that have worked on the deposits in the PRI have turned in more material (both voluntary and involuntary) because of more state and private ownership, as well as having more dealings with state agency personnel. Also, U.S. Steel and Teck Cominco have been forthcoming about data sharing over the years; whereas, other companies have not been in a position to share their proprietary data. Data density in the SKI is also lower because of the loss of most of the INCO core, but virtually all the core for the PRI is intact.

THE METALLURGICAL PROBLEM

Sulfide mineralization in these deposits is cubanite, chalchopyrite, pentlandite, and pyrrhotite, with lesser bornite, other copper-iron sulfides, and a wide range of platinum-group minerals. As discussed later in this paper, the ratio between these minerals varies widely. In the mineralized zones, copper is usually about 0.5% and seldom over 1.5%. Copper to nickel ratios range from 2:1 to 5:1, but tend to float around 3:1. The actual value for any subset of data is dependent on how the user parses out definitions of deposit area, "ore" zone, and other factors of the calculation.

The Pt + Pd + Au content of these deposits is about 300 ppb on average, with higher local concentrations. The available data show that some PGE-enriched zones could add value to a copper-nickel mine, but probably there are no PGE-enriched zones that could support a Pt + Pd + Au operation without some copper and nickel recovery.

Throughout the exploration phases during the 1950s through 1980s, the main focus of metallurgical work on the Complex was to make separate copper and nickel concentrates that were needed for smelting. There were mixed results for this work – the more separated the copper and nickel, the lower the recoveries of both. Advances in hydrometallurgy have changed this picture in that the three main projects (Dunka Road/NorthMet, Babbitt/Mesaba, Birch Lake) under consideration. Now these companies plan some version of a hydro-metallurgical application that will allow treatment of a bulk concentrate. Besides the environmental benefit of hydrometallurgy, the ability to deal with a bulk concentrate will permit engineers to focus on total recovery, especially for PGEs, rather than concentrate grade.

The ore mineral species at Babbitt/Mesaba are shown below in Table 2. Copper-nickel ore mineralogy is <u>essentially</u> the same for all deposits in the Complex.

The CESL process is Teck Cominco's proprietary hydrometallurgical process (<u>C</u>ominco <u>E</u>ngineering <u>S</u>ervices <u>L</u>abora-tory). PolyMet is developing the PlatSol™ process of pressure oxidation and chloridation for metals extraction. Pre-sumably other hydrometallurgical schemes may be able to work with the ores of the Complex.

The following, quoted from a CESL publication on Babbitt/Mesaba concentrate (Jones and Moore, 2002), is a succinct description of the mineralogy problem for

Table 2. Mineral Species in Babbitt/Mesaba Ore (Jones and Moore, 2002).

Mineral	Chemical Formula	% Metal in Mineral
Cubanite	$CuFe_2S_3$	23.4% Cu
Chalcopyrite	$CuFeS_2$	34.6% Cu
Bornite	Cu_5FeS_4	63.3% Cu
Covellite	CuS	66.5% Cu
Pentlandite	$(Fe,Ni)_9S_8$	34.2% Ni
Bravoite	$NiFeS_2$	32.8% Ni
Talnakhite	$Cu_9(Fe,Ni)_8S_{16}$	37.2% Cu
Sphalerite	ZnS	67.1% Zn
Pyrrhotite	FeS -	
Pyrite	FeS_2 -	

the Complex: "*In theory, the highest grade concentrate that can be made from cubanite is 23% Cu; in practice, however, 15% - 20% Cu grade is the maximum achievable at reasonable recoveries, and such a concentrate attracts high freight costs and high treatment charges at a smelter.*

The primary nickel mineral is pentlandite, with some bravoite; the copper and nickel minerals are tightly inter-grown, making efficient separation of the nickel from the copper difficult. Flotation testwork to make separate copper and nickel concentrates has indicated that it is possible to make a 20% copper concentrate with 0.5% nickel, with approximately 75% copper recovery. The nickel would be recovered to a low grade bulk concentrate (5% copper, 5% nickel) which would have a low value. Under these circumstances, however, the project is not financially viable.

Alternatively, it is possible to recover both metals to a bulk copper-nickel concentrate. Flotation tests at the laboratory scale have shown that a simple flotation arrangement with one cleaner step can produce a 14% copper, 2% nickel concentrate. Under these conditions, copper recovery can exceed 90%, and nickel recovery is fair at 70%. While this bulk concentrate is likely not saleable on the concentrate market, it is amenable to the CESL Process."

GEOLOGICAL BACKGROUND

South Kawishiwi Intrusion

The basal contact of the South Kawishiwi intrusion (SKI; Fig. 1) extends from the Serpentine deposit and the inactive Dunka Pit iron mine (LTV Steel Mining Company) east into the Boundary Waters Canoe Area Wilderness (BWCAW) south of the Kawishiwi River and east of Minnesota Highway 1.

The SKI is heavily drilled, with almost 780 drill holes and wedges, but unfortunately much of this core is gone or unavailable. About 290 INCO drill holes and about 165 LTV Steel Mining Company (Erie Mining at the time of drilling) drill holes have no core remaining, and 70+ drill holes and wedges are part of the ongoing Birch Lake exploration program and are not available to the public. Many of the cores for the NM-series drill holes in the Dunka Pit area are incomplete in that core intervals through the iron formation are missing.

Work in the SKI is complicated by a more diverse geology than that of the nearby PRI. At Babbitt and Dunka Road, as well as throughout the rest of the PRI, the tabular stratigraphic format of wide, but thin, major (map or cross-section) units works well in describing the igneous stratigraphy. This is especially true in the lowermost 3,000 ft. of the intrusion. In general, units in the PRI do not seem to repeat. However, in the SKI the drill hole data must be put on cross-sections and examined in context to fully make sense, as there are discontinuous horizons, many isolated textural and mineralogical changes, vertical repetition of many units (interfingering, not structural?), more inclusions of uncertain origin, stratigraphic continuity disruptions due to large anorthosite bodies, and less of an overriding and clear igneous stratigraphy (Severson, 1994).

The SKI is made up of many sub-intrusions or sub-pulses, as is the PRI, but the localized nature of the drilling, combined with the absence of core for many drill holes, makes understanding the SKI in the neat terms of the PRI problematic. Severson (1994) describes the SKI geologic units as "compartmentalized" rather than continuous. A generalized depiction of the igneous stratigraphy for the SKI is shown in Figure 2.

Most of the known SKI footwall is Archean granite and associated rocks (Giants Range Batholith), with limited areas where the footwall is Paleoproterozoic Biwabik Iron Formation and Virginia Formation.

Partridge River Intrusion

The Partridge River intrustion (PRI, Fig. 1) is arguably the most studied portion of the Duluth Complex, at least in drill core (~1,015 drill holes). It is host to the Babbitt deposit (formerly known as MinnAMAX and now under development by Teck Cominco as the Mesaba deposit), the Dunka Road deposit (now called NorthMet by PolyMet Mining), plus smaller projects in the Wetlegs and Wyman Creek areas. Lesser projects are found at Skibo and Skibo South.

Besides the above copper-nickel projects, there are ilmenite-rich "Oxide-bearing Ultramafic Intrusions" (OUIs) with possible economic potential at Longear, Longnose, Section 17, Section 22, Skibo, and Water Hen (Fig. 1).

Rocks of the PRI consist of varied troctolitic and minor gabbroic rock types that are subdivided in drill core into eight broad igneous stratigraphic units, plus some cross-cutting OUIs and other units (see Fig. 3). These igneous rocks overlie the Virginia Formation and, where the Virginia Formation was removed during intrusion and assimilation, the Biwabik Iron Formation. Nowhere in the drilled portion of the PRI is the footwall (basal) contact with Archean granitic rocks (with the possible exception of one drill hole at the east end of the Babbitt deposit), as the foot-wall is to the northeast in the South Kawishiwi intrusion. The PRI units have been described in detail by Severson and Hauck (1990), and there is further description and references in Miller et al. (2002a).

Other Intrusions

The Duluth Complex has many other sub-intrusions with varying degrees of mineral potential for copper-nickel-PGE, as well as other minerals. Note that there is virtually no natural outcrop of mineralized rocks in the areas of the large copper-nickel deposits, and thus there is no reason to think that a dearth of mineralized outcrop in areas such as the Bald Eagle intrusion, Greenwood Lake intrusion, or the Cloquet Lake layered series reflects any lack of mineral potential.

No documented bulk samples or known metallurgical tests have been done in the other intrusions of the Duluth Complex. There has not been extensive exploration drilling in intrusions other than the PRI and SKI.

Large excavations for road and development projects in Duluth (for instance, the Ulland Brothers quarry in the basal North Shore Volcanic Group rocks on Becks Road), and a few dimension stone quarries are all the large man-made exposures that are known in the other sub-intrusions. Some smaller iron and titanium

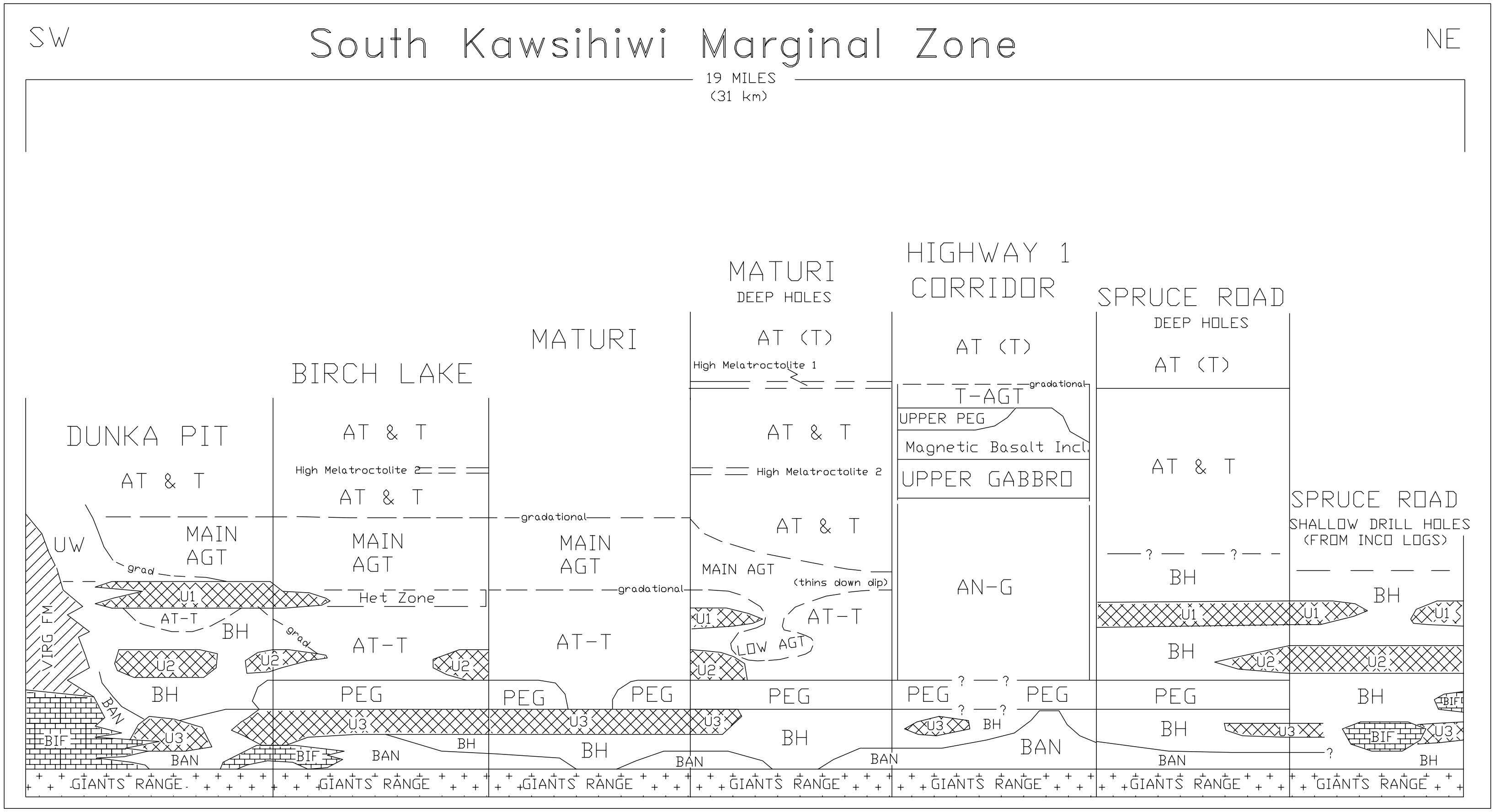

Figure 2. Generalized stratigraphy for the marginal zone of the South Kawishiwi intrusion (from Miller et al., 2002a; modified from Severson, 1994).

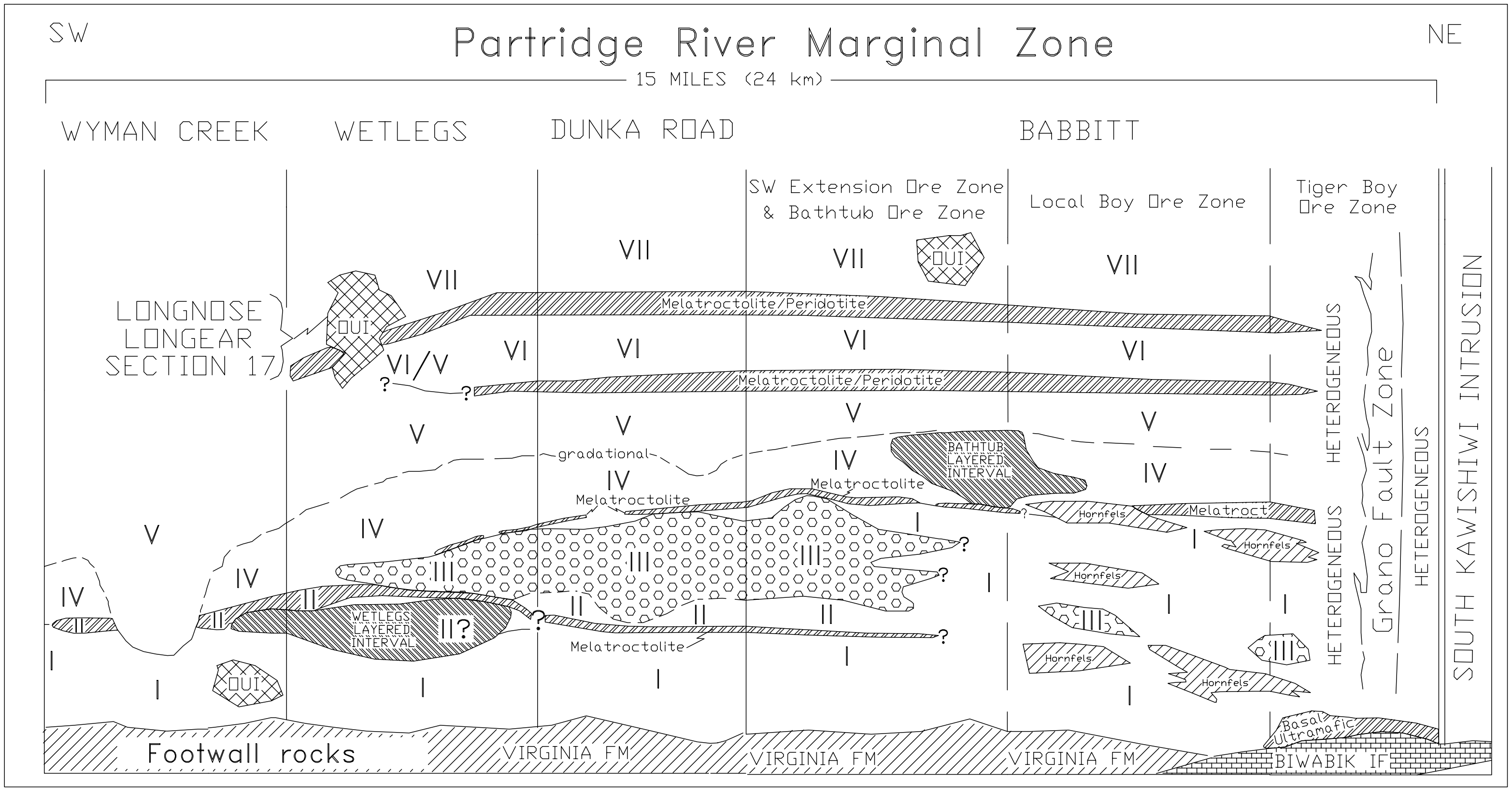

Figure 3. Generalized stratigraphy of the marginal zone of the Partridge River intrusion (from Miller et al., 2002a; modified from Severson, 1994).

ore test pits in the "Gunflint Corridor" (that area of the Complex largely accessed from the Gunflint Trail out of Grand Marais) penetrate the Complex. See Grout (1949-1950) for discussion about pits and drilling in the Gunflint area and Martin (1983) for overall records on historic test pits in Minnesota.

PROSPECTING HISTORY

Relatively poor exposure, difficult country to traverse, and a once difficult leasing process have limited prospecting by individuals. Hauck et al. (2002) mapped the history of company leasing and exploration in the Complex. Beyond that map presentation, there is nothing available that could be regarded as a comprehensive prospecting history for the Duluth Complex. Company records generally become public after leases are dropped, and those company records are the source for much information quoted in this paper.

Leasing in Minnesota

Minnesota state mineral lands are technically explorable only when under state lease. There is no federal claim process in Minnesota. Federal lands are leased by negotiation. See MDNR Publication "Leasing state-owned non-ferrous metallic mineral rights in Minnesota" (MDNR, 1997) about leasing state non-ferrous mineral rights in Minnesota. Contact the Forest Service in Duluth for information on leasing federal lands (contact names and addresses in Appendix 1).

Severson (2003) gives a review of permitting for mining and development in Minnesota, and it will also be helpful in determining a course of action for future test pit work because most pits will require at least some dealings with state regulatory agencies. Severson's report also outlines the leasing process as summarized from various MDNR reports and publications.

Private mineral rights leases are strictly between the owner and lessee. The only detailed public information about these properties <u>may</u> be tax payment records on file at various county offices.

EXPLORATION HISTORY

See Miller et al. (2002b) for a linear outline of the history of exploration including mapping, drilling, and assaying in the Complex.

DRILLING HISTORY

Over 2,100 holes have been drilled into the Duluth Complex (Patelke, 2003). Actual counts depend on one's definition of exploration, and how one treats wedges and re-drills. The PRI drilling includes ~1,015 drill holes, of which 222 are in the underground portion of the Babbitt deposit. There were about 780 drill holes in the SKI as of this writing. The MDNR retains core or samples for about 1,050 to 1,100 of the Complex holes (pers. comm., R. Ruhanen, MDNR, 2003).

Many INCO drill cores (over 300?) were lost in a core shack fire in Ontario in the 1970s. The upper, unmineralized portions of the holes had already been skeletonized with most of the core being discarded on site in Minnesota (unconfirmed rumor that core had been thrown into South Filson Creek (pers. comm., A. Bite, retired INCO); we looked near the bridge in 2004 and did not find any material). The lower mineralized portions were lost in the fire (M. Severson, NRRI, pers. comm., 2004; based on previous conversations with Mr. Andy Bite, formerly with INCO). About 160 holes drilled by Erie Mining (LTV) for iron-formation development in the LTV Steel Dunka Pit are stored in a small building at the Cliffs-Erie site. Core holes (about 170) drilled by United States Steel Corp. are now the property of RGGS Land and Minerals, Ltd., L.P. out of Houston, TX, and are stored at the Coleraine Minerals Research Lab (CMRL) at Coleraine, MN.

Around 87 holes drilled by PolyMet up to 2001, 109 PolyMet holes drilled in 2005, and about 70 holes and wedges drilled by Birch Lake Joint Venture/Franconia, mostly in the late 1990s, have not had data submitted to the public record, except for number, date, location, depth, and basic geologic intercepts. The available data is recorded on Minnesota Department of Health drill hole abandonment reports.

The database in Patelke (2003) details the extent of publically available drill hole location, downhole survey, and assay data, as well as extensive, searchable data for the lithologic logging done in the Complex.

DEVELOPMENT HISTORY

All of these projects had extensive drilling, and actual development starts have been done at:

- Spruce Road (mine plan and permit application by INCO in 1974);
- Maturi (shaft and mine plan by INCO);
- Birch Lake (resource definition, probably some mine planning by Franconia Mineral Resources of Spokane, WA;
- Babbitt/Mesaba (test pits, underground excavations, extensive mine planning);
- Dunka Road/NorthMet (bulk samples from surface and from drill hole, as well as mine planning).

Current Projects Status

Four projects are known to have work continuing at the present time:

- Birch Lake is undergoing the process of defining a deep PGE ore zone and consolidating land position (Franconia Mineral Resources);
- Babbitt/Mesaba is in metallurgical evaluation (Teck Cominco submitted information to the MDNR in 2003 indicating the desire to develop a 50,000 ton test pit);
- Dunka Road/NorthMet is moving towards development; PolyMet having secured the former LTV processing plant, continuing to drill, and being in the midst of the environmental review process. More re-evaluation has greatly improved the project economics over that proposed in 2001.
- South Filson Creek is undergoing some field mapping, geophysics, sampling, and core drilling (pers. comm., William Cronk, Encampment Resources, 2003).
- Wallbridge Mining from Ontario (now Duluth Metals Ltd.) is drilling the “Maturi Extension” (aka Highway One Corridor) in 2006.

Other areas are under state lease, but with little activity reported (contact the MDNR for other information, contacts in Appendix 1). The status of other private leases is unknown.

RECOMMENDATIONS

A broad review of the data available consistently indicates, from a geologist’s viewpoint, that there is a problem with test pit bulk sample grades relative to the expected grade from prior sampling of core holes or blast holes. There is also a persistent question among those working on the Complex as to assay continuity at all scales, from test pit to deposit. To the authors’ knowledge, no publically available studies have been done that definitively address the geologic and assay continuity of these copper-nickel deposits. These persistent unanswered questions are relevant here because they color one's view of the data related to this test work.

- The extensive geologic work on these deposits by NRRI over the last 20 years has concentrated on understanding of the geology at a deposit to regional scale through drill core logging and field mapping. More attention to 3-D structural, textural, assay, and geochemical mapping is probably needed.
- We believe the grade continuity question should be investigated by stripping and mapping of outcrop, coupled with a series of short core holes, to study the issue of continuity in 3-D over a small area. This study could then be tested against the available information from widely scattered exploration drilling. A corollary to this study would be in-depth statistical studies based on the available assay and lithologic data.
- Opaque mineral (sulfide and oxide) percentages have not been assessed and tabulated in a quantitative way, or even in a well constrained, qualitative way. Before these deposits go to development, better knowledge about the distribution of the bulk sulfide mineralogy (chalcopyrite, cubanite, pentlandite, and pyrrhotite) will be needed.
- Also, the oxide mineralogy and distribution of magnetite, ilmenite, their various intergrowths as well as any more valuable oxides (i.e., chromium- and vanadium-bearing) should be worked out. In all cases, carefully done broad studies would be more valuable <u>at this stage</u> of exploration than exhaustive studies on any particular deposit. The broader study would narrow the range of investigation for future studies.
- No company has yet drilled and core sampled multiple sites for a test pit and then chosen the best, i.e., most representative or typical site available. All pits were initially selected on the basis of a single exploration drill hole. Some sites were then tested with close-spaced core drilling and assaying prior to sampling or close-spaced blast hole drilling immediately prior to sampling. As far as we have determined, no site has ever been abandoned as inappropriate during the actual bulk sampling phase, nor have any sites been stripped and mapped prior to any decision on final excavation.
- No evidence was found for any study comparing assays from blast hole drilling (typically air hammer drilling) to assays from core drilling.
- During our study of the historical data, we constantly found that the metallurgical reports rarely stated up-front the origin of the sample that they tested. In many cases, it was impossible to determine where and what was sampled, and thus, the particular metallurgical report could not be put in context. In the future, individuals and companies doing metallurgical investigations would assist future geologists greatly by <u>including more details about sample source and location</u> in their reports. It is also up to the geologists to see that copies of their site reports are included with these metallurgical studies.

CONCLUSIONS

Conclusions to this report are limited because this study is primarily a review of existing data. The conclusions, therefore, reiterate the following recommendation: if the grade is lower than expected in the test pit material, <u>and if this matters</u> (it may not from a metallurgical point of view), then a large scale statistical approach combined and reconciled with a local surface stripping, mapping, and sampling program may shed light on some of these issues. Furthermore, if assay and geological continuity matter at the deposit scale, then some plan should be made to address this issue early on in any future bulk sample work.

TEST PIT AND BULK SAMPLE WORK

COMMENTS ON "PRECIOUS METALS"ASSAYS IN THE OLDER WORK

A major economic factor to recognize is that in the 1960s INCO (and Anaconda in assessing the INCO properties) were using a figure of 0.015 ounces/ton "precious metals" value in their mine feasibility calculations. This converts to about 0.46 grams/ton (assuming one ounce equals 31.103 grams), which is roughly 0.5 ppm "precious metals." We have seen no evidence that other companies ever calculated any value for these metals based on core assays. AMAX calculated precious metals credits from assays on concentrate, thereby avoiding any recovery issues.

Even though there are locations with better values than these, a value of 500 ppb is probably somewhat high across a single deposit. The Severson and Hauck (2003) PGE compilation paper indicates that 500 ppb is probably optimistic as overall values for Pt + Pd + Au for the SKI and PRI (for drill core intervals where all three elements have been assayed) average about 0.3 ppm (see Fig. 4, calculation by Patelke in 2004). There is not enough INCO core remaining to fully test this theory for either Spruce Road or Maturi. The older reports give no hint at assumed recoveries for these elements. Therefore, it is difficult to discern how much of the older resource economics are based on values returned from these other metals.

Given past analytical techniques, which was a total PGE value, the older assaying is suspect in general, and that for these metals only "modern" (post 1990) assays should be used.

There is insufficient, publically available assay data for precious metals to establish the geometry of the PGE mineralization at most of the deposits. In other words, we know where the assays are, but we do not know how or if these enriched zones connect (except for parts of the Dunka Road and Birch Lake deposits). Also, because there is little sampling available for areas without visible copper-nickel mineralization, the data at hand greatly precludes the possibility of finding hidden zones of Pt + Pd + Au mineralization.

The following three tables (Tables 3, 4, and 5) are derived from Severson and Hauck (2003) where "precious metals" means Pt + Pd + Au. The decrease in average grade with increasing length of sample indicates that at open-pit bulk mining scales the grades could drop substantially. This does not preclude mining with more selective methods. Note that the maximum values are suspect due to the possibility that some of the longer samples themselves may be physical composites.

It is interesting to note the composited values vary little relative to the actual sample support, and that this number (~300 ppb) is similar to the simple averages for the two intrusions. These data may reflect a "background Pt + Pd + Au" in the areas of copper-nickel mineralization, where the bulk of these samples have been taken. Sampling for these materials is limited in parts of the Duluth Complex that are outside the known copper-nickel deposits.

SOUTH KAWISHIWI INTRUSION BULK SAMPLES

Introduction

Historic bulk samples that were collected in the SKI are listed in Table 6.

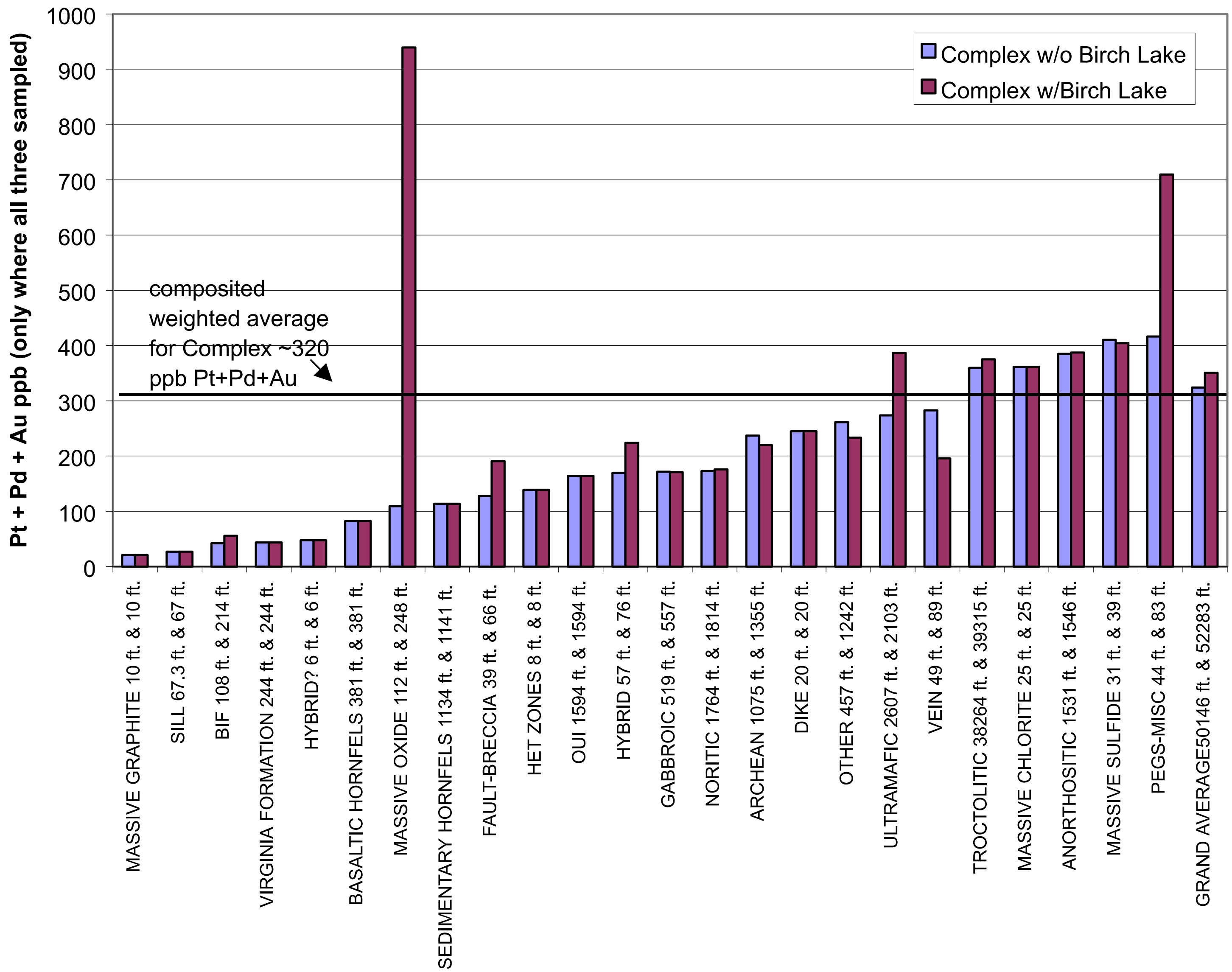

Figure 4. Bar graph comparing intrusive rock types, in the various copper-nickel deposits, with precious metals. Note that in general there is no one particular rock type that shows excessively high precious metal contents, except for massive oxide zones (variable digested Biwabik Iron Formation inclusions) and pegmatite (most from the PEG Unit) – both are somewhat unique to the Birch Lake deposit. Because Birch Lake mineralization is different than the other deposits, especially in the massive oxide category, it is shown as the dark bars on this bar graph. Footages are sampled footages for each rock type, Complex w/o Birch Lake first, then Complex w/Birch Lake second.

Table 3. Pt + Pd + Au values (from Severson and Hauck, 2003) for the South Kawishiwi intrusion. Using only samples from drill core where all three elements were sampled and are greater than zero, i.e., not weighted for all footage drilled.

	Average Au+Pt+Pd in ppb	Number of samples	Average length of sample-feet	Total feet of core sampled
All samples	382 ppb	2,119	6.48 ft.	13,749
All samples where footage greater than or equal to 20 ft.	64 ppb	21	44 ft.	924
All samples where footage greater than or equal to 15 ft.	114 ppb	38	32.3 ft.	1,227
All samples where footage greater than or equal to 10 ft.	261 ppb	112	18.8 ft.	2,106
All samples where footage greater than or equal to 5 ft.	260 ppb	963	10.4 ft.	10,334
Samples where footage less than 5 ft.	522 ppb	933	2.62 ft.	2,449

Table 4. Pt + Pd + Au values (from Severson and Hauck, 2003) for the Partridge River intrusion. Using only samples from drill core where all three elements were sampled and are greater than zero, i.e., not weighted for all footage drilled.

	Average Au+Pt+Pd in ppb	Number of samples	Average length of sample-feet	Total feet of core sampled
All samples	293 ppb	5,439	8.4 ft.	45,705
All samples where footage greater than or equal to 20 ft.	190 ppb	11	96.5 ft.	1,061
All samples where footage greater than or equal to 15 ft.	211 ppb	19	62.7 ft.	1,192
All samples where footage greater than or equal to 10 ft.	326 ppb	3,306	10.4 ft.	34,419
All samples where footage greater than or equal to 5 ft.	294 ppb	4,696	9.4 ft.	43,963
Samples where footage less than 5 ft.	283 ppb	743	2.3 ft.	1,742

Table 5. Composited Pt + Pd + Au values for the combined South Kawishiwi and Partridge River intrusions. Twenty foot composites calculated using data from Severson and Hauck (2003). Using only samples from drill core where all three elements were sampled and are greater than zero. Data are all composited to 20 ft. samples. Sample support is footage of actual sample used to create each 20 ft. composite.

	Average Au+Pt+Pd in ppb	**Average footage of sample support in 20 ft. composite**	**Total composite length**	**Percent of total Au+Pt+Pd in ppb dataset accounted for in this classification**	**Maximum value**
All 20-foot composites	291 ppb	14 ft.	84,048 ft.	100%	
Average of all composites with minimum of 5 feet of sample support	294 ppb	15.8 ft.	72,551 ft.	86.3%	
Average of all composites with minimum of 10 feet of sample support	304 ppb	18.2 ft.	58,368 ft.	69.4%	3,451 ppb
Average of all composites with minimum of 15 feet of sample support	301 ppb	19.55 ft.	49,317 ft.	58.7%	3,451 ppb
Average of all composites with minimum of 20 feet of sample support	283 ppb	20 ft.	42,705 ft.	50.8%	2,762 ppb

More recent and current company work in the SKI includes: mapping and drilling by Wallbridge Mining, and drilling at Birch Lake by the Beaver Bay Joint Venture, both in the 1990s. More recently there has been some reconnaissance work by others, especially at South Filson Creek. See Miller et al. (2002b) for details on government-sponsored work in this area during the last fifteen years.

As this report was being assembled (June, 2004), Franconia Mineral Resources (an owner of the Beaver Bay Joint Venture) had reached an agreement with American Copper and Nickel Company (ACNC), the United States subsidiary of INCO. This agreement transfers all of the INCO federal leases and data for Minnesota to Franconia. The leases are still active, and until Franconia completes their review of these data, it is unlikely any more information about INCO's past activities in Minnesota will be released by the company. The USFS (U.S. Forest Service) in Duluth may also hold some records of past INCO activities. Because these areas are still under lease, this information may be confidential information.

Table 6. South Kawishiwi intrusion bulk and composite samples for metallurgical testing.

SOUTH KAWISHIWI INTRUSION						
Project	***Responsible party***	***Year(s)***	***Tonnage***	***Comment***	***Grades***	***Reference***
Spruce Road	USBM	3 holes drilled in 1953, report issued in 1955		Lab / bench tests on composite from 3 drill cores and / or outcrop samples?	Reported head grade of 0.38% Cu, 0.14% Ni, 0.88% S	Grosh et al., 1955, USBM Report 5177
	INCO	1966-1967	1,150 tons	Source of sample uncertain, test work done uncertain.		1974 INCO project description on file at MDNR in AMAX archive
	INCO	1974	10,000 tons	Pit along south side of Spruce Road, processed by INCO at Sudbury(?).	Reported head grade of 0.47% Cu, 0.15% Ni, 1.08% S	1974 INCO project description on file at MDNR in AMAX archive
Maturi	INCO	1968	700 tons (?)	Shaft at Maturi, sample sent to INCO lab at Sudbury(?).		1974 INCO project description on file at MDNR in AMAX archive
	INCO	1968		Drift at Maturi, some drilling done from drift, but little information in NRRI or MDNR files. Assume some material must have been sent for metallurgical tests.		Misc files at MDNR and NRRI
Serpentine	Reserve Mining	19-	Uncertain tonnage	Exposure of massive sulfide assumed to be similar or related to Serpentine deposit in Peter Mitchell Mine. Exposed during iron-formation stripping.		Ruhanen (2002) for MDNR, Severson (1994) South Kawishiwi report
Dunka Pit	Eire/LTV	1960s - 1999	14-20 million tons in stockpiles?	Stockpiles at Dunka Pit represent material removed for iron ore mine development.	0.23% Cu, 0.09% Ni, 2.20% S are the approximate values from exploration drilling. MDNR (J. Sellner, pers. comm., 2002) reports values of 0.29% CuO, 0.10% NiO (uncertain about whether these are oxide or sulfide assays)	Files at MDNR, and Ron Graber at CCI, pers. comm. (2002)

Copper-nickel exploration drilling in the Duluth Complex started near the Maturi deposit in the SKI, along the south side of Birch Lake, west of Minnesota Highway One. Prospectors Childers and Whiteside initially drilled a single hole at Maturi in 1951 after seeing mineralization in a road cut in 1948. There is little exposure at Maturi, and this begs the question of where this road cut was. If it was at Spruce Road, rather than Maturi, why did they drill at Maturi? Also, why did the USBM later put down their three holes at Spruce Road rather than Maturi? After the Childers and Whiteside drilling, INCO and Bear Creek began their exploration programs, and the USBM drilled three holes along the Spruce Road east of Minnesota Highway One. In the mid-1950s, both INCO and Bear Creek secured leases and began drilling programs in other portions of the SKI and the nearby PRI.

In the 1960s and 1970s, INCO did extensive work on the Maturi and Spruce Road deposits in the SKI. This work included drilling, test pits, metallurgical sampling, a test shaft, and mine planning. Their notice to the U.S. Forest Service on January 7, 1974, pertaining to a permit application for open pit mining at the Spruce Road project, eventually led to Minnesota's "moratorium" on copper-nickel mining during the time of the "Regional Copper-Nickel Study." This application submittal was probably the first action requiring a major environmental regulatory response for the mining of these deposits (U.S. Forest Service, 1974).

According to a pair of early 1960s Anaconda documents (Swayne, 1963, mostly about Spruce Road; and Dyas, 1963, mostly about Maturi; both on file at MDNR) detailing examination of these properties for joint venture with INCO, the original plan was for an open pit at Spruce Road and an initial underground operation at Maturi. The economics of mining underground at Maturi were dependent on using the Spruce Road concentrator. In this INCO plan, as open pit mining waned at Spruce Road, the surface mining equipment would have been moved to two ore more small new pits updip(?) at Maturi where underground mining would already be in progress. INCO planned to ship concentrate off-site for smelting. At the time of the writing of the Anaconda reports, there was no mention of any test pits, and the reports predate the shaft development at Maturi.

Spruce Road

USBM Work at Spruce Road

In 1953, the U.S. Bureau of Mines drilled three holes at Spruce Road (Grosh et al., 1955). The locations of important drill holes and pits at Spruce Road are given in Figure 5. The Anaconda memo mentioned previously about the INCO Spruce Road properties (Swayne, 1963) makes reference to the USBM study. The Anaconda document says on page 13: *"In 1955 the USBM made preliminary laboratory tests on mineralized fresh outcrop and diamond drill core samples. This material was lower than average anticipated grade, but otherwise representative."* What is uncertain here is the phrasing of "…lower than anticipated grade…" and whether that meant that some sampling indicated that the grade as calculated from the original samples was greater than the head grade of the composite, or that overall, better grade results were expected. The available values for the USBM tests are given below in Table 7.

The 1955 USBM study was most concerned with three holes they drilled along Spruce Road, but also gives a good description of the state of knowledge at that time about this area with some outcrop sampling, basic mapping, estimates of footwall depth, drill logs, etc.

Reference is made in the USBM study to "test pits" in the area of drill hole number 3

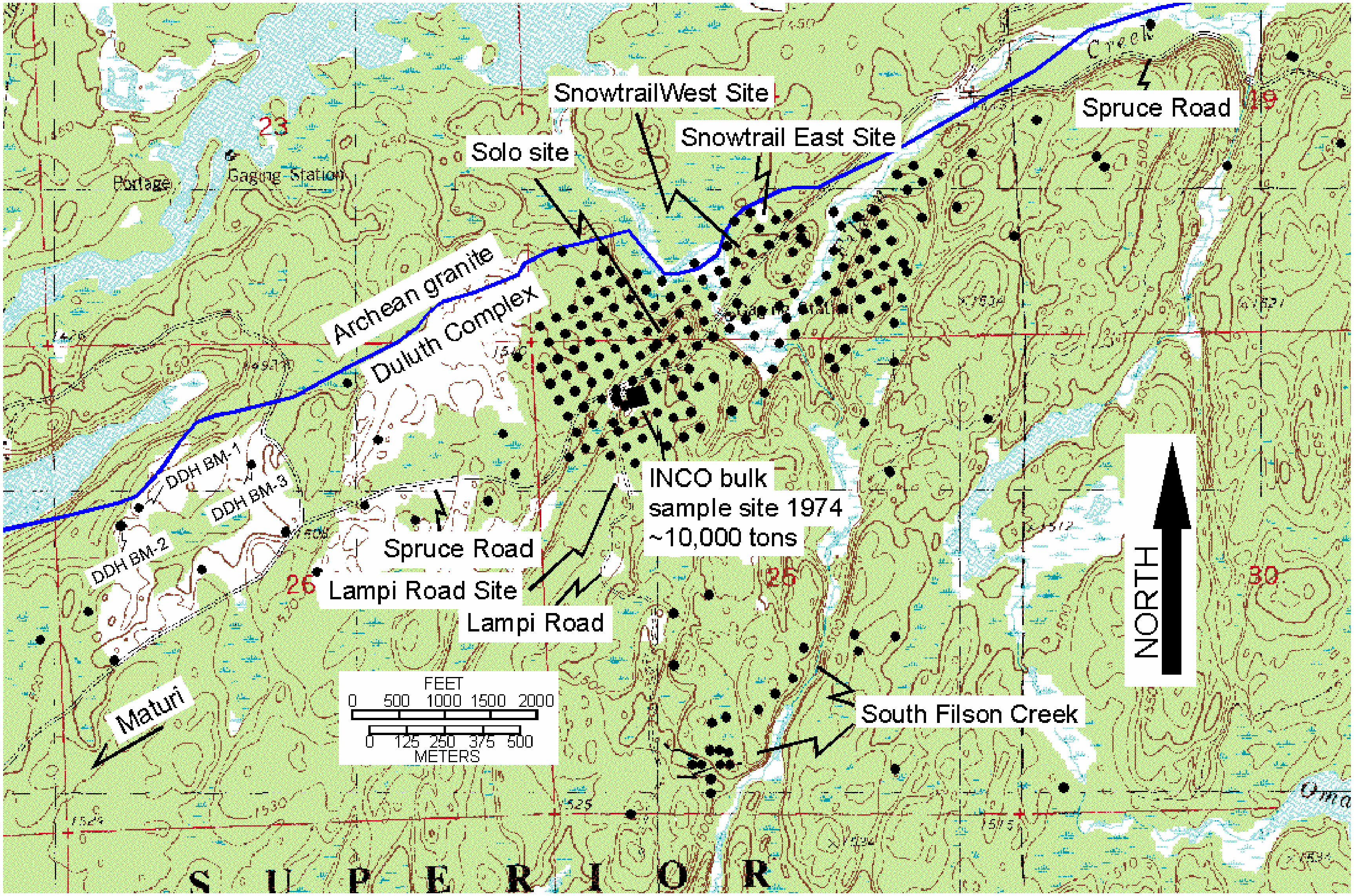

Figure 5. Topographic map of the Spruce Road deposit showing drill hole and bulk sample locations.

Table 7. Head versus concentrate for USBM 1955 samples from drill core and outcrop (?) (Grosh et al., 1955).

