GEOLOGY, STRATIGRAPHY, AND MINERALIZATION OF THE DUNKA ROAD Cu-Ni PROSPECT, NORTHEASTERN MINNESOTA

By

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ABSTRACT

The Dunka Road Cu-Ni prospect is located within what is informally known as the Partridge River Intrusion (T. 60 W., R. 13 W.), which is part of the 1.1 b.y. (Keweenawan) Duluth Complex. Seven major lithologic units, along with several internal ultramafic subunits, have been identified and are correlatable over the prospect. The ultramafic subunits (layers of picrite to dunite) exhibit relative uniform thicknesses and are present at the same relative stratigraphic position within the major lithologic units. The major lithologic units, delineated by Severson and Hauck (1990) and Geerts et al., 1990, are defined as upward from the basal contact as follows: Unit I, a fine- to coarse-grained sulfide-bearing anorthositic troctolite to pyroxene troctolite (450 ft. thick) with associated ultramafic subunits I(a) and I(b); Unit II, a medium- to coarse-grained troctolite to pyroxene troctolite (200 ft. thick) with a basal ultramafic subunit II(a); Unit III, a fine-grained, mottled textured troctolitic anorthosite to anorthositic troctolite (250 ft. thick); Unit IV, a coarse-grained pyroxene troctolite to anorthositic troctolite (300 ft. thick); Unit V, a coarse-grained anorthositic troctolite (300 ft. thick); Unit VI, a fine- to coarse-grained troctolitic anorthosite to troctolite (400 ft. thick) with basal ultramafic subunit VI(a); and Unit VII, a coarse-grained troctolitic anorthosite to anorthositic troctolite (400+ ft. thick) with basal ultramafic subunit VII(a).

Most sulfide mineralization occurs within Unit I. The sulfide mineralization is both interstitial and widespread, but variable in modal percentage (rare to 5%), continuity, and thickness (few inches to tens of feet). Sulfide mineralization is generally related with proximity to: hornfels inclusions; the basal contact with the footwall Virginia Formation; and some of the internal ultramafic subunits within Unit I. Primary sulfide mineralization includes chalcopyrite, pyrrhotite, cubanite, and pentlandite. Minor amounts of bornite, pyrite, sphalerite, galena, talnakhite, mackinawite, and/or valleriite along with both native copper and gold have also been identified.

Pt+Pd values range from 100 to >2400 ppb over 5 and 10 foot intervals, and occur as isolated values or within stratigraphic horizons within Unit I.

Several Cu/PGE-enriched horizons (using a 0.5% Cu and >800 Pt+Pd cut-off) have been identified and occur laterally throughout the prospect. Intersected by 76 drill holes, the most continuous horizon (RED Horizon) is found directly beneath ultramafic subunit II(a), within the uppermost portion of Unit I. This horizon ranges from 5 to 100 feet thick (average 33 ft.) and contains average values of 0.6% Cu and 1000 ppb Pt+Pd. Two other horizons (ORANGE Horizon and YELLOW Horizon) occur beneath the RED Horizon and are intersected by 67 and 48 drill holes, respectively. These are less continuous horizons that range from 5 to 140 feet thick (average 35 ft.) and contain average values of 0.6% Cu and 750 ppb Pt+Pd. Only one PGE-enriched horizon has been identified outside of Unit I. This horizon (MAGENTA Horizon) occurs in Unit VI, and is located approximately 150 feet beneath ultramafic subunit VII(a). Although it has been identified in only six drill holes to date, it ranges from 6 to 40 feet thick (average 25 ft.) and contains average values of 0.7% Cu and 1500 ppb Pt+Pd.

The predominant host rock for these Cu/PGE-enriched horizons is coarse-grained anorthositic troctolite, which may exhibit some subtle fracturing associated with minor alteration. The alteration assemblage within these mineralized zones is serpentine, uralite, and saussurite. This type of alteration assemblage has also been observed throughout the entire prospect, but is not always associated with mineralization. Although the majority of sulfide mineralization is believed to be primary, mineralized zones that are intersected by fractured/altered zones can contain secondary sulfides and textures, suggesting local enrichment. The majority of the sulfide is coarse-grained (5 mm) and commonly rimmed by secondary red-brown biotite. Ilmenite occurs in two habits within these zones, as euhedral to subhedral laths interstitial to silicate crystals, and as "bleb-like" shiny black droplets within the sulfides. This second ilmenite habit has only been identified in sulfide-bearing zones that are enriched in Pd and/or Pt.

A total of 16 samples (13 mineralized, 3 unmineralized) were analyzed for PGEs. Results of the PGE scans indicate that the original magma contained all of the dissolved sulfides and PGEs upon reaching the final site of the intrusion. Therefore, the mineralized horizons contain values of PGEs similar to that of the mantle. No PGE-enriched reefs are found at Dunka Road, most probably due to low concentrations of PGEs in the original mantle melt. The geochemistry of samples taken from the Dunka Road prospect support this theory.

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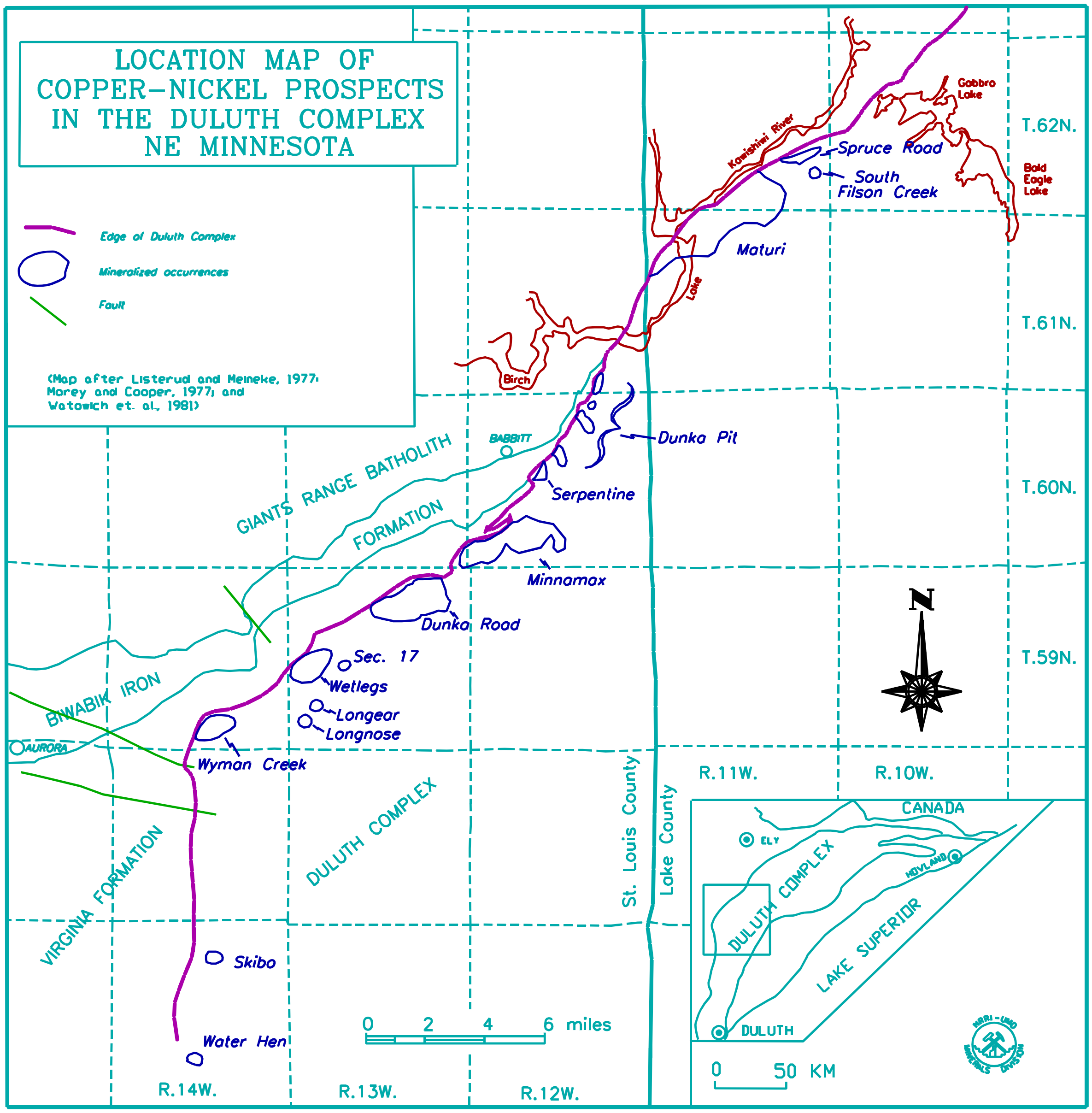
INTRODUCTION

The Duluth Complex is located in northeastern Minnesota (Fig. 1), and consists of 1.1 b.y. Late Precambrian (Keweenawan) mafic and ultramafic intrusions. The rocks of the Duluth Complex are generally divided into an older anorthositic series (Davidson, 1972) and a younger



(Map after Listerud and Meineke, 1977; Morey and Cooper, 1977; and Watowich et. al., 1981)

Figure 1. Location map of copper-nickel prospects in the Duluth Complex, northeastern Minnesota.

troctolitic series (Bonnichsen, 1972). Within the later troctolitic series, three large intrusive bodies have been described and have been informally designated as the: South Kawishiwi intrusion; Partridge River intrusion; and the Bald Eagle intrusion (Foose and Weiblen, 1986).

The Dunka Road copper-nickel prospect (T. 60 N., R. 13 W.), which occurs near the base of the Partridge River intrusion, was first discovered and drilled by U.S. Steel (U.S.S. -now USX) in the late 1960s. As part of a research grant to re-evaluate the economic potential of the Duluth Complex, a portion of the Partridge River intrusion was studied (Severson, 1988; Severson and Hauck, 1990), which included approximately 20 drill holes from the Dunka Road prospect. An additional 46 drill holes were relogged during the first phase of the Dunka Road project (Geerts et al., 1990), in an attempt to gain some understanding of Cu-Ni-Au-Ag and PGE mineralization. The second phase of this study (this report) continued the re-evaluation of the prospect in conjunction with Fleck Resources Ltd. (Vancouver, B.C.) and NERCO Exploration Company (Vancouver, WA).

The purpose of this study was to: 1) continue and complete relogging of the remaining drill holes at Dunka Road; 2) construct a detailed stratigraphic/lithologic model of the Dunka Road Cu-Ni prospect; 3) determine the extent, quantity, and distribution of platinum group elements (PGEs), gold, and silver content associated with the Cu-Ni mineralization; and 4) determine possible ore controls for the PGE-Au-Ag mineralization. Although some preliminary petrographic work has been completed, it is important to note that the findings in this report are based predominantly on the field logging of drill core and associated geochemistry.

ACKNOWLEDGEMENTS

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GEOLOGY

REGIONAL GEOLOGY

The geology of northeastern Minnesota is dominated by Precambrian age rocks; a large percentage of these rocks are Late Precambrian (1.1 b.y.-Keweenawan) and formed as a result of intracontinental rifting. Igneous rocks associated with this rifting event can be separated into the North Shore Volcanic Group (extrusive) and the intrusive counterpart, the Duluth Complex. The Duluth Complex (Complex) extends northward from Duluth, Minnesota, in an arcuate belt, to just south of Ely, and then eastward toward Hovland, Minnesota (Fig. 1). The Duluth Complex is divided into an early anorthositic series (Davidson, 1972) and a later troctolitic series (Bonnichsen, 1972). The rocks of the Duluth Complex are composed predominately of numerous mafic intrusions.

Along the western edge of the Duluth Complex, between Duluth and Ely, the troctolitic series is informally subdivided into three intrusions: the South Kawishiwi intrusion; Partridge River intrusion; and the Bald Eagle intrusion (Foose and Weiblen, 1986). The Dunka Road copper-nickel mineral prospect is located at the northwestern contact of the Partridge River intrusion and the footwall rocks. The footwall of the Partridge River intrusion consists of shallow dipping, Middle Precambrian (1.7 b.y.) metasediments of the Animikie Group. The Animikie Group is composed of the Virginia Formation, Biwabik Iron-Formation, and the Pokegama Quartzite.