	Cu%	Ni%	Co%	S%
Indicated Grade	?	?	?	?
Head grade	0.38	0.14	0.038	0.88
Concentrate grade	12.04	2.039	0.22	20.70

(BM-3), but these pits are located nearby in the footwall iron-formation and were not Cu-Ni sample sites.

INCO Spruce Road Bulk Samples – Introduction

INCO drilled a total of 221 holes in the Spruce Road area from 1954 to 1973 (Fig. 5). This includes 133,000 feet of drilling with about 9,600 copper and nickel assays over about 89,000 ft. They did not generally do assays for sulfur, but did do some assays for cobalt (about 10,000 Duluth Complex assays for cobalt are in the data set for Peterson, 1997).

A 1975 INCO document entitled "Description of operating concepts required to establish preoperational monitoring for INCO's proposed Spruce Road Project" (INCO, 1975, on file at MDNR) touches on all aspects of INCO's plans. Maturi (the "South Lease") is mentioned, but the main focus is on Spruce Road (the "North Lease"). The document was written as a base project description for the expected EIS (Environmental Impact Statement), and it includes pit development maps, tailings basin layouts, discussion of mining and processing steps, and infrastructure needs.

The 1975 INCO report is based on the assumption of a twenty year project life, though it mentions that it would probably run longer, and describes an open pit mine taking 52,000 tons of waste and 40,000 tons of ore (1.3:1 waste/ore stripping ratio) per day to make 1,200 tons per day of concentrate (around 14-15 million tons per year of ore to make about 500,000 tons of concentrate). After twenty years the pit would be a roughly east-west oval 5,700 feet by 3,000 feet and 1,000 feet deep. The tailings basin would be southwest of the project and tailings would be piped across Minnesota State Highway One. Waste rock would be stockpiled to the southeast of the pit. There would be no smelter on site.

The 1975 INCO paper describes two test bulk samples from the Spruce Road property and one from Maturi: *"In 1966-1967, 1,150 tons of mineralized material was removed from the North Lease and, in 1968, 700 tons was removed from the test shaft on the South Lease and shipped for metallurgical testing in INCO's Process Research laboratories and pilot plant facilities. In January of 1974, a 10,000 ton bulk sample was removed from the North Lease for similar testing."*

These tonnages are in agreement with Watowich et al. (1981) who reports a 1966-67 sample of 1,043 tonnes taken from "surface pits" and a 1974 sample of 9,072 tonnes from a single pit at Spruce Road. However, the "Exploration" volume of the "Regional Copper Nickel Study" reports a 50 short ton and a 10,000 short ton sample from Spruce Road (note that 10,000 short tons equals 8,929 tonnes, and that all of these larger numbers are assumed to be referring to the same sample).

INCO Spruce Road – Smaller Bulk Samples

The actual locations of the smaller bulk samples (comprising 1,105 tons) collected from the Spruce Road deposit is a bit uncertain. There are numerous older pits along the Spruce Road, and it is possible that the 1966-1967 sample was a composited bulk sample taken from multiple pits/sites. It may be that no record exists for this earlier sample (whether 50 ton, 1,150 ton, or 1,043 tonne) because no papers were filed with any regulatory agencies for the sample. Strict reading of the above quote from INCO doesn't actually say anything about the nature of the source for the smaller sample. The 50 ton number shows up only in the Copper-Nickel Study, whereas the ~1,000 ton number is reported elsewhere, indicating the 50 ton number is probably a mistake.

Nonetheless, there are sites along the Spruce Road that have the "look" of being shallow sample pits, but no documentation has been found for any other sample work. The locations for some of these sites are on Figure 5. Photos of some of the sites, taken in June 2004, are included in Appendix 4 on the CD-ROM accompanying this report. The sites may also be areas stripped for bedrock examination with minimal sampling.

These pits are about 100 feet north of the Spruce Road, and about 750 feet, 1,800 feet, and 2,350 feet east of the now reclaimed INCO larger bulk sample site. Four potential sites that may have comprised the 1,105 ton sample are described below. Estimated Cu-Ni grades for each of these sites are presented in Table 8.

"SOLO" SITE

The site closest to the reclaimed 10,000 ton INCO site (Fig. 5; "solo site" in photos in Appendix 4) is a small cliff-face about ten feet tall (note that the MDNR blasted some rock from this same site in the 1990s for a field trip). Mr. Andy Bite, formerly of INCO, related to Mr. Larry Zanko of NRRI that INCO had taken a sample there. There is no documentation for this, and this does not have the "look" of being a very large excavation. This site is located at 599084E, 5298684N (UTM, NAD 83).

SNOWTRAIL-WEST" SITE

The site on the north side of the Spruce Road to the west of the snowmobile trail (Fig. 5; "snowtrail-west" in photos of Appendix 4) is about 40 feet by 100 feet, and the depression at this site is probably 6

Table 8. Estimated grades at miscellaneous INCO test sites based on simple averages of assays for the first interval of bedrock intercept in nearby drill holes. Geology is from INCO logging, and assay data is from INCO.

Test Site and drill hole numbers	Copper%	Nickel%	Copper% high value	Copper% low value	Rocktype
Solo: 32716, 34806,34810, 34813	0.37	0.13	0.57	0.18	Heterogenous troctolite w/ melatroctolite
Snowtrail-east (cabin): 32717, 32783, 32791	0.37	0.14	0.52	0.18	Hornfels (basalt?), olivine-gabbro, and troctolite
Snowtrail-west: 32777	0.80	0.18			Troctolite
Lampi Road: 11510, 32706, 34829, 34839	0.48	0.15	0.58	0.26	Troctolite, melatroctolite, and olivine-gabbro

to 8 feet deep. There is no evidence for blasting such as a sharp wall or fracturing (the blasted face seen on one boulder in the photos is from work by the MDNR for a field trip in the 1990s). Overall, this site appears to be a location where a bulldozer and backhoe moved material around, either to take sample or to trench for a view of the mineralization. The site was probably out-cropping before excavation. There is a large boulder pile to one side, as if the boulders were too big and were pushed out of the way. This site is located at 599257E, 5298939N (UTM, NAD 83).

"SNOWTRAIL-EAST" SITE

The other undocumented site close to the Spruce Road (Fig. 5; north of Spruce Road and east of snowmobile trail; "snowtrail-east" in photos in Appendix 4) is a bit larger than the "snowtrail-west" site. At the "snowtrail-east" site a cabin has been built, and the land is now private. The characteristics of this site are the same as above. The general appearance is of an area cleaned or scraped with a backhoe and/or bulldozer. The ground is essentially broken sulfide-rich rock. There is a "pinnacle" (~6 feet high) of hornfelsed basalt in the middle of this area. This site is located at 599319E, 5299097N (UTM, NAD 83).

There is essentially no soil development on either of the "Snowtrail" sites, with only sparse vegetation.

"LAMPI ROAD" SITE

While working in the early 1990s, Mr. Larry Zanko of the NRRI surveyed the locations of similar sites ("Lampi Road" in Table 8). Those locations are shown on Figure 5. The sites were not visited during this study. Mr. Zanko has been to all of these sites and believes them all to be of the same appearances, origin, and purpose. Certainly, if these were done by a mining company, it was INCO, as no other companies have worked in the area.

<u>INCO Spruce Road – Larger Bulk Sample</u>

In 1973, prior to collecting the 10,000-ton (9,072 tonne) sample, INCO drilled 24 short core holes (23 to 31 feet deep) around their drill hole 34802 along the south side of the Spruce Road at its intersection with Lampi Road. The distribution of these short holes is portrayed on Figure 6. Drill spacing was 25 feet and assays averaged 0.48% copper and 0.12% nickel over 502 feet of assay interval. Hole 34802 averaged 0.48% copper and 0.15% nickel from 8 to 35 ft. in depth. No sulfur assays were taken for any of this drilling. Average overburden thickness was about six feet (data extracted from Patelke, 2003). INCO was satisfied by the drilling results and commenced extracting mineralized material from a pit that was probably about 100 feet by 150 feet and 18 feet deep (Regional Copper-Nickel Study, 1977).

Our interpretation of the lithological data supplied by INCO indicated that the pit was mostly troctolite with lesser hornfels and pegmatite. Note that for INCO logging, "hornfels" can be either Virginia Formation, Biwabik Iron Formation, or basalt. At the main Spruce Road bulk sample site, the hornfels is more likely to be basalt or Biwabik Iron Formation rather than Virginia Formation.

This pit is reclaimed with grass and a few small trees on top growing in apparent glacial till applied as a cap to the excavation. According to a monitoring report for the Regional Copper-Nickel Study (Anonymous, 1977), the site was re-contoured to correct for a small seep (which did not exceed one half gallon per minute flow rate). Pit fill was "locally available materials." The quality of the small amount of water coming from this seep was the subject of

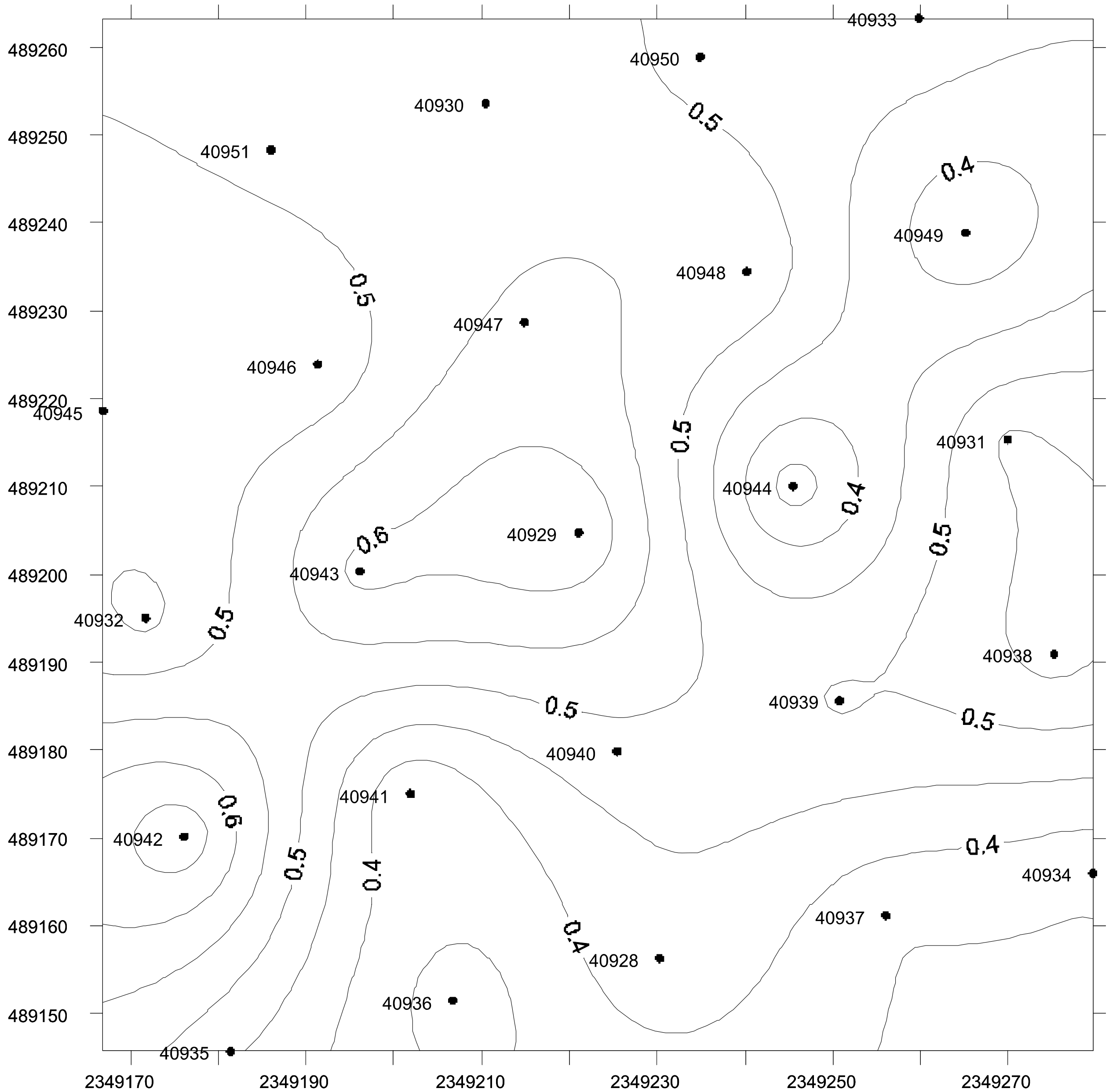

Figure 6. Contour of copper grade at Spruce Road 9,072 tonne bulk sample site based on INCO data. Contour of average copper grade of the bedrock intercept in each of these short drill holes. Most holes represent about six to eight samples. Contour interval is 0.05% copper; drill holes on 25 foot spacing. Units are 1927 state plane feet. North is top of frame. Important to note that the samples vary 0.4% copper over less than one hundred horizontal feet. Using calculated average grade for entire site (0.48% copper) for an area less than the entire site would give disappointing results over about one half of the area. The average grade for pit area is raised greatly by grade above 0.7% copper in DDH 40942 in southwest corner.

much communication between the Forest Service, INCO, and the MPCA (monitoring report for the Regional Copper-Nickel Study, 1977). This seep caused the MPCA to insist that the area be re-contoured to correct the seep, or else no baseline environmental data collected in the area would be accepted.

Figure 6 shows a contour of the average copper grade for each of these short drill holes (DDH 40928 to 40951) that were drilled before the bulk sample was collected. The main item of note in this figure is the variability in grade over very short distances. Grade in the holes varies from 0.32% copper to over 0.65% copper. If one assumed the grade was average over this drilled area, and sampled only a smaller portion of the area, there could be deceptively disappointing or encouraging results. Unfortunately, we do not know the exact location of the sample – the dimensions on page 24 equate to about 25,000 tons of material, so the sample seems to be a subset of a large area. The variability of copper versus nickel for the bulk sample collected from this area is shown in Figure 7.

The 1975 "Operating Concepts" document by INCO gives the grades and geochemical analyses for the test pit material shown in Table 9 below. The only process description given is that grinding, in rod and ball mills, produced a bulk copper-nickel concentrate through flotation in a closed system with minimal make up water.

A 120 ton sample from the 10,000 ton 1974 INCO pit was sent to the Twin Cities Metallurgy Research Center, of the USBM, for testing (Schulter and Landstrom, 1975).

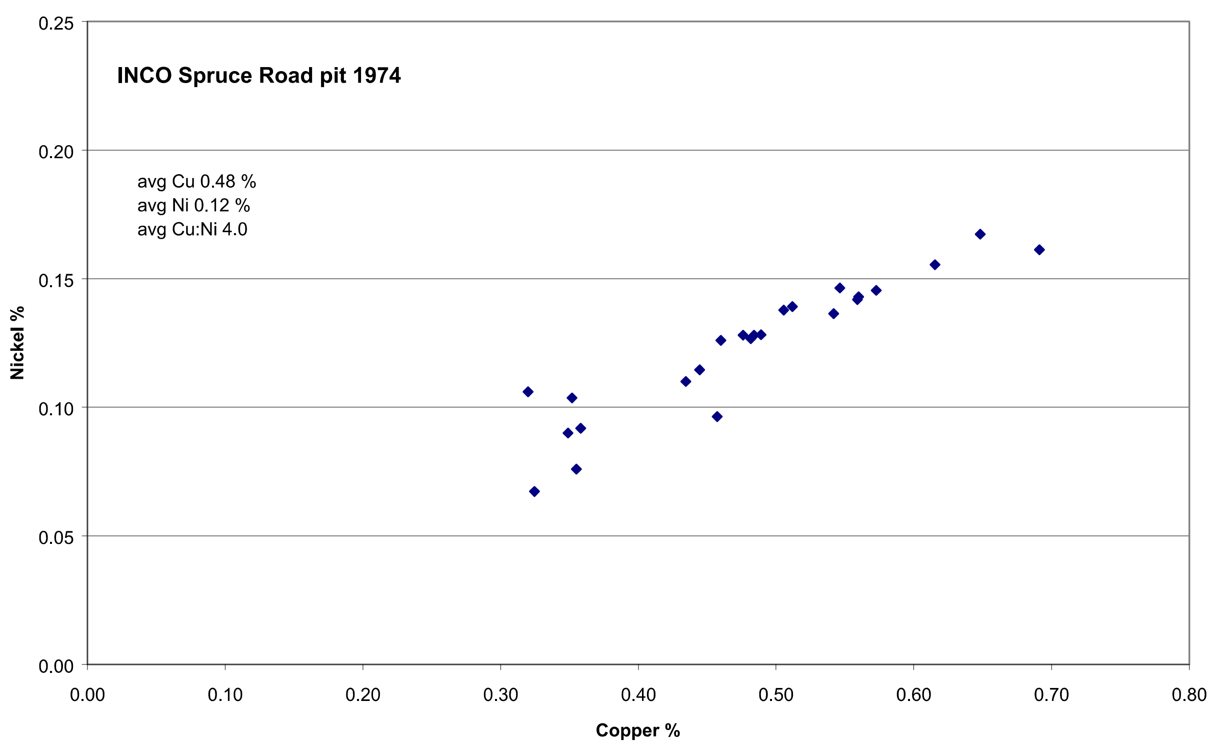

Figure 7. Variability of copper versus nickel at the 10,000 ton INCO bulk sample at Spruce Road.

Table 9. INCO Spruce Road large test pit assays and geochemistry analyses. Based on "wet chemical analyses," taken from INCO (1975). Other elements reported can be found in that paper.

Element/Oxide (%)	Head Sample %	Tailing Sample %	Concentrate Sample %
Cu	0.47	0.045	13.60
Ni	0.15	0.048	2.98
Co	0.019	0.0096	0.14
Fe	9.95	8.80	31.20
S	1.08	0.40	25.30
SiO_2	47.60	46.20	12.10
Al_2O_3	18.30	19.10	2.42
CaO	8.40	8.98	1.23
MgO	7.46	7.95	4.40
As	<0.001	0.0002	0.0031
Mo	0.002	Not Detected	Not Detected
Mn	0.10	0.11	0.032
Pb	Not Analyzed	0.0005	0.008
Zn	Not Analyzed	0.010	0.38
Cd	Not Analyzed	0.0006	0.004

The head and concentrate grades are included in Table 10 below. Copper recoveries were about 90% in this testing, with nickel at about 60% recovery. Concentrates produced in the USBM testing were also assayed for precious metals at the Reno Metallurgy Research Center (these data are also reproduced below in Table 10).

Maturi

INCO Maturi Shaft and Bulk Sample

In 1967-1968 INCO put down a shaft at the Maturi site, drifted from this shaft, and drilled eleven underground holes from the drifts. The location of the shaft relative to surface holes and topography at the Maturi deposit is portrayed in Figure 8. A plan map of the 1,000 ft. drift showing underground drill hole sites is presented in Figure 9.

Though simple inspection of the available assay data for the Maturi area shows that the more elevated copper grades are often located well above the basal contact (possibly contrary to other Duluth Complex deposits), the INCO shaft and drifts seemed to be oriented for study near the basal contact rather than what we would now consider to be the "better" ore zone.

Table 10. USBM grades on 120 ton portion of Spruce Road 10,000 ton bulk sample. Concentrates are weekly averages for three weeks of testing. Precious metals values were processed at the Reno Metallurgy Research Center.

Element/Oxide	Head grade of 120 ton sample as reported by USBM	Concentrate grade of 120 ton sample as reported by USBM-sample 1	Concentrate grade of 120 ton sample as reported by USBM-sample 2	Concentrate grade of 120 ton sample as reported by USBM-sample 3
Cu %	0.35	10.0	14.4	12.2
Ni %	0.11	2.2	3.1	2.5
Co %	0.015	0.11	0.14	0.12
Fe %	12.7	26.1	29.1	27.5
S %	0.80	18.3	24.0	21.1
SiO_2 %	43.1	20.4	13.6	15.7
Al_2O_3 %	18.5	6.4	3.6	4.3
CaO %	7.9	2.8	1.7	2.0
MgO %	7.2	5.3	4.0	4.4
TiO_2 %	1.0			
Au (oz./ton)		0.04	0.04	0.04
Ag (oz./ton)		1.1	1.5	1.4
Pt (oz./ton)		0.036	0.030	0.021
Pd (oz./ton)		0.120	0.128	0.122
Rh (oz./ton)		0.003	0.002	0.003
Ir (oz./ton)		0.001	0.001	0.002
Ru (oz./ton)		0.002	0.001	0.004

In general, as one goes down-hole at Maturi, copper and nickel values are almost non-existent in the hanging-wall intrusive rocks, then "kick" to high values at the top of the mineralized zone (corresponding to the U3 Unit). These values then show progressively lower values down-hole as one approaches the footwall – see an example of this relationship in three surface holes that are located in the vicinity of the Maturi Shaft (Fig. 10). Overall, the mineralized zone varies in thickness from 190 to 410 feet (data in Patelke, 2003; and pers. comm., D. Peterson and M. Severson, 2004).

The material from the Maturi shaft and drifts was used for various bulk sample programs. As stated above, the 1975 INCO

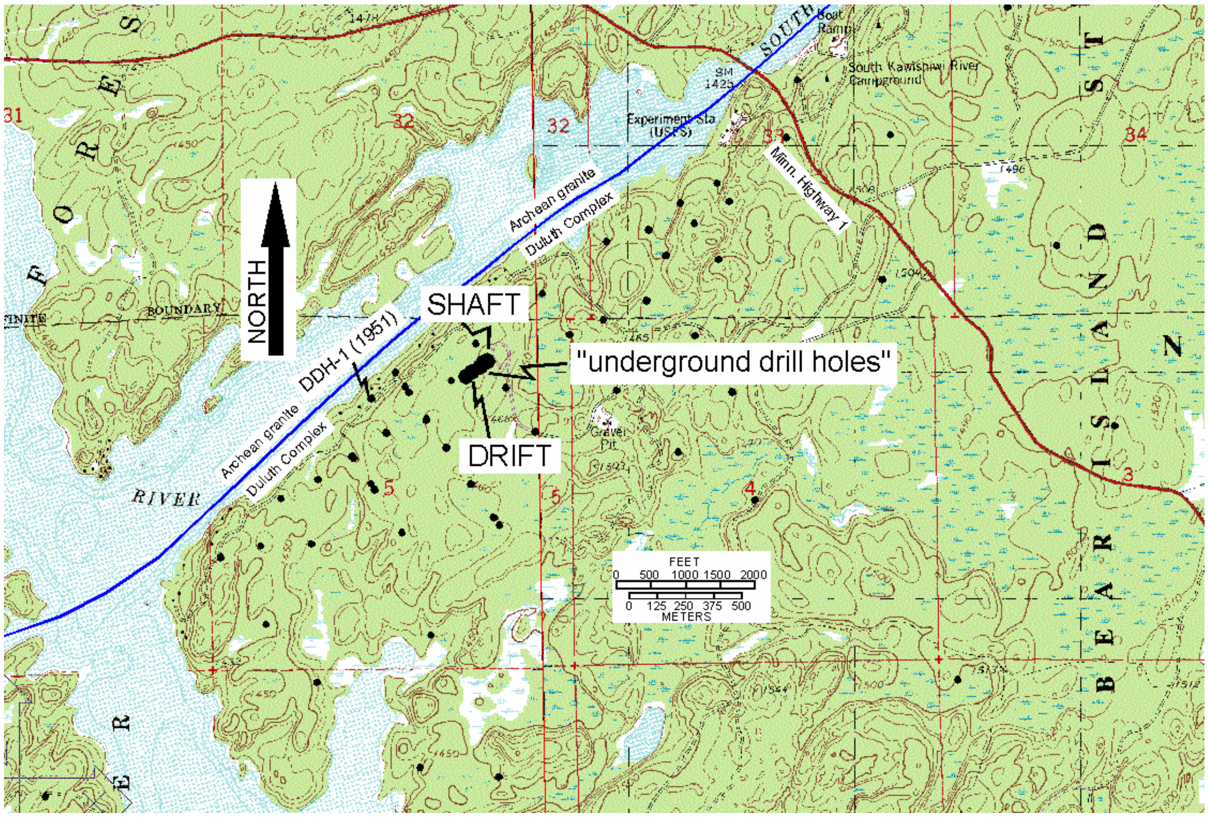

Figure 8. Distribution of drill holes at the INCO Maturi deposit. Note that the close-spaced holes in the center of the deposit are surface projections of the underground drill holes.

study makes reference to a 700 ton sample of shaft material being sent off site as a bulk sample. There have been no records found that define the grade of the sample, grade of the concentrate produced, nor any indication who actually conducted the subsequent metallurgical studies.

Reclamation of the shaft consisted of back-filling it with most of the mined materials, and then contouring the site with sand and gravel. All that is evident in the shaft area today is a 1.5 ft. high 1.0 ft. diameter pipe (capped) in the general vicinity of the shaft and a nearby sandy hill (about 10 ft. high) that has been the host for a fire-pit and beer-drinking parties.

NEARBY DRILL HOLES – ASSAYS AND GEOLOGY

INCO drilled a total of 62 (?) holes in the Maturi area from 1954 to 1970. This included 57,000 ft. of drilling with about 3,190 copper and nickel assays covering 22,600 ft. INCO did not do assays for sulfur, but did do some assays for cobalt. NRRI has records for 11 drill holes from the drift at Maturi, but no core remains.

Five of the surface holes are located near the underground workings (Fig. 8). Two are near the old shaft collar (34871 & 32714), two are about 300 ft. from the collar (11509 & 11530), and one is about 560 ft. from the

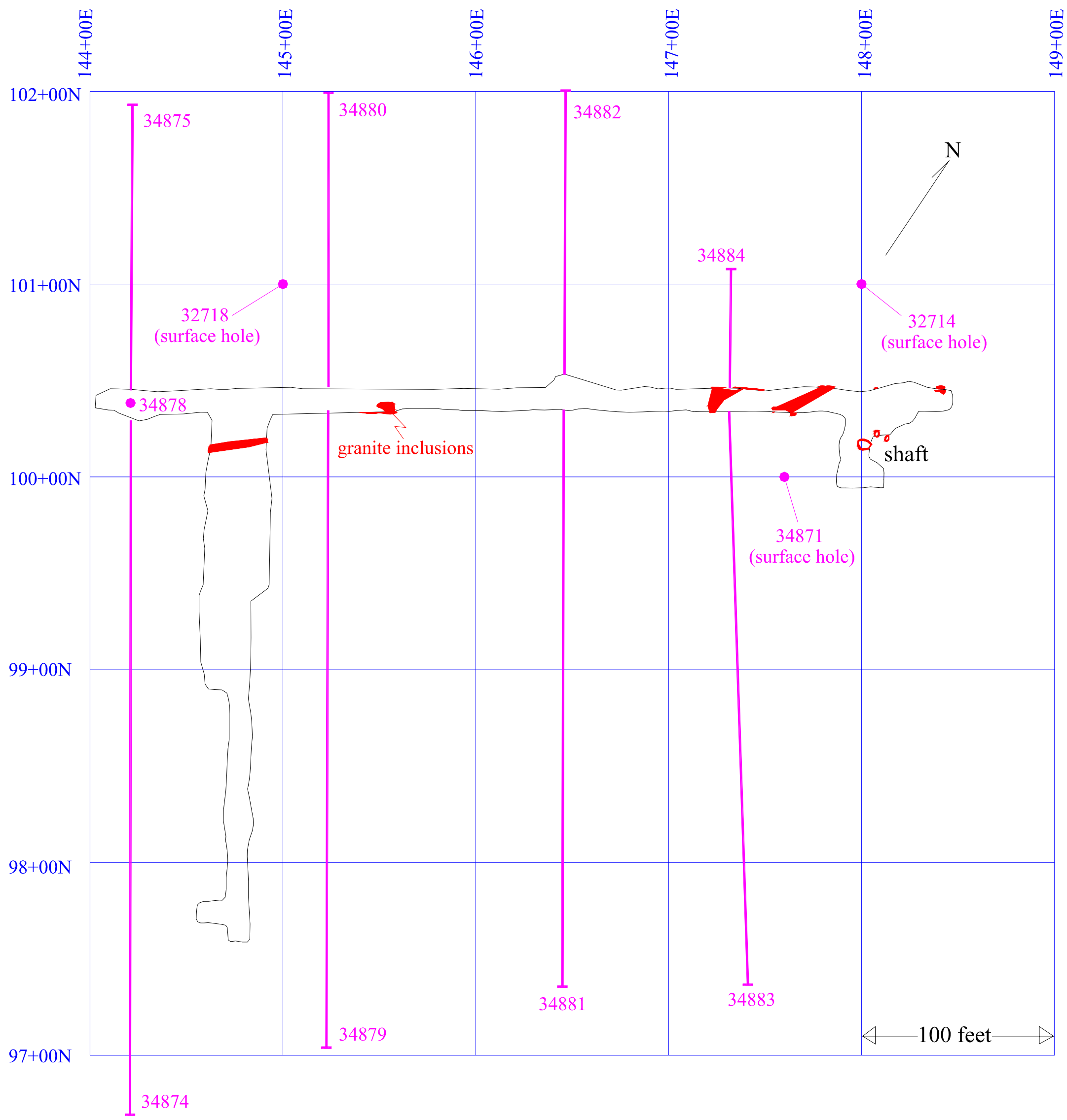

Figure 9. Plan map of the 1,000 ft. drift at the Maturi deposit showing locations of nearby surface drill holes (3), underground drill holes (9 — all but one 34000-series holes), and inclusions of granite (dark blobs) in otherwise heterogenous gabbroic rocks.

collar (32718). These five surface holes form a triangle around the drift with the shaft in the middle of one leg of the triangle. The grades in these holes are not spectacular, especially at the footwall interface, which would seem to be the target of the underground workings. Table 11 shows the average grades in the bottom 200 ft. of the drill holes near the shaft and drift.

DRILLING FROM DRIFT – ASSAYS AND GEOLOGY

As Table 12 shows, the drilling done from the drift at Maturi intercepted what is essentially an average grade for that area (also see Table 11). Grades improve at Maturi as one moves upward from the footwall in certain areas of the deposit. This

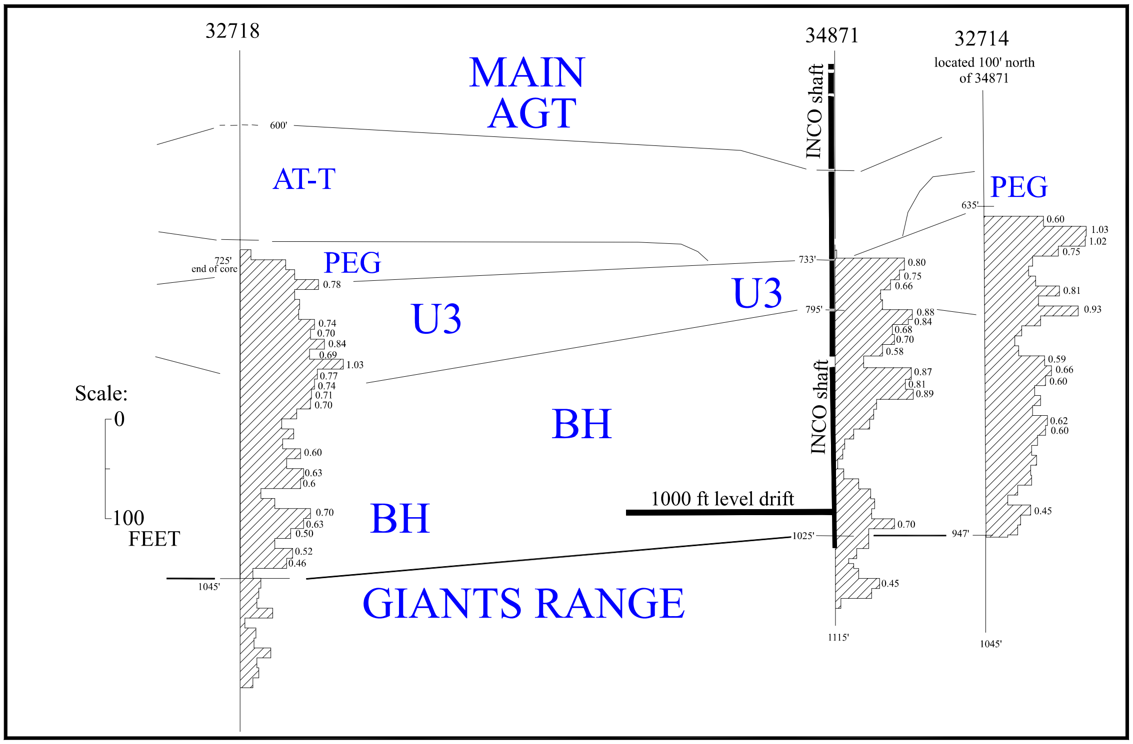

Figure 10. Cross-sectional relationships in the vicinity of the Maturi shaft and drift showing geologic units and abrupt appearance of copper (shown as bars to right of drill hole trace; listed values are in percent) in the U3 Unit, and the progressive decrease in copper with depth in the BH Unit toward the basal contact.

Table 11. Assays in the bottom-most 200 feet of surface drill holes 11509, 11530, 32714, 32718, and 34871 near Maturi Shaft and drifts.

	Cu%	**Ni%**	**Cu/Ni**	**S%**
Average grade in assays from five holes nearest shaft and drift – bottom 200 feet	0.54	0.18	2.80	1.06 (Not always reported by INCO)
Footage represented by sample (ft.)	990	980	980	749

Table 12. Average grade in assays from underground drilling at Maturi versus drilling in remainder of the deposit. Cu/Ni ratios averaged from pre-calculated data, not from Cu and Ni values shown here. "0" value intervals not included-this usually represents "not sampled" intervals. "n" is number of intervals in data files, includes many assay intervals split over two or more rock type intervals, and therefore, represent more than the original number of assays.

	Cu%	**Ni%**	**Cu/Ni**	**S%**
Average grade in assays from underground drilling at Maturi (INCO only)	0.50	0.19	2.70	Not reported by INCO
underground drilling n=	197	197	197	0
Average grade in assays from remainder of deposit at Maturi–footwall to surface (INCO and others)	0.46	0.18	2.59	1.12
surface drilling n=	2,809	2,803	2,802	1,051
Average grade for assays from footwall to 200 feet above footwall-entire deposit (INCO and others)	0.50	0.19	2.63	1.19
surface drilling n=	1,341	1,340	1,340	542
Average grade for assays from 200 feet above footwall to 400 feet above footwall-entire deposit (INCO and others)	0.55	0.21	2.55	1.17
surface drilling n=	765	765	765	336

change is very clear when viewing assay cross-sections, but is not clear when looking at the assay data *en masse* in plots of depth versus grade or plots of distance upwards from footwall versus grade. This deviation is because the thickness of the mineralized zone varies greatly.

Table 11 greatly oversimplifies the picture at Maturi, but does point out the question of why INCO chose to explore near the bottom at Maturi. One possibility is that they were using the Sudbury deposits as a conceptual model, wherein the higher grades are at the base of the intrusive rock units, with the very highest grades in the footwall itself. There is some massive sulfide at the basal contact at Maturi, but it seems volumetrically unimportant.

By the time of the 1975 submission to the Forest Service entitled "Description of Operating Concepts Required to Establish Preoperational Monitoring for INCO's Proposed Spruce Road Project," it had been decided by INCO that "*The exploratory drilling and the results obtained from the test shaft sunk in 1967-1968 led to the conclusion that the mineralization on the south lease (Maturi) required mining by underground methods and that the indicated grade was too low for economic recovery at the time. That judgment still applies to the south lease (Maturi), consequently this presentation relates only to the possible development of the north lease (Spruce Road).*"

INCO Maturi Surface Bulk Sample(s)

There are no surface bulk samples known to have been taken at Maturi. Mineralization does not appear to extend to the surface and sampling would not be expected. Peterson et al. (2004) believe that the outcropping mineralization along the "Little Lake Road" north and west of Birch Lake is related to the Maturi system (especially towards the northeast end of the "Little Lake Road" area).

South Filson Creek

This area was drilled in 1967 through 1970 by Hanna Mining Company with 25 holes (K-series holes), plus one drill hole by Duval (Fig. 11). No known test pits were dug here (John Owens, Chief Geologist, retired, The Hanna Mining Company, pers. comm., 2003). This is an area of anomalous mineralization in troctolitic rocks.

Nearby Drill Holes – Assays and Geology

The drill holes in the South Filson Creek area were logged by NRRI staff (Kuhns et al., 1990) prior to the more complete understanding of SKI igneous stratigraphy developed in the early and mid-1990s (Severson, 1994). Most likely the main geologic units at South Filson Creek are those units of the SKI seen in drill hole DU-07 at the southwest corner of the property. The top 1,761 feet of DU-07 is in the AT&T Unit of Severson (1994). The South Filson Creek deposit is stratigraphically well above the Spruce Road deposit to the north, and its mineralization should have no relation to footwall contamination, as is the suspected case for the other copper-nickel deposits. Besides DU-07, the South Filson Creek drill holes are not subdivided by geologic unit in the data presented in Patelke (2003).

Near surface lithology based on the NRRI logging at South Filson Creek (top 100 feet of ledge intercept) shows mostly mixed troctolitic rocks and lesser amounts of anorthositic rocks, with small intercepts of gabbros, ultramafics, and sedimentary hornfels. (Authors' note: We would have expected inclusions to be basaltic hornfels based on distance from footwall; this should be checked in the future.)

Copper and nickel values for the drilling as a group are slightly lower than the averages for the SKI, though slightly more nickel-rich than the bulk of the SKI (Table 13). The low average values may be because many of the holes in the area were virtually barren of sulfides, and when averaged with nearby strongly mineralized holes (Cu values commonly up to 1.0%), the average is lowered. The copper:sulfur ratio at South Filson Creek is also relatively high for the Duluth Complex.

Rod Ikola (ex-Hanna geophysicist) believes (but we did not check) that the geophysics work associated with this drilling is on file at MDNR in Hibbing.

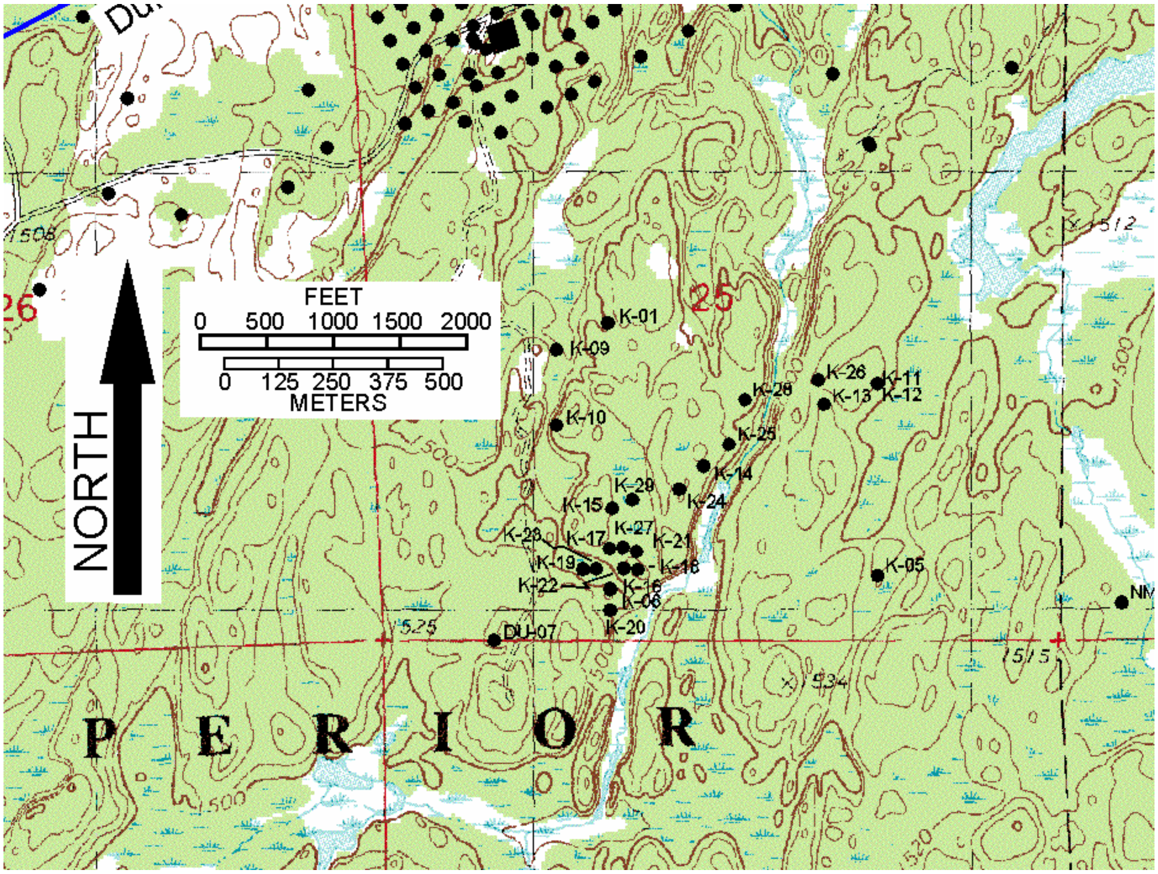

Figure 11. Distribution of drill holes at the South Filson Creek deposit; only Hanna (K-series) and Duval (Du-07) holes are shown. Unlabeled holes along the northern edge of this figure are INCO holes associated with the Spruce Road deposit.

Table 13. South Filson Creek: average grade in assays for top 100 feet of drill holes.

	Cu%	Ni%	Cu/Ni	S%
Average grade of assays in top 100 feet of drill holes at South Filson Creek	0.29	0.11	2.36	0.61
n=	110	110	110	110

Project Status

The South Filson Creek prospect is included here because it is currently under lease to Cowboy Exploration of Jelm, Wyoming (Encampment Resources), and is undergoing some evaluation with regard to sampling and drilling. At least six holes were drilled in the winter of 2004; those results have not been released (pers. comm. W. Cronk, 2004). Otherwise, the status of the project is unknown.

Birch Lake Project-Beaver Bay Joint Venture

No publically reported test pit or composite work is available for the Birch Lake project (Fig. 12). Because the target zone for PGE mineralization is deep, no surface samples would be expected. “Ore” grades are given below in Table 14, as taken from a 2003 press release on the Franconia Minerals website. No background information about these values is known. As an ongoing project, there is no expectation or obligation that the company would divulge data to the public.

The company website describes Birch Lake as a deposit “*potentially amenable to low cost, mechanized underground mining.*”

Project Status

Lehmann Exploration Management of Minneapolis continues to drill out the PGE-copper-nickel ore body at Birch Lake. No detailed data developed since 1995 have been made public. Available drill hole locations and depths are in Patelke (2003). Contact the “Beaver Bay Joint Venture,” which is managed by Lehmann Exploration,

Table 14. Metal grades at Birch Lake. Taken from press release on Franconia Minerals website (2003). Represents about 32 million ton resource.

	Cu%	**Ni%**	**S%**	**Co ppb**	**Ag ppm**	**Au ppb**	**Pt ppb**	**Pd ppd**	**Au + Pt + Pd ppb**	**Rh ppb**
Reported grade from company press releases	0.69	0.22	Not Given	0.011	2.8	248	573	1134	1955	54

Based on available information for the area, the target zone is oxide-rich rocks, mainly associated with the U3 Unit, with high PGE values, but not necessarily high sulfide content. These oxides may be related to digested iron-formation (Severson, 1994). The discovery zone was a thin oxide-rich interval in drill hole DU-15 that was re-assayed by the MDNR in the 1980s (Sabelin and Iwasaki, 1986). Severson (1994) has some cross-sections, and Severson and Hauck (2003) as well as Hauck et al. (in prep.) describe the setting and PGE mineralization for the area. Marma (2002) completed a petrographical and microprobe study on the association and location of PGE and PGM in rocks of the Birch Lake area.

for more information about this ongoing project (contact in Appendix 1).

As this report was being assembled (June, 2004), Franconia Minerals (an owner of the Beaver Bay Joint Venture) had recently reached agreement with American Copper and Nickel Company (ACNC), the United Status subsidiary of INCO. This agreement transfers all of the INCO federal leases and data for Minnesota to Franconia. The leases are still active, and until Franconia completes their review of these data, it is unlikely any more information about INCO’s past activities in Minnesota will be released.