The structure in the Duluth Complex is related to the Late Precambrian rifting event that formed the mid-continent rift system. Due to the structural complexity of the region, several theories have been proposed for the placement of the Complex. According to Weiblen and Morey (1980), the formation of the Duluth Complex is directly related to the formation of a half-graben type model due to extensional tectonism. This model is dominated by steep southeast-dipping, northeast-trending normal faults that produced fractures and voids into which individual pulses of magma were emplaced. Also, Weiblen and Morey (1980) state that northwest-trending strike-slip (transform) faults were also formed during rifting. Another theory has been proposed, involving little or no associated faulting. Green (1983) has pointed out "...a number of problems with the half-graben model, as applied to the Complex and the Keweenawan as a whole, and suggests an alternative model of subsiding sequences of plateau lavas..." (Holst et al., 1986).

DETAILED IGNEOUS GEOLOGY

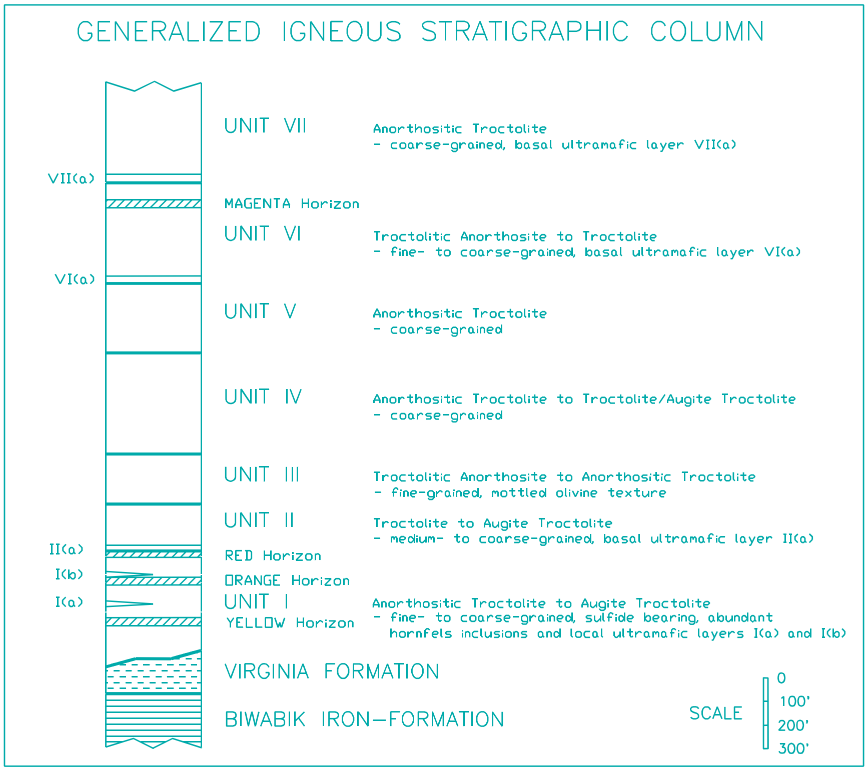

Figure 2. Generalized igneous stratigraphic column.

Within the Partridge River intrusion (renamed the Partridge River Troctolite Series by Severson and Hauck, 1990), rocks are divided into at least eight separate and distinct rock units (Units I-VIII; Severson and Hauck, 1990). Drill holes within the Dunka Road prospect contain seven of these rock units (Units I-VII; Fig. 2). These rock units are composed primarily of troctolitic anorthosite to pyroxene troctolite and in lesser amounts, gabbroic anorthosite to olivine gabbro. Rock types are classified by estimated varying modal percentages of plagioclase, olivine, and pyroxene, using a rock classification scheme (Fig. 3) by Phinney (1972).

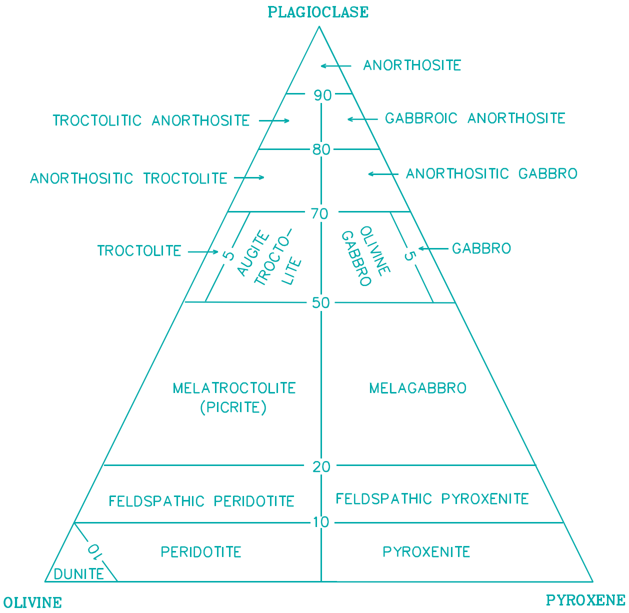

Figure 3. Rock classification scheme (after Phinney, 1972).

The surface area of the Dunka Road Cu-Ni prospect is approximately 4 square miles. A total of 114 holes have been drilled on the property (Plate 1; 112 diamond drill holes by U.S. Steel, late 1960s and 2 diamond drill holes by NERCO, 1991). U.S. Steel (U.S.S.) conducted diamond drilling along a geophysical grid on approximately 600 foot centers. The drill holes range in depth from 162 feet to 2,647 feet, and of these, 100 are vertical.

A down-hole orientation survey was conducted during the time of drilling, but due to unfortunate circumstances, the data were not relocated. It should be noted that the amount of drill hole drift is not presented on any of the cross sections (Plates 2-29). Because the average depth of drilling at Dunka Road is approximately 1,200 feet, a certain amount of drift can be expected. Any drift that occurred at depth most likely occurred to the same degree and relative direction for most drill holes. Therefore, only the relative positions of the units at depth will be affected. Information regarding the thickness and elevation of units has been tabulated in Appendix A.

Twenty seven NW-SE trending cross sections were constructed along the geophysical grid, incorporating all 112 U.S.S. drill holes (Plates 2-28). Also, a two mile longitudinal NE-SW trending cross section was constructed across the study area using correlations of the major lithologic units (Units I-IV) and internal ultramafic subunits (Geerts et al., 1990; Plate 29). This cross section was constructed using an assumed 20E dip for the footwall rocks (Severson, 1988), and the stratigraphic units were then projected onto the cross section line. Depending on which side of the cross section line the drill holes occurred (line A-A'; Plate 1), the stratigraphic contacts in the drill holes were adjusted in elevation using the 20E dip.