Franconia began the process of becoming a publically traded company in June, 2004. Their prospectus may offer

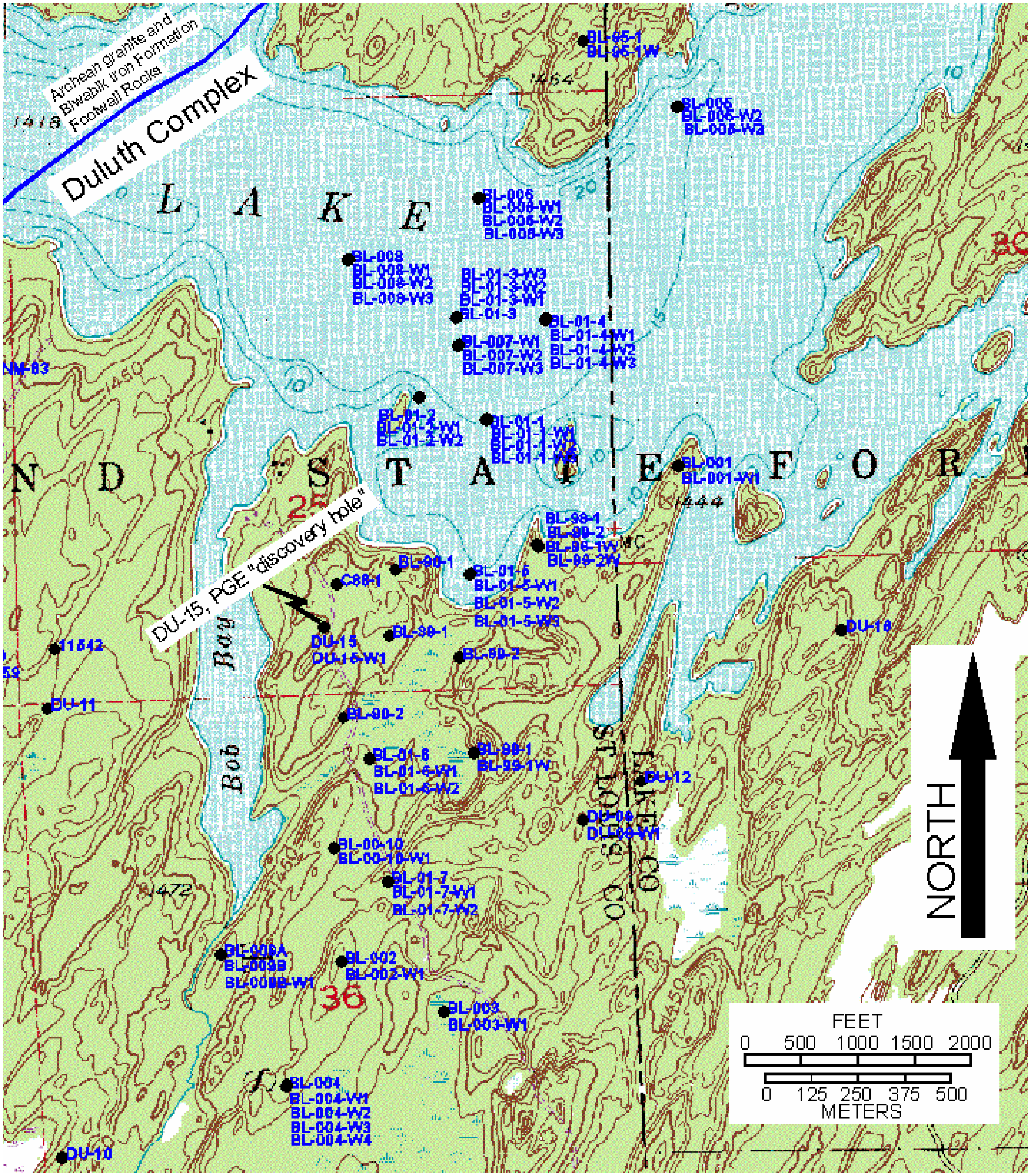

Figure 12. Distribution of drill holes at the Birch Lake deposit. Note that many of the holes have numerous wedge-off holes (listed in the figure as holes ending with a W suffix) into the mineralized zone.

more data on the project. Go to www.sedar.com to check for more recent publications and resource estimates.

Dunka Pit Area

In the process of mining the Biwabik Iron Formation taconite ore at the Dunka Pit of Erie Mining/LTV Steel Mining Company (LTV) 14 to 20 million tons of mineralized Duluth Complex material were removed as waste rock and stockpiled on site (Fig. 13).

The Dunka Pit iron-formation mineralization was discovered and outlined by Bear Creek in exploring the Duluth Complex in the area for copper-nickel mineralization. This is a particularly coarse, high magnetite content iron ore that was used by LTV as "sweetener" for their pellet production. Iron mining ceased at the Dunka Pit in 1999, largely because of the high costs of removing and dealing with the sulfide-bearing Duluth Complex material overlying the iron-formation as the pit got deeper (the pit was about 200 feet deep in 1999—from MDNR Iron Range mapping data).

During mining, the mineralized (sulfide-bearing) material was sorted by a low (less than 0.2%, but uncertain?) threshold value for copper assay. The rock in the stockpiles was generally not sorted by rock type but by grade and may be mixed Duluth Complex and Virginia Formation. The Duluth Complex component is probably from the "Basal Heterogenous" (BH), "Bottom Augite Norite" (BAN), and Updip Wedge (UW) units of the SKI (see Severson, 1994 for geology).

Where the higher grade (if any) was stockpiled is not clear.

Cleveland Cliffs International (CCI) was the last mine operator for LTV, through a subsidiary. CCI came into ownership of much of the property after the LTV shutdown in May, 2000. While they are responsible for the site reclamation, which is essentially done, they are not the legal owners of the material in the stockpiles (R. Graber of Cliff Mining Services, Ishpeming Michigan, pers. comm., 2003). Ownership of the stockpiles is a mix of state and private (J. Sellner, MDNR, pers. comm., 2003). From an environmental quality standpoint, it may be that these stockpiles should not be disturbed until the capacity exists to completely process them and concentrate their sulfide component.

No comprehensive effort has been made on the part of NRRI geologists to recreate the pre-mining detailed geology of the Dunka Pit area or develop an initial resource estimate. There are cross-sections in Severson (1994). Quadrangle scale (1:24,000) mapping by Miller et al. (Babbitt NE quad, 2005) includes this area. There are records for about 270 drill holes in the area penetrating the Complex (over about 139,000 feet of drilling), with about 4,200 copper assays. Much of this drilling is downdip (south) of the Dunka Pit proper. There is probably much more logging and assay data from iron-formation drilling that was done by LTV that could be useful in establishing and controlling the stratigraphy in the area. The creation of a complete set of geologic and copper-nickel grade cross-sections on spacing of hundreds of feet could be useful in sorting out some of the questions about mineralization that persist. These questions include: PGE distribution (see Severson and Hauck, 2003) and the nature of "confined versus open" mineralization as defined by Peterson et al. (2004).

Franconia Minerals drilled two holes down-dip at Dunka Pit in 2006. Complete assay results have not been released.

Nearby Drill Holes — Assays and Geology

Because there are limited detailed cross-sections for reference, it is not in the range of this report to calculate which drill holes

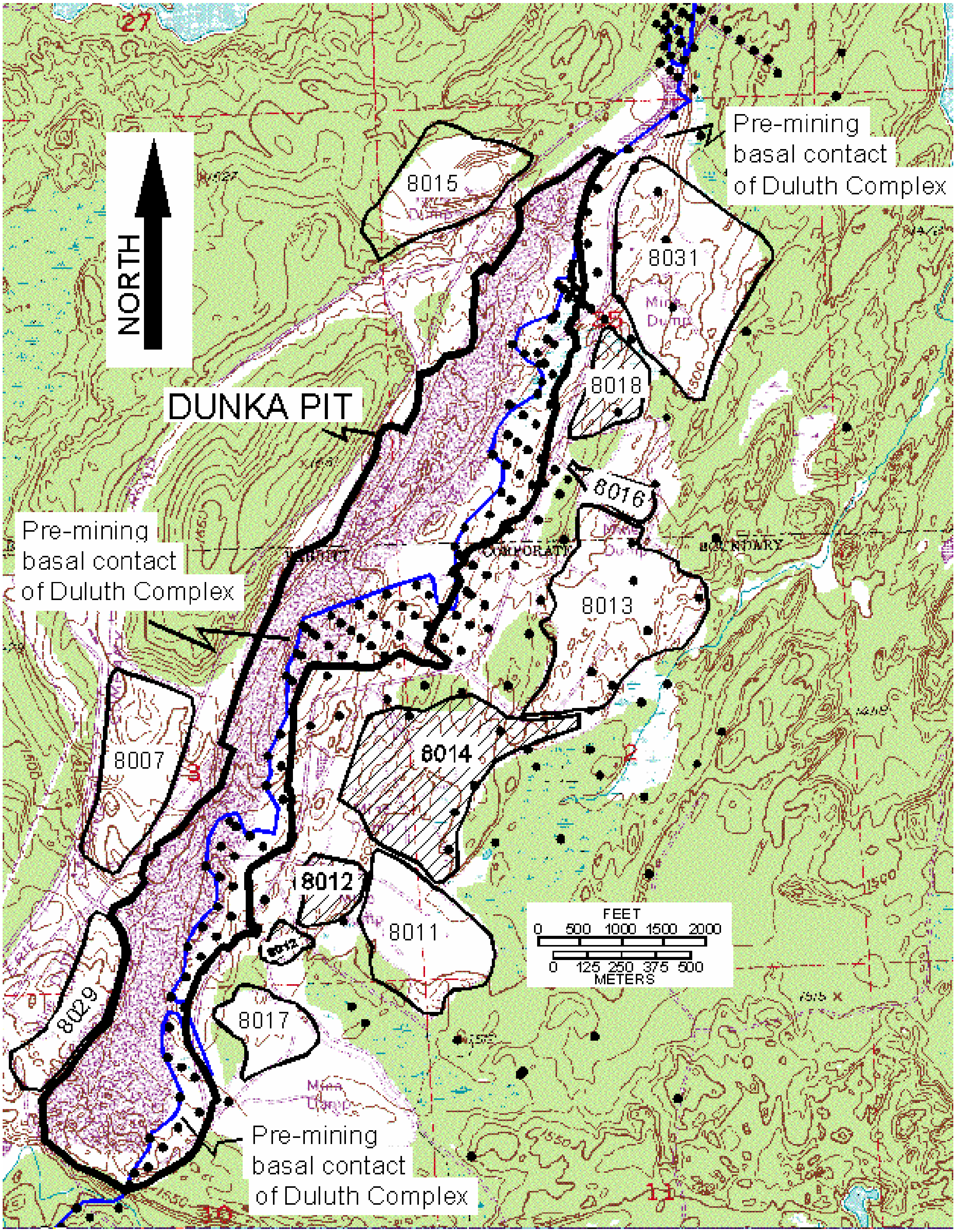

Figure 13. Distribution of drill holes (black dots) and stockpiles (numbered polygons) at the Dunka Pit area. The stockpiles are related to taconite mining—stockpiles containing mineralized Duluth Complex material (in addition to unknown amounts of Virginia Formation) are numbers 8012, 8014, 8016, and 8018.

penetrated the area now occupied by the Dunka Pit. However, drill holes in the general area have the assay grades shown on Table 15. Figure 13 shows the drill holes in the Dunka Pit area.

Figure 14 shown below is a plot of copper versus nickel variability for Dunka Pit. Note the extreme variations in copper:nickel ratios.

Table 15. Copper, nickel and sulfur percentages for drill hole derived assays in the Dunka Pit area (data extracted from Patelke, 2003).

Element	Footage	n=	Mean	Median	High
copper	42,735	4,234	0.23	0.25	10.64
nickel	40,008	3,919	0.09	0.09	2.95
sulfur	4,292	608	2.2	0.88	18.98

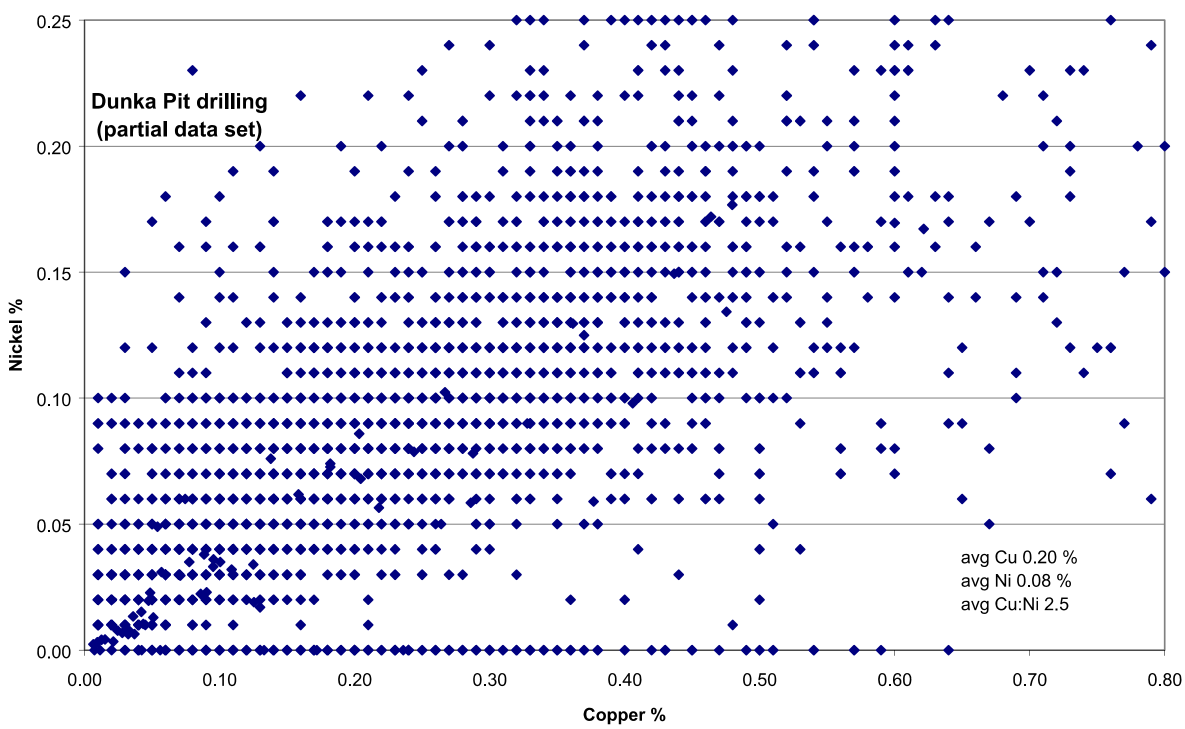

Figure 14. Variability in copper versus nickel for drilling at Dunka Pit.

Tonnage Estimate and Potential as Mineralized Bulk Sample

The MDNR records 570,478 cubic yards of loose material with a copper grade of 0.29% CuO and nickel grade of 0.10% NiO on their stockpiles (stockpiles number 8014, 8016, and 8018; see Fig. 13). These are stockpiles with no co-mingling of Duluth Complex material with iron-formation or Virginia Formation. There are also at least eight state stockpiles with some "gabbro" component in them. It is not certain if these numbers reported as oxides are really oxides, or a typographical error in reporting. At about 1.5 tons per yard for broken rock, this equates to about 855,000 tons of "clean" Duluth Complex material in the state stockpiles (J. Sellner, S. Saban, at MDNR, pers. comm., 2003), plus an unknown amount in the co-mingled stockpiles.

Cleveland Cliffs, who managed the mining at the LTV Dunka Pit, does not have these data reported separately, but agrees with a 14 to 20 million ton number for total available resource of broken Duluth Complex material in the area.

There is no information easily available about the portion of the stockpiles not under ownership or control of either CCI or the state. Tax maps and some research at MDNR would indicate who the actual owners are, as well as the distribution across stockpiles.

This material may be useful in the future for testing certain aspects of plant performance or cost studies. It is unknown if this material would be useful for any actual ore quality studies that could be applicable elsewhere. It is a fair assumption that the sulfide-bearing material in the stockpiles is now at least somewhat oxidized.

This site has been the subject of much study as an example of the potential for Duluth Complex rock to have acid rock drainage. Numerous papers have been written on these tests by Mr. Kim Lapakko and colleagues at the MDNR (see Severson and Hauck, in prep., for extensive references on waste characterization issues). Much of the water draining from this site was captured and processed in a water plant at the south margin of the site. This water plant is now shut down, and drainage is being treated by organic material (peat) in cells constructed around the toe of the stockpile slopes (R. Graber, Cliffs Mining Services, Ishpeming Michigan, pers. comm., 2003).

Obviously, there is great discrepancy in the reported total amount of Duluth Complex material stockpiled at Dunka Pit.

Authors' Note: Recent discovery of files at the old LTV office in Hoyt Lakes, MN, indicates that the Erie Mining Company collect a bulk sample for metallurgical tests in the 1960s. See Appendix 5 for details.

Serpentine

The Serpentine area is classed as both part of the Babbitt deposit and as a separate deposit. The drill hole numbering at Serpentine is continuous and intermixed with Babbitt, as both were drilled by Bear Creek/AMAX on the same grid, but with different land ownership.

The Serpentine drilling targeted an electromagnetic conductor, found in 1958, that turned out to be associated with both massive sulfide at the basal contact and a sulfide-rich graphitic argillite (BDD PO unit) in the footwall Virginia Formation. The massive sulfide is mostly pyrrhotite. Overall, the Serpentine deposit has average copper-nickel values slightly lower than the Babbitt deposit (Zanko et al., 1994). The massive sulfide of the Serpentine Deposit (or similar material) crops out at the south margin of the Peter Mitchell taconite mine of Cliffs NorthShore Mining.

The Serpentine area (Fig. 15) has about 43,000 ft. to 49,600 ft. of drilling over about 59 drill holes, depending on how one counts

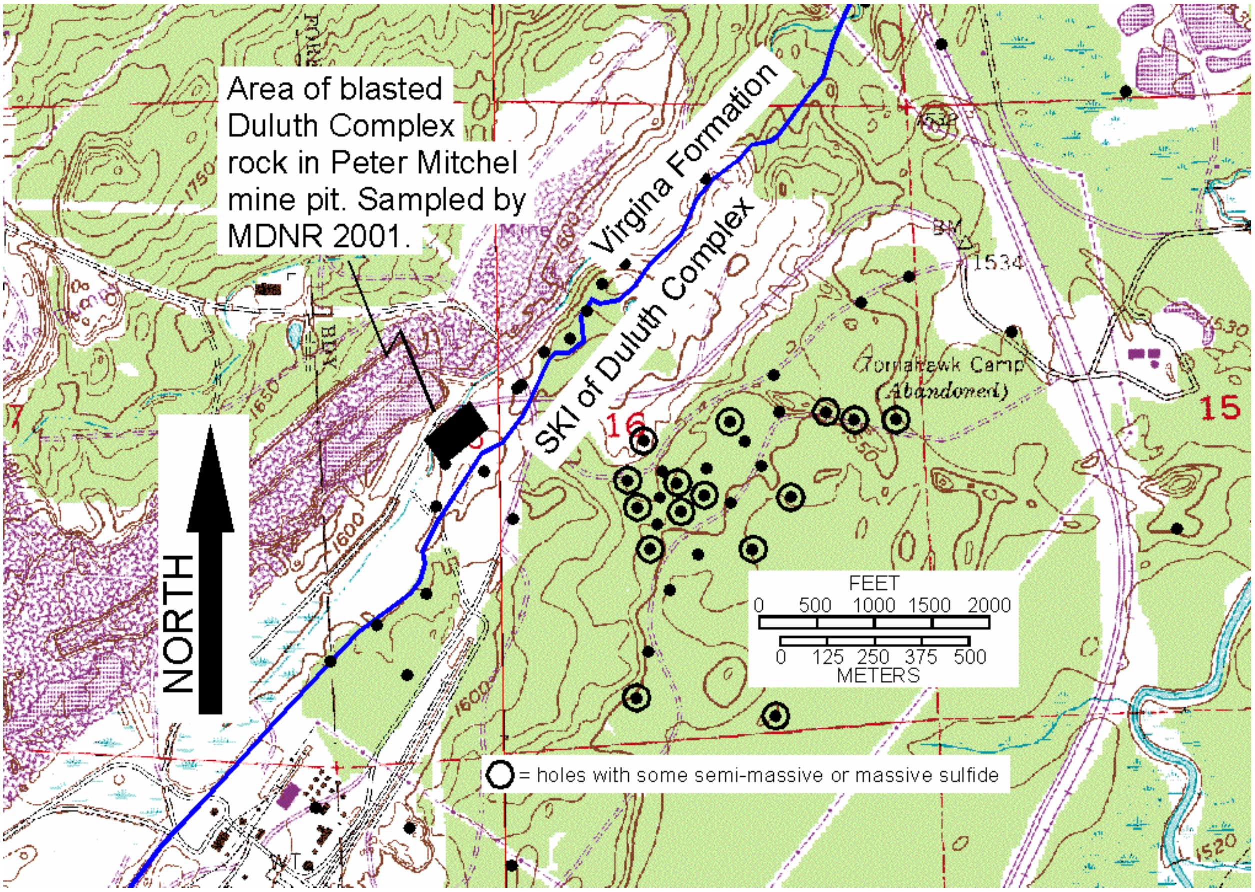

Figure 15. Location of drill holes at the Serpentine deposit and nearby incidental exposure of Serpentine-like mineralization at the Peter Mitchell taconite mine.

the drilling from AMAX, INCO, Resource Exploration, the MDNR, and Reserve Mining Company. Reserve drilled for taconite and often penetrated the overlying Duluth Complex. These cores were assayed and shared with Bear Creek/AMAX. AMAX was aiming for a 200 ft. by 200 ft. grid, but ground restraints (ownership and relocation of holes) caused the grid to be less than perfect for polygonal modeling.

There are about 2,130 copper assays for the Serpentine area (averaging 0.32% copper and 0.11% nickel; copper rarely above 1.0%) over about 16,280 ft. of core. Much of the core for Serpentine is intact and is stored at MDNR in Hibbing.

In general, the MinnAMAX documentation on file at MDNR does not say much about the Serpentine area. It seems they drilled the conductor, got poor copper-nickel results on the massive sulfide, and were constrained by land issues. There is one MinnAMAX document specifically focusing on Serpentine on file at the MDNR (Kulas, 1979). That report has land owner maps, polygonal reserve models, and mineralization structure maps.

Zanko et al. (1994) and Severson (1994) describe this area in the most detail, with Miller et al. (2002a) providing the most recent background information on the South Kawishiwi intrusion.

No formal bulk sample has been taken from the Serpentine deposit, but there is incidental exposure of (presumably) similar massive sulfide material in the Peter Mitchell Iron Mine (former Reserve Mining Company property) just to the north of the

Serpentine deposit (Fig. 15). This exposure contains a large amount of Duluth Complex and Virginia Formation blasted during the 1980s in preparation for iron-formation stripping. The material may conceivably be usable as a sample for some process testing, but it is highly oxidized. The property is controlled by the MDNR. This exposed area is also the most accessible location to see geologic relations at the basal contact of the Complex along with copper-nickel mineralization. Much of this material has been moved for drainage control purposes in 2006.

In 2001, Rick Ruhanen of the MDNR Lands and Minerals Division took surface grab samples from the area blasted by Reserve in the 1980s. These samples were a mix of Duluth Complex and Virginia Formation (hornfels). The summarized results are shown below in Table 16; for a more complete listing see Ruhanen (2002).

Authors' note: This blast pile (#2393) was moved westward across the pit to a covered stockpile in 2006. Details about how this pile was moved and capped are in a report submitted to the Minnesota Pollution Control Agency.

PARTRIDGE RIVER INTRUSION BULK SAMPLES

Test work in the Partridge River intrusion includes copper-nickel bulk samples at Babbitt/Mesaba and Dunka Road/NorthMet, and Fe-Ti oxide samples at the Longnose OUI and Waterhen OUI. Table 17 presents a brief synopsis of all the known bulk samples collected in the Partridge River intrusion.

Babbitt/Mesaba Deposit

In the 1950s, Bear Creek began reconnaissance studies on a number of grids along the basal contact of the Duluth

Table 16. Serpentine: grab samples from muck piles at Peter Mitchell pit. Sampling by R. Ruhanen, MDNR, October, 2001. Copper and nickel originally reported in ppm, converted here to percent for comparison with other tables in this report. More samples and elements reported in Ruhanen (2002). These are weathered samples with attendant difficulties in exact rock type identification.

Sample number	Rock type	Copper %	Nickel %	Sulfur %
1007	Hornfels	0.50	0.12	2.09
2010	Hornfels	0.21	0.05	0.53
1003	Hornfels w/gabbro	0.04	0.02	0.63
1005	Augite troctolite	0.27	0.10	1.85
2011	Gabbro w/hornfels	0.24	0.07	0.99
1006	Gabbro w/biotite	0.17	0.06	0.73
1004	Gabbro	0.56	0.09	1.33
3013	Gabbro	0.21	0.06	0.91
3014	Gabbro w/massive sulfide?	0.74	0.28	3.75
3015	Massive sulfide(?)	0.13	0.02	1.39
4003	Massive sulfide	0.78	0.48	2.77
2012	Massive sulfide	0.92	0.56	4.87
3012	Massive sulfide	0.39	0.13	2.56

Table 17. Synopsis of all known bulk samples collected in the Partridge River intrusion.

PARTRIDGE RIVER INTRUSION						
Project	***Responsible party***	***Year(s)***	***Tonnage***	***Comment***	***Grades***	***Reference***
Babbitt (Mesaba) deposit	AMAX B1-341	1978	1,150 ton excavation, 560 tons sent as sample	Surface pit in NE corner of deposit. Sample may actually have been taken in South Kawishiwi intrusion, not Partridge River	0.43% Cu, Ni est. at 0.12%.	Various files in AMAX archive at MDNR
	AMAX (shaft)	1976		Shaft samples listed as "disseminated." Some of this material used by MDNR for various leaching and ARD tests	Various disseminated ore samples. Est. at 0.43% Cu, 0.13% Ni, S unknown.	Various files in AMAX archive at MDNR
	AMAX (Local Boy)	1976		Drift samples listed as "massive" or "semi-massive." Some of this material used by MDNR for various leaching and ARD tests	Various massive and semi-massive sulfide samples.	Various files in AMAX archive at MDNR
	Arimetco B1-374	1994	200 tons excavated, sample split to 85 and 115 ton portions	Surface pit. Sample probably in weakly mineralized pegmatitic zone of Unit 3	0.22% Cu, 0.06% Ni, 0.52% S from blast holes; sorted sample had head grade of 0.30% Cu, 0.08% Ni, 0.63% S.	MDNR and NRRI files
	Arimetco B1-411	1995-1996	150 tons sent to CMRL, January 1996	Surface pit. Sample in western part of deposit, location in Unit 1. Reasonably typical material.	0.61% Cu, 0.12% Ni, 1.02% S from blast holes; CMRL reports head grade at 0.36% Cu, 0.08% Ni, 0.76% S.	MDNR and NRRI files
	Teck Cominco B1-321	2001	5,000	Surface pit at location drilled by Severson for Arimetco in Unit 1 near center of north edge of deposit. Very typical material. Final sample much larger than 500 tons outlined by Severson.	Severson estimate 460 tons at 0.62% Cu.	Communication w/Teck Cominco and NRRI files
	Teck Cominco B1-321	Future	50,000	Planned surface pit, at same location as Teck Cominco B1-321. EAW approved by State in 2003.		EAW approved June, 2003

Project	*Responsible party*	*Year(s)*	*Tonnage*	*Comment*	*Grades*	*Reference*
Dunka Road (NorthMet) deposit	USS Bulk No. 1	1971(?)	unknown tonnage	Surface pit near drill hole (26058) with mineralization only in top few feet. Small pit, found by Zanko and Severson in 1995, no definitive records available.	Drill hole 26058 grade from 8 to 20 ft. was 0.82% Cu, 0.20% Ni, 1.21% S; below this mineralization the hole is not mineralized for hundreds of feet; head grade of bulk sample was 0.39% Cu, 0.14% Ni, 0.50% S.	NRRI files.
	USS Bulk No. 2	1971	300 tons	Surface pit near drill hole 26105. Intended to intercept mineralization seen in that hole. Material contaminated with hornfels, poor grade.	Expected grade based on DDH 26105 was 0.77% Cu, 0.28% Ni(?), 1.23% S; head grade of sample was 0.40% Cu, 0.13% Ni, 0.97% S.	NRRI files.
	USS Bulk No. 3	1971	20 tons	Surface pit near drill hole 26105. Re-entry of Bulk No 2 site to get material uncontaminated with hornfels.	Expected grade based on DDH 26105 was 0.77% Cu, 0.28% Ni(?), 1.23% S; head grade of sample was 0.58% Cu, 0.22% Ni, 0.98% S.	NRRI files.
	Fleck / Nerco	1990	2 large diameter core holes	PolyMet report states they have no records for this work, other than that it was done in 1991. Two large diameter holes and two smaller twins for submission to state. All four twin existing two USS drill holes.	No data.	PolyMet January 2006 Prospectus.
	PolyMet Composite	1998-2000	At least 37 tons shipped to testing laboratory	Reverse circulation drilling composite from about 55 (?) reverse circulation holes. Data not available on how many or which holes constituted the bulk sample.	Head grade in 1999 SME/AIME presentation is 0.43% Cu, 0.12% Ni. PolyMet has not published sulfur numbers.	PolyMet press releases and 2001 pre-feasibility study.

Project	*Responsible party*	*Year(s)*	*Tonnage*	*Comment*	*Grades*	*Reference*
Longnose Fe-Ti oxide (OUI)	American Shield (?)	1984		Surface pit, sample sent to CMRL for process testing.		CMRL reports in 1990s on projects, but ore sources for individual projects uncertain.
	American Shield (?)	1991		Surface pit, sample sent to CMRL for process testing.		CMRL reports in 1990s on projects, but ore sources for individual projects uncertain.
Water Hem Fe-Ti Oxide (OUI)	Water Hen drill holes SL-27 and SL-28	Drilled in 1975	about 400 ft. of drill core	USBM samples to test reduction processes on Fe-Ti ore; with goal of producing saleable or processable titanium slag product.	Study concluded that a high TiO_2 product could be made, but that concentration that removes iron is important. MgO content is not mentioned as a processing issue.	Nafziger and Elger (1987) USBM report; drill hole desc. In Ross, 1985.

Complex. Footwall conductors drilled at the Babbitt site (B-1 grid) were related to a sulfide-rich graphitic argillite member (BDD PO Unit) of the Virginia Formation. However, this drilling also intercepted disseminated sulfide mineralization in the Duluth Complex, and Bear Creek continued to drill on private lands in the area from 1958-1960. This program was followed by a six year hiatus in drilling as the state worked out a leasing process, and then drilling resumed after state leases became available in 1967.

Drilling of the low grade mineralization resumed, but interest in the deposit was waning due to low grades, when the 105th drill hole intercepted a large massive sulfide ("Local Boy") at about 1,700 feet below surface. The renewed possibilities for the area kept Bear Creek drilling up to hole B1-204 in 1971. When Bear Creek partnered with AMAX, the project became MinnAMAX, and surface drilling re-started in 1974 with another 234 holes drilled up until 1978. During 1977 and 1978, AMAX also drilled 230 holes from a shaft and drifts in the Local Boy area.

The state then suspended leasing of non-ferrous mineral lands from 1976 to 1981 during the time of the "Regional Copper-Nickel Study," which was intended to act as a generic Environmental Impact Statement for copper-nickel development. When leasing resumed in the 1980s, the copper market was poor and most companies left Minnesota.

When the MinnAMAX project was shut down, all the core and core-related data was donated to the state, along with some engineering data. The shaft was capped and some waste rock piles from the shaft moved to the MDNR facility in Hibbing for continued acid mine drainage testing (history after description in Miller et al., 2002b).

A number of bulk samples have been taken from the Babbitt/Mesaba deposit (Fig. 16). These include: one test pit by AMAX (Bear Creek did not sample any test pits during their development at Babbitt/Mesaba); large samples derived from the shaft and underground drift excavations; a large number of drill hole composite metallurgical samples by AMAX; two pits by Arimetco; and a single pit by Teck Cominco. There may be another Teck Cominco pit in the planning stage at the time of this writing (see MDNR Environmental Assessment Worksheet, 2003).

Much of the available MinnAMAX documentation for this area is rather unidirectional. The materials from MinnAMAX on file at MDNR are copies of outgoing correspondence with labs, and some memos. The memos are both local and directed to various corporate offices. There is generally nothing filed with this type of correspondence about test results. Some of the results are found in the other MinnAMAX material, but some seem to be lost for the present. Essentially the communications with labs are lists of what was shipped to them and when. MDNR has some of the MinnAMAX engineering files – most of this discussion is from that archive (see MDNR AMAX file 3.4.1.3).

Overall, the AMAX files center on solving the metallurgy (a selective flotation scheme to separate copper minerals and then nickel minerals seems to be the process of choice) and on determining cut-offs, of which there were many, for both underground and open-pit reserves. AMAX intended an on-site smelting operation; their tests and planning were all based on that assumption.

NRRI and MDNR have some records for the more recent work, but the public records are not as complete as one would like for any of these test projects.

Babbitt/Mesaba differs from the other deposits in the area in that it has two distinct styles of mineralization. It contains a large tonnage of the subcropping, generally disseminated "ore" as seen for the other deposits, and a possibly minable concen-

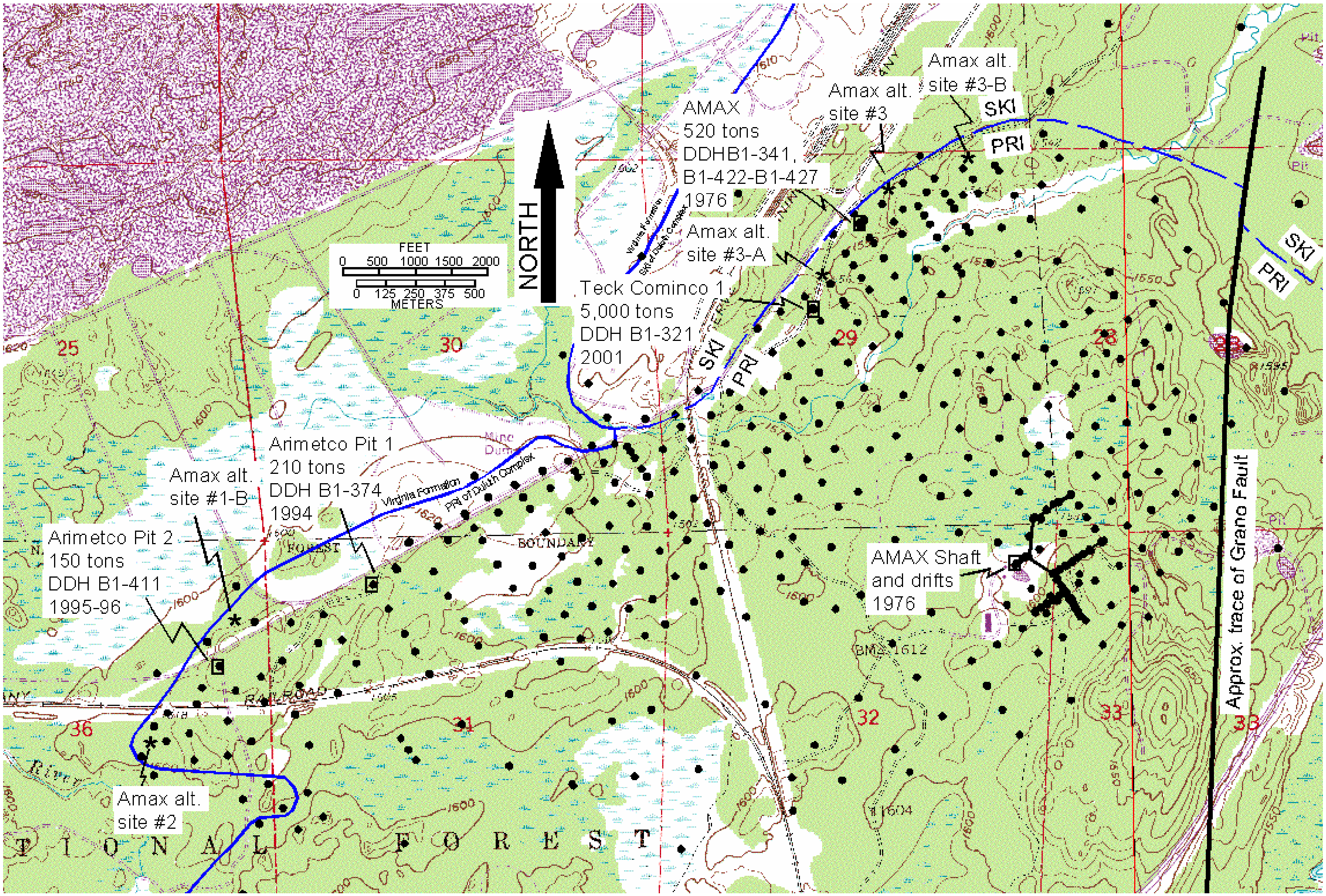

Figure 16. Distribution of drill holes and location of surface bulk samples (4) as well as potential bulk sample sizes (5) for the Babbitt/Mesaba deposit. Note that the AMAX shaft and projected trace of drifts and underground drill holes for the Local Boy ore zone are shown in the right lower portion of this figure.

tration of massive sulfide in the "Local Boy" zone at a depth of about 1,700 feet. Table 18 shows the raw assay values for these broad two classifications.

We think that AMAX discriminated two types of lower grade ore underground: "disseminated," which graded about 0.75% copper and about 1.30% sulfur, and "high Po-Cb," which also graded about 0.75% copper, but had a higher sulfur of about 3.5%. There was also a definition for "semi-massive and massive" ore grading somewhere over 2.0% copper and over 5.0% sulfur. We presume this grade designation is based on the grades and labels given to the larger samples sent from the underground work, not from any specific written evidence.

Figure 17 shows the "ore zone" names used at AMAX. There is a dearth of detailed maps or lists from AMAX specifically showing which drill holes were in which "ore zone," but that definition may have changed over time. For instance, we

Table 18. Babbitt/Mesaba average of raw assay data. All drill holes in area, unweighted for footage, based on all intervals where copper assay is greater than zero percent. Mostly 10 foot long assays.

Drill hole type	Copper %	Nickel %	Sulfur %
Surface drilling, 208,000 feet	0.40	0.10	1.17
Underground drilling from drift, 56,600 feet	0.82	0.17	2.34

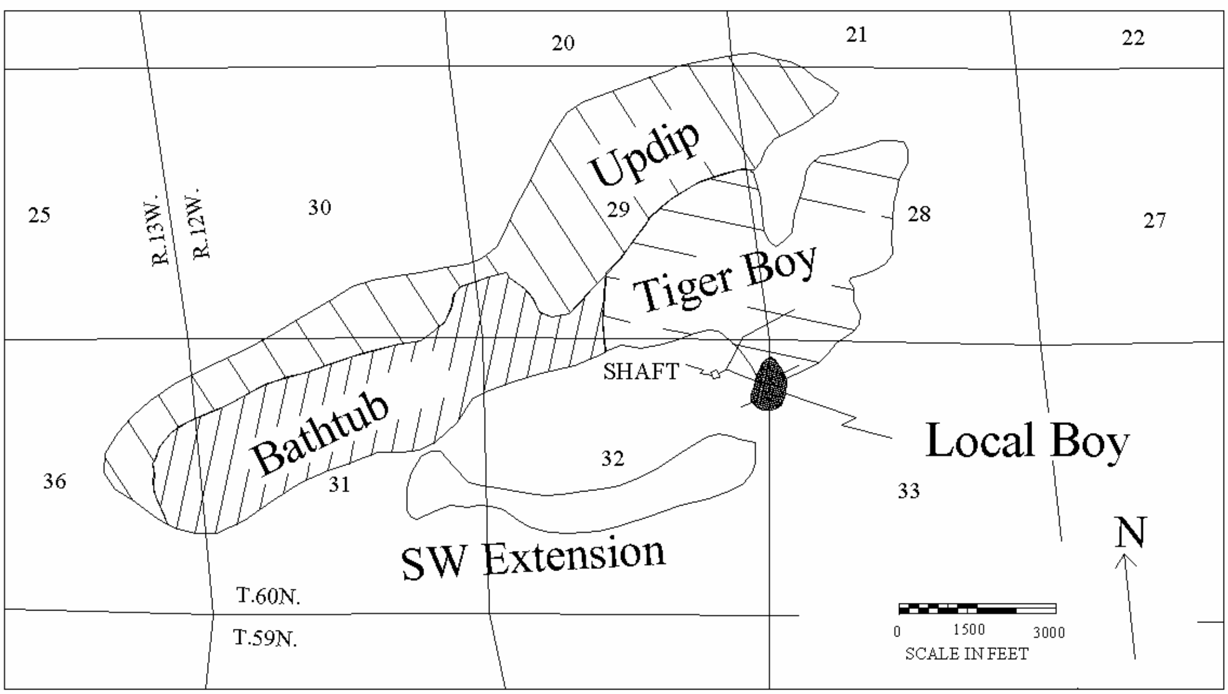

Figure 17. Individual ore zones of the "MinnAMAX" deposit as defined by AMAX. Locations for "Partridge Zone" and "Updip Tiger Boy" are not known, and thus are not displayed.

are unsure about what the "Partridge Zone" actually included or whether or not the "Updip" area is the same as the "Updip Tiger Boy" area. The sketch map shown is one NRRI has used in the past without negative comment from any individuals who might know otherwise.

Underground geology at Babbitt is detailed in Severson and Barnes (1991). Some 1990s assay work derived from NRRI work for Arimetco is also recorded in Hauck and Severson (2000).

From Severson and Barnes, 1991: "*The massive sulfide ore is hosted dominantly by hornfels inclusions just above the basal contact and by the footwall rocks just below the basal contact. With the exception of massive sulfide occurring at the contacts between footwall material and intrusive material, the intrusive rocks are relatively barren of massive sulfide mineralization. This suggests that the footwall rocks must have been structurally prepared and flooded by an immiscible sulfide during some early intrusive phase. At some later point the massive sulfide ore zone was re-intruded by multiple troctolite/norite sills along bedding planes in the footwall rocks. The end result is a disjointed zone of mineralized inclusions and mineralized footwall rocks separated by "barren" intrusive rocks.*

In summary, the massive sulfide ores of the Local Boy area appear to have been injected into structurally prepared footwall rocks in a "vein-like" manner. Sulfide ore textures indicate that the sulfides were formed by cooling of a MSS (mono sulfide solution) followed by limited replacement of early formed sulfides at very low temperatures. The MSS may have been formed in a secondary magma chamber at depth and was later emplaced as "veins" within the footwall rocks associated with a major pre-Duluth Complex structure (EW-trending anticline)."

<u>AMAX Bulk Samples</u>

AMAX took numerous bulk samples and composites, and planned many others. Table 19 lists a fraction of this work. In general, we chose not to detail every piece of data for the AMAX drill core composite work because a complete understanding will require an individual to go through all the files, come to their own comprehension of how AMAX was proceeding, and establish whatever data links they think are needed to the drill data and project geological and metallurgical models. The AMAX bulk samples that are more clearly understood (from shafts, drifts, and surface) are described below.

AMAX SHAFT AND DRIFT (1976 – Local Boy Ore Zone)

The Local Boy massive sulfide was first intersected in drill hole B1-105. This intersection led to renewed interest in the deposit by Bear Creek, who up to that point had been planning a large, open pit in the Tiger Boy and Bathtub areas with shallower mineralization. They partnered with AMAX in 1974, and a vertical shaft was sunk in 1976 (Fig. 16).

The shaft was placed in essentially the same location as drill hole B1-162, towards the southeastern corner of the deposit. There are about 15 surface drill holes in the area adjacent to the shaft. The shaft (now capped, but not filled) was about 1,728 feet deep, including the sump. About 3,760 feet of drift were completed at the 1,700 foot level. About 220 underground holes (drilled in a fan arrangement at 31 stations) were drilled to further define the massive sulfide zone. The geology of the Local Boy massive sulfide ore zone is discussed in two NRRI reports: Severson (1991) and

Table 19. Summary of all known bulk samples (drill core composites, surface, and underground) collected, and planned, from the Babbitt/Mesaba deposit.

Year	Sample	Date (mo./yr.)	Area / Ore Type	Number of drill holes	Footage length (ft.)	Weight (pounds)	Cu%	Ni%	S%	Description	Type
1975	6 Core	05/75	High PO Dissem.	1	71.6		0.96	0.35	7.27	B1-222	core
1975	6A Rejects	06/75	High PO Dissem.	1						Similar to 6 Core	core
1975	12A Core	07/75	Semi-massive	1	96		3.65	0.88	NA	B1-139	core
1975	1 Core	08/75	Average dissem.	3	254		0.82	0.18	NA	B1-207, B1-209, & B1-211	core
1975	1A Rejects	08/75	Average dissem.	3						Similar to 1 Core	core
1975	2 Core	08/75	Average dissem.	1	307		0.73	0.15	NA	B1-217	core
1975	2A Rejects	08/75	Average dissem.	1						Similar to 2 Core	core
1975	4 Core	08/75	Low grade dissem. (Cloud Zone)	1	80		0.55	0.12	NA	B1-159	core
1975	4A Core	08/75	Low grade dissem. (Cloud Zone)	1	90		0.42	0.11	NA	B1-146	core
1975	6B Core	09/75	High PO Dissem.	1	150		0.70	0.18	3.38	B1-225	core
1975	12B Core	09/75	Semi-massive	1	92		2.51	0.45	6.61	B1-105	core
1975	13 Core	09/75	Area number 1 dissem. and semi-massive	1	135.3		0.98	0.22	3.51	B1-227	core
1975	13B Core	09/75	Average dissem. Similar to Met. Sample number 1 (?)	1	60		0.84	0.17	1.98	B1-238	core
1975	12C Core	11/75	Semi-massive	1	57		3.33	0.57	8.52	B1-135	core
1975	14 Rejects	11/75	Average dissem.	2	219		0.98	0.20	2.57	B1-219 & B1-227	core
1975	15 Rejects	12/75	Average dissem. (Tiger Boy)	4	528		0.77	0.18	1.58	B1-206, B1-210, B1-221, & B1-226	core
1976	241	02/76		1	76	51	0.87	0.21	4.45	B1-241	core
1976	121-U	02/76		1	70	40	0.84	0.16	1.78	B1-121	core
1976	121-L	02/76		1	65	31	0.90	0.15	1.99	B1-121	core
1976	150-U	02/76		1	98	81	0.79	0.19	3.06	B1-150	core
1976	150-L	02/76		1	107	93	0.94	0.27	5.89	B1-150	core
1976	156-U	02/76		1	89	82	0.78	0.15	1.71	B1-156	core

Year	Sample	Date (mo./yr.)	Area / Ore Type	Number of drill holes	Footage length (ft.)	Weight (pounds)	Cu%	Ni%	S%	Description	Type
1976	156-L	02/76		1	70	63	0.84	0.18	3.58	B1-156	core
1976	Partridge	04/76	Up-dip Bathtub	2	696	46	0.44	0.11	1.44	B1-264 and B1-265	core
1976	Comp. 2	04/76	Tiger Boy	11	1,883	557	0.83	0.19	2.05	B1-230, B1-233, B1-235, B1-239, B1-240, B1-241, B1-246, B1-247, B1-253, B1-254, and B1-259	core
1976	Comp. 3	10/76	Deep Bathtub	5		435	0.89	0.21	1.69	B1-073, B1-078, B1-090, B1-100, and B1-101	core
1976	Comp. 4	11/76	Up-dip Tiger Boy	7	2,015	255	0.42	0.10	1.09	B1-107, B1-108, B1-110, B1 111, B1-113, B1-114, and B1 186	core
1976	Comp. 5	11/76	Up-dip Bathtub (upper)	17	2,859	123	0.43	0.10	1.11	B1-256, B1-258, B1-263, B1-264, B1-265, B1-267, B1-270, B1-271, B1-273, B1-278, B1 280, B1-283, B1-284, B1-287, B1-294, and B1-310	core
1976	Comp. 6	11/76	Up-dip Bathtub (lower)	11	3,741	112	0.54	0.12	1.89	B1-205, B1-260, B1-263, B1-267, B1-271, B1-273, B1-276, B1-278, B1-80, B1-290, and B1 294	core
1976	B1-048	12/76		1		48	0.43	0.12	0.75	B1-048	core
1976	267	12/76	North Flank Bathtub	1	38	19	1.22	0.64	19.64	B1-267	core
1976	48	12/76	Up-dip Tiger Boy	1	135	48	0.43	0.12	0.75	B1-048	core
1977	128-G	?	Local Boy	A Drift		59				Semi-massive mineralization shipped to AMAX lab in Golden Colorado.	bulk
1977	W-3	11/77	Local Boy-bench tests for 500 ton diss. Sample below.	Local Boy-bench tests for 500 ton diss. Sample below.		180	0.73	0.15	1.33	Local Boy-bench tests for 500 ton disseminated ore. Sample below.	bulk
1977	W-4	11/77	Local Boy-bench tests for 186 ton semi-massive sample below.	Local Boy-bench tests for 186 ton semi-massive sample below.		202	2.50	0.44	5.99	Local Boy-bench tests for 186 ton semi-massive sample below.	bulk

Year	Sample	Date (mo./yr.)	Area / Ore Type	Number of drill holes	Footage length (ft.)	Weight (pounds)	Cu%	Ni%	S%	Description	Type
1977	W-5	11/77	Local Boy-bench tests for 202 ton high Po-Cb sample below.	Local Boy-bench tests for 202 ton high Po-Cb sample below.		215	0.77	0.16	3.54	Local Boy-bench tests for 202 ton high Po-Cb sample below.	bulk
1977	500 ton dissemi-nated	11/77	Local Boy	Drift A & B	Rounds 180-188, 199-268, 340-344, & 362	500 tons	0.83	0.18	1.94	Dissem. Also referred to as 600 ton.	bulk
1977	186 ton semi-massive	11/77	Local Boy	Drift C	Rounds 241-294	186 tons	2.93	0.46	6.10	Semi-massive ore, also referred to as 200 ton.	bulk
1977	202 high Pyrrhotite-Cubanite	11/77	Local Boy	Drift A	Rounds 305-337, 57-83, & 99-103	202 tons	1.14	0.25	3.77	Blend of both low grade PO mineralization and high grade PO & CB mineralization (both from A Drift).	bulk
1977	MRRC-1	11/77	Local Boy	Shaft dissem.		304 tons	0.67	0.14	1.15	Process tune up bulk sample at MRRC.	bulk
1977	MRRC-2	11/77	Local Boy	Drift A dissem.		259 tons	0.79	0.18	1.61	Disseminated.	bulk
1977	MRRC-3	11/77	Local Boy	Drift A & B dissem.		334 tons	0.64	0.13	1.66	Disseminated +/- low grade massive PO.	bulk
1977	MRRC-4	11/77	Local Boy	Drift B dissem.		426 tons	0.92	0.20	2.26	Disseminated.	bulk
1977	USBM-1	11/77	Local Boy	Muck from shaft-dissem.		200 tons?	0.67	0.14	1.15		bulk
1977	Comp. 2-G	?	Tiger Boy	11	1,883	177	0.94	0.21	0.25	Remains of Comp. 2, shipped to AMAX lab in Golden, Colorado.	core
1977	Comp. 5-6-7G	?	Mixed	Mixed	Mixed	206	0.42	0.10	1.22	Remains of Comp. 5, 6 and 7, shipped to AMAX lab in Golden, Colorado.	core

Year	Sample	Date (mo./yr.)	Area / Ore Type	Number of drill holes	Footage length (ft.)	Weight (pounds)	Cu%	Ni%	S%	Description	Type
1977	Comp. 7	03/77	Up-dip Tiger Boy	16	5,798	130	0.42	0.09	1.18	B1-321, B1-322, B1-326, B1-329, B1-333, B1-337, B1-340, B1-341, B1-344, B1-345, B1 347, B1-348, B1-349, B1-351, B1-352, and B1-354	core
1978	Surface	07/78	Up-dip 520 ton sample	Bulk	20 ft. by 45 ft. pit	520 tons	0.43	0.10	1.09	11 out of 22 muck piles went to Lakefield as Types 4, 5, 6, and Blend 1 & 3.	bulk
1978	Comp. 8	04/78	Up-dip, surface bulk sample drilling	4	120	56	0.48	0.11	1.00	B1-422, B1-423, B1-424, and B1-427 prior to surface bulk sample.	core
1978	No. 260	04/78	Up-dip Bathtub (Partridge Zone)	1	270		0.37	0.09	1.42	B1-260?	core
1978	124-U	04/78	Drift area samples	2	215	1/4 core	0.81	0.17	1.60	B1-124	core
1978	124-L	04/78	Drift area samples	2	214	1/4 core	1.01	0.20	2.05	B1-124	core
1978	154-U	04/78	Drift area samples	2	50	1/4 core	0.95	0.22	1.62	B1-154	core
1978	154-L	04/78	Drift area samples	2	55	1/4 core	0.92	0.26	4.83	B1-154	core
1978	Massive Sulfide Leach Test	09/78	Local Boy	2		5	2.99	0.92	17.38	B1-239, B1-247	core

Severson and Barnes (1991). The latter report documents the presence of high precious metal values (13 ppm Pd, 10 ppm Pt, and 13 ppm Au) associated with Cu-rich massive sulfides. A cross-sectional sketch of the shaft is presented in Figure 18, and a plan map of the 1,700 foot level drift is portrayed in Figure 19.

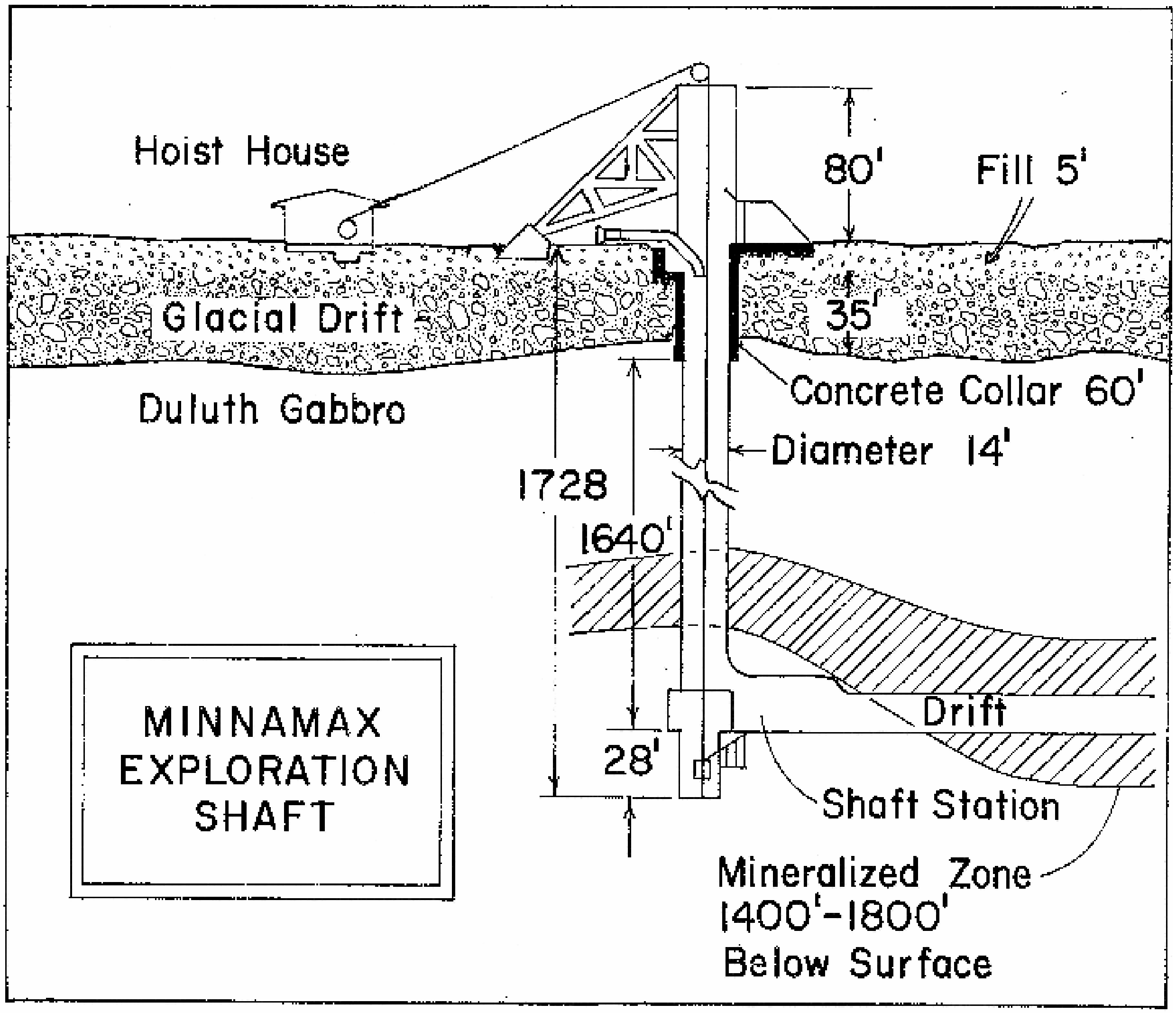

Figure 18. Simplified cross-sectional sketch of the MinnAMAX shaft and drift (from non-referenced AMAX brochures and hand-outs).

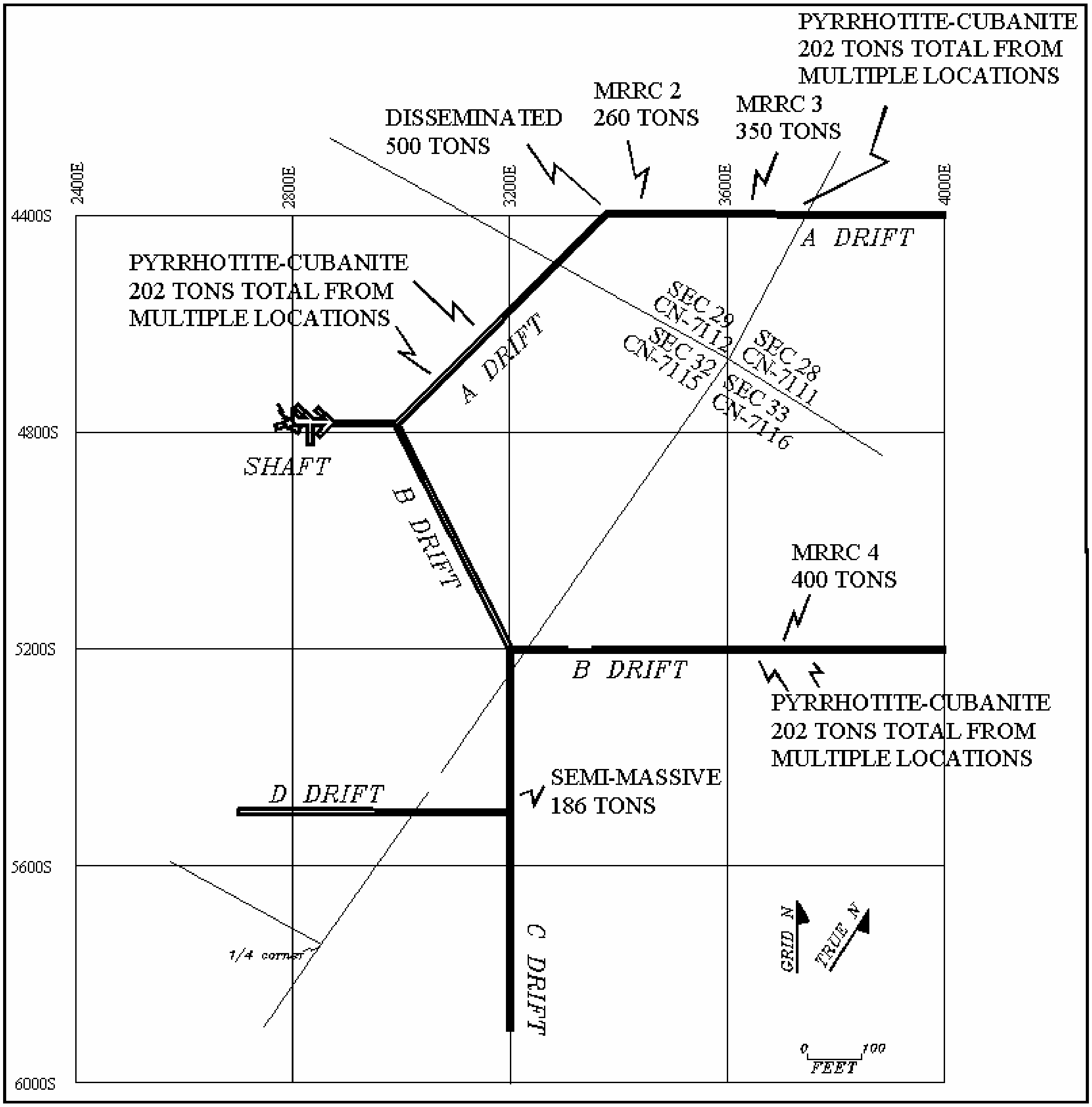

Figure 19. Plan map of the drifts (Drifts A through D) for the 1,700 ft. level of the MinnAMAX shaft showing generalized locations of underground bulk samples.

Table 20 details the bulk material taken from this underground excavation for process testing. Materials from the shaft and drift were treated separately and some were blended with ore from the surface sampling.

Drilling Program From Drift – Assays and Geology

AMAX drilled about 220 holes from the drifts. This was done in a "fan drilling" pattern, with sets of holes every 50 to 200 feet.

AMAX SURFACE BULK SAMPLE (1978 – drill hole B1-341)

Besides the one surface sample AMAX took, their maps show five alternate sites for test pits (Fig. 16). The Arimetco and Teck Cominco sites are located at alternate sites that were also considered by AMAX.

Table 20. MinnAMAX underground samples. Accounting of source, destination, size, and grade. From a December 5, 1977 MinnAMAX memo from J. Malcolm to S. Watowich. No certainty as to completeness. Found in folder 54, MDNR MinnAMAX data archive. MRCC is "Minerals Resource Research Center" of the Twin Cities Campus of the University of Minnesota, closed in the early 1990s. "Lakefield" is Lakefield Laboratories in Lakefield, Ontario, Canada. Lakefield was the main contract process lab for MinnAMAX. "USBM" is the United States Bureau of Mines laboratory at Fort Snelling in Minneapolis, closed in the mid-1990s.

Destination	Sample identity	State lease	Tons	Cu%	Ni%	S%
MRRC	Number 1	CN-7115	304	0.67	0.14	1.15
MRRC	Number 2	CN-7112	259	0.79	0.18	1.61
MRRC	Number 3	CN-7112	264	0.71	0.14	1.85
MRRC	Number 4	CN-7111	70	0.36	0.07	0.92
MRRC	Number 4	CN-7116	426	0.92	0.20	2.26
		subtotal:	1,323			
Lakefield	Disseminated	CN-7112	400	0.79	0.17	1.81
Lakefield	Disseminated	CN-7116	100	0.98	0.21	2.45
		subtotal:	500			
Lakefield	Semi-massive	CN-7116	186	2.93	0.46	6.10
		subtotal:	186			
Lakefield	Pyrrhotite-Cubanite	CN-7115	86	2.12	0.47	7.22
Lakefield	Pyrrhotite-Cubanite	CN-7112	51	0.49	0.10	1.57
Lakefield	Pyrrhotite-Cubanite	CN-7111	65	0.36	0.07	0.92
		subtotal:	202			
USBM	Shaft disseminated		200	0.67	0.14	1.15
		subtotal:	200			
		grand total:	2,411			

AMAX's test pit site selection was based on the assumption that two of their composites were relatively representative of the ore body. Table 21 shows these typical composites. These samples were chosen as "*a compromise of material most approximating the metallurgy established in the near surface drilling program.*"

Of these 22 piles, 11 piles were sent by rail (in 7 cars, about 70-75 tons each) to Lakefield labs in Lakefield, Ontario. The grades for these 11 piles were 0.37% to 0.47% copper, and the average was 0.43% copper. One rail car was set aside at Lakefield as contaminated with "straw," leaving six cars available for processing.

Table 21. Typical composites for MinnAMAX area. These are composites that AMAX selected as representative of the deposit. Note similarly in grade to 208,000 ft. sample in Table 18.

Area	Composite number	Number of drill holes	Feet of core	Copper %	Nickel %	Sulfur %
Bathtub	5	17	2,859	0.43	0.10	1.11
Tiger Boy	7	16	5,798	0.42	0.09	1.18

In 1978, AMAX took a 520 ton bulk sample from a pit at the northeast edge of the Babbitt deposit (Figs. 16 and 20). The excavation itself was probably about 1,050 tons. Six shallow drill holes (cored), roughly grouped along a line southwest to northeast, about 30 ft. north of drill hole B1-341, outlined a 50 ft. by 100 ft. by 30 ft. deep block with high copper grade variability (0.07 to 0.61% copper). The western side of this block was deemed a desirable sample location. During stripping of the overburden, a bedrock ledge with substantial relief was encountered (Fig. 20). Mapping of the stripped area by AMAX geologists indicated that the bedrock surface shape was largely controlled by joints and shear zones (Fig. 20).

During excavation, 22 piles were set out in mucking sequence; each of these piles was estimated to weigh about 47 tons. The assayed grade of the individual piles ranged from 0.34% to 0.51% copper, and the average was 0.43% copper. Figure 21 shows the variability in Cu:Ni ratios for samples collected from the AMAX surface bulk sample.

Table 22 tabulates the compositing for this delivery. It is not clear what happened to the 11 piles that were not sent to Ontario—at one time it was rumored that some piles of mineralized gabbro from the shaft were stockpiled near the railroad at the "town" of Skibo.

We have not been able to reconcile all the sample tonnages reported by MinnAMAX for both the surface and underground samples. There certainly are some losses, and they mention a 20 ton estimated loss, but their January 12, 1979 memo lists about 800 tons as the starting weight with a summary table in the same memo accounting for only 250 tons of material.

A memo from S. Watowich to J. Malcolm on July 18, 1978 (on file at MDNR and NRRI) describes the geological condition at the test site prior to blasting and excavation: "*The initial overburden removal exposed a more rugged bedrock topography than expected from the test drill hole data. The shape of the exposure is controlled and sculpted by a strong jointing-fracture*

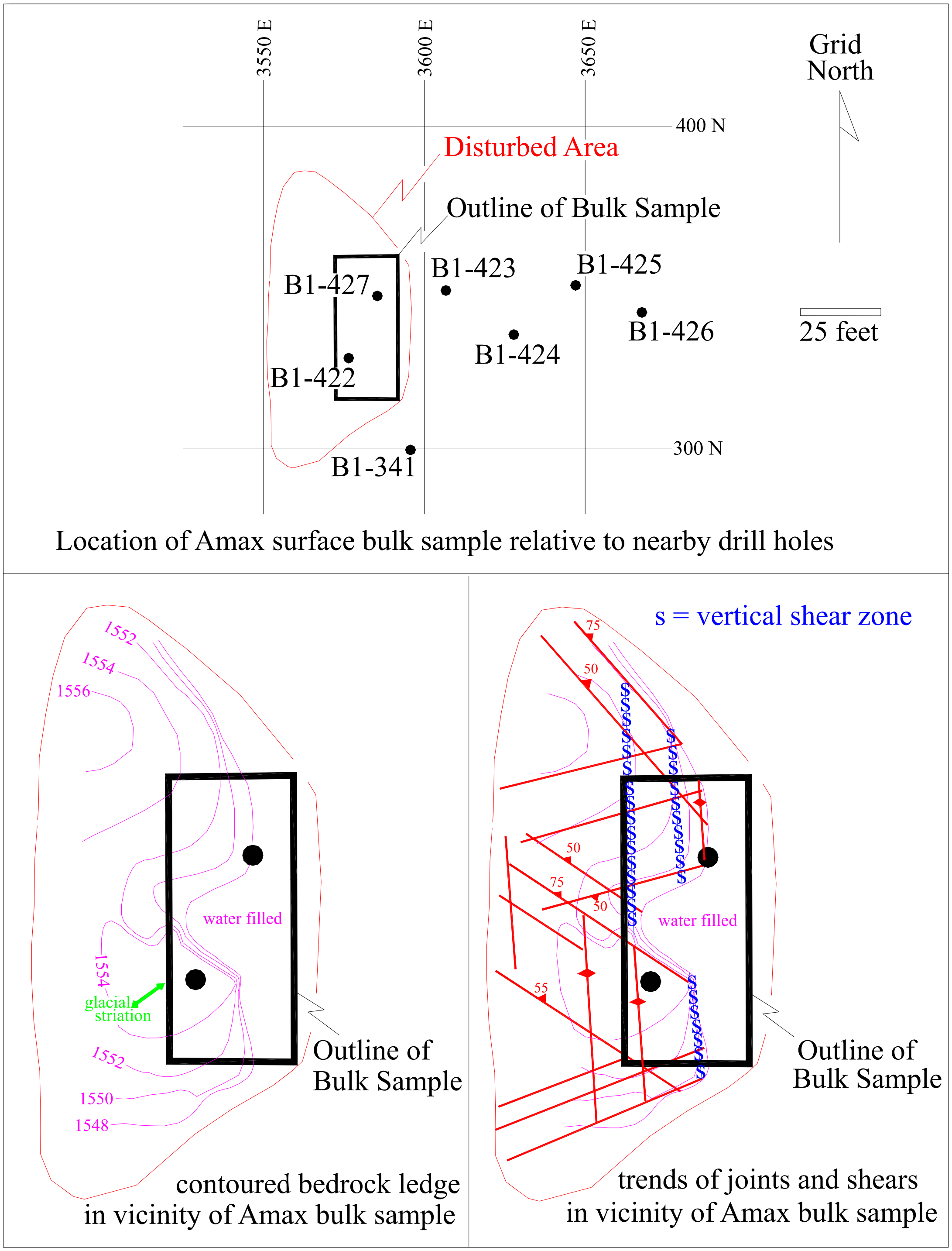

Figure 20. Detail of AMAX bulk sample collected in the vicinity of B1-341 at the Babbitt/Mesaba deposit. Top half of figure shows location of the bulk sample relative to nearby drill holes and area that was stripped of overburden ("disturbed area"). Dimensions of the bulk sample were 45 ft. long by 20 ft. wide by 4-5 ft. deep. The lower left portion of the figure is a close-up of the stripped area with a contoured surface of the ledge rock. The distribution of joints and shears as mapped by MinnAMAX geologists is shown in the lower right portion of the figure – note that the distribution of joints and shears largely controls the form of the undulating bedrock surface (see later discussion).

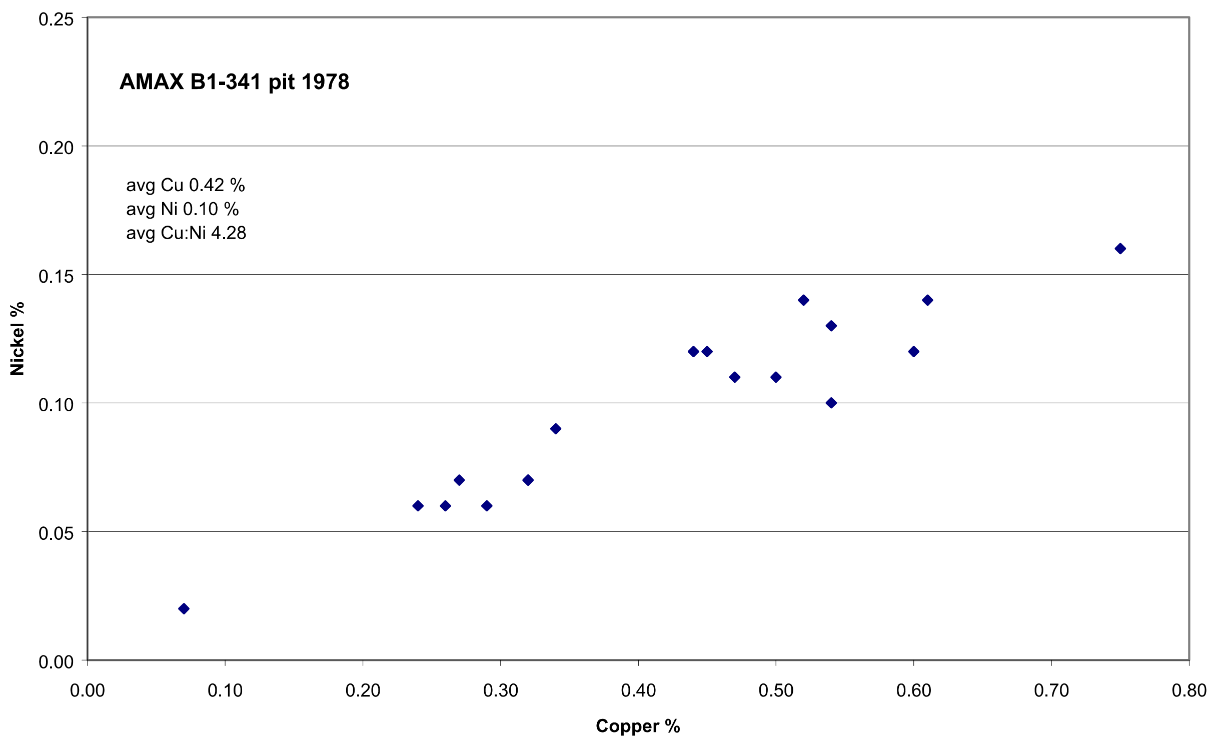

Figure 21. Variability of copper versus nickel for the AMAX B1-341 bulk sample.

system, some of which has an associated shear zone. Consequently the exposure is rectangular in shape, as shown on attached diagram 3.3.10 [Fig. 20], *and composed of steep walls, 4 to 5 ft. high.*

Using mine grid references the bearing of the structure system is basically a steeply dipping, north-south fracture-shear system with a spacing of 4 to 10 ft. The east-west joint system is in two distinct directions, N70°E and N40°W with dips from vertical to 50° in a northerly direction. A flat lying shear dips at 10° southwest and strikes E-W. A distinct gouge of one to two inches is present. Spacing appears to be over 3 ft.

Glacial scouring is evident on the rock and has generally cleaned the exposure of oxidation on the flat surfaces with the exception of a thin rusty veneer. However, the steep fractures are well coated with oxidation. The shear zones may exhibit oxidation over a few inches to local pockets, [there is] one foot thick of oxidized segments which deplete the metal content.

This exposure is not uniform in composition and texture. Essentially the rock is a coarse-grained troctolite with rare very coarse grained segregations. Sulfides are restricted to this lithologic type. Sulfides ranging from 0.5% to 3.0% are persistent. The sulfides are typically coarse grained and interstitial. Chalcopyrite and cubanite dominate the pyrrhotite in a ratio of about cpy/cb/po = 4/4/1. The percent silicate distribution is plagioclase 65-70, olivine 15-20, pyroxene 5-10, biotite 1-2, oxides 1-3.

Two other lithologic types occur within this troctolite. Contacts hazily indicate rounded block-like forms which are 1-2 ft. in diameter and scattered irregularly throughout the exposure. These may be inclusions. The most common type is a fine-grained, equigranular augite troctolite with

Table 22. AMAX 520 ton bulk sample disposition. Surface sample was mixed with at least a 280 ton sample of three underground ore types.

Sample name or type	Source	Use	Tons	Copper grade %	Nickel grade %
520 tons from the surface sample were sent to Lakefield labs. At least four classes of sample were separated out from the surface sample at Lakefield:					
Culled	One car	Set aside due to contamination with straw	74.3		
Type 4	From one car	Semi-autogenous grind tests	20 tons	0.49%	0.12%
Type 5	Composited from other five cars	Random sample from other five cars	50 tons (also listed as 44.75 tons)	0.60%	0.12%
Type 6	Remainder from five cars ("heaped together")	Mixed with Type 1 and Type 3 at a ratio of 3:1 surface:underground (see below)	390? tons	0.52%	0.12%
Two blends of underground material were made.					
Type 1	Blended underground sample from shaft and drift		Tons uncertain, 72% dissem. ore, 18% massive ore, and 10% semi-massive ore.	1.05%	0.21%
Type 3	From "0.6% Cu stockpile"		Made from 280 tons from underground 0.6% Cu stockpile-not clear if this was a blended stockpile or not.	0.57%	0.12%

a hornfelsic-like appearance. The silicates are euhedral to subhedral. Sulfides are rare. The composition is plagioclase 55-60, olivine 15-20, pyroxene 10-15, biotite 2-4, oxide 2-5. Less commonly medium to coarse-grained mafic-rich rock types occur. These due to their susceptibility to oxidation are rather decomposed, particularly the pyroxene and olivine. Plagioclase content is about 25 percent. Sulfides are rare."

Nearby Drill Holes – Assays and Geology

AMAX drill holes B1-422 through B1-427 (all short core holes) were drilled in a 50 ft. by 100 ft. area just north of exploration drill hole B1-341. This pit was the only test pit area that was drilled in detail by AMAX in the Babbitt deposit. Presumably, the location was also chosen on the basis of access, assays in drill hole B1-341, and thin glacial overburden.

Note that in reviewing assay and lithologic cross-sections in 2002 for this area, for the Duluth Complex digital logs project (Patelke, 2003), the authors came to the conclusion that these holes (and therefore the pit itself) were possibly in the South Kawishiwi intrusion rather than the Partridge River intrusion. This conclusion remains to be tested and may have relevance to bulk sample grade and metallurgical results. The main criteria for discriminating the PRI rocks from the SKI rocks at a drill hole to drill hole scale are dependent on establishing a local stratigraphy. Assay values, other geochemical methods, and gross rock type are not recognition criteria in looking at small sample sets. Petrographically, the SKI contains plagioclase symplectite in its upper portions, while the PRI contains symplectite in its lower portion; inverted pigeonite is present in all units of the SKI, and rare in all units of the PRI (Severson, 1994).

Arimetco Bulk Samples

Arimetco International (Arizona Metals Company International?) leased the Babbitt deposit from the state of Minnesota and the Longyear-Mesaba Trust in 1994. Their initial modeling of the pre-existing drill hole data led them to conclude that an open pit operation with both a milling operation for higher grade material and a heap leaching system for lower grade material would be economic.

Towards that end Arimetco took two bulk samples and planned a third. NRRI has labeled the test pits by the nearby original drill hole: B1-374 and B1-411 for the two completed samples, and B1-321 for the third, which was later taken by Teck Cominco.

Arimetco filed for bankruptcy in May, 1997, with a final sale of their assets by the court in April, 1999 (Auction announcement in Northern Miner, March 6, 1999). PolyMet Mining had sued the state in bankruptcy court to get the Arimetco leases for Babbitt to add to their controlling United States Steel lease at the nearby Dunka Road/NorthMet deposit. PolyMet lost their case, and the Babbitt/Mesaba deposit reverted to the state and the Longyear-Mesaba Trust, who then leased the property to Cominco. Cominco merged with their majority owner Teck to become Teck Cominco in 2001. They continue to pursue study of the deposit as of this writing (2004).

ARIMETCO TEST PIT B1-374 (1994)

Arimetco took their first sample in the fall of 1994 from a small area near drill hole B1-374 (Fig. 16). There is some question as to whether the sample was taken at the actual site of drill hole B1-374, or just nearby. Arimetco reported (A. Wells, Arimetco Geologist, pers. comm. to Mark Severson, 1994) at the time that they never actually found the drill collar location for B1-374 (many, but not all, holes at Babbitt/Mesaba are still capped with a numbered pipe). Forty-nine blast holes (10 ft. deep and 4 ft. apart) were drilled in a 24 ft^2. area prior to blasting and collecting the sample. The cuttings from all the blast holes were taken to CMRL for Cu, Ni, and S analyses. Figure 22 illustrates the variation in copper grades in the blast holes at this site.

The sample was divided into an 85 ton and a 125 ton portion on arrival at the Coleraine Minerals Research Lab (CMRL) of the NRRI. Site selection was based on assay data for drill hole B1-374, as well as thin overburden in the area. This site was

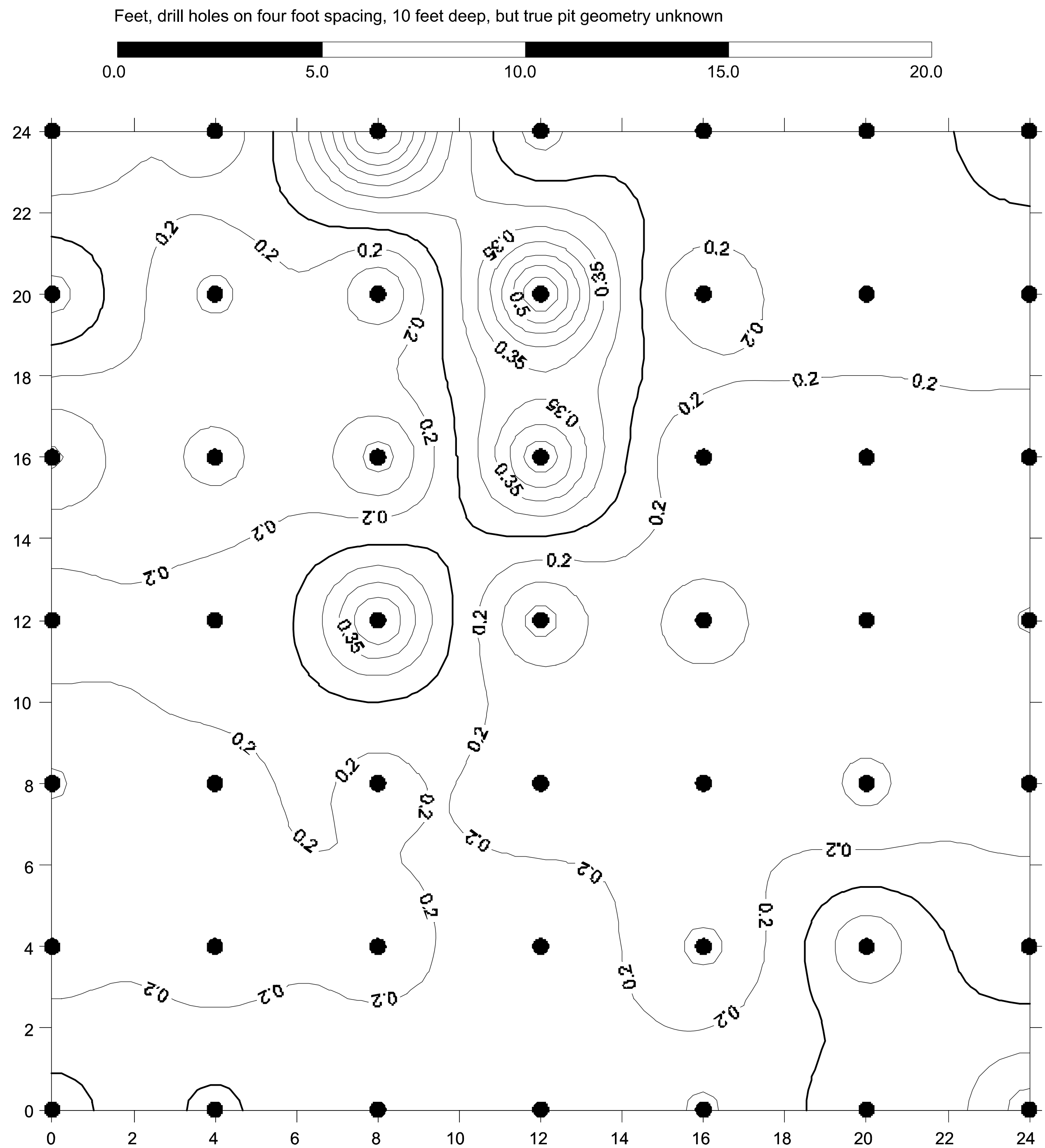

Figure 22. Contoured copper grades in blast holes (49) in the area of Arimetco bulk sample B1-374. Note that this map is inferred from meager data (Table 24) supplied by Arimetco at the time they took their bulk sample. It is not known exactly where within this figure Arimetco took their sample (in fact, the whole area could have been sampled); the dimensions of the pit itself are unknown. Also, it is not even known which direction is north on this figure – the top of this figure has been assumed to reflect north.

also listed by AMAX as a possible location for a test pit. The portion shipped off-site as the bulk sample was almost certainly in Unit IV of the PRI, or an inclusion of Unit III within Unit IV. While the drill core (B1-374) assays in the area were representative of the average grade of the deposit, the geology was not. CMRL attempted to process this sample and was not able to make an acceptable concentrate at an acceptable recovery (CMRL Staff, 1995). Table 23 shows a comparison between the grade in B1-374 and the grade in the sample itself.

Table 23. Test pit B1-374: grade comparison of test pit and nearby drill hole.

Hole ID	From (feet)	To (feet)	Copper %	Nickel %	Sulfur %
B1-374	0.00	14.0	NS	NS	NS
B1-374	14.0	15.0	0.43	0.10	0.90
B1-374	15.0	25.0	0.43	0.10	0.90
B1-374	25.0	35.0	0.44	0.11	0.87
Average for 14 to 35 feet in DDH B1-374:			0.43	0.10	0.89
Average head grade for pit material tested at CMRL:			0.30	0.08	0.63
Average grade of 49 blast holes for pit at 4 foot spacing:			0.22	0.06	0.52

According to Severson, who visited the B1-374 pit the day after it was excavated, some reclamation had already begun (replacing some loose rock back into pit), and some of the material loose on surface was oxidized. His observations at the site include: 1) the majority of sulfide mineralization is associated with pegmatitic zones (veins, pods, and irregular patches) that are unevenly distributed throughout the host troctolite; 2) sulfides within the pegmatites are very coarse-grained and vary from 5-30% of the rock; 3) the pegmatitic zones are rarely greater than a few feet across; 4) the sulfides are dominantly pyrrhotite and cubanite; and 5) the rock that hosts the pegmatitic zones is a fairly fine-grained troctolitic rock that he believed to be Unit III. Olivine oikocrysts, as are common in Unit III, were revealed by later thin section examination of samples from the pit.

In communicating with CMRL staff and Arimetco, Severson wrote: "*I believe that the bulk sample site is situated within a large inclusion of Unit III that has strong sulfide mineralization associated with late pegmatite veins. Thus the rock types from the bulk site are not typical Unit I ore material (Unit III is rarely mineralized elsewhere within the Babbitt and Dunka Road deposits). Also, the sulfide mineralization (dominantly pyrrhotite and cubanite that is associated with pegmatites) is not typical of Unit I material which generally has higher contents of chalcopyrite and pentlandite. And last, the strong replacement by pyrite and violarite in these samples is also not common to the Unit I ore material.*"

Records at MDNR and NRRI for this pit are incomplete at best. This location does not seem to be the site where Arimetco had told both MDNR and MPCA that the pit would be placed. Their submittal to the regulatory agencies indicated the sample would come from the area of either B1-017 or B1-256 (D. Antonson, MDNR, pers. comm., 2003). Why the site was changed is not clear in any available record. The submittal indicated that a 200 ton sample would be taken. An 85 ton portion was sent to CMRL before blasthole assays were completed, and the remaining 125 tons were then stockpiled separately on arrival at CMRL because the blast hole assays had made it abundantly clear that the grade was not consistent throughout the test pit area (see Fig. 22 and Table 24). The variability of copper versus nickel for the B1-374 bulk sample is presented in Figure 23.

CMRL reported difficulty in making a suitable bulk concentrate with this material, and testing of this sample was terminated before a full scale pilot run. However, the lack of success in concentrating should not be interpreted as wasted effort. The CMRL report did produce useful parameters for application in further testing. Notably, these are: chemistry by size fractions for various concentrates, response of concentration process to various pHs, notation that material seems to be acid consuming rather than acid generating (important for acid rock drainage issues), and grade-grind relationships. These parameters may not all translate to future work on the "ore zone," but are useful nonetheless.