FOOTWALL - ANIMIKIE GROUP

The footwall rocks of the Dunka Road prospect consist of Middle Precambrian (Animikie Group) rocks, approximately 1.8 b.y. in age. These rocks are represented by three formations that are, from oldest to youngest: the Pokegama Quartzite; the Biwabik Iron-Formation; and the Virginia Formation, all of which are present at Dunka Road. The stratigraphy of the Animikie Group represents a single depositional event, characteristic of a transgressing sea, beginning with well-sorted clastic materials of a stable shelf and ending with fine silty/muddy materials of a deep basin (Morey and Ojakangas, 1970). These rocks were later tilted and metamorphosed during the "Penokean" orogeny, approximately 1.6 b.y. ago.

Pokegama Quartzite

The Pokegama Quartzite is the oldest formation within the Animikie Group. It is characterized by mostly coarse-grained, massive to thinly bedded quartzite and feldspathic quartzite. Due to local irregularities in the pre-Pokegama erosional surface, the Pokegama Quartzite varies greatly in thickness. Only two drill holes at Dunka Road were drilled deep enough to intersect and completely penetrate the Pokegama Quartzite. Seventeen feet of Pokegama quartzite were cored in drill hole 26076, while only four feet occurred in 26084. The upper contact with the Biwabik Iron-Formation is generally sharp.

Biwabik Iron-Formation

The Biwabik Iron-Formation is characterized by alternating thick sequences of ferruginous chert and slate. Wolff (1917) subdivided the Biwabik Iron-Formation into four major lithostratigraphic units, which from bottom to top are: 1) the lower cherty; 2) the lower slaty; 3) the upper cherty; and 4) the upper slaty. These four members can be traced over most of the Mesabi Range in northeastern Minnesota. A total of 55 drill holes intersect the Biwabik Iron-Formation on the Dunka Road property. Most of these holes only penetrate the upper slaty member, which averages 100 feet thick in the area. Three distinguishable submembers or horizons are present within the upper slaty member of the Biwabik Iron-Formation (Gundersen and Schwartz, 1959). The upper, A submember (1 to 3 feet thick) is composed of a light colored, coarse-grained, massive marble. The B submember (1 to 12 feet thick), below submember A, is composed of a fine- to medium-grained, green, irregular bedded diopside and chert. The majority of the Biwabik Iron-Formation in the study area is made up of a lower, C submember (approximately 100 feet thick), which is composed primarily of massive, banded magnetite and chert. Submembers A and B are not always present, thus indicating pinch-outs or facies change. Because of limited drilling completely through the formation, an average thickness for the Biwabik Iron-Formation at Dunka Road is estimated at 425 feet thick. Dips on undeformed bedding planes average 20E.

Virginia Formation

The Virginia Formation is the dominant footwall rock unit at the base of the Complex in the Dunka Road area. Overlying the Biwabik Iron-Formation, the Virginia Formation occurs as a downward-tapering wedge of metasediments that thins to the southeast (Andrews and Ripley, 1989). Due to differential scouring and/or assimilation by the intruding magma, the Virginia Formation varies greatly in thickness from hole to hole. However, there is a general consistency of thinning from the surface contact toward the interior of the Complex. It is likely that at some point beyond the deepest drill holes at Dunka Road, the Complex is in contact with the Biwabik Iron-Formation. A total of 106 drill holes intersect the Virginia Formation within the Dunka Road property. Thicknesses range from 2 to 464 feet drilled beneath the Complex, to greater than 1,087 feet thick in a drill hole northwest of the surface contact (Appendix B). The majority of rocks composing the Virginia Formation are fine- to medium-grained argillites and graphitic argillites. These argillites are commonly biotite-rich (5-10%). They also commonly exhibit deformation that is illustrated by weak to strongly contorted bedding planes. Dips on remnant, undeformed bedding planes range from 15E to 25E. The argillaceous units also contain interbeds of graywacke, siltstone, and minor calc-silicate layers. Some of the calc-silicate beds occur as pitted, saccharoidal layers, 6 to 24 inches thick, with cherty contacts. Their occurrence is limited to shallow holes, possibly due to scouring and/or assimilation by the intruding magmas down dip (Geerts et al., 1990). These saccharoidal layers may prove useful as 'marker beds' in a stratigraphic interpretation of the Virginia Formation. Minor mudstone and graywacke also have sharp contacts with the recrystallized argillite. Cordierite (usually found near the footwall contact) and pyrrhotite (increasing abundance toward the footwall contact) are present in many of the drill holes. The basal contact of the Virginia Formation with the Biwabik Iron-Formation is usually sharp.

PARTRIDGE RIVER TROCTOLITE SERIES (PRTS)

The igneous rock identification for this study is based on estimated modal percentages of plagioclase, olivine, and pyroxene (Fig. 3) for rocks in the Duluth Complex (after Phinney, 1972). Due to small lateral changes in the modal percentages of these minerals, a slight variation in the rock types within the rock units may be present from hole to hole. This is especially true for Unit I. Because of this mineral variation, it is important to note that the description of the igneous rock units in this report are generalized. Also, because of the slight differences in grain sizes and lithologies between rock units, the rock units directly above and below should be examined (to correctly identify the <u>overall</u> rock unit).

The igneous unit descriptions include detailed explanations of the individual ultramafic subunits or horizons. However, with the continuation of the Dunka Road project, there have been some minor changes to the total number of continuous ultramafic subunits delineated in Geerts et al., 1990 (Fig. 2). As a result, the ultramafic subunits I(a'), I(c), II(b), III(a), IV(a) and IV(b) are now believed to be only very localized (laterally discontinuous) and non-correlative ultramafic occurrences. A total of five ultramafic subunits have been identified within the Dunka Road prospect. The laterally continuous basal ultramafic subunits VI(a) and VII(a) were not observed in Geerts et al. (1990), but were recognized during the continuation of the Dunka Road project. VI(a) and VII(a) were originally delineated by Severson (1988) and Severson and Hauck (1990). Generally, all ultramafic subunits range in composition from picrite (melatroctolite) to peridotite. The subunits commonly exhibit modal grading with increasing olivine content toward the subunits' basal contact. The upper contacts are diffuse whereas the basal contacts are abrupt and sharp. The subunits are labeled numerically and alphabetically, corresponding to the major rock unit in which they occur (Fig. 2). They are labeled in ascending order within Unit I.