David Antonson of MDNR states that this site is reclaimed to the satisfaction of MDNR (pers. comm., 2003), with the land sloped to a low relief contour.

Nearby Drill Holes – Assays and Geology

Table 23 gives the copper-nickel-sulfur assay and lithology for the top portion of drill hole B1-374. The other nearby drill

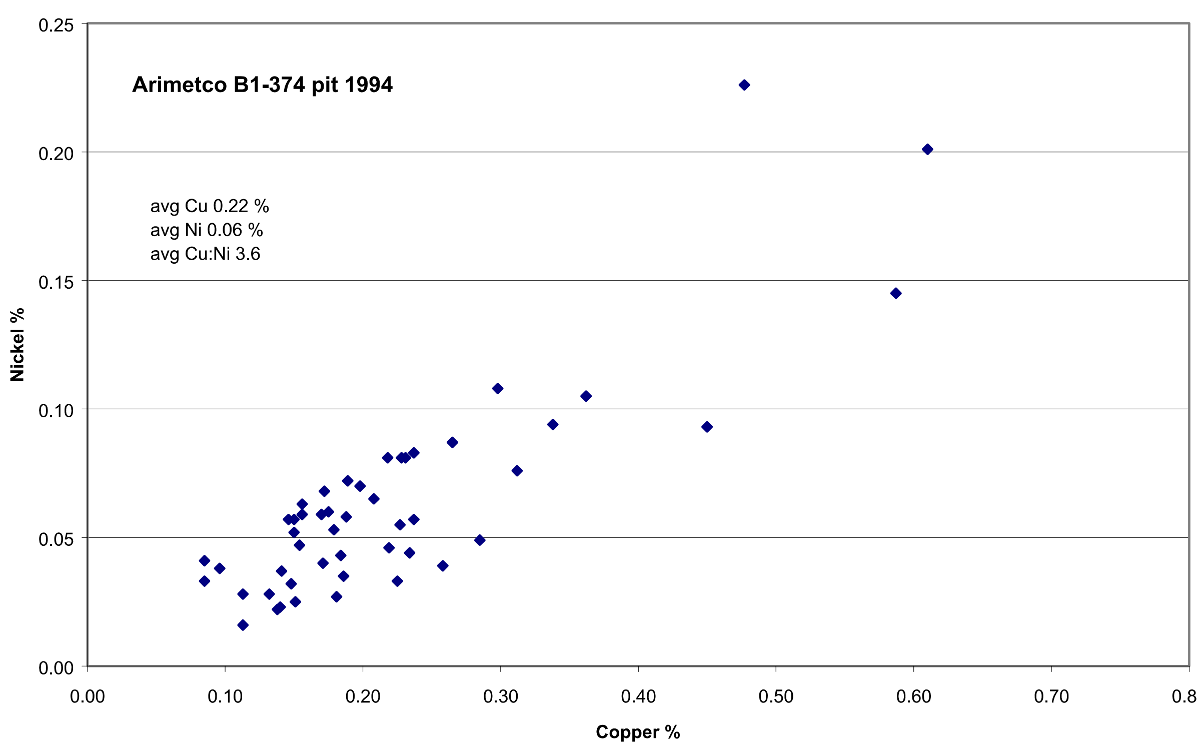

Figure 23. Variability in copper versus nickel for Arimetco bulk sample B1-374.

Table 24. Blasthole assays for B1-374 pit. Arimetco number 1. Assays by CMRL, 1994.

Blast hole number	Location X	Location Y	Copper %	Nickel %	Sulfur %	Cu/S
1	0	6	0.150	0.057	0.36	0.42
2	1	6	0.179	0.053	0.45	0.40
3	2	6	0.610	0.201	1.70	0.36
4	3	6	0.188	0.058	0.40	0.47
5	4	6	0.218	0.081	0.49	0.44
6	5	6	0.227	0.055	0.49	0.46
7	6	6	0.298	0.108	0.76	0.39
8	0	5	0.312	0.076	0.66	0.47
9	1	5	0.141	0.037	0.27	0.52
10	2	5	0.113	0.016	0.19	0.59
11	3	5	0.587	0.145	1.34	0.44
12	4	5	0.154	0.047	0.38	0.41
13	5	5	0.228	0.081	0.53	0.43
14	6	5	0.237	0.057	0.52	0.46
15	0	4	0.096	0.038	0.20	0.48
16	1	4	0.132	0.028	0.30	0.44
17	2	4	0.085	0.033	0.17	0.50
18	3	4	0.477	0.226	1.09	0.44
19	4	4	0.150	0.052	0.31	0.48
20	5	4	0.151	0.025	0.35	0.43
21	6	4	0.175	0.060	0.43	0.41
22	0	3	0.219	0.046	0.48	0.46
23	1	3	0.208	0.065	0.41	0.51
24	2	3	0.450	0.093	1.02	0.44
25	3	3	0.085	0.041	0.19	0.45
26	4	3	0.113	0.028	0.24	0.47
27	5	3	0.156	0.063	0.33	0.47
28	6	3	0.148	0.032	0.40	0.37
29	0	2	0.146	0.057	0.23	0.63
30	1	2	0.186	0.035	0.37	0.50
31	2	2	0.189	0.072	0.45	0.42
32	3	2	0.171	0.040	0.42	0.41
33	4	2	0.172	0.068	0.45	0.38
34	5	2	0.138	0.022	0.30	0.46
35	6	2	0.156	0.059	0.36	0.43
36	0	1	0.184	0.043	0.46	0.40
37	1	1	0.170	0.059	0.39	0.44
38	2	1	0.181	0.027	0.37	0.49
39	3	1	0.237	0.083	0.68	0.35
40	4	1	0.140	0.023	0.32	0.44
41	5	1	0.338	0.094	0.82	0.41
42	6	1	0.234	0.044	0.53	0.44
43	0	0	0.265	0.087	0.65	0.41
44	1	0	0.258	0.039	0.62	0.42
45	2	0	0.231	0.081	0.61	0.38
46	3	0	0.225	0.033	0.55	0.41
47	4	0	0.198	0.070	0.55	0.36
48	5	0	0.285	0.049	0.64	0.45
49	6	0	0.362	0.105	1.01	0.36
		Averages:	0.219	0.063	0.52	0.44

holes are B1-025 and B1-031 about 400 feet to the east-northeast and B1-373 about 400 feet south-southeast. While the grade in B1-374 seems to be representative of the Babbitt (Mesaba) deposit as a whole, the geology is not. Specifically, the NRRI maps and cross-sections would show this area as being in the base of Unit IV (homogenous augite troctolite), which is a sulfide poor unit on a deposit scale. As noted above, Severson (Sept. 15, 1994 memo) also postulated that this may be an inclusion of Unit III with scattered pegmatitic veins that contain the majority of sulfides.

Samples from this pit (a few preserved by Severson at NRRI) show an interlocking network of coarse-grained (pegmatitic) zones surrounding enclaves of finer-grained material. Almost all mineralization (chalcopyrite/cubanite/pyrrhotite) is in the coarse-grained zones. Based on drill core experience, these data are not typical for the deposit, where most mineralization is in disseminated sulfides.

It is interesting to note that when samples from the B1-374 pit, which appeared to be sulfide-rich were sawn, the interiors of the samples were seen to be barren of sulfide. This condition is because the rocks tend to break through the coarse-grained, sulfide-rich patches and give a false impression of high sulfide content throughout.

ARIMETCO TEST PIT B1-411 (1995-1996)

Arimetco took their second sample (intended to be 150 tons) in December of 1995, with final closure and clean-up of the pit area in January, 1996. Patelke was the on-site geologist for this project. Prior to stripping overburden at the site, 34 assayed samples were collected from 12 air-hammer-drilled blast holes to establish the overall grade of the sample, as well as to determine the exact best location and level from which to take the sample. Figure 24 shows the location of the bulk sample relative to drill hole B1-411 and the 12 air-hammer blast holes (along with posted Cu-Ni-S values for specific intervals in each of these holes).

Figure 25 is a generalized cross-section of Figure 24 that shows the amount of rock removed relative to a ramp and the actual bulk sample collected. Lastly, Figure 26 is a cross-section (looking south) that depicts the grades encountered in blast holes 411E-4 northward to 411E-5.

After the blast holes were completed and assayed, it was decided to collect the actual bulk sample from an area centered between blast holes 411E1 and 411E5 (Fig. 26). Though the bulk sample was taken at a convenient site, it may not have been as representative of the deposit geology and mineralization as the data may indicate. It did, however, greatly improve on the previous Arimetco sample taken at drill hole B1-374. The grade information from Benner et al. (1998) is given below in Table 25. The variability of copper versus nickel for the B1-411 bulk sample is shown in Figure 27.

Quoting from Patelke's (1996) report to Arimetco: "*The actual sample sent was estimated by truck counts to be 138 tons. The assays for the area samples indicated that the grade should be about 0.61% copper, 0.12 nickel, and 1.02 sulfur.*

(Authors' note: The CMRL report (1998) lists this sample as both 100 tons and 125 tons.)

The rock was a medium-grained troctolite with about 10% coarse- to pegmatitic augite-troctolite. Ilmenite was the main oxide phase, increasing in coarser parts of the excavation. There was interstitial potassium feldspar or granophyric mesostasis, also most common in the pegmatitic material, but present throughout the pit area. Grain size changes abruptly over short distances, with the coarser grained parts appearing to be discrete pods of material ranging in size

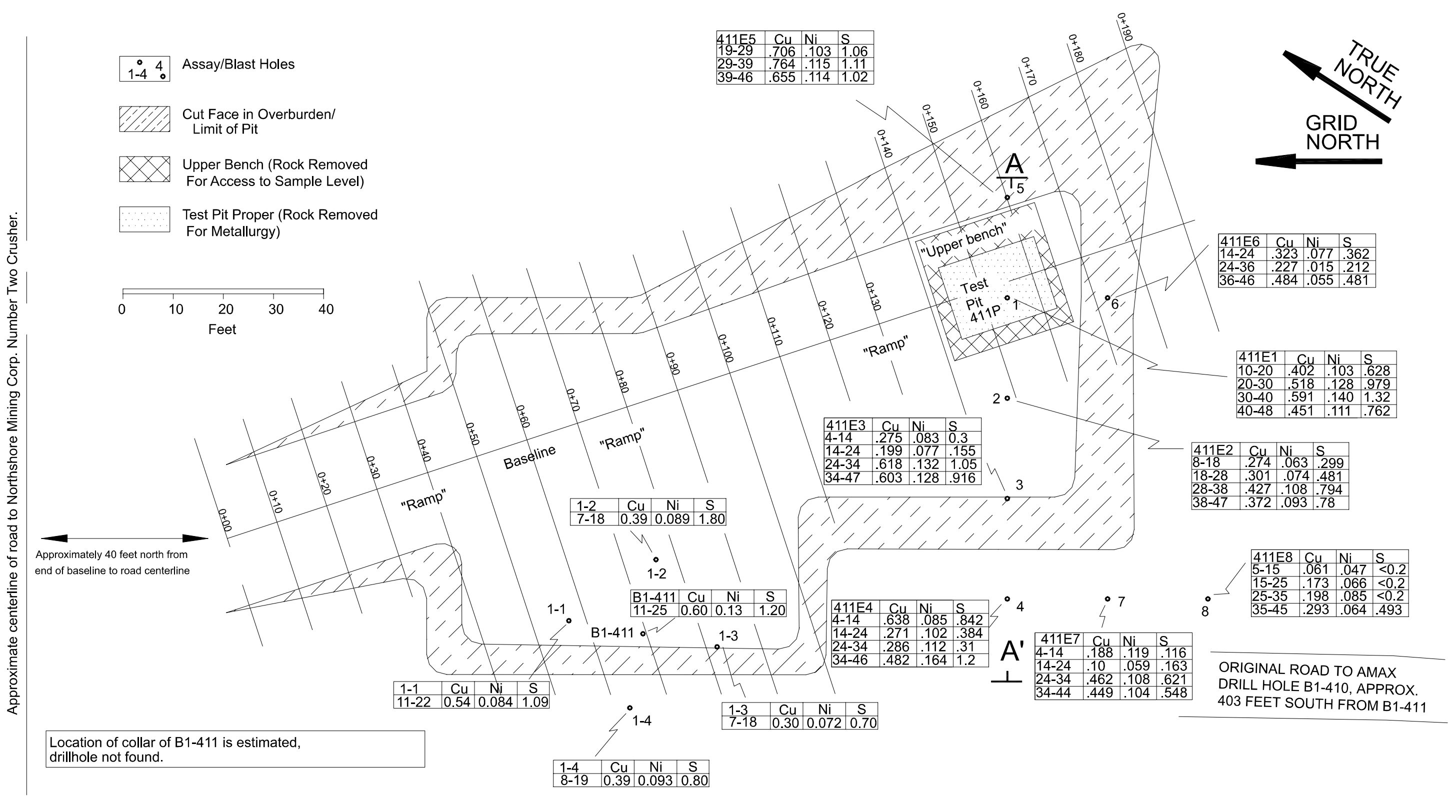

Figure 24. Plan map of Arimetco bulk sample #2 at B1-411 site. Shown in the figure are blast holes (1-1 through 1-4) relative to core hole B1-411, blast holes (411E1 through 411E8) located to the east of B1-411, and the final location of the bulk sample (411P). Cu-Ni-S percentage values are posted for each of the blast holes (intervals in feet are also posted). Note that the collar for B1-411 was accidentally bulldozed over while clearing the site of vegetation, and its exact location in this figure is approximate, but close. Figure from an internal Arimetco report by Patelke (1996).

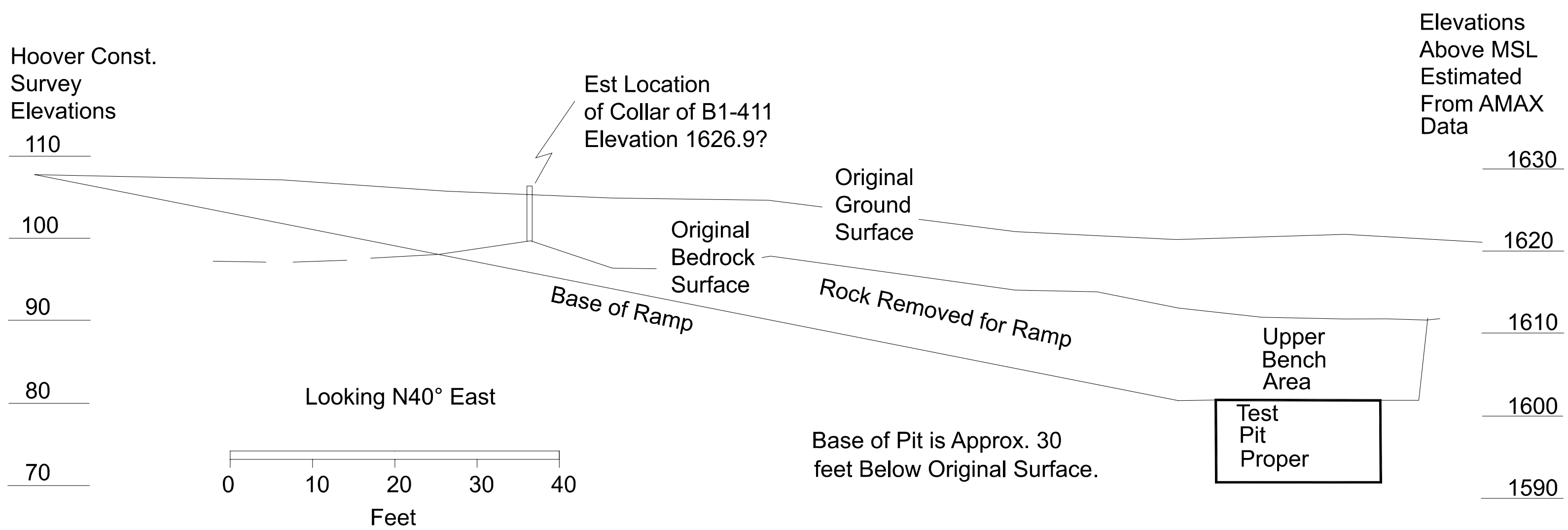

Figure 25. Cross-sectional sketch of ramp and material removed from Arimetco 411P bulk sample (cross-section is along baseline in Fig. 24). In order to gain access to unoxidized material, a block (upper bench – 25 ft. long by 25 ft. wide by 10 ft. deep) of somewhat oxidized gabbro was removed first and set aside. Next, material was removed on the north side of this pit to establish a ramp. Last, a block (lower bench – 15 ft. wide by 20 ft. long by 10 ft. deep) was collected at this site for metallurgical tests. Figure from an internal Arimetco report by Patelke (1996).

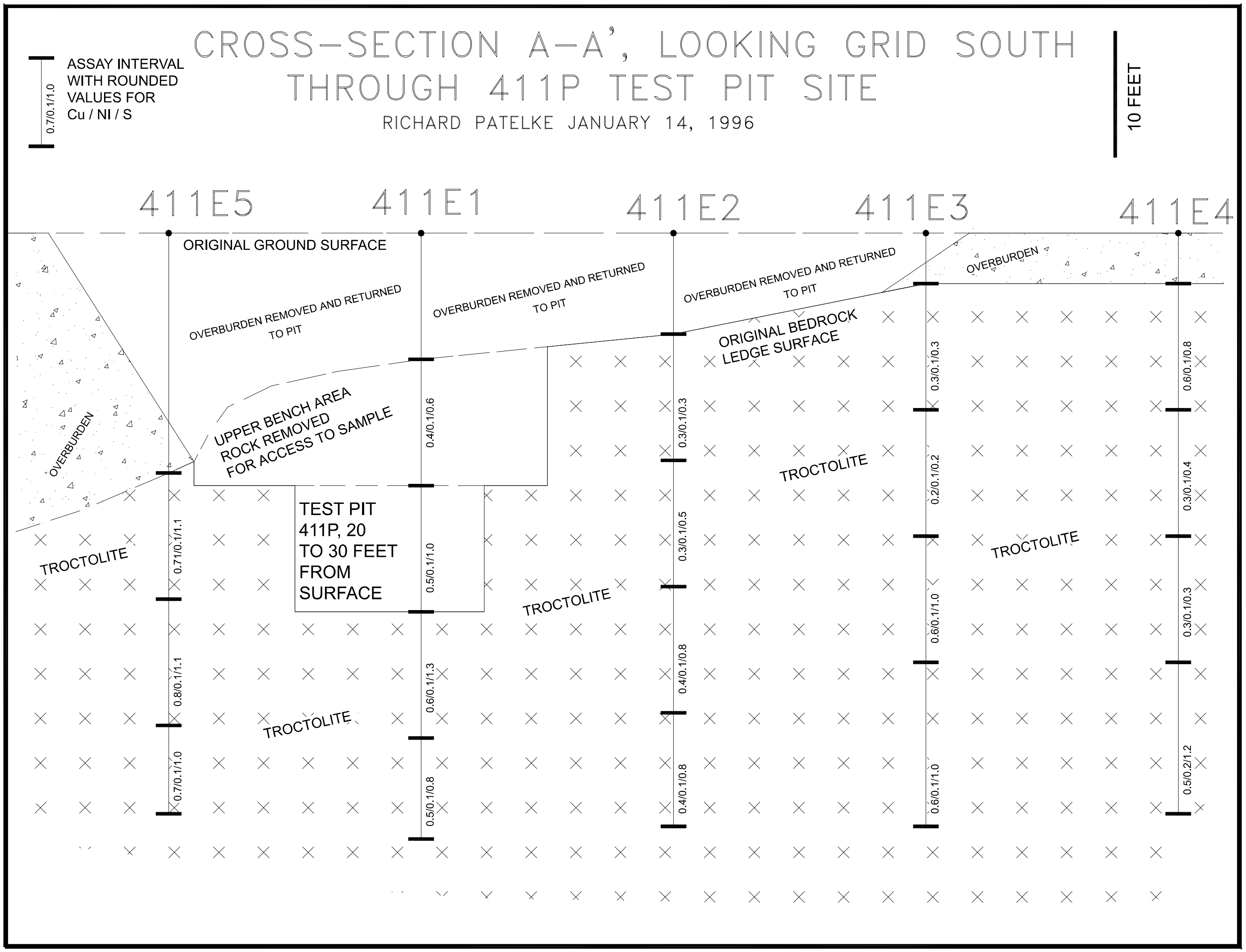

Figure 26. Cross-section, looking grid south, through blast holes and the material ultimately sampled at Arimetco 411P bulk sample. See Figure 24 for blast hole and pit locations. This figure from an internal Arimetco report by Patelke (1996).

Table 25. Head grades for Arimetco B1-411 sample and expected grades from drilling. Values from CMRL report (Benner et al., 1998). More elements are reported in that study.

	Cu %	Ni %	S %	Fe %	Co %	TiO2%
Expected grade from drilling	0.61	0.12	1.02	NA	NA	NA
CMRL reported grade	0.356	0.077	0.76	9.9	0.12	1.92

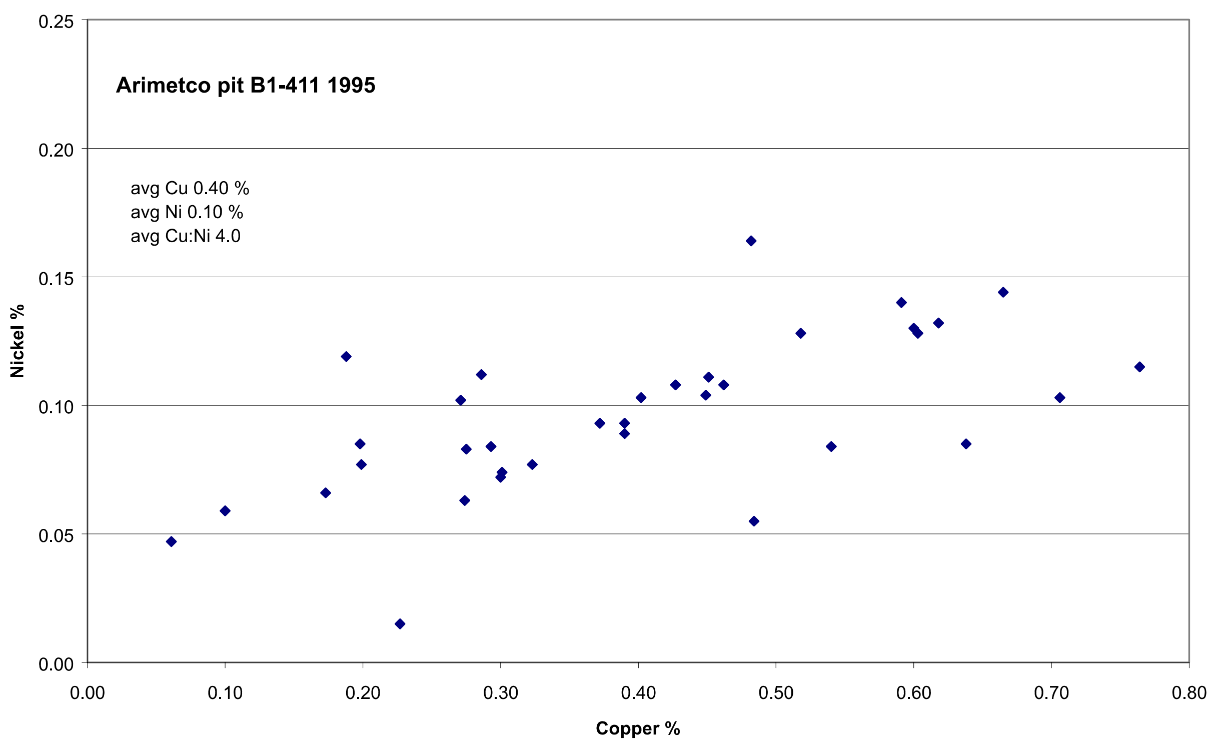

Figure 27. Variability in copper versus nickel values for the Arimetco bulk sample 411P (lower bench).

from inches to feet. Contacts between medium- and coarse-grained material are gradational over about one inch. There is no evidence for an interlocking network of coarse-grained [pegmatitic] *zones as seen in the samples for the test pit at drill hole B1-374 in 1994.*

Sulfide mineralization is pyrrhotite > chalcopyrite (cubanite?), 1 to 3 mm in length and well disseminated. Generally pyrrhotite dominates in the medium grained rock and copper sulfides in the coarser-grained rocks. Sulphide distribution is erratic over short distances. The sparse fine-grained zones in the pit are usually devoid of sulfides, and the common medium-grained portion is generally mineralized, but may show spots inches across that are completely barren of sulfides. The coarse-grained parts of the unit appear to always be mineralized.

Patelke, Severson, and Pete Niles of CMRL all inspected this pit and agreed that it seemed to be representative of the rock in the area in terms of lithology and mineralization. There was also agreement that the sample itself came from well below any surface weathering. The deepest visible effect of weathering was a seam of rotten rock about eight feet below the surface.

(Authors' note: Arimetco was concerned about deep weathering causing problems in the metallurgical work, and therefore nullifying the value of the sample. Probably this concern was related to their stated intention to heap leach some parts of the deposit.)

In further regard to the weathered rock found within two to four ft. of ledge and avoided as sample material because it is not suitable for metallurgical testing, George Spaeth, long-term employee of NorthShore Mining, commented that wherever they have dug into the Duluth Complex on their mine property they have seen the deeply weathered/oxidized rock and very irregular surface as found at this test site. In the small area stripped of overburden at this site the surface showed local slopes on the order of 10 ft. in 20, along with subcrops with acute angles and slight overhangs.

The weathered rock was not recognizable in the cuttings brought up by blast hole drilling. Specifically I did not see iron-stained faces on joint planes, tarnished sulfides, or copper-oxide blooms by hand lens inspection. As various photos show, the deeply weathered rock is coincident with extreme subhorizontal fracturing in the uppermost few feet of the ledge. It did seem that the penetration of the weathering and oxidation into the ledge decreased with increasing depth of overburden, but because the original ledge surface was very irregular this may not be true on a broad scale. The subhorizontal fracturing [with oxidized film coatings] *definitely diminished with depth.*

Drill cores stored at MDNR in Hibbing, and logged by Severson, Hauck, Patelke, and Zanko (mostly by Severson) seldom, if ever, show weathered material at the top of the hole. It follows that if the rock is commonly weathered at the top, the original drillers for Bear Creek/AMAX did not start coring until they hit competent rock, therefore the depth to bedrock numbers that are in use may be somewhat in error and possibly greater than the actual case.

The assays shown in the Table XXX [Table 26] *include the single sample from each of four holes drilled by Allen Wells* [holes 1-1 through 1-4 in Fig. 24] *and the 30 samples taken by Patelke for the drill holes done on December 12, 1995* [holes 411E1 through 411E8 in Fig. 24], *see enclosed map for drill hole locations. Combined with the AMAX assay for the interval 11 to 25 feet from drill hole B1-411, there is 359 feet of rock drilling at an average grade of 0.40% copper (low 0.061%, high 0.764%), 0.10% nickel (low 0.015%, high 0.164%) and 0.72% sulfur (low 0.116%, high 1.324%). By inspection of the assays it seems that the rock nearer the surface has lost sulfur relative to copper. This is somewhat confirmed by the presence of traces of native* *copper in the weathered surface rock (slight supergene enrichment?) and copper oxide blooms seen on joint faces in the near surface zone. The variability in assays is not any greater than the visible differences in grain size and mineralization seen in the test pit samples.*

(Authors' note: Blasthole samples were taken by setting a large sheet of plastic with a hole in it around the drill stem. As the blasthole was drilled (rotating percussion "chisel"), most of the chips and dust from the hole fell onto the plastic. Once every 10 ft. or so, the entire sample on the plastic was collected and bagged for transport to CMRL. As far as we know, no one has conducted any study on these rocks that would tell if there should be a conversion factor between the assay values from this type of chip samples versus those taken by coring. In particular, at the time of sampling, we discussed whether or not there might be some density sorting by the air blast from the drill, allowing the sulfide fraction to fall back into the hole (thereby lowering the grade of the sample), or blowing the finer (lighter) silicate fraction away from the hole (thereby raising the grade of the sample), or both. Unfortunately, the measuring of hole diameters and weighing of samples, which would have made it possible to estimate the sample recovery was not done.)

<u>*Swell Factor*</u>
Using a specific gravity of 3.00 for this rock gives a value of 2.52 tons per yard of rock in place, the broken rock loaded to CMRL averaged 4.7 tons per 3 yard bucket or ~1.566 tons per yard of broken rock. This gives a swell factor of 1.608.

Following is the edited "log of activities" from Patelke's January 1996 report to Arimetco:

<u>*December 5, 1995*</u>
Visited site with Allen Wells of Arimetco, Mark Severson and Larry Zanko of NRRI, and Dick Spry of Hoover Construction. Located sump pits for B1-11 and B1-321, the collar area of B1-321 was flagged as a possible test site. Located area of B1-411 [the collar was accidentally found and knocked over by bulldozer while clearing the site] *and assisted in the monitoring of the drilling of four assay holes (1-1 through 1-4) through 11 feet each of bedrock and varying amounts of overburden. These four assay samples were taken to Coleraine Minerals Research Laboratory of NRRI on December 6, 1995 by Mark Severson of NRRI.*

<u>*December 11, 1995*</u>
Prior to my return on December 11 the B1-411 site (411P) was chosen as a test site by Harrison Matson and Allen Wells on the basis of acceptable assays. Overburden removal had shown that the near surface rock was deeply weathered along fractures and not acceptable for metallurgical tests. During this visit it was decided to continue work at this site and to move the proposed test pit slightly south and east. We [myself and Harrison Matson] *laid out a pattern of eight drill holes south of the original partially dug test pit. See enclosed map for location of drill holes* [Fig. 24].

<u>*December 12, 1995*</u>
Hoover Construction drilled the eight assay holes (411E-1 through 411E-8) to depths of 44 to 48 feet and encountering 27 to 43 feet of ledge rock. Thirty samples weighing 30 to 70 pounds each were delivered to CMRL by Richard Patelke on December 12, 1995. See table [Table 26] *for these assays, interval lengths, etc. Total footage for the assay holes was 446 feet, including 101 feet of overburden and 345 feet of bedrock.*

<u>December 18, 1995</u>
Based on the assays [see Table 26] *it was decided to attempt to take the sample from the interval 20 to 30 feet from surface and centered between drill holes 411E-1 and 411E-5, see cross-section (looking South)* [included here as Fig. 26]. *It was estimated that this interval should give an average grade of about 0.6% copper, above the 0.4% cut-off for metallurgical testing. Hoover Construction began digging a pit to access bedrock on this day, Al Klaysmat of MDNR briefly visited site.*

<u>December 19, 1995</u>
Hoover Construction continued clearing away overburden, blast hole drilling, and surveying what rock would have to be blasted to make a truck ramp to the test pit. Material originally removed around drill hole B1-411 was put back into the west half of that pit, the rest of that pit will be a portion of the truck ramp [see Fig. 23] *constructed to load out the sample. Informed Dave Antonson and Paul Pojar of MDNR of intention to blast the next day.*

<u>December 20, 1995</u>
Hoover Construction blasted the material from above the test pit (the upper bench). This upper bench is the material directly over the sample site. A 25 X 25 X 10 feet deep block was removed here. Drillers used a 5 foot spacing (36 blast holes). Hand samples were taken for both Arimetco and NRRI. Visit by David Antonson of MDNR and Mark Severson and Pete Niles of NRRI. Small amount of water that had collected in lowest part is dispersed by blast.

(Authors' note: None of the blast hole drilling done during actual pit development was assayed.)

<u>December 21, 1995</u>
Hoover made first blast of material needing to be removed for truck ramp, drill rig broke down and worked was terminated for day. Hand samples taken for both Arimetco and NRRI.

<u>December 22 and 26, 1995</u>
Hoover Construction continued to remove material for truck ramp and began drilling the test site proper.

<u>December 27, 1995</u>
The actual 20 X 15 X 10 test pit was drilled and blasted. A single truck load was sent out to be weighed to establish tonnage per yard of blasted material (average weight per yard of blasted material is estimated to be 1.566 tons/yard). Suite of located samples was collected for NRRI, and hand samples selected for Arimetco.

<u>December 28, 1995</u>
In very early morning material was loaded on six trucks and sent to CMRL. Inspected the cleaned out pit, took samples for Arimetco and NRRI.

<u>January 2, 1996</u>
Visited site with Mark Severson of NRRI to collect samples and continue to attempt to map out geological relations on pit wall.

<u>January 5, 1996</u>
Visit site with Harrison Matson of Arimetco, discuss plans to fill in site and obtain water (ice) sample to be tested for background metals values.

<u>January 8, 1996</u>
Obtained ice samples—3 bags full, kept frozen until delivered to Northeast Technical Services of Virginia Minnesota on January 9, 1996. Monitored the filling of the test pit as per approved by MDNR-freshest blasted rock in bottom, weathered blasted rock on top, all covered by a minimum of five feet of overburden material. David Antonson of the MDNR also observed the bulk of this work and made a few suggestions about where to put specific materials. These suggestions were followed.

January 9, 1996

Continued to monitor and direct the filling of the test pit. No MDNR employees came by to monitor today. Pit was finished today—will require additional shaping and mounding in spring, after frost is out of ground. Knocked down trees were not burned—but moved away from edge of site to facilitate their being moved at a later time with a bulldozer rather than backhoe. Delivered water (ice) sample to Northeast Technical Services. Labeled as 411P water sample. Conversion of pace and compass map into AutoCAD drawing indicates that size of the disturbed area is about 1 acre (I estimate 44,224 square feet).

David Antonson of MDNR (pers. comm., 2003) states that this site is not reclaimed to the satisfaction of MDNR. The site was filled in very cold weather with the intent that the equipment and crews would return in the following summer (1996) to complete the reclamation. Arimetco's financial situation worsened, and no effort was made to return to the site. Patelke was contacted by Arimetco in 1999(?) concerning returning to direct reclamation work at the site, but there was never any follow-up communication from Arimetco about this issue.

Nearby Drill Holes – Assays and Geology

Drill hole B1-411 is about 400 ft. from the nearest holes (B1-410 and B1-413). NRRI logging indicates that the ledge of B1-411 is in the middle to upper parts of Unit 1 and about 350 ft. vertical above the footwall (basal contact). Table 27 is the assay and lithology data for B1-411.

METALLURGICAL RESULTS FOR ARIMETCO SAMPLES

Coleraine Minerals Research Laboratory (CMRL) of the Natural Resources Research Institute, University of Minnesota Duluth did the metallurgical testing on the Arimetco surface bulk samples. CMRL was originally the United States Steel ore research facility. Many employees who worked on the Arimetco samples had some experience with the USS Dunka Road bulk samples, as well as experience with the Longnose "peridotite" (an "OUI" by NRRI terminology) bulk sample colleted in the 1990s. Overall, they were quite qualified to assess the properties of the samples.

The first of the CMRL reports (CMRL Staff, 1995) covers the work done on the 1994 test pit near drill hole B1-374. As described above, the material from this pit was of unexpectedly low grade and probably not within "Unit I" (the main sulfide bearing unit). This report covers some discussion of the blast hole assays, possible problems with sample grade, and Severson's microscope study of sulfides in polished section.

Nevertheless, CMRL pursued some process testing on the B1-374 sample. Their 1995 report includes discussions of: grinding and flotation (what grain sizes and reagents worked best to maximize metals recovery); some high pressure roller press testing (its parameters and its effects on flotation recovery); microscopic examination of concentrate and tailing products; and results of acid leach tests for copper and nickel on small samples.

In the 1995 testing, CMRL produced a bulk sulfide concentrate rather than separate copper and nickel products. Arimetco planned a scheme of concentrating, then

Table 26. Blasthole assays for test pit B1-411, Arimetco number 2. Assays done by CMRL, December 1995.

HOLE #	FROM	TO	INTERVAL	Copper%	Nickel%	Sulfur%	Cu/S
411E1	10	20	10	0.402	0.103	0.628	0.64
38 Ft. assayed	20	30	10	0.518	0.128	0.979	0.53
	30	40	10	0.591	0.14	1.324	0.45
	40	48	8	0.451	0.111	0.762	0.59
411E2	8	18	10	0.274	0.063	0.299	0.92
39 Ft. assayed	18	28	10	0.301	0.074	0.481	0.63
	28	38	10	0.427	0.108	0.794	0.54
	38	47	9	0.372	0.093	0.78	0.48
411E3	4	14	10	0.275	0.083	0.3	0.92
43 Ft. assayed	14	24	10	0.199	0.077	0.155	1.28
	24	34	10	0.618	0.132	1.048	0.59
	34	47	13	0.603	0.128	0.916	0.66
411E4	4	14	10	0.638	0.085	0.842	0.76
42 Ft. assayed	14	24	10	0.271	0.102	0.384	0.71
	24	34	10	0.286	0.112	0.31	0.92
	34	46	12	0.482	0.164	1.2	0.40
411E5	19	29	10	0.706	0.103	1.056	0.67
27 Ft. assayed	29	39	10	0.764	0.115	1.11	0.69
	39	46	7	0.665	0.144	1.02	0.65
411E6	14	24	10	0.323	0.077	0.362	0.89
32 Ft. assayed	24	36	12	0.227	0.015	0.212	1.07
	36	46	10	0.484	0.055	0.481	1.01
411E7	4	14	10	0.188	0.119	0.116	1.62
40 Ft. assayed	14	24	10	0.1	0.059	0.163	0.61
	24	34	10	0.462	0.108	0.621	0.74
	34	44	10	0.449	0.104	0.548	0.82
411E8	5	15	10	0.061	0.047	<0.2	
40 Ft. assayed	15	25	10	0.173	0.066	<0.2	
	25	35	10	0.198	0.085	<0.2	
	35	45	10	0.293	0.084	0.493	0.59
B1-411	11	25	14	0.6	0.13	1.2	0.50
1-1	11	22	11	0.54	0.084	1.09	0.50
1-2	7	18	11	0.39	0.089	1.8	0.22
1-3	7	18	11	0.3	0.072	0.7	0.43
1-4	8	19	11	0.39	0.093	0.8	0.49
Total footage			359.00				
Averages			10.26	0.40	0.10	0.72	0.70

Table 27. Copper-nickel-sulfur assays and lithological logging for top portion of drill hole B1-411 (Patelke, 2003). AGT Homo=Homogenous Augite troctolite, AGT Het=Heterogenous Augite troctolite, MS=Massive sulfide, AT=Anorthositic Troctolite, Mott=Mottled, NS=not sampled.

Hole-ID	From	To	Cu%	Ni%	S%	Length	Rocktype	Unit
B1-411	0.0	11.0	NS	NS	NS	11.0	OVB	OVB
B1-411	11.0	25.0	0.60	0.13	1.2	14.0	Troct	1
B1-411	25.0	35.0	0.24	0.06	0.42	10.0	Troct	1
B1-411	35.0	45.0	0.26	0.06	0.5	10.0	Troct	1
B1-411	45.0	55.0	0.42	0.1	1.09	10.0	AGT-Troct	1
B1-411	55.0	65.0	0.59	0.12	1.17	10.0	Troct-AGT	1
B1-411	65.0	75.0	0.64	0.13	1.37	10.0	AT Peg & Troct	1
B1-411	75.0	85.0	0.85	0.23	2.11	10.0	Troct-AT	1
B1-411	85.0	95.0	0.48	0.12	0.92	10.0	Troct-AT	1
B1-411	95.0	105.0	0.59	0.12	1.16	10.0	Troct-AT	1

using SX/EW, plus heap leaching of the lower sulfide grade rock. How much detailed work went into Arimetco's plan is not clear.

In June 1998, CMRL released a progress report (Benner, 1998) on the metallurgical testing done for both the B1-374 pit and the B1-411 pit from 1995-1996. This paper summarized the pilot plant work on both samples.

The final CMRL report (Benner et al., 1998) was released in December, 1998. Numerous tests are detailed in this report. The broad conclusions were:

- A bulk sulfide concentrate with recovery of 90% of the copper and 60% of total nickel (described as 85-90% of sulfide nickel) was produced in the laboratory, with slightly lower nickel recovery in the pilot plant runs. Concentrate grades were 16-17% copper and 2% nickel;
- High quality copper concentrates can be made (24% copper and less than 0.5% nickel), but at the expense of total nickel recovery;
- Pressure oxidation as a method to recover copper, and nickel from the concentrate worked;
- Bacterial leaching with ferroxidans showed promise, but required repeated washings and reinoculation;
- PGEs do not seem to be preferentially concentrated in either the copper or nickel concentrates; so, to maximize PGE recovery, produce a bulk concentrate and treat it hydrometallurgically.

<u>Teck Cominco (Mesaba Metals LLC) Bulk Samples</u>

TECK COMINCO TEST PIT B1-321 (2001)

Teck Cominco took this bulk sample (Fig. 28) in the spring of 2001 at a site recommended by Severson from NRRI to Arimetco in 1996 (Severson, 1996). Only ~460 tons were originally outlined by core drilling around drill hole B1-321 by Severson (see Fig. 28). However, Teck Cominco wanted a much larger sample (5,000 tons) to run a pilot test through their CESL process. In order to obtain a large enough sample, they used the recommended "Severson site," but expanded this site outward to the east and south (extremely

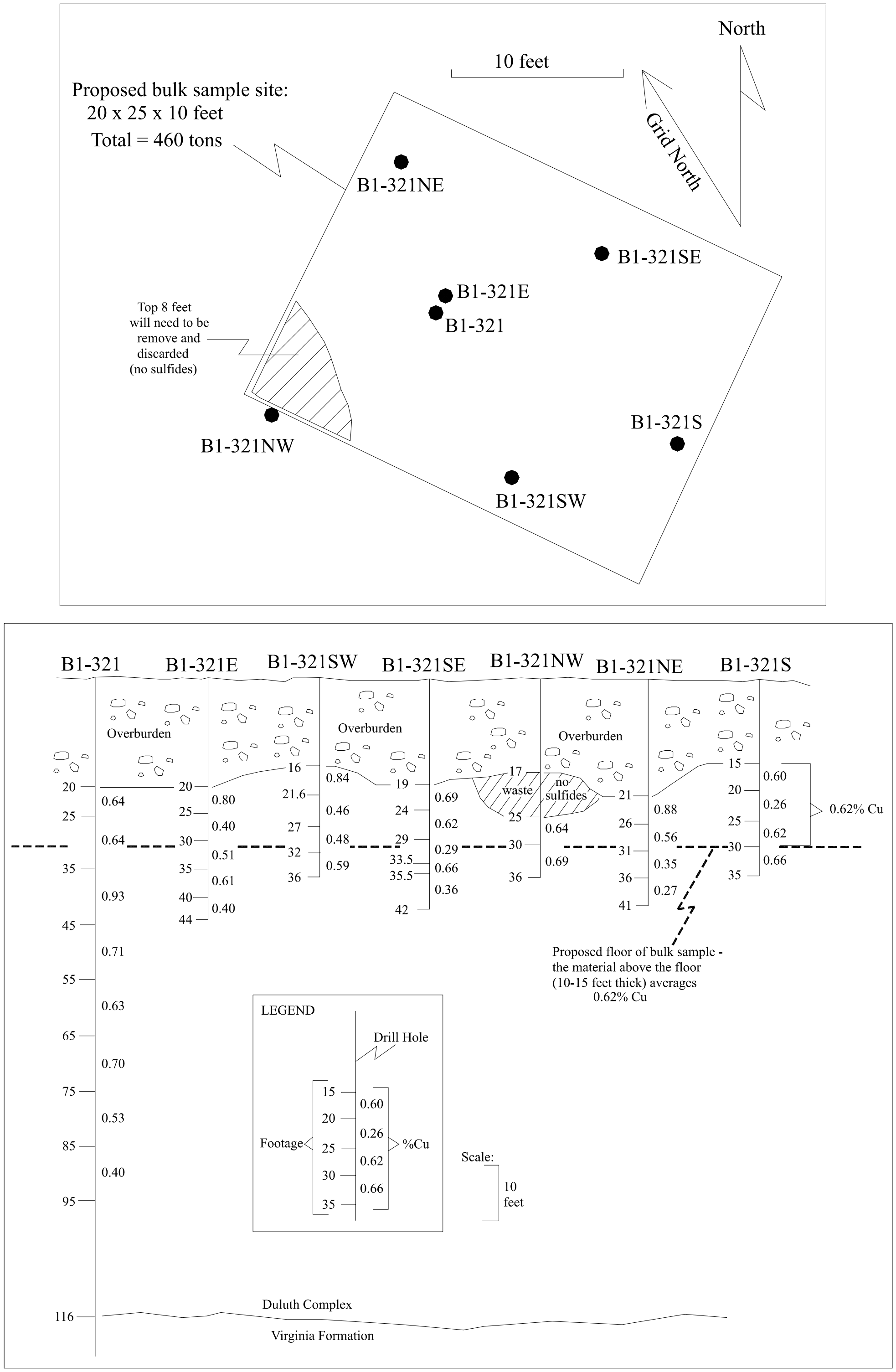

Figure 28. Proposed pre-Teck Cominco bulk sample site at B1-321 area, Babbitt/Mesaba deposit. Upper half of the figure shows the location of core holes, drilled by Severson in 1996, used to define potential boundaries of a pit with approximately 460 tons of material. Lower half of figure shows the copper variation (in percentage) in the holes in a cross-sectional relationship.

large boulders in the glacial overburden prevented the pit to be extended in either a north or west direction). The final pit was approximately 60 ft. by 120 ft. by 20-30 ft. deep (Fig. 29). The sample area was stripped of overburden (which revealed a highly undulatory ledge surface – no oxidized zones were present), drilled, blasted, and loaded by Luestek Construction Company with assistance from NorthShore Mining.