Unit I

Of the seven rock units represented within the study area, Unit I is the only unit that contains significant sulfide mineralization. However, Unit I is also the most complex unit, with internal ultramafic subunits, multiple PGE-bearing mineralized horizons (discussed later), and abundant hornfels inclusions. As evident by its complex internal framework, the placement of Unit I may be the result of multiple pulses of magma. Overall, Unit I averages 450 feet thick, ranging from 205 to 1,047 feet thick. Although difficult to characterize lithologically, the majority of Unit I is composed of two predominant rock types. Anorthositic troctolite is abundant in the upper more mineralized portions of Unit I, whereas pyroxene (augite) troctolite becomes increasingly more abundant toward the basal contact. Grain size fluctuates dramatically throughout most the unit, ranging from very fine-grained (<1 mm) to very coarse-grained (>5 mm). These grain size changes do not consistently correspond to any one rock type. However, overall grain size decreases toward and is consistently finer-grained near the basal contact. The lithology at the basal contact can vary from drill hole to drill hole, and can consist of pyroxene troctolite, norite, or occasionally gabbro. These basal igneous lithologies commonly show evidence of assimilation of the footwall Virginia Formation, i.e., the rounded and partially dissolved hornfels inclusions and a noticeable increase in fine-grained biotite content. Even though some degree of assimilation is usually visible, in addition to the abundant hornfels inclusions, the contact between the Duluth Complex and the Virginia Formation is almost always sharp. The most variable contacts within Unit I are the contacts between igneous rock lithologies. These internal contacts range from abrupt to gradational and take place over distances of 1 foot to tens of feet. The ultramafic layers can be correlated between drill holes with some degree of certainty, and thus some of the lithologies between the ultramafic layers can also be correlated. The lithologies for similar intervals can vary from hole to hole, due to a slight lateral variation in the modal percentage of olivine or pyroxene.

Ultramafic Subunits

Following the relogging of drill holes deeper into the Duluth Complex, i.e., southeast of the surficial expression of the basal contact, it was discovered that the internal ultramafic subunits of Unit I were not as continuous as was previously believed (Geerts et al., 1990). Therefore, due to the lack of continuity, subunits I(c) and I(a'), as delineated by Geerts et al. (1990), were only very local and non-correlative ultramafic occurrences. Two lateral, partially continuous ultramafic subunits or layers, I(a) and I(b), occurred predominantly in the southwestern half of the property. These subunits were composed primarily of varying modal percentages of plagioclase (10-50%), olivine (50-90%), and pyroxene (usually <5%), lesser amounts of oxides (magnetite/ilmenite <5%), and trace sulfides. The olivine content increased from top to bottom, e.g., picrite top to a peridotite base. Similarly, the contacts were almost always gradational at the top and sharp on the bottom.

Alteration of the ultramafic rocks is minimal. However, the ultramafic subunits have an internal foliation characterized by thin wisps of serpentinized olivine. As a result of serpentinization, the ultramafic subunits are commonly weak to strongly magnetic. Fracture cleavages, having average dips of 20E, occur along the serpentinized olivines.

Subunit I(a) - is the lowest ultramafic horizon and occurs beneath I(b), approximately 250 feet above the basal contact. The composition of subunit I(a) varies from picrite to peridotite. This subunit is discontinuous on a hole by hole basis. Thickness of subunit I(a) averages 10 feet and ranges from 1 to 20 feet thick.

Subunit I(b) - is the most continuous of the two internal subunits within Unit I. I(b) is composed of a medium- to fine-grained picrite to peridotite. This subunit is also limited to the southwest half of the Dunka Road property, but is more continuous on a hole by hole basis than subunit I(a). Subunit I(b) occurs above subunit I(a) and is approximately 350 feet from the footwall contact. It has an average thickness of 10 feet and ranges from 2 to 19 feet thick.

Hornfels Inclusions

Although inclusions of Virginia Formation can be found at any elevation and within any of the rock units, the majority of the inclusions appear to be contained within Unit I. Many of the inclusions occur near the basal contact with the Virginia Formation. Hornfels inclusions range from a few inches up to 36 feet in drill core. Many of the inclusions are fractured and contain vein-like intrusions of troctolite. In most cases, the dip of bedding planes within the inclusions are undisturbed, dipping 15E to 25E; thus inclusions near the basal contact are probably *in situ* or local in origin, with minimal transportation. The inclusions are the result of intrusion of troctolite into fractures along bedding planes of the Virginia Formation.

These hornfels inclusions have experienced partial assimilation as evidenced by gradational and often undefined contacts with the adjacent troctolitic rocks that contain an increased biotite content. These contacts exhibit varying degrees of chloritization and serpentinization within the contact zone. Due to partial assimilation and alteration of the inclusions, contacts are usually distorted or gradational. Mineralogically, the contact zone between Unit I and the Virginia Formation, as well as hornfels inclusions, is generally higher in biotite and has a higher orthopyroxene to clinopyroxene ratio (3:1 versus 1:5). Thus, it is not uncommon to find a norite at the basal contact or within the immediate vicinity of a hornfels inclusion. Some of the inclusions, as well as the basal contact, are also associated with an increase in sulfide mineralization, usually as pyrrhotite. However, there is no apparent vertical or lateral correlation of this related pyrrhotite mineralization from hole to hole.

Unit II

Unit II is characterized by even-grained, cumulate-textured (plagioclase/olivine cumulate), medium- to coarse-grained troctolite and pyroxene troctolite and a consistent basal ultramafic subunit, II(a). Although Unit II is composed primarily of plagioclase (50-70%), olivine (20-40%), and pyroxene (0-10%), it can also contain rare/trace oxides (mostly ilmenite) and sulfides. The continuity of this basal ultramafic subunit, in addition to the relatively uniform grain size and homogeneity of the troctolite, makes this unit easily distinguishable from Units I and III. Although the basal zone of Unit III is generally gradational (decreasing olivine content upward), the upper contact of Unit II with Unit III is generally abrupt. The basal contact of Unit II with Unit I is almost always sharp and recognized by: 1) the basal ultramafic subunit II(a); 2) lack of sulfides in Unit II; and 3) an even-grained cumulate texture in Unit II. The average thickness of Unit II is about 200 feet, ranging from 29 to 354 feet.