The 5,000 tons were sent to an unspecified mine in Montana for concentrating where 96 tons of concentrate were produced. The concentrate was then sent to Vancouver, B.C., and fed into the CESL (Cominco Engineering Services Laboratory) pilot plant that is owned and operated by a subsidiary of Teck Cominco (Jones and Moore, 2002). The CESL process is a proprietary hydrometallurgical method for refining copper-nickel concentrate. CESL uses pressure oxidation followed by atmospheric leaching, copper solvent extraction, and electrowinnowing. Teck Cominco is working to improve the precious metals recovery by this system, which are reportedly low. They expect to recover

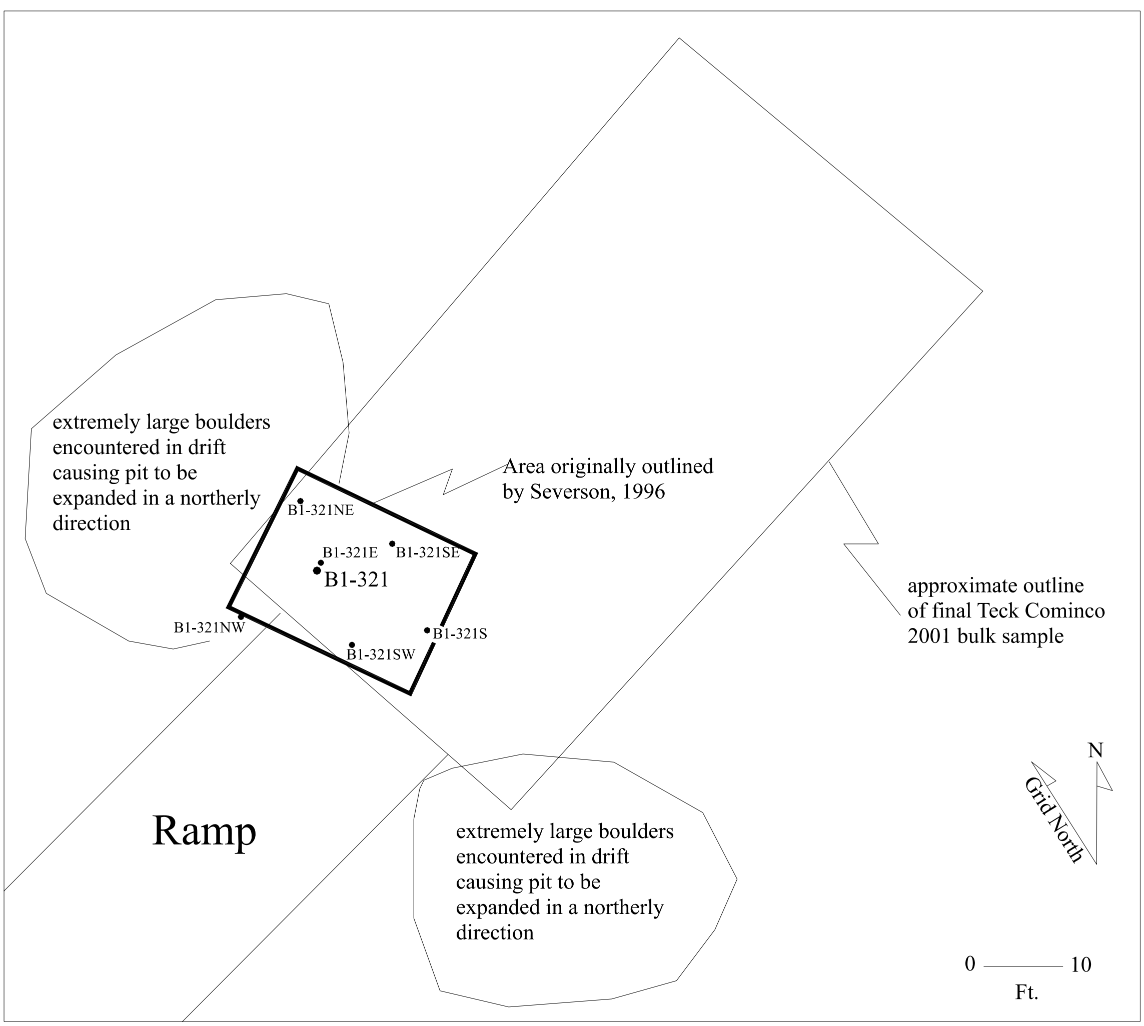

Figure 29. Sketch map showing the approximate area sampled by Teck Cominco in 2001 at the B1-321 site relative to the potential bulk sample outlined by Severson in 1996 (see Fig. 28).

copper, nickel, zinc, and cobalt from Mesaba ores, as well as a suite of precious metals (platinum, palladium, silver, and gold).

Nearby Drill Holes – Assays and Geology

Severson drilled six short core holes around AMAX hole number B1-321 (Fig. 28) in 1996. All holes intersected (mostly heterogenous) sulfide-bearing troctolite of Unit I with small amounts of gabbro and pegmatitic gabbro. No hornfels was reported. The site is estimated to be about 70-100 ft. above the basal contact (footwall). Drilling by Severson outlined a 20 ft. by 25 ft. by 10 ft. deep zone (~460 tones) with an average grade of 0.62% copper (Fig. 28). The variability in copper versus nickel for the drilling by Severson is shown in Figure 30. The actual grade of the final bulk sample collected by Teck Cominco averaged 0.30% Cu and 0.05% Ni (Jones and Moore, 2002). This discrepancy between Severson's grade numbers and the bulk sample grade are related to the fact that Teck Cominco took a much larger bulk sample than the area outlined by Severson (460 tons versus 5,000 tons). Thus, one lesson to be learned here is that **if** grade is important, it is imperative to conduct detailed drilling of a site to establish the boundaries of the future bulk sample! The extreme variability of Unit I, both in geology and mineralization style, can produce dramatic changes within a few tens of feet (both horizontally and vertically).

Other drill holes in this area are B1-011 about 200 ft. north-northwest, B1-012 about 200 ft. south-southeast, and B1-375, B1-326, B1-114, B1-132, all about 400 ft. away.

TEST PIT B1-321 #2 (to be done in the future?)

Teck Cominco has proposed a 50,000 ton test pit be dug at the area around drill hole B1-321 and their previous test pit. The corners of this new square pit would be B1-321 and B1-011. This would enlarge and surround the previous excavation. The material from this pit would be trucked to the former LTV Steel Mining Company taconite processing plant. That plant would be modified to concentrate this material and a tailings containment built. The plant would produce about 700 tons of concentrate that would be sent to Vancouver, B.C., for testing in Teck Cominco's proprietary hydrometallurgical process (CESL) for separation of copper, nickel, and precious metals products. This plan is detailed in an EAW (Environmental Assessment Worksheet) submitted to the MDNR in 2003 and approved in June 2003.

PROJECT STATUS

The agreements reached between PolyMet and Cliffs-Erie in December 2003 and February 2004 for the future use of the LTV concentrator will probably affect Teck Cominco's planning. There has been no publically announced change in status for this project. Teck Cominco has not withdrawn their EAW nor pursued the air and water quality permit application procedure to take and process this sample.

REVIEW OF MINNAMAX MATERIALS

As a part of this project, a review was conducted of the MinnAMAX material on file at MDNR. There are two general classes of documents; one is longer reports and publications, the other is mostly memos from AMAX to labs doing metallurgical work. The focus of the search was for items that might shed some light on the MinnAMAX test pit and sampling work, and some documentation was found. The review also clarifies some other matters.

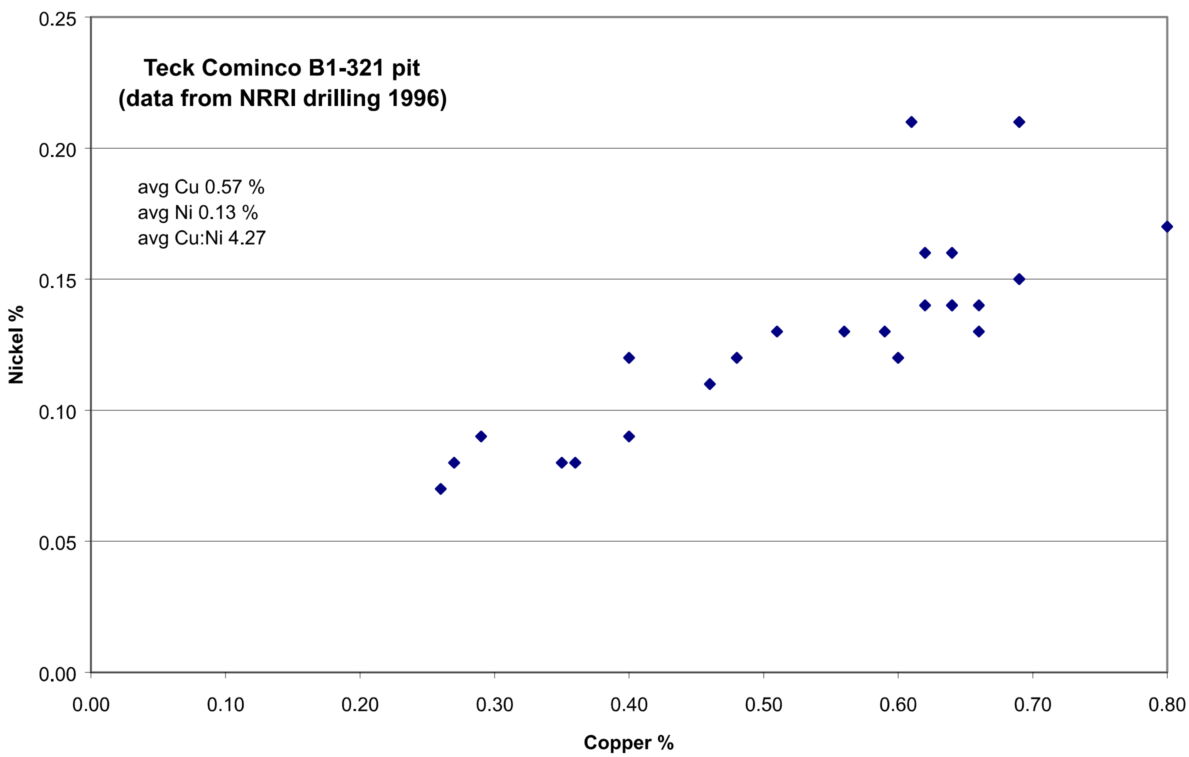

Figure 30. Variability in copper versus nickel for the Teck Cominco bulk sample at the B1-321 site.

The MDNR archive on AMAX is not as complete as might be expected. In questioning individuals who might have some knowledge of how the material came to be in MDNR files (Daniel England, Steve Hauck, Rick Ruhanen, Al Dzuck, Penny Morton, and others), as well as looking at the subject distribution of the files, it appears these materials probably represent the documents out of one or two offices on site at the end of the project. The archive is not a complete library of all documents related to MinnAMAX.

There are great number of maps and engineering drawings for the project stored at MDNR. Other than looking at these for sample information, we did no review of their content or completeness.

Some of the more interesting items found in the AMAX files are noted below. It is worth a day's time to peruse these manuscripts if one has any interest in further work in this area. We avoid attempting to summarize all their results and conclusions because it is not always clear what was the final result, and some items, such as work index or grade-grind relations, are best not taken out of context.

The number of cut-offs and mining concepts studied for Babbitt is high, as might be expected for such a large, low grade deposit. AMAX clearly saw that minor changes in cut-off changed the project economics and mining plan in large ways. Different cut-offs were applied not just to the underground and surface ore, but to subsets of both. From these readings, it is very uncertain what the company had really accepted internally for final cut-offs and mining plan.

Information that has not come to light in this archive review includes: no tabulations of specific gravities used for resource/ reserve calculations, though some reports mention various gross assumptions (10.6 cubic ft./ton?); no detailed geology, beyond what is already known from reviewing the company logging; no structural geology reviews; and no spatial analyses of the RQD data; among other subjects.

As far as we know, Kennecott or AMAX have not been approached about releasing all of the historical information on their activities in Minnesota. There is very little Bear Creek information in the MDNR archive.

What is included in these AMAX reports is:

- There are many versions of reserve calculations, mostly for the underground portions of the deposit. Difficult to tell by inspection if there was a "final calculation" of grade for the entire deposit. Covered in too many documents with too many different names for subparts of the deposit to list here. Again, note that this does not seem to be a complete collection of MinnAMAX materials.
- Bergendahl (1973) is a review by AMAX Exploration of the ore reserve data for the underground resource. Includes land ownership plates as well as drill hole location maps.
- A 1975 geostatistical report by Dagbert and David (no affiliation given) indicates that the variogram range is about 800 ft. Presumably they sorted out the higher grade massive material for this analysis. There is about four times as much continuity in the horizontal direction as in the vertical direction. Because the mineralized zone (Unit I) is about 800 ft. thick, and the deposit length and width are measured in miles, this is not a surprise.
- There are two 1976 reports from Lakefield to AMAX about "Summary of Test Data" (one referring to work done in 1975). This mostly concerns drill core composites. These include drill hole numbers and footages for many composite samples referenced elsewhere, specific gravity data for those samples, head assays, bench tests for concentration, selective flotation, grind effects on grade, chalcopyrite/cubanite ratio, work indices, tailings assays, and much other material.
- In 1976 (Scobie and Sarbutt, 1976), Lakefield did a short study on the recovery of an alumina concentrate from the MinnAMAX tailings. They produced a 47.1% by weight alumina concentrate. It is not clear from the report what the overall chemistry of the concentrate was.
- Erickson wrote a 1976 study about the Bathtub deposit that summarizes the process of determining the reserves in the Bathtub area of the MinnAMAX deposit, but does not address how the cutoffs, central to this calculation, were determined.
- Gumble (1976) addresses the same issues as Erickson (above, 1976) for the Tiger Boy semi-massive sulfide deposit.
- "Geology and Mining report" (1977) written as part of the 1976 feasibility study by AMAX staff. Mostly discusses underground mining approaches and costs. This report details some of the sensitivity of the reserve calculations to chosen mining cutoffs. Raising the cutoff in the massive sulfide mining zones from 0.60% copper to 0.70% copper reduced the high grade (massive) mineralization by 55% to 65%. Reducing the cutoff to 0.50% results in "tremendous reserve increase at a reduced grade of about 0.10% Cu and 0.02% Ni." (page 3)
- Watowich et al. (1977) wrote a MinnAMAX report that covers mineralization concepts (isolated versus continuous mineralization in terms of mine planning), statistical aspects

(histograms and the nugget effect), and a review of the 1,700 foot level geology in the drifts.

- Erickson (1977) describes some of the methods for reserve assessment. Of note is the reserve was being calculated using 100 ft. by 100 ft. by 40 ft. blocks with an inverse distance cubed weighting, 40 ft. composites, and an 800 ft. search radius for samples around each point being estimated. The model also used 0.20% copper cutoff, and 10.6 cubic ft. per ton as the density factor. The geological restraints are not clear; presumably the reserve was bracketed by unmineralized footwall and the overlying (relatively) barren troctolite.
- In 1978, Lakefield Research proposed a piloting program to AMAX intended to do the following:
  1) improve the estimation of mill metallurgy;
  2) test autogenous grinding;
  3) compare bench test and pilot plant results;
  4) improve the understanding of relation between concentrate grade and recovery;
  5) improve estimate of cost parameters;
  6) make available more concentrate and tailings for further testing;
  7) test effects of recycling tailing pond solution on concentration process.

  The report is notable for having a good listing in its appendices of bench test work and results up to that point.
- "Reliability of MinnAMAX assay data" by Nemgar (1979) addresses the correlation between the Bear Creek and AMAX assay work, the accepted values for the copper and nickel standards used, assesses the performance of various labs over time relative to these standards, and addresses concerns about laboratory quality. This memo seems to be a very good reference for this issue. The MinnAMAX logs and assay sheets (on file at NRRI and MDNR) report the assays for these standards over time. The standards were inserted as blind samples to the original labs. The Nemgar report gives the values the company expected for these samples.
- A 1979 report reviewing the grinding test work (AMAX Exploration, 1979). This paper summarizes the evaluation of at least five grinding flowsheets, and gives work index results for various grind scenarios. The report mentions fairly large sample sizes, up to seven tons, which would indicate that these tests were done on material either from the test pit at drill hole B1-341 or used materials excavated from the shaft. The source of these large samples is not given in the report.
- A 1979 report from Lakefield assessing the effects of weathering on sample stored outside (Wyslouzil and Sarbutt, 1979; see later discussion).
- A 1979 report from Braun Engineering to AMAX detailing: 1) shallow geotechnical drilling at the proposed plant site; 2) the proposed starter dam for the tailings impoundment; and 3) the proposed borrow areas for tailings dam materials. These are shallow drill holes, penetrating only a few feet of bedrock. These plant site holes are not the same as B1-428, B1-429, B1-430, B1-431, B1-432, which are deeper, assayed, holes that AMAX labeled as "plant site holes," which were probably drilled for site condemnation purposes.
- In conjunction with the above paper on the tailings dam, there is a 1974 report by the MDNR and MNDOT about their preferred locations for a tailings impoundment for the Reserve Mining Corporation tailings basin. That basin eventually was sited at MilePost 7 northwest of Silver Bay, but this report describes the best location as that which was also chosen by AMAX, south of

Babbitt. Interestingly, essentially this same site was also the preferred location given in the 2001 PolyMet prefeasibility study (released December, 2003) for the NorthMet tailings basin (that study prepared by Independent Mining Consultants of Tuczon, Arizona).

- A report of unknown age (but with some 1984 data) about "glacial drift monitoring wells" with soil boring logs and some water table data. The report seems intended to assess groundwater issues around the shaft area. It may be a collection of copies of data from other reports (Anonymous, no year, item number 208 in MDNR AMAX archive).
- There are a series of reports from Lakefield that address the issues of bulk concentrate versus separate copper and nickel concentrates, as well as a comparison of autogenous versus semi-autogenous grinding. The tests are all done using the AMAX bulk samples. As is common with the Lakefield reports, there is no narrative, but the extensive data tables may assist any metallurgist trying to avoid recreating past work in any modern testing program. These reports are listed in the reference section of this paper under "AMAX Exploration" (1976, items 395, 397, and 398 in MDNR MinnAMAX archive; 1978, item 381 in MDNR MinnAMAX archive, and 1979, item 385 in MDNR MinnAMAX archive.

MDNR has a printed index of these materials (contact Mr. R. Ruhanen or Mr. D. Dahl). We have annotated our copy of this index with our comments from quick review of these reports.

Dunka Road/NorthMet Deposit

The Dunka Road deposit (now NorthMet by PolyMet Mining) has had several hulk samples taken by United States Steel Corporation (USS), NERCO, and PolyMet (Fig. 31). The deposit was initially drilled in the 1970s by USS with core holes, mostly vertical. Their aim was to define a deposit that could be mined underground. The discovery hole, 26010, intercepted a thin, copper-rich massive sulfide 300 ft. above the basal contact. This intercept was better than in any hole drilled afterward. In total, USS drilled 112 core holes over 133,340 ft. with about 131,400 ft. of bedrock intercept. There were about 2,075 assay intervals taken by USS over about 19,000 ft. USS did not sample all mineralized intervals. The assays were for copper, nickel, sulfur, and iron. Table 28 covers the USS drilling, plus a small amount of other drilling in the area.

Table 28. Dunka Road/NorthMet raw assay data. All drill holes in area, unweighted for footage, and based on all intervals where copper assay is greater than zero percent.

Drill hole type:	Copper %	Nickel %	Sulfur %
USS surface drilling, 22,800 feet of assay	0.36	0.13	0.93

A single page internal memo from USS labels as "Description of Mineral Deposit," attached as an appendix to a report commissioned by Fleck Resources in 1989 (Manning, 1989), is the only written values we have found that actually ascribe any sort of resource estimate for Dunka Road.

The USS memo reads as follows: "*Preliminary estimates indicate 109 million tons of material containing 0.77% copper and 0.24% nickel. Geologic considerations suggest that the bulk of this material would have to be mined by underground methods. Reserves could be doubled if average combined grade is dropped by 0.2%.*"

(Authors' note: Mark Severson worked for USS in the late 1970s and early 1980s.

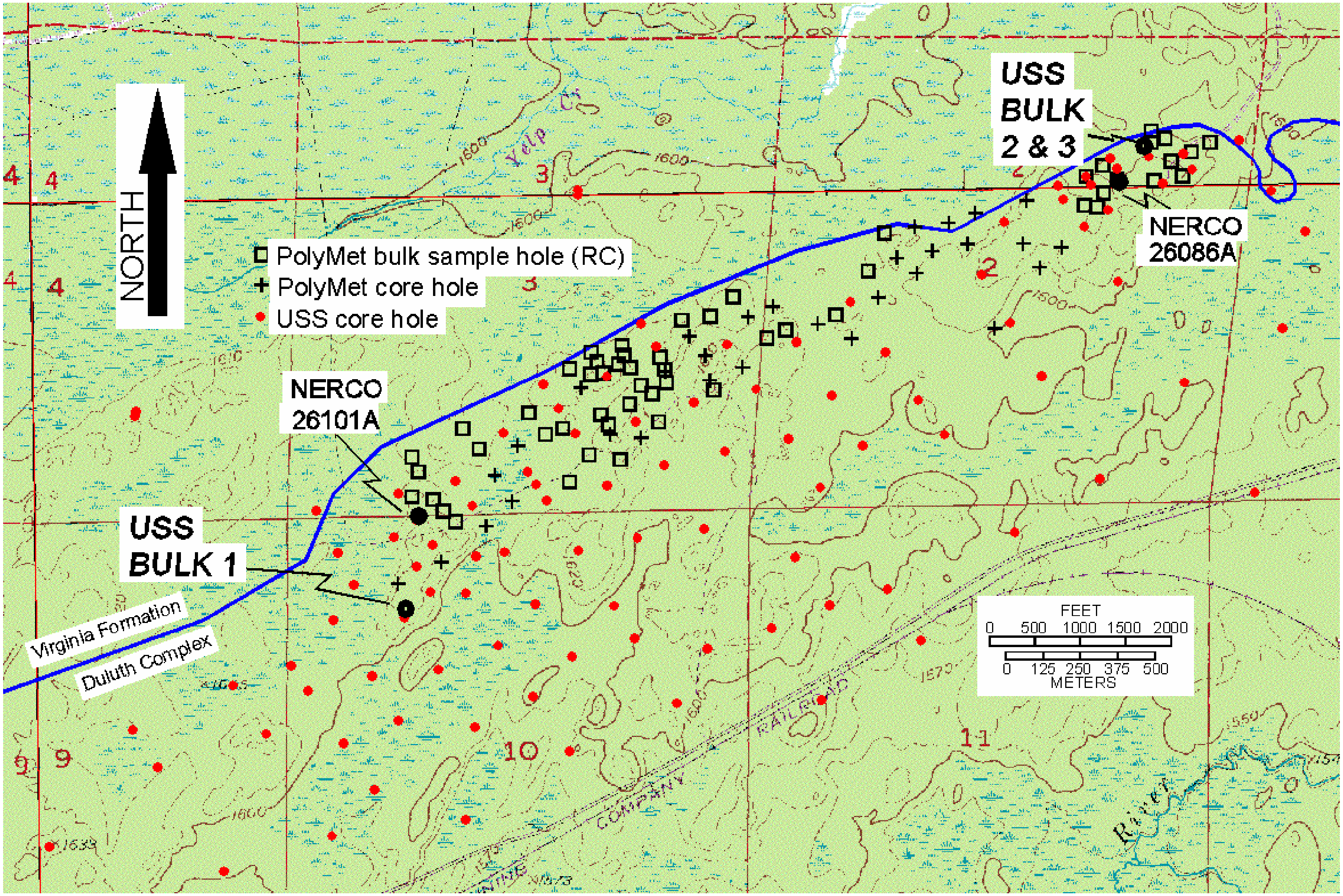

Figure 31. Locations of drill holes (USS, PolyMet/reverse circulation, and PolyMet/core) and bulk samples (surface pits and core composites) at the Dunka Road/NorthMet deposit.

His supervisor, Mr. Cedric Iverson, did at some point show Mark crudely done resource estimates for the Dunka Road deposit. We have seen no other study indicating there was ever a formal geostatistical assessment of this property by USS.)

It is historically interesting to note that USS first explored and drilled areas well to the south, in the Western Margin intrusion of the Duluth Complex. Most of these sites were geophysical targets. However, only weakly mineralized material was found, and USS quickly moved their emphasis to the Dunka Road deposit, which corresponds to an area adjacent to where Bear Creek was drilling the Babbitt deposit at the time, and in an area where USS already had extensive mineral rights.

Fleck Resources, of Vancouver, B.C. optioned the Dunka Road property from USS in 1989, worked with Nerco Minerals in 1990 in drilling two large diameter holes for metallurgical testing, and Argosy Mining (Argosy Minerals?) in the mid-1990s for mapping and development planning. Fleck's main contribution up to that point had been the assaying of all the available USS pulps for PGEs, as well as re-assaying for copper and nickel. This interest was probably a response to Morton and Hauck's (1987) paper detailing re-assaying for PGEs in parts of the Duluth Complex. Geerts and others at NRRI (Geerts et al., 1990; Geerts 1991, 1994) used the Fleck assay data and their own lithological logging to redefine the igneous stratigraphy of the deposit. Notably, they delineated stratabound PGE enriched horizons across much of the deposit.

Fleck did none of their own drilling, but did commission a few property reports and "pre-feasibility" studies in the early 1990s, such as the Manning report listed above (1989), which is a careful review of the project data at that point and recommendations for future emphasis. Manning (1990) also did an update addressing comparisons of reserve estimates, and Fluor Daniel Wright also did a "Preliminary Project Review" in 1991 during the time that Fleck was working with NERCO on the deposit. These reports add little to the current knowledge, mostly being reviews of other work, project economics, and processing options.

In June, 1998, Fleck Resources became PolyMet Mining Company, with a new set of directors and a new focus. They sold off or released their properties around North America to concentrate on the Marathon Platinum-Palladium Project northeast of Lake Superior (which they have since sold) and the Dunka Road property, which they renamed NorthMet. At NorthMet, they have a 20 year renewable lease at a 3% net smelter return. PolyMet drilled 87 core and reverse-circulation holes totaling over 49,500 ft. in 1999 and 2000, and 109 holes for 78,000 ft. in 2005. Only a few assays have been released for this drilling. The NorthMet project is still active as of this writing (May 2006).

USS Bulk Samples at Dunka Road/ NorthMet

USS took at least three bulk samples from the Dunka Road deposit, labeled in their documentation as Bulk No. 1, Bulk No. 2, and Bulk No. 3. USS also took a few small trench samples and processed some drill core composites from the site. These are recorded in the sample receiving books at Coleraine Minerals Research Laboratory (CMRL, formerly the USS minerals processing laboratory). We did not pursue details about these additional samples. Also, we did not see records indicating that any blast hole sampling was done by USS immediately prior to collecting their bulk samples.

USS TEST PIT #1 – 26058 (1970)

USS Bulk No. 1 (Fig. 31) was taken in the vicinity of drill hole 26058 during September 1980. It is certain that this sample was taken, but no definitive documentation has been found for site selection or metallurgical testing. USS sample logbooks at CMRL record seven "truckloads" being delivered to CMRL. One notation in the log book shows "24/100#" next to a truckload number. Could this indicate small samples, as in 24 buckets at 100 pounds each? Seven truckloads would equate to about a 9 ton sample, possibly consistent with the size of the pit. (*Authors' note: Recently found files (2007) indicate that a 70 ton sample was collected from this site.*) The site location was near DDH 26058 (approximate center of NW ¼, Section 10, T59N, R13W; drilled in 1970). Severson and Zanko found vestiges of this pit while taking GPS readings of outcrops in the area in 1995. The original pit geometry is unknown, the pit is now filled and heavily-vegetated with large boulders strung "fence-like" about its periphery. The reasoning for site selection is unknown. The grade for the top portion of DDH 26058 is shown in Table 114. The first core interval (8-20 ft.) is sulfide-bearing and was assayed (Table 29); whereas, the interval 20-524 ft. is not sulfide-bearing, and it was never assayed. Severson logged this interval as altered (uralitized) anorthositic troctolite).

Table 29. DDH 26058 assay grades in top of ledge intercept.

DDH 26058	Copper %	Nickel %	Sulfur %	Fe %
8-20 ft.	0.82	0.20	1.21	8.39

Apparently the bulk sample was collected from poor grade material in Unit III, which is typically a barren anorthosite, but can have rare chalcopyrite- cubanite-rich sulfide veining. NRRI logging shows the top of Unit III at 55 ft. of depth in this hole, based on the first occurrence of "mottled" anorthositic troctolite. So, possibly the sample is from near the base of Unit IV and not part of Unit III. Either way it probably represents an isolated patch of mineralization. Results for the head grade for this sample, reported in a later USS report, are in Table 30.

USS next planned on collecting a 94,000 ton bulk sample and processing it at their Pilotac iron ore operation. However, this concept was deemed to be too ambitious, and rather, a sample was collected at the test pit #2/#3 site (see below).

USS TEST PIT #2 and #3 – 26105 (1971)

Bulk sample No. 2 (Figs. 31 and 32) was the first of two samples USS recovered in 1971 from the second location (site of USS bulk samples number 2 and 3) at their wholly-owned Dunka Road deposit. This pit was positioned directly above (north of) the updip projection of drill hole 26105 (Fig. 33). Drill hole 26105 (drilled and assayed in 1971) was angled to the north to penetrate the footwall near the northeast corner of the deposit. This pit location assumed that the best interval in the hole, 0.77% copper and nickel, at 22-32 ft., would follow a dipping horizon and be intersected in a pit near the surface (Fig. 33). This idea was probably a reasonable assumption. Drill hole 26112 just down dip (south to southeast) shows similar assays at about the same level above the footwall.

A 300 ton sample was taken for Bulk No. 2. However, this pit did not intersect the grade expected, with the low head grade blamed on presence of footwall rock. NRRI logging by Severson (indexed in Patelke, 2003) shows numerous inclusions of Virginia Formation in heterogenous olivine-gabbro to augite-troctolite in this area. The

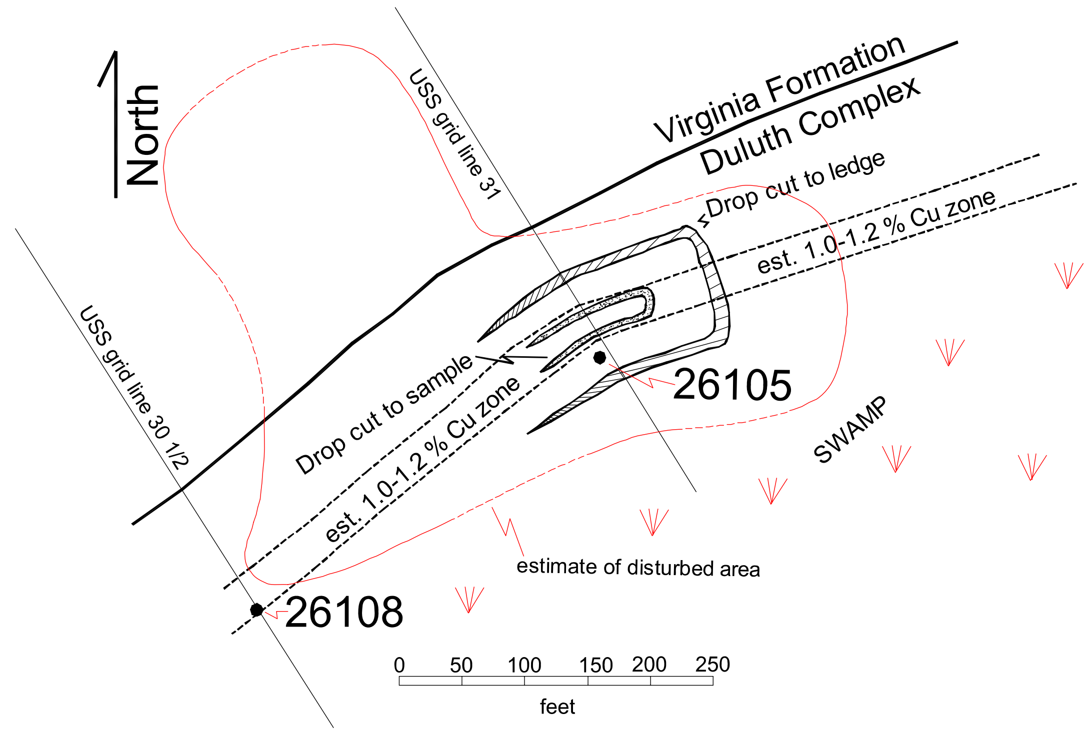

Figure 32. Plan map of USS bulk sample #2 (and #3) at the 26105 site. Bulk #2 was approximately 100 ft. long by 32 ft. wide (at the bottom) by 10 ft. deep and covered by about three feet of overburden/muskeg. Bulk #3 consisted of about 20 tons taken from the southern edge of bulk #2.

Table 30. Comparison of expected grade with head grade for USS bulk samples at Dunka Road (data from USS). See comments near end of paper concerning "total" versus "sulfide" nickel.

	Bulk No. 1 Expected Grade (based on intercept in DDH 26058)	**Bulk No. 1 Head Grade**	**Bulk No. 2 Expected Grade (based on values in DDH 26105)**	**Bulk No. 2 Head Grade**	**Bulk No. 3 Expected Grade (based on values in DDH 26105)**	**Bulk No. 3 Head Grade**
Copper %	0.82	0.39	0.77	0.40	0.77	0.58
Nickel % (total)	0.20	0.14		0.13		0.22
Nickel % (sulfide)		0.087	0.28	0.088	0.28	0.167
Sulfur %	1.21	0.50	1.23	0.97	1.23	0.98
Iron %	8.39	8.3	10.84	11.0	10.84	10.1

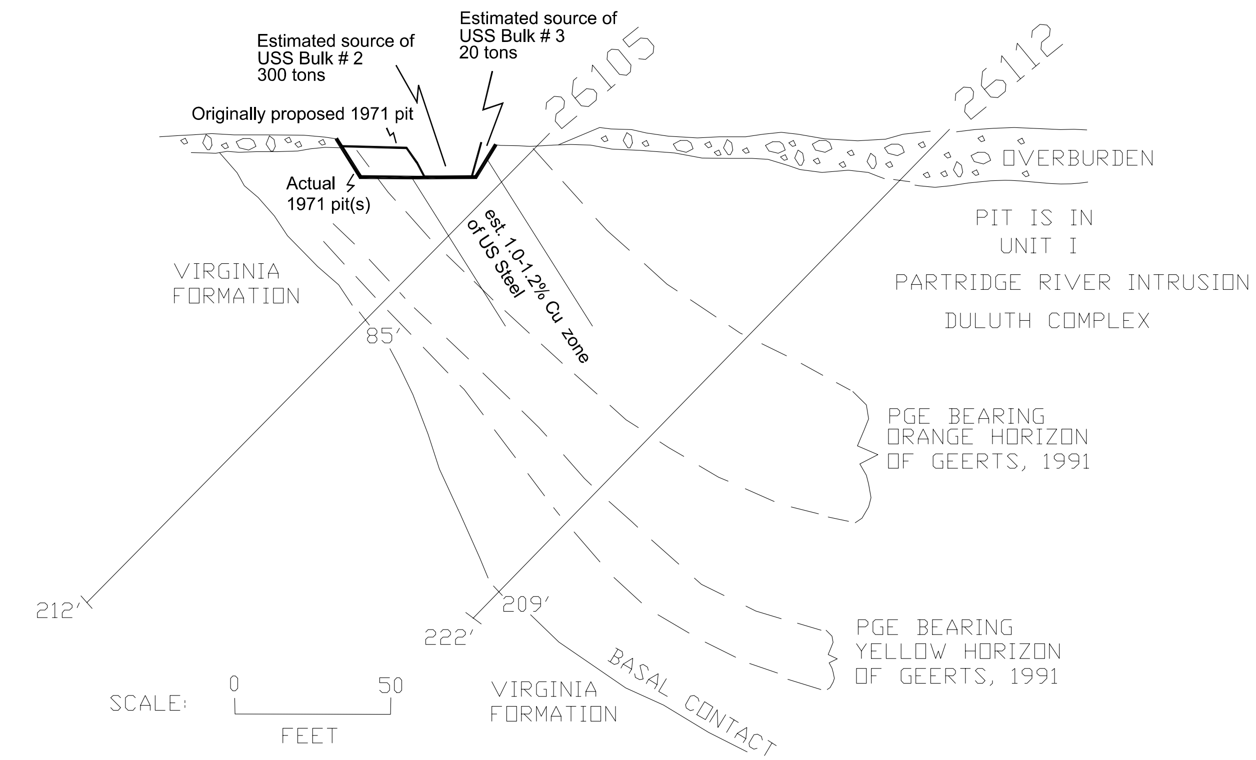

Figure 33. Cross-sectional sketch of USS bulk samples #2 and #3 relative to the geology and mineralization in the vicinity. Modified from Severson et al. (1998).

footwall rock referenced by USS was probably inclusions, not *in situ* Virginia Formation.

USS Bulk sample No. 3 (see Fig. 33) is a later sample from the same site as USS Bulk No. 2. This sample was collected at the south (stratigraphically higher) edge of the sample pit in an attempt to move up-section from the footwall-related contamination. This second sample weighed about 20 tons. Bulk No. 3 did improve the head grade (see Table 30).

The USS memo and other papers for this pit do not mention any drilling or sampling prior to collecting the bulk sample. Only core hole DDH 26105 is mentioned, and thus, it is not known if any blasthole assay studies were performed.

USS concluded that: "*Pilot-plant tests on three test pit samples of copper-nickel sulfides from the Duluth Gabbro deposit have confirmed that 83 to 89 percent of the total copper and 72 to 85 percent of the sulfide nickel can be recovered in a cleaned bulk sulfide concentrate containing 20 percent copper and 4.5 percent nickel. Mineral liberation requires grinding to about 75 percent minus 200 mesh and consumes about 23 net kwhr per short ton. Differential flotation of the bulk sulfide concentrate to make separate copper and nickel concentrates was unsatisfactory, as a clean separation was not achieved. A selective flotation scheme, wherein only copper sulfides were floated in the first step and previously-depressed nickel sulfides were floated in the second step, showed good selectivity and high metal recovery in bench-scale tests put pilot plant results were erratic because of difficulty encountered in control of critical parameters, notably pH of the pulp at various stages of flotation.*"

USS felt that more work would be needed for actual cost estimation, but that this work established the fact that concentration at the deposit would be economically feasible. Further test work was pending a decision to pursue mining the deposit, and was never done.

The pit is still open, and filled with water (photo in Appendix 4).

Nearby Drill Holes – Assays and Geology

USS based the location of Bulk Sample No. 2 (and Bulk Sample No. 3 as its extension) on the assays in drill hole 26105 (Table 31).

Nerco Bulk Sample (Large Diameter Drill Cores)

In 1990, Nerco took samples from two large diameter drill cores (holes 26086A and 26101A, twinning USS holes 26086 and 26101). Drill hole 26086A was in the northeast corner of the deposit, and 26101A near the northern contact in the western on third of the deposit (Fig. 31). Hole 26101A is at the western edge of the area drilled by PolyMet. These holes were themselves first twinned by smaller core holes for submission of samples to landowners and the state.

Neither NRRI nor MDNR seems to have any paper record of these holes, such as assays, downhole surveys, or abandonment reports. The smaller diameter holes are stored with other USS Dunka Road drill cores at CMRL. Both holes ended short of the length of the originals (26086A at 522 ft. vs. 574 ft. in 26086, and 320 ft. in 26101A vs. 655 ft. in 26101). Both of these holes have been logged by Severson (Patelke, 2003).

Table 31. Footages and assay values for drill hole 26105 at Dunka Road bulk sample site for samples No. 2 and No. 3. NS indicates not sampled.

Hole-ID	From	To	Cu%	Ni%	S%	Length (ft.)	Rocktype	Unit
26105	0.0	4.0	NS	NS	NS	4.0	OVB	OVB
26105	4.0	12.0	0.71	0.18	1.03	12.0	OG-AGT HET	1
26105	12.0	22.0	0.49	0.15	0.8	10.0	OG-AGT HET	1
26105	22.0	32.0	0.77	0.28	1.23	10.0	OG-AGT HET	1
26105	32.0	42.0	0.6	0.21	1.04	10.0	OG-AGT HET	1
26105	42.0	52.0	0.27	0.11	0.83	10.0	OG-AGT HET	1
26105	52.0	62.0	0.3	0.12	1.47	10.0	OG-AGT HET W/HNF	1
26105	62.0	72.0	0.4	0.16	2.57	10.0	OG-AGT HET W/HNF	1
26105	72.0	82.0	0.55	0.24	3.41	10.0	OG-AGT HET W/PEG	1
26105	82.0	85.0	0.32	0.16	3.38	3.0	OG-AGT HET	1 & 1NZ
26105	85.0	212.0	NS	NS	NS	127.0	VF-CORD	VF

To quote from a PolyMet report (Peatfield, 1999): "*In 1991, Nerco drilled four core holes to collect material for metallurgical testing, and to do detailed assay work. The drilling was at two separate sites; at each site a PQ (3 11/32") and a supplementary BQ (1 7/16") hole were drilled (Pancoast, 1991). The purpose of the BQ holes was to provide material for the State core library. The whole of the PQ core was shipped unsplit to Lakefield in Ontario. Details of the assaying are not readily available, but it is reported (Zunkel, 1991) that Lakefield prepared two composites from this material. A lower composite graded 0.42 percent copper and 0.14 percent nickel; a higher one had grades of 0.71 percent copper and 0.20 percent nickel.*"

It is uncertain if the terms "lower composite" and "higher one" refer to grade or stratigraphic position. The PolyMet Pre-Feasibility Study summary (written in 2001, released in 2003) also indicates that they had no further data on the Nerco work. Mark Severson heard that some of the sample was sent to Spain for metallurgical testing.

A Skillings Mining Journal article from July 25, 1992, states that NERCO and Fleck were "*evaluating the deposit for application of a ferric chloride leaching solvent extraction-electrowinnowing process, (the "Cuprex Metal Extraction Process or CMEP") for economic extraction of copper and nickel with by product cobalt, platinum group metals, gold, silver, and ilmenite production.*" The article also states that at least some portion of the two cores mentioned above was sent to Lakefield labs in Ontario for bulk and selective flotation testing, and that the CMEP extraction testing yielded "encouraging results."

NEARBY DRILL HOLES – ASSAYS AND GEOLOGY

The assays and lithologic logging records for the original USS holes are fairly typical in their geology and assays, with assays in Unit I on the high side in 26086 (0.49% copper, 0.18% nickel) and the low side in 26101 (0.38% copper, 0.14% nickel). The assays from the NERCO holes are not available.

PolyMet Bulk Samples (Drill Hole Composites)

PolyMet (formerly Fleck Resources) currently has the Dunka Road property under lease as NorthMet. In 1998 through 2000, PolyMet drilled 87 holes, 32 with core (22,146 ft.) and 55 reverse circulation holes (27,357 ft.). These holes, locations shown in Figure 31, were a mix of infill drilling and check holes used to confirm the USS assay results. The chips from the reverse circulation drilling were carefully separated and extensively assayed. The intervals were then combined to make large metallurgical samples for testing of hydrometallurgical processes.

METHOD

From a PolyMet presentation at a mining conference in Duluth, 1999, their method of developing the bulk sample composite was as follows: six inch reverse circulation drilling produced about 135 pounds of sample for every five feet of drilling. This material was split into two samples and placed in plastic bags, stored underwater, in five gallon plastic buckets. A 1/16th sample was taken by rotary splitter from each five feet of chip sample and assayed. The assay values were used to develop a composite pilot plant sample from bucket samples. Actual composting was done after samples had been shipped to Lakefield. PolyMet says that the first 14 holes produced 83 tons of sample, and that 37 tons were shipped to Lakefield labs in Lakefield, Ontario, for the pilot concentrator runs, as well as PlatSol™ testing. Head grade of the composite is shown in Table 32.

The drilling footage would indicate that about 350 tons of sample were generated (27,000 feet of reverse circulation drilling at 135 lbs. per five ft. sample). The total tons generated from drilling for PolyMet's samples may not total to the amounts quoted for the pilot run, because the pilot run probably had some start up "scoping" runs, as well as other losses. Not all material is assumed to have been used for the pilot plant runs. Much of the material would presumably have come from the upper, barren intervals in the Complex.

PolyMet processed another forty ton sample from drill core in 2005, but limited results have been made public. Other than that, all testing met or exceeded expectations.

NEARBY DRILL HOLES – ASSAYS AND GEOLOGY

An assessment of nearby drilling for the PolyMet bulk sample is not realistic because the material they used for a bulk sample was derived from intervals across the area that they drilled and composited to represent the deposit as a whole for hydrometallurgical purposes. It is not known or possible to calculate what intervals they sent for the compositing. See Patelke (2003) for the NorthMet drill hole locations in relation to the USS drill hole locations and copper-nickel-sulfur assays.

PolyMet has released less than 5,000 ft. of assay data from the approximately 50,000 ft. they had drilled up to 2001, and only limited averaged data for the drilling done in

Table 32. Head grade of various elements in PolyMet bulk sample. Data from PolyMet presentation at SME/AME conference in Duluth, Minnesota, 1999, with drilling data from various company press releases. Data incomplete, given only for discussion, and should not be used for any assessment of PolyMet's overall grade at NorthMet.

	Cu%	Ni%	S%	Co%	Ag g/t	Au g/t	Pt g/t	Pd gt	Au + Pt + Pd g/t
Reported grade in PolyMet drilling–calculated from company press releases	0.39	0.11	Not given	0.0008	Not given	0.05	0.09	0.37	0.51
Composite head grade	0.43	0.12	Not given	0.0009	1.48	0.06	0.08	0.37	0.51
Concentrate grade	15.5	3.69	Not given	0.149	41.5	2.8	2.49	11.1	16.39
Percent recovery	93.7%	77.1%	Not given	46.4%	69.9%	76.6%	76.4%	75.8%	NA

Table 33. NorthMet grade and recovery values given in PolyMet, October 2003, press release.

	Copper	Nickel	Cobalt	Platinum and Palladium	Gold	Silver
Grade in mine plan (808 million ton resource)	0.43%	0.11%	not given	0.553 g/t	0.061 g/t	1.5 g/t
Recovery	92.2%	71.4%	42.6%	71.4%	72.4%	not given

2005. Those data are summarized in Table 33, taken from various company press releases available online. See www.sedar.com for resource evaluation and mine planning released in 2005.

METALLURGICAL RESULTS

The overall results of PolyMet's testing are covered in papers they released in 2001 (Ferron et al., 2001). Because they are leasing private mineral rights, they are under no obligation to make further results public and would not be expected to share information.

PolyMet indicates that testing has so far been acceptable, that a viable concentrate can be made, and that reasonable metals recoveries can be shown, including precious metals.

The 2001 study reports that 2/3 of the copper is in chalcopyrite and 1/3 is in cubanite, while 3/4 of the nickel is in pentlandite with the rest in nickel silicates. They quote these as somewhat variable ratios.

Table 33 records PolyMet's recovery values and grades as given in an October 2003 press release. The discrepancies in values between Table 32 and 33 probably have no significance when considering that all these data were taken from non-rigorous presentations at different times.

PROJECT STATUS

In July 2001, PolyMet completed a pre-feasibility study indicating that mining the deposit could be economic, but would be marginal. Their conclusion was to pursue investment and the development of their proprietary hydrometallurgical process (PlatSol™) in hopes of improving the project economics. In 2003, PolyMet press releases indicated that the extended slowdown in mining investment in North America had led the company to reassess its plans. Subsequently, there were management changes and some new investment into the project. Largely the changes will be to alter the mine plan, rework the more capitol intensive parts by sending some concentrate off site, and use contract mining. This approach will lead to a more complete feasibility study and hence help attract investors. In December of 2003, PolyMet released their 2001 pre-feasibility study (prepared by Independent Mining Consultants of Tucson, Arizona). While the pre-feasibility study contains much useful information, the available summary does not shed much more light on the specifics of their bulk sampling process.

Press releases in December 2003 indicated PolyMet had arrived at an understanding with Cliffs Mining Services for the use of the now idled LTV concentrator as the concentrator for ore from

NorthMet. At this point (September 2004), it appears that research on the project is going forward.

Oxide-bearing Ultramafic Intrusions (OUIs) in the Partridge River Intrusion

The Oxide-bearing Ultramafic Intrusions (OUIs) are a series of small, oxide-bearing (ilmenite and titanomagnetite) intrusive bodies with localized, semi-massive to massive oxide zones (see Fig. 1). The OUIs are located relatively high up in the stratigraphy of the PRI. There are at least six OUIs in the Partridge River intrusion large enough to have been drilled as separate targets. They are:

- Section 17, near the Wetlegs Cu-Ni prospect, along the Dunka Road;
- Section 22, about three miles southeast from Hoyt Lakes, six drill holes;
- Skibo, about twenty drill holes, four miles south-southeast of Hoyt Lakes;
- Longear, south of the Wetlegs Cu-Ni prospect, only three drill holes;
- Longnose, south of Wetlegs Cu-Ni prospect, about six miles northeast from Hoyt Lakes, with twelve drill holes;
- Water Hen, 37 drill holes, east of St. Louis County Highway 130, two miles north of St. Louis County Highway 16, about eight miles south from Hoyt Lakes.

There are also smaller OUIs in the PRI at the southern margin of the Babbitt deposit and at depth at Wyman Creek.

In the Western Margin and Boulder Lake intrusions there are OUIs at Section 34 (aka Marshall Trail), Boulder Creek, Boulder Lake North, Boulder Lake Central, and Boulder Lake South. Reference and discussion about these is in Severson (1995) and is much expanded in Miller et al. (2002).

OUI appear to be generally composed of coarse-grained to pegmatitic clinopyroxenite, dunite, peridotite, melatroctolite, and melagabbro, all with oxide, and seem to cross-cut the troctolitic country rocks. No drilling has penetrated a root zone for these intrusions.

The Longnose, Longear, and Section 17 OUIs in the PRI appear to be lined up along a mapped fault in the Allen Quadrangle (Severson and Miller, 1999). This fault is inferred from well defined offsets in the iron-formation seen in drill hole correlations. The fault affects the thickness of Unit I in the PRI, but not the upper units, indicating that fault movement stopped some time after intrusion of the Complex began. A half-graben geometry is assumed for this fault.

The OUIs of Water Hen, Skibo, Section 22, and possibly Wyman Creek seem to lie along an as yet unconfirmed north/south-trending fault.

The OUIs are enigmatic in their formation and may be magmatic segregations, hydrothermal or metasomatic replacements, related to assimilation of iron-formation, or some combination of the above. One scenario would be the mixing of fluids driven out of the footwall with magmatic fluids as some have proposed for IOCG (Iron-oxide-Copper-Gold) deposits. Besides containing titanium, in ilmenite and titanomagnetite, the OUIs may contain economic amounts of other economic metals (vanadium, chromium) in oxides (Severson, 1995). In the Duluth Complex, the highest <u>average</u> values for the sum of platinum, palladium, and gold in a single rock type occur in the combined OUI and massive oxide rock type. However, as a group, the OUIs rarely contain over 500 ppb combined platinum, palladium, and gold (calculations based on data in Severson and Hauck, 2003).

Only the Longnose OUI body has had documented surface bulk samples recovered from pits for further testing. One was taken in 1984 and a second in 1991. See comments below about a small drill core-based bulk sample at the Water Hen deposit.

Longnose OUI Bulk Sample

The Longnose body is described in Severson and Hauck (1990), Linscheid (1991), and Miner (1995). Severson and Hauck (1990) have a short description based mostly on Linscheid's work. Linscheid (1991) has a good description of the general geology, shape, and petrography of the body. Miner (1995) covers microprobe analysis and addresses the origin of the body through mineral chemistry. These reports do not mention the bulk samples nor address the mineral potential of Longnose specifically. The site is east of St. Louis County Highway 666, north of Hoyt Lakes and south of the former LTV property. See Figure 34 for map with generalized pit locations.

Hauck et al. (1997) quote a personal communication from William Ulland of American Shield (1989) for a resource of 25 million tons of greater that 15% TiO_2 material at this site. A later source (copy of a report by William Ulland, June 19, 2000, on file at the MDNR) states that the Longnose deposit contains an indicated and

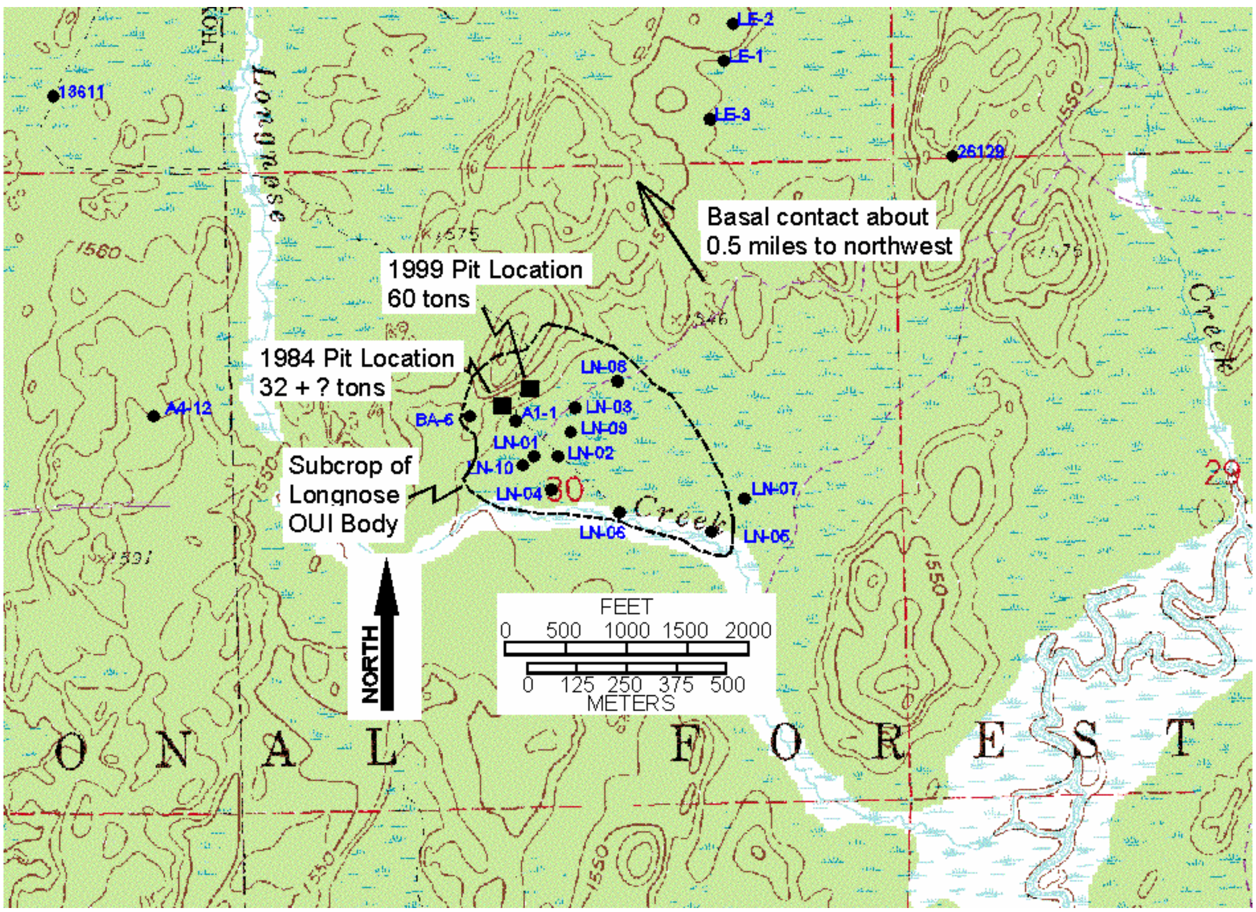

Figure 34. Locations of drill holes (LN-series) and approximate locations of bulk samples (2) at the Longnose OUI deposit. LE-series holes to the north of Longnose are in the Longear OUI prospect. Dotted line outlines the inferred edge of the OUI at the surface.

inferred resource of 50 million tons of material grading 21% TiO_2 (at a 75% estimated recovery).

Two bulk samples were taken at Longnose (Fig. 34), the first, in 1984, by American Shield and NICOR and a second, in 1999, by American Shield. CMRL processed both of these bulk samples. The processing issues are related to final use of the ilmenite. The goal has been to produce ilmenite concentrate that was amenable to the production of synthetic rutile. But, there are two routes to synthetic rutile. One is by smelting and production of a high TiO_2 slag product, and the other by a hydrochloric acid leach method. Smelting has no grain size limitations, but the acid leach process requires a narrow range of grain size for oxidation and reduction roasting, else the finer material will be lost in the reactor.

These two concentration methods are in conflict because of two general issues for this ore: 1) the ilmenite is intimately mixed with titanomagnetite that is best removed with fine grinding and flotation; and 2) the ilmenite is relatively high in MgO, which is detrimental to the smelting process, but not a problem in the acid leach process. Therefore, the challenge is to remove the titanomagnetite while controlling the grain size distribution to a size amenable to use in the acid leach process.

CMRL had mixed results in their testing. Usable concentrates were made, but at lower recoveries than were desired. The details of processing are confidential, but it appears the problems can be overcome with time and effort (Benner and Niles, 1994; Niles, 1996).

CMRL also processed some of the titanomagnetite tailings material from the testing and concentration of ilmenite to test the concentration and extraction of vanadium from the titanomagnetite. This was successful in creating a concentrate containing 1.0% to 1.6% V_2O_5. This concentrate was used for salt (sodium carbonate) roasting, then leached, and solvent extracted to make a 98% V_2O_5 product (Engesser, 1997).

NEARBY DRILL HOLES – ASSAYS AND GEOLOGY

There are about 12 drill holes in the Longnose area. They cover 8,750 ft. of drilling with 8,266 ft. of bedrock intercept. In 1,346 ft. of assaying, copper grades average 0.19% and nickel averages 0.08%. There are few assays for sulfur.

In the PGE data of Severson and Hauck (2003), there are just a few intercepts for Longnose assayed for Pt + Pd + Au; all but one of these are less than 100 ppb. There are a few intervals that were assayed for vanadium, with results in the range of 0.1% or less. It is uncertain if this is the full extent of sampling for vanadium, chromium, and other metals.

The majority of the drill intervals are ultramafic rocks or "OUI," generally all oxide-bearing. Lesser intervals include troctolite, anorthosite, and hornfels.

PROJECT STATUS

This project is currently (2004) under lease (?) by American Shield/Hartley Fee Office to unknown parties. No current interest is known in other OUIs, though advances in ilmenite and rutile metallurgy could make them attractive targets for synthetic rutile production feedstock.

Water Hen OUI Bulk Sample

The Water Hen OUI also represents a potential titanium resource. It is estimated to contain 62 million tons of material grading 14% TiO_2 at 75% TiO_2 recovery (copy of a report by William Ulland, June 19, 2000, on file at the MDNR). Two of the last holes drilled at the Water Hen deposit (SL-27 and SL-28, see Fig. 35) were taken in their entirety for tests at the United States Bureau of Mines (USBM) lab in Minneapolis. The USBM tests are covered in a USBM Report of Investigations 9065 by Nafziger and Elger (1987). Their project was an attempt to make a feedstock for synthetic rutile processes, a major step in both pigment and titanium metal production. They smelted the ilmenite concentrate in electric furnaces using woodchips, coke, and soda ash for carbon source and flux. They produced a slag containing 67% to 77% "titanium oxides." That slag was then run through a sulfation process to create sulfated slag that was then acid leached to remove impurities. The final product was a 95.5% TiO_2 material technically suitable for chlorination, which is the critical purifying step in this process. The USBM report contains no detailed discussion about the source or geologic characteristics of the raw material they used.

The USBM report says that their work was at the request of NICOR Ventures

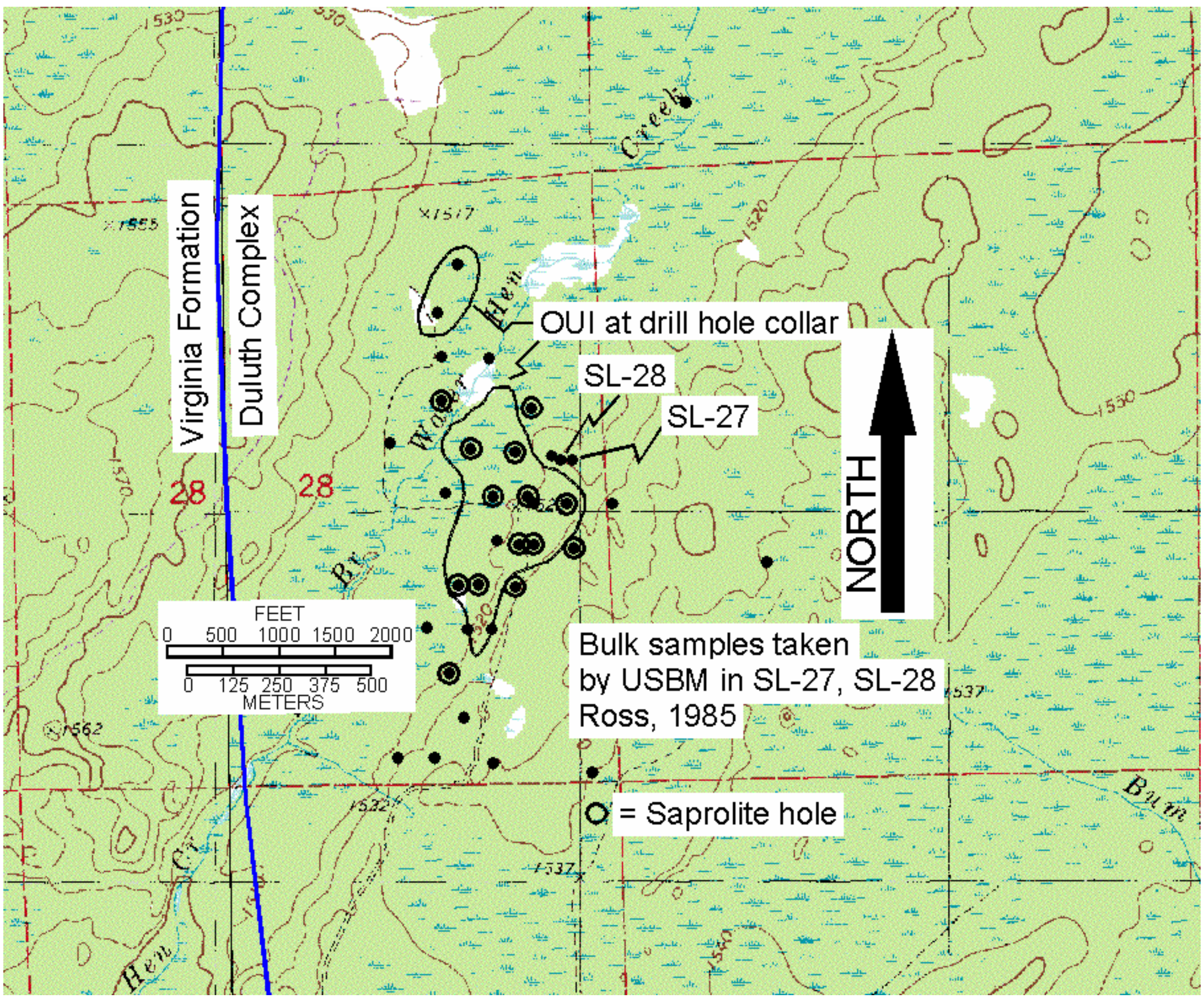

Figure 35. Locations of drill holes and bulk samples (drill holes SL-28 and SL-29) at the Water Hen deposit. The inferred boundaries of OUI at the surface are shown. Note that drill holes that encountered a thick saprolite cap are common within the main OUI body.

(Authors' note: probably in partnership with American Shield of Duluth) and that Water Hen held "*60 million short tons of* TiO_2 *with the ore averaging 13 weight percent* TiO_2." The interest of the USBM was that there is limited production of ilmenite in the US, and a domestic source would be desirable.

No surface sample was taken from the Water Hen OUI body.

Brian Ross (1985) compared a few aspects of the Water Hen deposit with the Bardon Peak peridotite, located in western Duluth. He had access to skeletonized samples from the two cores (SL-27 and SL-28) used by the USBM, previous logging, and some thin sections. He apparently did not look at other holes at Water Hen. Personal communication between Ross and Severson in 1995 provided the link between the USBM report and the known drilling.

Numerous reports (Mainwaring and Naldrett, 1977; Strommer et al., 1990; Severson, 1995) have detailed and revised the geology of the deposit. Essentially this is a "plug" of oxide-bearing ultramafic material (OUI) cross-cutting the lateral edge of the PRI in an area where the steep cliff-like geometry of the Virginia Formation footwall disrupts and obscures the neat "igneous stratigraphy" of the PRI. Water Hen is unusual in having a persistent enigmatic orthopyroxene-rich unit at its base, a saprolitic cap, and massive graphite zones up to 5 ft. thick. Lehmann and Mancuso (1958) wrote a brief discussion on the relative importance (at that time) of this graphite resource (on file at MDNR).

Files at the MDNR indicate that at one time New Jersey Zinc was interested in processing only the saprolitic cap at Water Hen for titanium. They used virtually all of the saprolite material from many of the core holes; thus, very little of this material is now available for scrutiny.

NEARBY DRILL HOLES – ASSAYS AND GEOLOGY

There are at least 37 drill holes in the Water Hen deposit, with a total length of about 28,000 ft. Over 12,800 ft. of assaying indicates an average of 0.19% copper and 0.1% nickel (this includes the OUI and the surrounding troctolitic rocks). Very few sulfur assays were conducted.

Severson and Hauck's PGE review (2003), with values developed from many sources, indicates an average of about 38 ppb Au, 50 ppb Pt, and 75 ppb Pd over approximately 2,000 ft. of core assayed for precious metals at Water Hen. Vanadium assays average 540 ppm over about 900 ft. of core.

Figure 36 is a typical cross-section through the Water Hen OUI. The fault shown beneath the body is entirely speculative.

PROJECT STATUS

As far as any records available to NRRI show, the Water Hen deposit is available for development. Besides sampling by NRRI, no new publically-recorded work has been done here since the last drilling in 1975 (?).

Section 17 OUI

No bulk sample was taken at the Section 17 OUI, but an inspection of that area shows where some material was removed, apparently for construction of the railroad bed located just west of the site, where the railroad crosses Wetlegs Creek (Fig. 37).

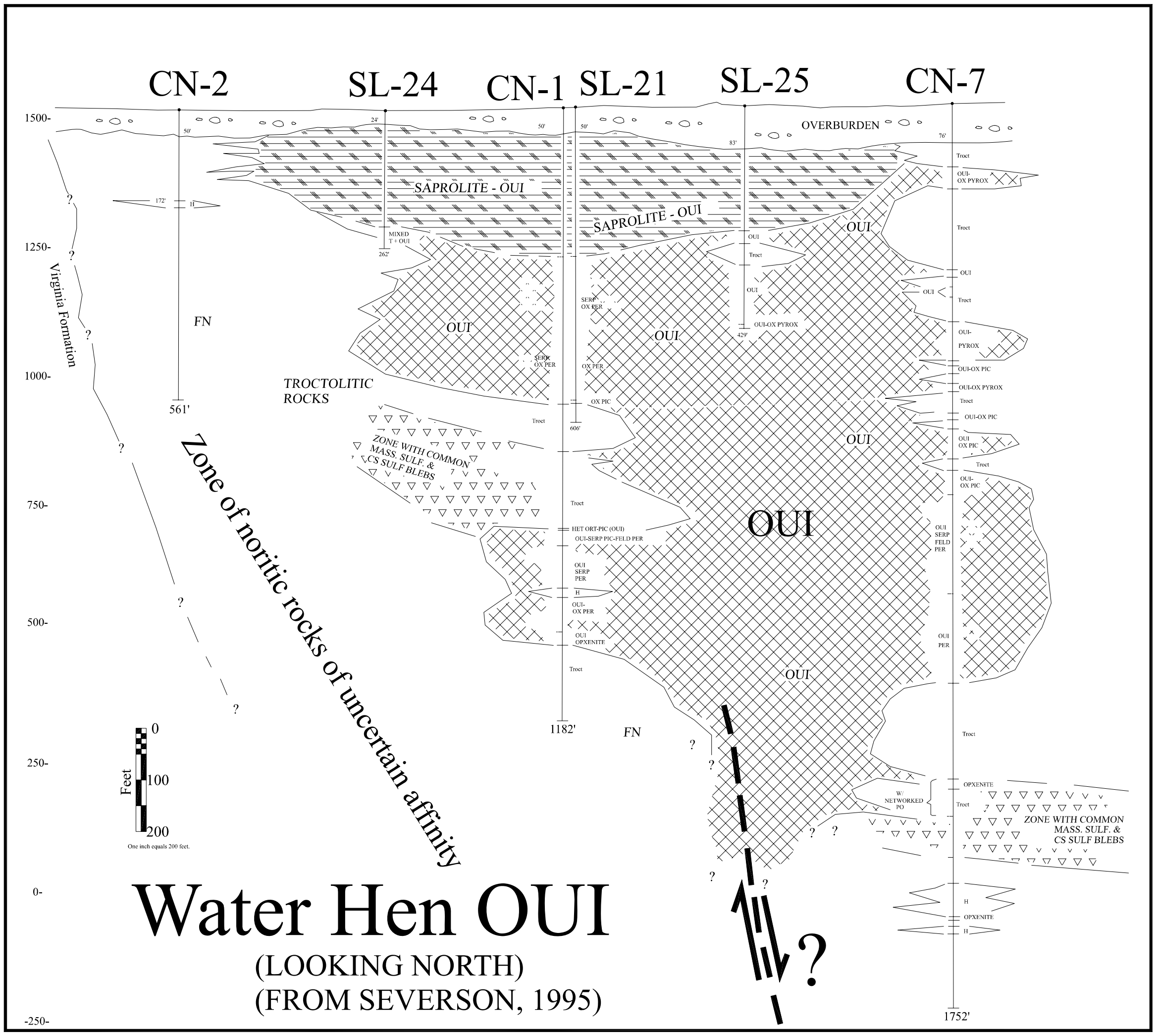

Figure 36. Schematic cross-section through a portion of the Water Hen deposit showing the OUI "plug and saprolite cap. Note that the OUIs are inferred to have been emplaced along fault zones – the root zones of these fault zones have yet to be encountered in drill holes.

OTHER DULUTH COMPLEX-RELATED TEST PITS

No test pit work or metallurgical work is known in any other Duluth Complex copper-nickel prospect or exploration area. It probably has been done, particularly on core samples, but no records have been found. Discussed below are test pits or quarries that are located within the Duluth Complex, and related Keweenawan rocks, that are not related to known copper-nickel mineralization.

Iron Ore Test Pits in Duluth Complex Near the Basal Contact

There are scattered small iron ore test pits (Little Lake Road area, Spruce Road, Nickel Lake/Omaday Lake area) that have removed small amounts of Duluth Complex material incidental to recovering samples of iron ore. These iron ore samples probably came from inclusions in the Duluth Complex. None of these pits are known to have any documentation.

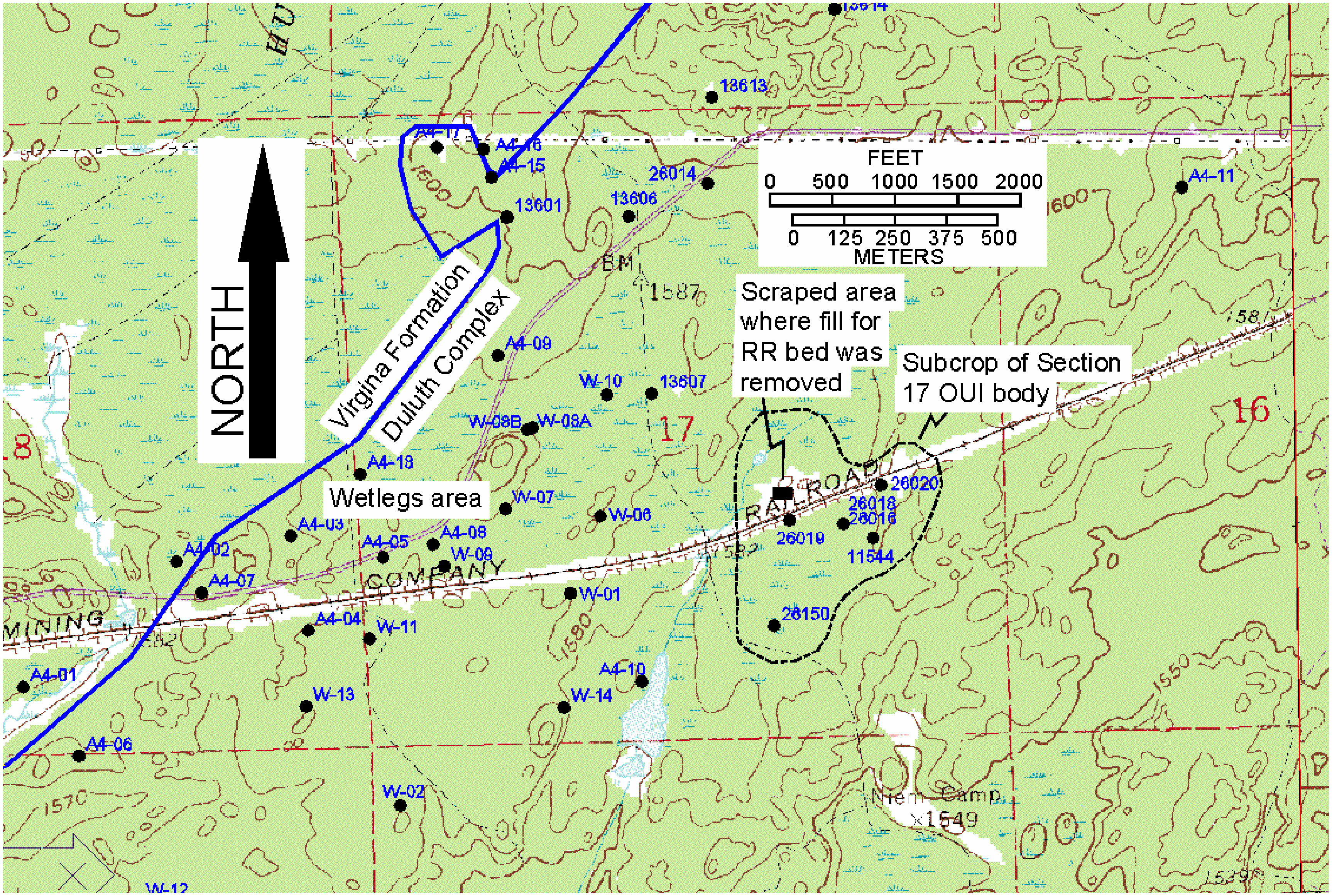

Figure 37. Location of drill holes in the Section 17 OUI body (circular outlined area in the center of the figure). Drill holes to the immediate west (A4-series and W-series holes) are in the Wetlegs Cu-Ni deposit.

Dimension Stone Quarries in the Duluth Complex

There are two active dimension stone quarries in the Duluth Complex. One is north of the Tomahawk Road, east of Babbitt, and one is near Katydid Lake by Isabella; both are in Lake county. These are operated by Cold Spring of Saint Cloud. Material is removed on an "as-needed" basis. Past visits to these operations have indicated no sulfide mineralization (not expected because sulfide would obviously be detrimental to building stone aesthetics), and it is unknown (and unexpected) if these deposits have been tested for other metals. There is an abandoned quarry on Minnesota State Highway 1 south of the Kawishiwi River (Sec. 11, T61N, R11W).

"Lake Superior Green" stone comes from the Isabella quarry which encompasses 385 acres, and "Babbitt Black" comes from the Tomahawk Road location whose operating area covers 240 acres. Cold Spring Granite Co. mines the stone and ships large blocks (approximately 8 ft. by 10 ft. by 4 ft.) to Cold Spring, Minnesota, for final processing.

Through 1998, the Isabella quarry had been the most productive; however, since that time, the stone from the Tomahawk Road quarry has become one of the most sought after in the nation. So far, over 250,000 ft^3. of stone have been removed by Cold Spring Granite from both quarries.

The stone is used in many applications, including, but not limited to: building cladding (the outer surface of large buildings), counter tops, mausoleums, monuments, and gravestones. Of particular note is that the green stone was used in the National D-Day Memorial in Bedford, VA (quarry information from Superior National Forest website).

There are numerous abandoned trap rock quarries in the Beaver Bay Complex such as Carlton Peak near Schroeder and Tofte, one on Lake County Highway 4 north of Silver Bay, one just west of the harbor in Silver Bay, and others. Most of these mined anorthosite inclusions. The source of the ferrogabbro building stone used for the structures at Gooseberry Falls is unknown.

Test Pits Along Gunflint Corridor

Severson et al. (2002), in Miller et al. (2002b), discuss the known work on mineralization in the far northeastern portion of the Duluth Complex and associated rocks. This area has seen historic exploration for iron-titanium oxides and Silver Islet type Ag-vein mineralization. No modern comprehensive studies have been done in this area. Known drill data as collected by Severson is indexed in Patelke (2003).

DISCUSSION

RELATIONS BETWEEN EXPECTED GRADES FROM DRILLING DATA AND ACTUAL PIT RECOVERIES

Some of the impetus for this project was a perception, based on the experience that NRRI and CMRL had with the Arimetco test pits, that the grades of the final samples varied greatly from the grades expected and defined through drilling. We found this reasoning to be somewhat true for most of the bulk samples collected over the years by various companies working in the Duluth Complex. Only INCO in their 1974 pit at Spruce Road got about the same head grades for their bulk sample as indicated by drilling. However, even then a 120 ton portion of the INCO sample sent to the USBM in the Twin Cities returned much lower grades. AMAX also had some success with their drill hole bulk samples—however, it should be noted that they selected and combined mineralized portions from specific drill holes. Table 34 shows the available data for Duluth Complex test

Table 34. Summary of expected grades from drilling relative to the final head grades for all of the bulk samples.

DEPOSIT	LOCATION	ORIGINAL DRILL HOLES, TEST HOLES, AND FINAL SAMPLES	Copper %	Nickel %	Sulfur %
Spruce Road	INCO Spruce Road	Original INCO drill hole 34802 8-35 feet	0.48	0.15	NA
		INCO short core holes for bulk sample, 40928-40951 (all)	0.48	0.12	NA
		Final sample, INCO Operating Concepts Report (1975)	0.47	0.115	1.08
		Final sample, USBM, 120 ton portion of INCO sample	0.35	0.11	0.80
Babbitt/Mesaba	MinnAMAX B1-341 pit	Original core hole B1-341, 31-53 feet	0.52	0.12	1.03
		Core holes for sample B1-422 to B1-427 (all)	0.42	0.10	0.85
		Average of assays on ore piles at sample site (MinnAMAX data)	0.43		NA
Babbitt/Mesaba	Arimetco B1-374 pit	Original core hole B1-374, 14-25 feet	0.43	0.10	0.90
		Air drilled blast hole samples, 10 feet each, averaged	0.22	0.06	0.52
		Final sample grade in CMRL in Dec. 1998 report, page 1 section 2	0.29	0.078	0.63
		Final sample grade in CMRL in Dec. 1998 report, table 2 in appendix 1	0.30	0.081	0.62
Babbitt/Mesaba	Arimetco B1-411 pit	Original core hole B1-411, 14-25 feet	0.60	0.13	1.20
		original core hole B1-411, 25-35 feet	0.24	0.06	0.42
		Patelke estimate of sample grade in report to Arimetco, based on air-drilled holes prior to sampling (1996)	0.61	0.12	1.02
		Final sample, CMRL in June 1998 progress report	0.363	0.085	
		Final sample, CMRL Dec. 1998 table 2 in appendix 1	0.359	0.075	0.76
		Final sample, CMRL in Dec. 1998 report	0.356	0.077	0.76
Babbitt/Mesaba	Teck Cominco B1-321 pit	Original core hole B1-321, 20-35 feet	0.64	0.14	1.21
		Original core hole B1-321, 35-45 feet	0.93	0.18	1.37
		Severson core drilling all B1-321XX holes	0.55	0.13	1.03
		Severson 460 ton sample block calculation	0.62	NA	NA
		Final sample grade-gross estimate based on back calculation from CESL report (Jones and Moore, 2002)	0.30	0.05	NA
Dunka Road/ NorthMet	USS Bulk 1	Original core hole 26058, 8-20 feet	0.82	0.20	1.21
		Final bulk sample number 1, head grade	0.39	0.14	0.50
Dunka Road/ NorthMet	USS Bulk 2	Original core hole 26105, 22-32 feet	0.77	0.28	1.23
		Final bulk sample number 2, head grade	0.40	0.13	0.97
Dunka Road/ NorthMet	USS Bulk 3	Original core hole 26105, 22-32 feet	0.77	0.28	1.23
		Final bulk sample number 3, head grade	**0.58**	**0.22**	**0.98**

pits, along with the original drill hole grades and blasthole grades where possible.

- When many short core holes were drilled and assayed for testing of expected grade (INCO Spruce Road and the B1-341 MinnAMAX pit), the results were better than when air drill blasthole assays were used, or a pit was sited based on a single drill hole.
- The larger pits generally had better results.
- It appears that there are some slight reporting differences among reports; over time and with rounding, these could be misinterpreted.
- It is important here to recognize that even though a pit did not return the expected grade, the samples have proven to be useful. CMRL and Teck Cominco were able to perform the needed tests on samples as recovered. PolyMet was able to composite a sample from rotary drilling chips that met their needs. The Dunka Road project did not go forward under USS, and the Spruce Road project did not go forward under INCO, but neither was derailed by bulk sample issues as far as we can tell.
- The metallurgical (mineralogical) problems attendant to the Duluth Complex are inherent and are not a matter of sample size or grade.

The real issue as far as grade is concerned may simply be the attendant variability associated with these types of deposits. Table 35 shows the range of values for copper, nickel, and sulfur in Unit I for four holes across the Babbitt deposit. Our attempts over the years to correlate drill holes on assays or thin lithological horizons have met with limited success. At any given level in these deposits, it is not unusual to see good grades in one hole and poor grades in the next, even in holes wedged from the original. Similarly, rock types, textures, and grain sizes may not carry from one hole to the next.

NICKEL CONTENT IN SILICATES (Olivine)

In an Anaconda memo about the INCO Minnesota properties (Swayne, 1963, p. 14), there is a statement, "*Low nickel recovery is believed related to variable amounts of nickel contained in the molecule of the olivine gangue mineral, and hence not recoverable by flotation.*" This statement is essentially repeated on page 16 of the same document.

In a USS memo (Niles, April 15, 1974) regarding an investigation of the nickel content in olivine separates, it was found that the calculated nickel in olivine ranged

Table 35. Vertical range of assay values in Partridge River intrusion drill holes at the Babbitt deposit.

	% copper		**% nickel**		**% sulfur**		**total footage (ft.)**	**n=**
	High	Low	High	Low	High	Low		
PRI DDH A	1.35	0.01	0.22	0.01	2.97	0.01	672	101
PRI DDH B	2.64	0.03	0.15	0.02	2.56	0.10	403	45
PRI DDH C	2.05	0.02	0.48	0.01	7.35	0.14	585	67
PRI DDH D	4.51	0.01	1.26	0.01	12.81	0.03	886	89

from 0.021% to 0.073%. AMAX found that "…nickel silicate values in the disseminated ore should be expected to assay in the order of 0.02%" (File 3.4.1.3 in MDNR Archive). Additional nickel values as determined by microprobe, or chemistry, are listed in Tables 36 and 37. As can be seen in Table 36, there are wide ranges and disparate averages in the nickel content of olivine as determined by both analytical and microprobe methods.

Geerts et al. (1990) state that "*Since the Dunka Road geochemical data file…contains both USX values (total Ni, i.e., total acid dissolution) and Fleck values (soluble Ni, i.e., HNO3 + HCL dissolution), comparison of sulfide (soluble) Ni to total (silicate + soluble) Ni content is possible* [their Figure 9]. *There is strong correlation coefficient of 0.7802 calculated with 1,512 pairs. The calculated slope of total Ni is 0.7657, with a ratio of total Ni to soluble Ni of 3:2, respectively.*"

While there is some assayed nickel contained in olivine (and thus, not recoverable in a sulfide concentrate) in these rocks (the rocks have 0-50% olivine, with local concentrations much higher), there is no clear-cut evidence for this to be a major factor in the discrepancy between assayed nickel and nickel recovery. On the other hand, some of the contrary evidence is as follows:

1) Using the data for Dunka Road from Geerts et al. (1990) and plotting the USX total nickel vs. the Fleck soluble nickel by gross rock type (ultramafic versus other mafic rocks), shows that there is essentially no difference between the mafic and ultramafic rock type. One would expect silicate nickel to be concentrated in the ultramafic rock type considering their high olivine content. What is seen in the ultramafics is essentially the same ratio (0.655) of soluble to total nickel as the mafic rocks (0.665), and no discernable concentration of nickel in the ultramafic rocks, either soluble or total. Using data for the entire Duluth Complex, the nickel average is 0.12% for about 11,400 ft. of ultramafic rock and 0.118% over 312,500 ft. of intercept for the remainder of the Complex.
2) For 50 olivine analyses (supplied by Hauck), the average Ni content is 0.26%. The nickel average is 0.12% for about 11,400 ft. of ultramafic rock.
3) Over the entire Duluth Complex there is about 3,930 feet of drill intercept out of 339,000 feet (where both nickel and sulfur values are available), where the nickel value is equal to or greater than the sulfur value. Where nickel is higher than sulfur is one of the easy ways to sort this data out of large databases, but within this group of 3,900 samples are many where both values are very low, and could well be assays of marginal quality.

That being said, none of the above really addresses the quality of any particular set of assays. One discrepancy could come from the cores being analyzed by a different lab or method than the metallurgical samples.

In their test pit work, USS showed about 85% of the total nickel as "sulfide nickel." Does this then mean that they assumed the rest was in olivine?

In summary, the amount of silicate nickel in the assay results has not been tested rigorously for any of the deposits. Microprobe data suggest that olivine contains anywhere from 0.00% to 0.70%! Waste characterization work underway for Franconia and PolyMet may supply some better numbers for this assessment. These extreme values do not appear to be related to rock type differences. To date, no compilation of different assay techniques has been

Table 36. Determinations of nickel in olivine (silicate nickel) within Unit I of the PRI. DH = drill hole, comps. = composites.