The presence of sulfide mineralization within Unit II is generally rare and occurs as disseminated chalcopyrite and pyrrhotite. The majority of oxides present within Unit II occur as trace amounts of ilmenite and magnetite that are most abundant within the ultramafic subunit II(a).

Subunit II(a)

Ultramafic subunit II(a) is the lowest and most continuous (occurring in 83% of the drill holes) basal ultramafic horizon at Dunka Road. It divides the unmineralized rocks of Unit II from the mineralized rocks of Unit I. Subunit II(a) consists of medium- to fine-grained picrite to peridotite and minor dunite. It is primarily composed of varying modal percentages of plagioclase (5-50%), olivine (50-95%), pyroxene (usually <5%), and minor ilmenite/magnetite (usually <5%). The thickness of II(a) is quite variable, ranging from 1 to 70 feet thick. The top of II(a) consists of interlayered troctolite and picrite that grades downward into peridotite. Whereas the upper contact is usually gradational, the lower contact is almost always sharp. Alteration is characterized by thin wisps/layers of serpentinized olivine with associated magnetite, interbedded with layers of unaltered olivine. The layers of altered olivine generally increase in size and intensity toward the base of the subunit. This alternating sequence of altered and unaltered olivine gives the rock a layered or foliated (15-25E dips) appearance. Fractures are often developed along this same foliation.

Unit III

According to Severson (1988), Unit III is an excellent 'marker bed' in drill core. This unit is characterized by cumulate textured, fine-grained troctolitic anorthosite to anorthositic troctolite. Mineralogically, the unit is defined by plagioclase (70-90%) and poikilitic olivine (10-30%) that gives the rock an overall mottled appearance. Olivine occurs as random, 3 to 5 cm oikocrysts in a predominately plagioclase-rich groundmass. The plagioclase occurs as 3 to 5 mm, lath-shaped crystals. Clinopyroxene (0-5%) also often occurs as oikocrysts (3 to 4 cm in diameter) that are randomly distributed. Unit III has an average thickness of 250 feet and ranges from 76 to 623 feet thick.

The presence of sulfide mineralization is generally rare in Unit III, occurring as widely scattered and finely disseminated chalcopyrite and pyrrhotite. Also, rare oxides are present and are usually associated with ultramafic rocks as minor amounts of magnetite.

Unit IV

Unit IV is characterized by homogeneous, cumulate textured, coarse-grained augite troctolite with some anorthositic troctolite. These rocks are made up of modal percentages of plagioclase (55-75%), olivine (15-35%), augite (5-10%), and minor biotite and ilmenite. The rock is relatively uniform in texture and modal proportions, although a gradational increase in olivine and pyroxene toward the base is not uncommon. The thickness of Unit IV averages about 300 feet and ranges from 62 to 578 feet thick. Variation in thickness of Unit IV may be due in part to the highly gradational upper contact with Unit V. It is often difficult to identify the contact between Units IV and V. Furthermore, Unit IV may actually be the lower, more mafic half of Unit V. The idea that the two units may actually be one unit was first proposed by Severson and Hauck (1990). The lower contact of Unit IV with Unit III is generally sharp. Sulfides in Unit IV are generally rare and occur as finely disseminated grains of chalcopyrite and pyrrhotite.

The most prominent differences between Units II and IV, other than being separated by Unit III, are Unit IV containing significant amounts of anorthositic troctolite and being generally coarser grained than Unit II. Upon relogging the remaining drill holes at Dunka Road, ultramafic subunits IV(a) and IV(b), previously described by Geerts et al. (1990), are only local ultramafic occurrences and not correlative horizons.

Unit V

Unit V is characterized by homogeneous, cumulate textured, coarse-grained anorthositic troctolite. Anorthositic troctolite is the predominant rock type of Unit V, but can locally grade into troctolite and augite troctolite toward the base of the unit. As mentioned previously, the lower contact of Unit V can be gradational, making it difficult to distinguish from Unit IV. Thicknesses also vary dramatically because of this unclear gradational contact. The thickness of this unit averages about 300 feet and ranges from 80 feet to 508 feet thick. Sulfides are generally rare and occur as fine-grained disseminated grains of chalcopyrite and pyrrhotite.

Unit VI

Unit VI is generally characterized by homogeneous, cumulate textured troctolitic anorthosite to augite troctolite. It can, however, vary locally in composition and grain size. These variations may range from anorthosite to gabbro and from fine-grained (1-2 mm) to coarse-grained (5-10 mm) to pegmatitic (>15 mm). Unit VI is also characterized by a basal ultramafic subunit VI(a) that occurs consistently at its lower contact with Unit V. Both upper and lower contacts of Unit VI are sharp. The average thickness of this unit is approximately 400 feet, ranging from 222 to 591 feet in thickness. Alteration includes some widespread uralitization (tens of feet), along with some patchy saussuritization (4-12 inch intervals). Although alteration occurs only locally within Unit VI, the zones that have been altered can be extensive, affecting intervals tens of feet thick. Sulfide mineralization is generally rare, although a mineralized horizon was intersected by 6 drill holes in the southwestern half of the Dunka Road property. Sulfides within this horizon occur as disseminated blebs (1-5 mm) of predominantly chalcopyrite. This mineralized occurrence is discussed in detail later in this report (chapter on mineralization).

Subunit VI(a)

The basal ultramafic subunit VI(a) consists of fine- to medium-grained picrite to peridotite. It is primarily composed of varying model percentages of plagioclase (15-50%), olivine (50-85%), pyroxene (usually <5%), and minor ilmenite/magnetite (usually <5%). Although it is generally thinner than any of the other basal subunits (ranging 4 to 26 feet thick), VI(a) is consistently found at the base of Unit VI. It usually has a gradational top (mixed bands of troctolite and picrite) that grades to a sharp peridotite base. Alteration occurs as alternating bands (15-25E dips) of serpentinized olivine and unaltered olivine, with the amount of alteration increasing downward.

Unit VII

Unit VII is the uppermost unit intersected by drill core and occurs directly above Unit VI. It consists predominantly of anorthositic troctolite, although the presence of troctolitic anorthosite and augite troctolite is not uncommon. Rocks of Unit VII are generally homogeneous, coarse-grained, and plagioclase-rich. Unit VII can also be characterized by its continuous basal ultramafic subunit VII(a). Therefore, the lower contact with Unit VI is almost always sharp. Because drill holes containing Unit VII are all collared within Unit VII, the total thickness could not be determined. However, a minimum of >500 feet is present in drill hole 26117. The occurrence of sulfide mineralization within Unit VII is rare.