Deposit	Ni% range in olivine	Average Ni% in olivine	Number of assays	Type of assays	Reference
Dunka Road	0.02-0.07%	0.045%	9	chemistry on olivine separates	USS memo by Pete Niles (1974)
Dunka Road	0.040-0.093%	?	4 DH comps.	chemistry on flotation tailings	USS memo by Kokal (1970)
Babbitt	0.07-0.70%	0.15%	14	microprobe	Ryan (1984)
Babbitt	0.03-0.13%	0.08%	18	microprobe	Al-Alawi (1985)
Babbitt	0.079-0.089%	0.085%	6	microprobe?	Hardyman (1969)
Babbitt	0.01-0.06%	0.02%	17	comparative analytical results on samples from 5 drill holes using different digestion techniques	AMAX (1985) (file 3.4.1.3 at MDNR)
Wetlegs	0.00-0.20%	0.08%	57	microprobe	unpubl. data (Komppa, 1998) assembled by Steve Hauck
Wyman Creek	0.07-0.16%	0.10%	3	microprobe	Nabil (2003)

Table 37. Determinations of nickel in olivine (silicate nickel) within mineralized units of the SKI.

Deposit	Nickel % range in olivine	Average Ni% in olivine	Number of assays	Type of assay	Reference
South Filson Creek	0.00-0.40%	0.15%	70	microprobe	unpubl. data (Cronk) assembled by Steve Hauck
Spruce Road	0.02-0.30% (190-2,985 ppm)	0.13% (1,288 ppm)	35	microprobe	unpubl. data (Lee, 1994) assembled by Steve Hauck
Maturi	0.12-0.15%	0.13%	5	microprobe	Pasteris (1984)
Birch Lake (U3 Unit)	0.05-0.19%	0.11%	33	microprobe	unpubl. data (Hauck) assembled by Steve Hauck

done for the copper-nickel deposits of the Duluth Complex. Copper assays are less sensitive to differences in common digestion and exploration assay methods than assays for nickel. Therefore, comparisons of copper grade between deposits may be reasonably valid; whereas, comparisons of nickel grade may actually reflect differences in assaying technique or assay labs. These differences would have ramifications for: 1) copper-nickel ratios between deposits; 2) assumptions about the amount of nickel in silicates (olivine); and 3) in perceptions of recovery efficiencies in bench scale and pilot plant testing.

COPPER OXIDATION IN COARSE REJECTS ("Save Samples")

In 1979, AMAX had Lakefield conduct a study (Wyslouzil and Sarbutt, 1979) wherein samples of surface ore (from the test pit or shaft sample, not clear in documentation) were left outside for about six months. The actual samples consisted of three-inch pieces, from the original ore pile, that were crushed to minus one half inch and then left out to weather. Smaller samples from this "oxidized ore" were then assayed and bulk flotation-tested after periods of 0, 1, 2, 4, 6, 8, 16, 24, and 32 weeks.

The conclusion was "*Concentrate grades and recoveries were somewhat variable during this series of tests, but there was no noticeable deterioration in concentrate grade or recovery because of weathering.*" This report is on file in the AMAX material in the MDNR archive files (item number 410).

IMPORTANCE OF SULFUR ASSAYS

In these deposits, the higher PGE assays seem to be associated with areas of higher copper to sulfur ratio, probably indicating chalcopyrite and/or cubanite being relatively greater than pyrrhotite. Empirically, it seems that the higher PGE values are found where there is more chalcopyrite-rich mineralization (Severson and Hauck, 2003).

However, besides the Bear Creek/ AMAX and USS data, there is not a consistent, large database for sulfur values for the rest of the Complex. Outside of the Bear Creek/AMAX and USS data, there is about 564,750 ft. of core assayed for copper, and of that, about 354,400 ft. of core, or about 63%, assayed for sulfur. The average sulfur assay is 1.35%. Copper averages 0.38% for all intervals. For uncertain reasons, the average copper assay where sulfur was not assayed is 0.25%, and contrarily, the copper value is 0.45% where sulfur was assayed (these values are not footage weighted).

So, if the copper to sulfur ratio is a useful exploration tool, it is not available for about 35% of the drilled footage. It would not appear to be economic to acquire this data.

IMPORTANCE OF COBALT ASSAYS

Cobalt has not always been assayed in Duluth Complex work. Peterson (1997) is the most complete digital listing for cobalt from INCO and others. That work plus review of assays from Teck Cominco at the Mesaba deposit (Patelke and Hovis, 2002) indicates that usually the cobalt is at a value about one-fifth to one-tenth of nickel and seems to track fairly well. The available cobalt assays seem fairly reliable in that they keep a relatively constant ratio to nickel. Because there is not enough cobalt to drive the economics of any particular deposit, it has largely been treated as a simple by-product where the company "would take what they can get," but not optimize for cobalt recovery. Price changes in cobalt could certainly change this picture.

IMPORTANCE OF PGE-PATHFINDERS

Severson and Hauck (2003) recompiled all the existing PGE analyses. They excluded some older assays reported in ounces per ton, as well as many of the older assays taken by AMAX at the Babbitt (Mesaba) deposit. Their basic conclusion is that throughout the Complex the relations between PGE and other elements are not clear enough that other elements can yet be used as pathfinders to PGE mineralization.

CONSIDERATIONS FOR LOCATIONS OF FUTURE TEST PITS

Pit Size vs. Need for Environmental Review

Only the proposed Teck Cominco 50,000 ton pit at the Babbitt (Mesaba) deposit has gone through mandatory environmental review. In other recent bulk sampling cases, there has been no environmental review, but the state regulatory agencies (MDNR and MPCA) have been notified about test pit plans and made some changes to the plans to accommodate their reclamation requirements. There are no formal size criteria for mandatory review. Generally, if the final ground surface will direct water away from the site, and there are no wetland or groundwater problems foreseen, a formal environmental review will probably not be needed.

Most of the issues for developing a pit are obvious and include: overburden thickness; road access; groundwater and surface water in proximity; and the relation of all of these to successful reclamation. However, satisfying all these criteria is meaningless if the site does not have the geological and assay continuity to be a reasonable representative of the entire deposit. Past history has shown that control of water flow and re-vegetation are by far the major reclamation issues.

Private vs. Public Property

Property owners will have different requirements for test pits. Notably, the state would likely not allow a pit on their land unless the land was under minerals lease.

<u>Backfill Material</u>

Teck Cominco filled their 2001 test pit, and proposes to fill their 50,000 ton test pit, at Mesaba with taconite waste rock. The other (smaller) pits at Babbitt were backfilled with the unmineralized and/or oxidized rock taken from the pits. The Minnesota Iron & Steel iron-formation test pit at Nashwauk (1,000 tons, 1998) was filled with waste taconite. The USS pit at Dunka Road/NorthMet was not backfilled. The INCO Spruce Road pit(s) were backfilled with unknown material. One of the INCO pits at Spruce Road was revisited, recovered, and re-contoured to remediate a small seep (Regional copper-nickel study, 1977). Overall, most of the bulk sample sites were contoured to direct water away from the pit area. All manner of backfill, be it glacial or unmineralized rock, is available in the area.

AREAS WITH OUTCROP INDICATING NEAR SURFACE MINERALIZATION

Overall, mineralized outcrop of the Duluth Complex makes up a very small portion of the known outcrop. Presumably this is due to easy weathering caused by sulfide and olivine content and the generally resistant nature of the anorthositic rocks that are seldom mineralized. In a few locations, there are accessible outcrops. These are listed below.

South Filson Creek

There is chalcopyrite in anorthositic troctolite rocks in low-lying outcrops in a spruce bog.

Spruce Road

There is scattered mineralized outcrop at Spruce Road, including small zones of copper mineralization in the underlying granite.

Little Lake Road

See Peterson et al. (2004) for specifics on outcrops of mineralized SKI along the "Little Lake Road" on the north side of Birch Lake, Kangas Bay quadrangle.

Peter Mitchell Pit

As stated earlier, the iron mining in the Peter Mitchell pit has encountered the edge of mineralized Duluth Complex rock that includes massive sulfide (as pods). This sulfide is assumed by NRRI staff to represent the far northern edge of the Serpentine deposit in the South Kawishiwi intrusion.

Rail Grade Outcrops at Babbitt (Mesaba) Deposit

There are a few mineralized outcrops at Babbitt (Mesaba) in the eastern edge of the deposit. They may not be representative of the entire deposit.

Wetlegs Railroad Cut Outcrops

The railroad cut through the Wetlegs area is weakly mineralized.

Wyman Creek Railroad Cut Outcrops

The railroad cut through the Wyman Creek area is weakly mineralized.

DISTRICT POTENTIAL FOR OTHER METALS: GOLD, SILVER, VANADIUM, CHROMIUM, NATIVE COPPER

Nothing in the test pit work we have reviewed confirms or denies any possibility for other valuable metals. Titanium, vanadium, chromium, and other oxides may exist in economic quantities in the Complex, as they seem to in the OUIs. Their recovery is a matter of processing technology and market demand, neither of which has changed enough to make these bodies into "ore." There are some high silver values in assaying, but generally it is low. Native copper is rare in the Complex and is related to both surface weathering phenomenon and hydrothermal redistribution (as seen in the deeper portions of some drill holes).

POTENTIAL MINERALOGICAL PROBLEMS

There are a few potential mineralogical problems that might affect both the permitting of a test pit and the operation of concentrate testing if not recognized.

Cubanite vs. Chalcopyrite

While the copper mineralization in these deposits is often described as chalcopyrite ($CuFeS_2$, 34.6% copper), it is more likely to be a mix of chalcopyrite and cubanite ($CuFe_2S_3$, 23.4% copper). The actual mineralogic ratio in the rocks is an unknown. Much logging has noted cubanite and/or chalcopyrite (as "cp") and attempts have been made in discriminated between these two (in addition to recognizing pyrrhotite). However, making a definitive distinction between cubanite or chalcopyrite can be a time consuming identification when logging the core for lithologic reasons. Detailed petrographic studies to characterize the ratios of Cu-sulfide types through vertical sections of the various deposits would greatly aid in understanding the true amount of cubanite present, but these studies have not been conducted to date.

Watowich et al. (1981) estimated about 2:1 cubanite/chalcopyrite in the disseminated ores and about 6:1 cubanite/chalcopyrite in the massive sulfides at Babbitt (the latter number seems way too high). Furthermore, Watowich (or anyone else at AMAX) failed to recognize the presence of large amounts of talnakhite ($Cu_9(Fe, Ni_8)S_3$, 35-38% copper) in localized zones of the Local Boy massive sulfides as reported by Severson and Barnes (1991).

Compilation of some of Lakefield labs work done for AMAX shows very variable ratios between cubanite and chalcopyrite. See Figure 38 for the plot of these ratios, which cover a variety of mineralization types.

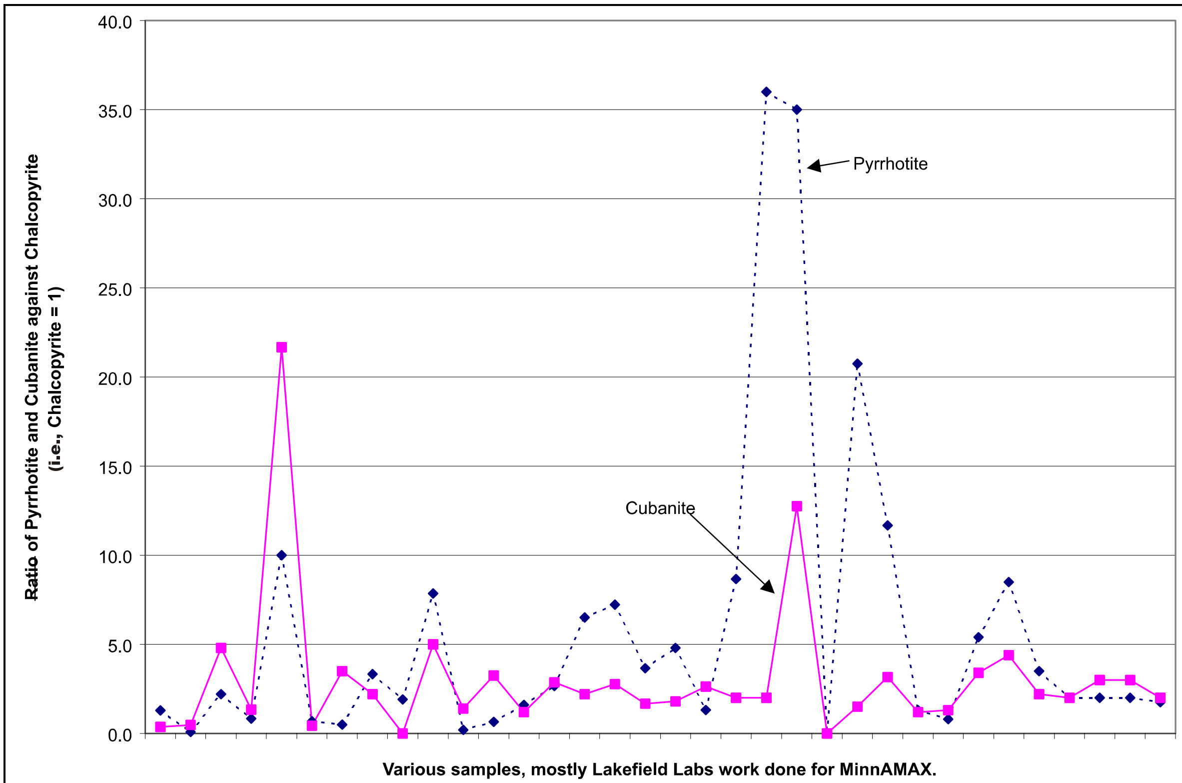

Figure 38. Graphical representation of ratio of cubanite to chalcopyrite (solid line) and pyrrhotite to chalcopyrite (dashed line). Note that most of the data points lie above the 1.0 value on the y-axis (equal to 1:1 ratio). Data for various samples taken largely from various MinnAMAX metallurgical reports on file at the MDNR.

Hessevick (in Benner et al., 1998) indicated that copper values in sulfide concentrates (Babbitt tests, CMRL) are usually less than 30% copper, indicating that if these are clean of other gangue, there would be about 1:1 cubanite/chalcopyrite ratio, which he confirmed through petrographic examination and estimation, but not point counting.

Fundamentally, there is no definitive study in the records at MDNR or NRRI addressing these mineralogic ratios other than for a few samples at a time. The available evidence indicates that without well constrained sample locations and a large sample set, these ratios will remain speculative with a very wide range of values.

Pyrrhotite vs. Pentlandite

Much pentlandite may be in "flames" in pyrrhotite and not readily recoverable, though it will assay as "sulfide nickel." Hessevick (in Benner et al., 1998) comments on this as where pentlandite contains exsolution textures of cubanite/chalcopyrite. He also believed some pentlandite was trapped in the pyrrhotite.

No Known Recognition Criteria for PGE-Rich Areas

Severson and Hauck (2003) completed some new PGE assays in 2003, as well as a re-compilation of the previous PGE assay data. There are some good values, but what is striking is the absence of any recognition criteria for higher grade material short of assaying. The closest concept to a usable criteria is that copper-rich zones are more likely to have higher PGE values.

Fibrous Minerals

The nature and behavior of fibrous minerals in the Duluth Complex is at present unresolved. The local alteration of ultramafic intrusive rocks of the Complex to serpentinite is common; in addition, uralitized zones containing small amounts of amphibole are locally common. Various state and federal agencies are currently addressing this issue in regards to permitting for Duluth Complex mining projects. A conference was held in 2003 ("International Symposium on the Health Hazard Evaluation of Fibrous Particulate Associated with Taconite and Adjacent Duluth Complex," St. Paul, MN, March 30, April 1, 2003) to establish a framework for future study of the fibrous mineral issue in taconite (Biwabik Iron Formation). Because the existence of fibrous minerals in taconite is related to contact metamorphism by the Duluth Complex, these studies may also apply to the Complex. So far, no proceedings from this forum have been published.

This issue will need to be addressed in any future Duluth Complex mining operation. Whether or not a future test pit itself would require considerations concerning the release of fibrous minerals is a matter for the permitting agencies to decide.

The importance of this issue to northeastern Minnesota is best exemplified by the Reserve Mining Case where taconite tailings were placed into Lake Superior. The final outcome of the Reserve Case was moving the tailings disposal system from the Silver Bay plant inland to the "Milepost 7" area located northwest of Silver Bay. One of the greatest difficulties in the fibrous minerals issue is still the definition of terms.

Sausserite vs. Granite

At Dunka Road (NorthMet), several intervals of sausserite (calcic plagioclase altered to a white mix of albite and zoisite with variable amounts of epidote, calcite, sericite, and zeolite) were logged as white granite in the past. If excessive amounts of granitic rock would be detrimental to a sample and logs show large amounts of granite in areas not near major structures or near the footwall, it is suggested that one refer back to the original drill core if possible. It may be well that the material logged as granite is strongly sausseritized troctolite.

Graphite

Graphite can be found locally in very high concentrations in the Complex, but usually in short intervals (less than 1 foot; Patelke, 2003). It is usually associated with OUIs or near the footwall of the Complex. Some of the hornfelsed footwall (Virginia Formation) rock can also be quite graphitic. If graphite would be a detriment to a metallurgical test, its possible occurrence in the area of interest should be investigated before taking a metallurgical sample.

Chlorine from Core Drilling

Much has been made of the chlorine drops found forming new minerals on the surface of cores of Duluth Complex rock stored in humid conditions (Hauck et al., 1997 and references therein). These drops are naturally occurring and relatively localized. However, drillers in Minnesota are required by law to add chlorine (household bleach or swimming pool treatment, seldom used in actual practice) to the water used in drilling to avoid contamination of the aquifer. Fresh core should be carefully washed as soon as possible coming out of the ground if chlorine will be an issue in the sample, and tested as a carrier for PGE.

Oil on core samples - flotation problems

NRRI has had some reports in 2001 of difficulties with flotation on samples crushed from core that had been cut with an oil-lubricated saw. This problem should be investigated and avoided if flotation problems could be an issue for metallurgical samples.

DRILLING TO SELECT A SAMPLE LOCATION VERSUS DRILLING TO CHARACTERIZE A SELECTED SITE

An issue to be considered in the selection of future test pits, and one that we have not fully examined for historic pits, is the difference between an intense drilling campaign to select a sample location site versus simply picking a single site and then drilling to characterize it.

The first option consists of defining a reasonable area to develop a test pit, and then drill a series of reconnaissance holes at several different potential sites within the area. The best of these "recon" holes (as in most appropriate to the need at hand) would then have more close-spaced holes drilled in their immediate vicinity. If continued logging, sampling, and assaying showed acceptable results in a group of close-spaced holes, then a pit would be permitted and excavated.

The other option shortens the time frame by selecting and permitting a single site based on available drilling only. After a single site is chosen, drilling prior to excavating would be used to modify the pit outline. Permitting multiple possible sites can be much more complex than permitting a single site. Provided that the gamble works and the pre-selected site is acceptable, a company could save substantial time and money by using the holes simply to characterize the sample one already intends to take.

As noted earlier, we see no records indicating that any companies have fully tested multiple sites or abandoned a preselected site prior to excavation.

EXISTING BULK SAMPLE MATERIAL STORED AT THE SURFACE

Oxide Bulk Samples

As of September 2003, there is a substantial bulk sample from the Longnose OUI stored at the Coleraine Minerals Research Laboratory of the NRRI. The ownership of this material is unknown.

Sulfide Bulk Samples

As of September 2003, there is a substantial bulk sample from the Babbitt/Mesaba deposit stored at the Coleraine Minerals Research Laboratory of the NRRI. This sample was taken by Arimetco in 1995-1996 (Arimetco Number 2). Its current ownership is uncertain because of the bankruptcy of Arimetco. Teck Cominco now controls the leases on this property.

There are a few tons (estimated at about 100 tons by size of pile in 2003) from the 2001 Teck Cominco B1-321 5,000 ton bulk sample at the Babbitt (Mesaba) deposit stored on site at the NorthShore Mining Company Peter Mitchell Mine.

As stated elsewhere, the waste rock dump(s) at the Dunka Pit can also be considered as a bulk sample at the surface. This material is owned by the State of Minnesota, Gardner (Rendrag) Resources, and probably others.

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CMRL/TR-99-20 - (No NRRI number) - Extraction of Copper from Chalcopyrite Concentrates Without Sulfuric Acid Generation via Chlorination II. Selective Oxidation of Chlorinated Products - I. Iwasaki, T. Tamagawa, N. X. Fu and M. Kobayashi - October 22, 1999 - Sponsor: Ministry of International Trade and Industries - Project #N/A - CUFS #N/A. (This report is based on work done when I. Iwasaki was with Mitsubishi Materials in Japan.)

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APPENDICES

APPENDIX 1:

CONTACT INFORMATION FOR DULUTH COMPLEX MINING AND EXPLORATION ISSUES

SOME USEFUL CONTACT INFORMATION FOR MINNESOTA MINING AND EXPLORATION ISSUES

Revised May 2004

For general data issues, and geologic questions:

At NRRI:

Steve Hauck, Mark Severson, Larry Zanko, Richard Patelke, Dean Peterson and John Heine at:

Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth MN 55811-1442
218-720-4294
(The NRRI is an economic development group associated with the University of Minnesota Duluth.)

At MDNR:

Marty Vadis, Dave Dahl, Rick Ruhanen, Al Dzuck at:

Minnesota Department of Natural Resources
Lands and Mineral Division
525 Third Ave. East
Hibbing MN 55746-1461
218-262-6767
(The MDNR has extensive drill core and data files for historic exploration and mining projects in Minnesota; Mr. Al Dzuck is not directly involved in this work anymore, but might be a useful contact if others are not available.)

For initial mineral leasing information questions:

State lands:

Kathy Lewis
Minnesota Department of Natural Resources
Lands and Mineral Division
500 Lafayette Road
St. Paul MN 55155
651-296-4807

For Federal lands:

Lorretta Cartner
United States Forest Service
8901 Grand Ave. Place
Duluth MN 55808
218-626-4382

For general tax questions related to Minnesota mining:

Tom Schmucker
Minnesota Department of Revenue
Eveleth MN 55734
218-744-7420

Lawrence M. Zanko
Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
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For information about economic development issues in northern Minnesota:

Brian Hiti
Iron Range Resources and Rehabilitation Agency
PO Box 441
1006 Highway 53 South
Eveleth MN 55734-0441
218-744-7400

John Chell-Director
Arrowhead Regional Development Commission
221 West First Street
Duluth MN 55802
218-722-5545

Minerals Coordinating Committee
St Paul MN
(Group from Minnesota state agencies that decides on distribution of state minerals research funds; includes MDNR, MPCA, NRRI, MGS.)

For regional geology:

Dr. James D. Miller Jr.
Minnesota Geological Survey
c/o Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth MN 55802
218-720-4294

and:

Harvey Thorleifson, Director
Terry Boerboom and Mark Jirsa, Geologists Minnesota Geological Survey
2642 University Avenue W.
St. Paul MN 55114-1067
651-627-4700

Trade groups related to exploration and mining in Minnesota:

Minnesota Exploration Association (MExA)
Suite 622, Plymouth Building
12 South 6th Street
Minneapolis MN 55402-1506
612-338-5584
(This group is concerned with promoting non-ferrous development in Minnesota.)

Iron Mining Association of Minnesota
505 Lonsdale Building
302 West Superior Street
Duluth MN 55802
218-722-7724
(This group covers many vendors and service companies, everything from haul trucks to environmental services which may be of interest to others outside the iron-mining industry.)

Land Offices representing some private mineral interests in Minnesota (not an exhaustive list):

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(RGGS is a Houston, Texas-based company that purchased much of the U.S. Steel mineral lands nationwide in early 2004.)

Albert Haertlein, Daniel Clark
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P.O. Box 188 / One Gayley Avenue
Coleraine, MN 55722
Tel 218-245-4201, Fax 218-245-4219

For exploration and mining permitting and environmental review information:

Ann Foss
Minnesota Pollution Control Agency (MPCA)
520 Lafayette Road
St. Paul MN 55155-4194
651-296-7512

Rebecca Wooden
Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul MN 55155

Drilling regulation:

Also note that Minnesota Department of Health governs drilling operations on areas outside of permitted mine properties. (Test pits are governed by MDNR and MPCA if large enough.)

Minnesota Department of Health
Well Management Unit
P.O. Box 64975
St. Paul MN 55164-0975
651-215-0812
(Note: drilling requires the explorer company to be registered with both the MDNR and the Department of Health; there must be a "responsible individual" who is approved by the Department of Health to sign off on the drill hole closure.)

Geological groups in northern Minnesota:

Mesabi Range Geological Society
Generally meets third Wednesday of month
No fixed address or meeting location
Contact: Daniel L. England
Eveleth Fee Office
301 McKinley Avenue
P.O. Box 521
Eveleth MN 55734-0521
218-744-4646

Institute on Lake Superior Geology
Meets in Lake Superior region of Minnesota, Wisconsin, Michigan, Ontario; usually in first or second week of May, no fixed address, Contact Mark Jirsa at Minnesota Geological Survey or try www.lakesuperiorgeology.org.

Also see:

The following report has a description of the permitting processes and many links to a variety of environmental regulation publications:

Severson, M.J., 2003, Required metallic exploration, mining, processing permits in Minnesota-the who, what, where, and when to non-ferrous metallic mine permitting: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2002/20 87 p., 1 plate, 1 CD-ROM.

Websites:

See NRRI Economic Geology Group, www.nrri.umn.edu/egg for data and reports online.

Minnesota Geological Survey has numerous reports available for download.

Minnesota Department of Natural Resources has some good sites: the "Data Deli" is general statewide GIS data, such as topographic maps and air photos, as well as many ArcView shapefiles to list for elevation, roads, lakes, public land survey, land ownership, etc. Their "Public access to minerals information" website has downloadable copies of much of the minerals assessment data on file at the Hibbing office.

"LMIC" (the Land Management Information Center) has a large amount of Minnesota GIS data.

The NRRI, MDNR, and MPCA also all have a wealth of ecological data available in GIS format, but not necessarily easily found. Another place to start looking online for Minnesota GIS data is "geogateway," a search engine that goes through content on many GIS sites.

APPENDIX 2:

DRILL HOLE NUMBERING GENERALITIES

A short note about general drill hole numbering may help here:

Holes designated with a Roman Numeral are usually Phelps Dodge drill holes in the South Complex (Iron Range to Duluth) area.

SL (St. Louis) series and CN (Cloquet North) series holes are at Water Hen area in the PRI.

CV (Cloquet Valley) drill holes are in the South Complex (Iron Range to Duluth) area.

A series (A-3, A-4) are Allen grid drill holes drilled by Bear Creek.

W series holes are at Wetlegs and Wyman Creek holes by Exxon.

26000 series holes are, in the majority, USS holes at Dunka Road and Wyman Creek, but also include drill holes in the South Complex (Iron Range to Duluth) area.

99-XXX and 00-XXX followed by a B or C are PolyMet holes at Dunka Road (NorthMet).

B1-series holes are mostly Babbitt and Serpentine by Bear Creek and AMAX.

B2-series are Dunka Pit holes by Bear Creek.

10000 series are drill holes underground in the Local Boy part of the Babbitt Deposit.

BL and C series are Birch Lake (except for BL-1-MDNR near Bear Lake).

E series holes 1 through 11 (formerly NM series holes) are Erie mining holes at Dunka Pit, renumbered by USBM.

8000 series are mostly Erie Mining (LTV) drilling at Dunka Pit.

NM series holes 1 through 6 are Newmont holes, mostly in the Highway 1 corridor.

NM series holes 12 through 63 are Newmont holes at Dunka Pit.

11500 series are INCO drill holes, mostly in the South Kawishiwi intrusion (Maturi and Spruce Road) with a few in the Partridge River intrusion.

13600 series are INCO holes mostly in the Partridge River intrusion with a few in the South Kawishiwi intrusion.

32700 series are INCO drill holes in the South Kawishiwi intrusion (Maturi and Spruce Road).

34800 are INCO holes, mostly at Spruce Road.

40900 series are INCO drill holes mostly at Spruce Road, but also scattered throughout the South Kawishiwi intrusion and the Partridge River intrusion.

KA and KAF are Bear Creek holes at Little Lake Road (KA=Kangas Bay Quad?).

K series drill holes are mostly South Filson Creek drilling by Hanna Mining. Those not at South Filson Creek are all in the South Kawishiwi intrusion.

CDC drill holes are MGS drill holes in the Central Duluth Complex.

GLI drill holes are MGS holes in the Greenwood Lake intrusion.

1000 series are drill holes at the Reserve Mining Company (NorthShore mining) tailings basin north of Silver Bay.

This list is not complete. There are numerous other small groups of drill holes, but these are the main ones. Note that there is no hole numbering duplication in the Duluth Complex, but that some of these numbers may be duplicated elsewhere in Minnesota.

APPENDIX 3:

VERSION OF "A BRIEF HISTORY OF COPPER-NICKEL-PGE EXPLORATION IN MINNESOTA, RELATED DRILL HOLES, AND REPORTED GRADES AND TONNAGES FOR VARIOUS DEPOSITS." HANDOUT BY STEVEN HAUCK AND MARK SEVERSON, WITH CONTRIBUTIONS FROM G.B. MOREY, DAVID SOUTHWICK, MARTY VADIS, DAVID DAHL, AND RICHARD RUHANEN.

(on CD-ROM)

APPENDIX 4:

PHOTOGRAPHS OF BULK SAMPLE SITES IN THE DULUTH COMPLEX (on CD-ROM)

Spruce Road Bulk Samples

<u>"Snowtrail-east" Pit</u> (all photos taken in 2004) *spruce-snowtrail-east-pit1-2004.jpg* = general view of pit (looking E) - note hunting shack
spruce-snowtrail-east-pit2-2004.jpg = same as above, showing mound of hornfelsed basalt(?) in center of pit; note hunting shack
spruce-snowtrail-east-pit3-2004.jpg = mound (of hornfelsed basalt?) in center of pit (looking N)
spruce-snowtrail-east-pit4-2004.jpg = mound in center of pit (looking E) - note shack
spruce-snowtrail-east-pit5-2004.jpg = mound in center of pit (looking E) to right of pit4 photo
spruce-snowtrail-east-pit6-2004.jpg = center of pit (looking SW)
spruce-snowtrail-east-pit7-2004.jpg = same as above
spruce-snowtrail-east-pit8-2004.jpg = SW corner of pit (looking SW)
spruce-snowtrail-east-pit9-2004.jpg = NW corner of pit (looking NW)
spruce-snowtrail-east-pit10-2004.jpg = NE corner of pit (looking NE) to left of pit4 photo - note hunting shack
spruce-snowtrail-east-pit-ground-2004.jpg = close-up of gossanous floor of pit

<u>"Snowtrail-west" Pit</u> (all photos taken in 2004)
spruce-snowtrail-west-pit1.jpg = northern edge of site (looking E)
spruce-snowtrail-west-pit2.jpg = general overview of pit along south edge (looking E)
spruce-snowtrail-west-pit3.jpg = general overview of most of pit (looking NE)
spruce-snowtrail-west-pit4.jpg = same as pit1 photo
spruce-snowtrail-west-pit5.jpg = north-central edge of pit (looking E); note gossanous boulders of mineralized material
spruce-snowtrail-west-pit6-boulders.jpg = close-up of pit5 photo (north-central edge of pit); gossanous mineralized boulders in foreground were drilled by MDNR for a field trip in 1996?

<u>Spruce 10,000 ton sample</u>
spruce-digging-1974-1.jpg = close-up of southern end(?) of pit in 1974 (before a blast?)
spruce-digging-1974-2.jpg = overview of pit with snow in 1974 (looking SE??)
spruce-digging-1974-3.jpg = end-loader in pit in 1974
spruce-digging-1974-4.jpg = close-up of "bucket" of end-loader in pit in 1974.

<u>All of next photos taken in 2004</u>
spruce-INCO-pit1-in-2004.jpg = break in slope in NW corner of reclaimed pit (looking SW)
spruce-INCO-pit2-in-2004.jpg = NW/top corner of reclaimed pit (looking SW)
spruce-INCO-pit3-in-2004.jpg = top plateaued portion of reclaimed pit (looking E)
spruce-INCO-pit4-in-2004.jpg = east corner of reclaimed pit (looking E)
spruce-INCO-pit5-in-2004.jpg = similar to pit1 photo (looking SW)

<u>Outcrops and gossan along Spruce Road in SW of NE Sec. 19, T.62N., R.10W.</u> (taken in 2004)
spruce-otc-east-end-road1-2004.jpg = weakly mineralized outcrop on south side of road (looking SE)
spruce-otc-east-end-road2-2004.jpg = as above but different view (looking W)
spruce-otc-east-end-road3-2004.jpg = close-up of road2 photo
spruce-rubble-sulfide-east-end-road1-2004.jpg = close-up of gossanous material and road aggregate on north side of road at major bend in road

spruce-rubble-sulfide-boulders-east-end-road-2004 = close-up of gossanous boulders (same location as above); cobbles of Biwabik Iron Formation also found at this site.

Maturi Deposit

Maturi - old air photos
maturi1-preconstruction-from-air-from-zanko-2004.tif = aerial view of Maturi shaft site with buildings in process of being built (photo given to Larry Zanko by INCO)
maturi2-during-construction-headframe-from-zanko-2004.tif = slightly different aerial view of Maturi shaft site during headframe construction.

Babbitt/Mesaba Bulk Samples

Arimetco Sample #1 (B1-374)
bab-374-pit-wide-1994.jpg = partially reclaimed pit in 1994 (looking S)
bab-374-pit-close-1994.jpg = close-up of large blocks of material in wall of partially reclaimed pit in 1994 (looking S)

Arimetco Sample #2 (B1-411)
bab-411pit-assaydrilling-1995.jpg = blast hole drilling and collecting Cu-Ni-S chip sample in 1995 (looking N?)
bab-411pit-irregular-surface-1995 = close-up of stripped oxidized bedrock ledge with undulating surface
bab-411pit-sample-blast-1995.jpg = just blasted upper bench (discarded) in 1995 (looking N)
bab-411pit-rotten-rock-seam-1995-or-1996.jpg = close-up of oxidized west-top of upper bench (discarded) in 1995 or 1996 (looking W)
bab-411pit-loading-the-ramp-shot-1995.jpg = preparing to remove the ramp to eventually get at, and sample, the lower bench (looking S)
bab-411pit-mucking-1995-1.jpg = shovel beginning to load and discard either the upper bench or ramp in 1995 (looking S)
bab-411pit-mucking-1995-2.jpg = same as above
bab-411pit-digging-1-1996.jpg = collecting the actual bulk sample from the lower bench
bab-411pit-mjs-pit-wall-1995.jpg = collecting character hand samples from the lower bench in 1995 (looking W)
bab-411pit-mjs-and-weathered-rock-1995-or-96.jpg = collecting character hand samples from the partially oxidized upper bench in 1995 (looking W)
bab-411pit-clean-up-1995.jpg = final phase of lower bench sampling in 1996 (looking N) reclaimed-bab-411pit-1-2004 = general view of partially reclaimed pit taken in 2004 (looking E)
bab-411pit-note-general-depression-of-ground-1-2004.jpg = general view of partially reclaimed pit taken in 2004
bab-411pit-2-2004-note-collapse-in-ground.jpg = general close-up of collapsed holes with gossanous material in partially reclaimed pit in 2004
bab-411pit-collapsed-ground-1-2004.jpg = as above (different locale)
bab-411pit-collapsed-ground-2-2004.jpg = close-up of collapsed hole in partially reclaimed pit in 2004
bab-411pit-collapsed-ground-4-2004.jpg = as above

Teck Cominco Bulk Sample #1 (B1-321)
bab-321pit-tc-2001-drilling-phot2.jpg = two rigs drilling blastholes in stripped pit in 2001 (looking E)
bab-321pit-tc-2001-pumps-phot1.jpg = water pumps in SW corner of pit (close proximity to B1-321). Note steeply dipping bedrock ledge and overlying unoxidized overburden overlain by oxidized overburden with large glacial boulders.
bab-321-tc-2001-mucking-phot3.jpg = shovel in pit and beginning loading of sample in 2001 (looking E)
bab-321-tc-2001-rock-phot4.jpg = close-up of water-filled hole in bottom of sampled pit (SW corner) during early stage of backfilling (looking N). Note large glacial boulder on left side of photo.

Reclaimed site photos taken in 2004
bab-321pit-from-2000-1-2004.jpg = reclaimed southern edge of site (looking S)
bab-321pit-from-2000-2-2004.jpg = counter-clockwise of above (photo1); reclaimed eastern edge of site (looking E)
bab-321pit-from-2000-3-2004.jpg = counter-clockwise of photo 2; reclaimed northeast edge of site (looking NE)
bab-321pit-from-2000-4-2004.jpg = counter-clockwise of photo 3; reclaimed northern edge of site (looking north). Actual pit was located at the base of the hill on the left side of the photo and extended to the right (east) to about where M. Severson is standing.
bab-321pit-from-2000-5-2004.jpg = counter-clockwise of photo 4; reclaimed northwest edge of site (looking NW). Actual pit was located at the base of the hill.
bab-321pit-from-2000-6-2004.jpg = counter-clockwise of photo 5; reclaimed western edge of site (looking W)
bab-321pit-from-2000-7-2004.jpg = close-up of northern edge of bulk sample site. Most of the area with little vegetation is actually local overburden that contains abundant erratics of the BDD PO Unit (unit within the Virginia Formation). The actual pit was probably located just south of (in foreground) of this area.
bab-321pit-from-2000-8-2004.jpg = close-up of gossanous glacial overburden that is shown in photo 7
bab-321pit-from-2000-9-2004.jpg = overview photo of entire reclaimed site in 2004 (looking N)

Peter Mitchell Muck Pile of mineralized gabbro and Virginia Formation

peter-mitch-sulfide-pile-east-end-1-2004.jpg = muck pile in 2004 (pretty dark photo)

Longnose Bulk Sample (1999)

longnose-pit-digging-1999-1.jpg = just blasted pit with Pete Niles in foreground in 1999 (looking NE)
longnose-pit-digging-1999-2.jpg = overburden removed and charges placed before blasting in 1999 (looking NE)

APPENDIX 5:

DUNKA PIT BULK SAMPLE (10 TONS) – JANUARY, 1967

On January 25th, 1967 a special 10 ton gabbro sample was collected by the Erie Mining Company and shipped to their Hibbing Laboratory via Seppi Brothers trucking. This sample was initially part of two 40 ton loads of gabbro that were blasted out of the following mine grid coordinates:

- Load #1 was located at 9260N, 2960E and contained slight to moderate amounts of sulfides (based on comparing the sulfides in this blast with previous blasts that were known to contain +0.30% Cu);
- Load #2 was located at 9068N, 2992E and contained moderate to abundant sulfides (same basis as above).

Both loads were hauled from their respective blast sites to a nearby area and both were spread out separately. Out of this spread-out material, individual rock chunks of gabbro that contained the greatest amounts of sulfides were then hand-picked from the two loads. All of Load #1 was looked at in order to hand-pick 5 tons worth of material; whereas; about half of Load #2 was looked at in order to hand-pick another 5 tons worth of material. Both 5 tons were then combined to form a 10 ton bulk sample that was later reported to assay at 0.30% Cu and 0.0.88% Ni.

Preliminary beneficiation tests were conducted by Erie Mining Company at Hibbing using three flowsheets, with results, as follows:

- Bulk Sulfide Flotation - yielded a concentrate assaying at 12.04% Cu and 2.32% Ni with 75.2% and 53.8% recoveries, respectively (Table 1). The screen analysis of the flotation feed is given in Table 5.
- Differential flotation - resulted in: 1. a copper concentrate assaying 13.72% Cu and 2.92% Ni with 71.3% and 54.7%, respectively; and 2. a pyrite concentrate assaying 2.78% Cu and 0.31% Ni with 10.2% Cu and 4.1% Ni distribution, respectively (Table 2).
- Gravity separation followed by flotation was found not to be suitable for this type of ore because the Cu-Ni values are finely disseminated in the crude ore (Table 3).

A grind of approximately 40% -325 mesh was required for optimum liberation of the sulfide minerals. About 75% of the Cu and 50% of the Ni were reported to be recovered at this size (Table 4).

Based on the price of copper and nickel in 1966, and using an estimated 80% copper recovery and 50% Ni recovery, Erie determined the value of one short ton of crude ore to be about $2.25. Overall, these results were considered negative by Erie and instead of trying to process this low-grade ore (estimated at 29 million tons assaying at 0.20-0.25% Cu in 1966) it was placed in stockpiles that have already been mentioned in this report.

TABLE 1

BULK SULFIDE FLOTATION

Flotation Feed -10 M Crude Ground to 40% -325 M Size

Product	% Wt	Assay %		Distribution %		Remarks
		Cu	Ni	Cu	Ni	
Bulk flot. cleaner conc	1.76	12.04	2.32	75.2	53.8	Rougher bulk sulfide
Middlings	1.76	0.519	0.29	3.3	6.7	Conc was reground in the
Flotation Tail	96.48	0.063	0.031	21.5	39.5	ball mill prior to
						cleaner flotation
						Reagents - 0.10 lb/St Z-4 and 0.20 lb/St MIBC
Feed (calc)	100.0	0.282	0.076	100.0	100.0	

TABLE 2

DIFFERENTIAL SULFIDE FLOTATION

Flotation Feed -10 M Crude Ground to 44.5% -325 M Size

Product	% Wt	Assay %		Distribution %		Remarks
		Cu	Ni	Cu	Ni	
Copper cleaner conc	1.51	13.72	2.92	71.3	54.7	Cu rgh circuit. pH = 10.5
Copper Middlings	2.16	0.54	0.39	4.0	10.4	Lime 2.0 lb/St flot. feed
Pyrite cleaner conc	1.06	2.78	0.31	10.2	4.1	Pyrite rgh circuit. pH = 6.0
Pyrite Middlings	1.56	0.30	0.096	1.6	1.8	H_2SO_4 2.0 lb/St flot. feed
Tails	93.71	0.04	0.025	12.9	29.0	
Feed (calc)	100.0	0.291	0.081	100.0	100.0	Z-4 as collector and MIBC as frother

TABLE 3

TABLING FOLLOWED BY FLOTATION

Table feed - minus 28 mesh crude
Flotation feed - ground table concentrates No. 1 & 2
Differential flotation to separate copper concentrate and pyrite concentrate

Product	% Wt	Assay % Cu	Recovery % Cu
Cu cleaner conc	0.23	17.72	14.2
Cu middlings	0.15	0.65	0.4
Pyrite cleaner conc	0.48	8.42	14.1
Pyrite middlings	0.12	0.53	0.2
Flotation tail	7.45	0.064	1.7
Table middlings	19.74	0.33	22.7
Table tails	49.18	0.13	22.2
Table slimes	22.65	0.31	24.5
Feed	100.0	0.287	100.0

These products represent combined table conc 1 & 2 (Cu cleaner conc through Flotation tail)

TABLE 4

GRIND SERIES

Test No.	Cleaner Conc		Middlings		Tails		% Cu Rec.	Grind % -325 M	Remarks
	% Wt	% Cu	% Wt	% Cu	% Wt	% Cu			
65	2.26	9.12	1.51	0.367	96.23	0.075	72.6	33.1	0.10 lb/St Z-4 & 0.20 lb/St MIBC
66	2.20	10.35	1.35	0.338	96.45	0.058	79.0	39.9	" " "
67	2.16	9.94	1.20	0.314	96.64	0.053	79.6	44.5	" " "

TABLE 5

SCREEN ANALYSIS OF GROUND FLOTATION FEED USED FOR BULK SULFIDE FLOTATION TEST

Size, M	% Wt	Cum % Wt
+35	0.1	0.1
+48	0.1	0.2
+65	1.5	1.7
+100	6.9	8.6
+150	14.4	23.0
+200	14.2	37.2
+325	22.9	60.1
-325	39.9	100.0

TABLE 6

SCREEN ANALYSIS OF TABLE FEED

Size, M	% Wt	Cum % Wt
+35	14.0	14.0
+48	15.2	29.2
+65	14.2	43.4
+100	10.8	54.2
+150	9.1	63.3
+200	6.6	69.9
+325	9.2	79.1
-325	20.9	100.0