Subunit VII(a)

The basal ultramafic subunit VII(a) consists of fine- to medium-grained picrite to peridotite and dunite. The top of subunit VII(a) is usually an interlayering of troctolite and picrite, grading downward into feldspathic peridotite, peridotite, and finally dunite at the base. It is primarily composed of varying modal percentages of plagioclase (5-50%), olivine (50-95%), pyroxene (usually <5%), and minor ilmenite/magnetite (usually <5%). Thickness of VII(a) ranges from 5 to 44 feet thick. Alteration is similar to that of the other ultramafic subunits throughout the prospect. Generally, alteration is in the form of thin wisps of serpentinized olivine surrounded by unaltered olivine. The amount of alteration does, however, increase downward toward the base as the content of olivine increases. Tiny red-orange droplets form on the core surface of some serpentinized, olivine-rich zones within VII(a). These droplets might represent the remnants of a late-stage chlorine-rich fluid phase responsible for the transport of PGEs (Dahlberg and Saini-Eidukat, 1991).

ACCESSORY MINERALS

Although comprising one or two percent of the total composition of a particular rock, accessory minerals are commonly found in all rock types and within all seven major rock units at Dunka Road.

Biotite

Two types of biotite have been recognized in drill core. The majority of biotite occurs as small (1-3 mm), black interstitial plates and is a common constituent (averaging 1%) of most rock types within Dunka Road. Biotite associated with sulfide mineralization (generally averaging 1-2%) occurs as large (3-5 mm), reddish-brown rims around chalcopyrite. These biotites obtain their red-brown color due to high titanium contents (Rao, 1981). An estimated 50-60% of the sulfide accumulation at Dunka Road is represented by irregular sulfides associated with biotite (Ripley, 1981).

Ilmenite

Ilmenite is the most common oxide mineral (averaging 1%) within the Dunka Road prospect. It occurs as subhedral prismatic grains (1-5 mm), interstitially between cumulus silicate minerals. However, when associated with coarse-grained sulfide mineralization, it can occur as 'bleb-like' shiny black droplets (2-3 mm) within chalcopyrite. This second ilmenite habit has only been observed in sulfide-bearing zones that are "enriched" in Cu and/or Pt+Pd. More work is needed to determine whether or not these different habits represent two different generations of ilmenite or just two different environments of crystallization.

Apatite

Rare to trace apatite is found as a minor constituent throughout Dunka Road. The majority of apatite (average 0.5%) is associated with sulfide-bearing zones within Unit I. Apatite occurs as euhedral prismatic crystals (5-15 mm), interstitially between cumulus silicate minerals.

<u>MISCELLANEOUS/SPORADICALLY OCCURRING ROCK TYPES</u>

Pegmatitic Zones

Numerous pegmatitic zones occur sporadically (overall, <1% of the total drill core) throughout Dunka Road. These zones are characterized by large grain size (1-5 cm) and sharp contacts with the troctolitic rocks. They are present in all seven rock units and vary in composition from anorthosite to augite troctolite and olivine gabbro. Their size is also variable, ranging from 10 cm to several meters in thickness. Because of their erratic occurrence, composition, and size, no attempt has been made to correlate these zones between drill holes. Some zones contain abundant sulfide mineralization, whereas others are barren. There is no relationship, however, between the mineralogy and the presence or absence of sulfides.

OXIDE-BEARING ULTRAMAFIC INTRUSIONS (OUIs)

Numerous small intervals of clinopyroxene-rich rock occur within all seven rock units at Dunka Road. These rocks have been described and delineated as Oxide-bearing Ultramafic Intrusions (OUIs) by Severson and Hauck (1990). Unlike some of larger OUI bodies in other parts of the Partridge River Troctolite Series (correlatable along particular stratigraphic horizons), the occurrences of OUIs at Dunka Road are smaller and more difficult to trace laterally. The majority of OUIs at Dunka Road occur as small lenses averaging 2 to 5 feet thick, but range from 1 to 56 feet thick. They are predominantly coarse-grained, and range from melagabbro to pyroxenite, containing varying modal percentages of plagioclase (5-45%), augite (35-85%), olivine (0-5%), and ilmenite/magnetite (10-15%). Sulfide mineralization varies greatly within OUIs (absent to 5%) and can be characterized mostly by disseminated chalcopyrite. In general, the contact relationship with the troctolitic rock is sharp. This may be due to the formation of OUIs from late stage fluids. Distribution of OUIs among the different rock units is extremely variable. Although OUIs are found within all seven rock units, their presence has only been observed in the deeper drill holes (holes greater than 2,000 feet deep) positioned at the southern margin of the Dunka Road prospect. If OUIs are related to the assimilation of iron-formation (as proposed by Severson and Hauck, 1990), this might explain why OUIs are confined to only the deeper holes at Dunka Road toward the interior of the Complex where the Biwabik Iron-Formation may be the footwall contact.

STRUCTURE

The structural interpretation of Dunka Road is complicated by the combination of gently dipping and variably assimilated basement rocks. However, dramatic offsets are present within the basement rocks, taking into account an assumed constant bedding dip of approximately 20E southeast. The offset of troctolitic rock units and ultramafic subunits between drill holes further supports the presence of faulting. Although little or no hard evidence, i.e., slickensides, breccia, has been detected on the surface or in drill core, records of faulting could have been obscured if continued movement occurred along pre-existing faults when the troctolitic rocks were a crystal mush.

Two northeast-trending, steeply dipping (southeast) normal faults (Plates 1-28) were identified during the construction of the 27 northwest-trending cross sections. Similar offsets in the basement rocks, as well as the individual rock units, occur in the same relative position from section to section. The most dominant of these proposed faults is represented by a major northeast-trending monoclinal and/or fault-like structure (Severson, 1988). This particular feature can be traced throughout the entire Dunka Road property. The second postulated northeast-trending fault occurs approximately 600 feet to the southeast and parallels the shallower monoclinal fault-like structure. This offset can also be traced across the entire property. Both of these faults conform to Weiblen and Morey's (1980) half-graben type model.

It was suggested by Weiblen and Morey (1980) that northwest-trending strike-slip (transform) faults are also associated with the half-graben model. The northeast-trending faults are crosscut by and sometimes offset by the transform faults. Five northwest-trending strike-slip faults (Plate 1) can be explained by several unrelated offsets and Severson's (1988) basement contour maps of the area. The location of these faults has been approximated, due to sparse information provided by drilling. Also, because these faults appear to be predominantly pre-Duluth Complex, they are not depicted on any of the cross sections (Plates 2-29). In the southwest half of the property, two convergent strike-slip faults have been delineated between grid lines 5279 SW and 2568 SW (Plate 1). Additional offset involving only Unit I and the basement is notable between drill holes 26062 and 26124. This may be evidence that Unit I was the earliest intruded magma in the Dunka Road area. Within the northeast half of the property, three roughly parallel strike-slip faults have been delineated (Plate 1). A horst-like feature is located between two of these faults, in proximity of drill hole 26120, and is represented by an uplifted block of Virginia Formation. Severson's (1988) contour map on the top of the Biwabik Iron-Formation also supports these northwest-trending faults.

MINERALIZATION

SULFIDE MINERALIZATION

Sulfide mineralization is both complex and widespread within the Duluth Complex. Approximately 90% of the total sulfide mineralization within the Dunka Road prospect occurs within Unit I. The remaining sulfide mineralization (excluding a mineralized horizon in Unit VI, to be discussed later) occurs sporadically throughout the other rock units as isolated rare/trace amounts. Most sulfide mineralization occurs within rocks ranging in composition from anorthositic troctolite to pyroxene troctolite.

In a study by Weiblen and Morey (1976) done on basal sulfide mineralization in the Complex, sulfide occurrences were classified into one of four textural types: 1) interstitial sulfides in a plagioclase dominated framework; 2) fine sulfide veinlets cross-cutting silicates; 3) included sulfides enclosed in plagioclase and clinopyroxene; and 4) sulfide-silicate intergrowths. Textures observed in core at Dunka Road are included in the first three textural types. Approximately three-quarters of the sulfide mineralization observed in core is texturally interstitial to a dominating plagioclase framework. These sulfides occur as anhedral bleb-like grains, interstitial between subhedral plagioclase, clinopyroxene (augite), and olivine. Primary sulfide minerals most often found interstitially include chalcopyrite, pyrrhotite, cubanite, and pentlandite. They occur predominantly as disseminated grains ranging from <1 mm to 15 mm in size. The second most common sulfide texture observed involves sulfide veinlets cross-cutting silicates. This texture is generally observed in the upper half of Unit I, most often associated with laterally continuous mineralized horizons (discussed in more detail later). These veinlets are usually <1 mm wide, and are predominantly composed of chalcopyrite with or without trace bornite. Included sulfides are the least abundant textural type observed in core. This may be due to the fact that most sulfide inclusions are tiny isolated droplets (usually <1 mm) that can be easily overlooked. Sulfide inclusions have been observed in plagioclase and augite grains, and are predominantly chalcopyrite and less commonly pyrrhotite.

Varying relationships between the size and composition of sulfide mineralization have been observed throughout Unit I. Just as there is a general decrease in the grain size of the rock toward the basal contact, so there is in the grain size of sulfide mineralization. In general, the grain size of the host rock reflects the grain size of the sulfides. There is also a change in the ratio of chalcopyrite and pyrrhotite in relationship to hornfels inclusions and/or the basal contact. The pyrrhotite to chalcopyrite ratio increases noticeably toward the contact of hornfels inclusions and the basal contact with the Virginia Formation. Therefore, an anorthositic troctolite near the top of Unit I is more likely to be coarse-grained and dominated by chalcopyrite. The abundance of cubanite and pentlandite also seem to be controlled by the grain size of the host rock. The majority of cubanite has been observed in coarse-grained mineralized zones, occurring as blade-like lamellae within chalcopyrite. Pentlandite is also more abundant in coarse-grained mineralized zones; however, petrographic observations show that most of the pentlandite has undergone replacement by chalcopyrite. Pentlandite is often represented by skeletal remnants within chalcopyrite and/or flame-like exsolutions within pyrrhotite.

Minor amounts of bornite, pyrite, sphalerite, galena, talnakhite, mackinawite, and/or valleriite along with native copper and gold have been identified during petrographic observations. Secondary sulfide minerals are usually limited to coarse-grained, copper-rich mineralized zones. In these zones, veinlets of chalcopyrite ± bornite are often observed connecting larger grains of sulfides. This is evidence for the mobilization of copper sulfides, and may explain the presence of secondary enriched copper sulfides in these zones.

The origin of sulfide mineralization within the Dunka Road prospect is an interesting and complex problem. Sulfur isotope data indicate that the majority of sulfur found in the deposit is of sedimentary derivation (Ripley and Al-Jassar, 1987). These data also indicated that *in situ* derivation is unlikely and that the sulfur was incorporated into the magma elsewhere, possibly an auxiliary magma chamber.

There is a positive relationship of platinum group elements (PGEs) to that of sulfide mineralization. Generally, mineralized zones containing higher values of copper (>0.5%), also contain higher values of palladium (>800 ppb). On average, a ratio of 3:1 palladium (Pd) to platinum (Pt) is found at Dunka Road. Mass balance calculations indicate that all of the bulk-rock Pd can be accounted for by that held in chalcopyrite and cubanite (at Babbitt deposit; Ripley, 1990). The ratio of cubanite to chalcopyrite tends to be greater within plagioclase-rich zones of coarse-grained sulfide mineralization. Ripley's (1990) analysis also showed that, on average, cubanite contains more Pd than chalcopyrite. Thus, coarse-grained mineralized zones containing abundant cubanite would most likely favor higher values of Pd. Cubanite increases toward the top of Unit I, along with the general increase of coarse-grained, copper-rich mineralized zones. This is also supported by an increase in the average value of Pd in several individual mineralized horizons (to be discussed later) toward the top of Unit I. Average values for Pd range from 737 ppb in the lowest horizon of Unit I, to 986 ppb in the uppermost mineralized horizon at the top of Unit I.

Geerts et al. (1990) studied 46 relatively shallow drill holes at Dunka Road. That study concluded that there was insufficient evidence for the correlation of specific PGE-bearing/sulfide mineralized horizons throughout the prospect. However, after additional relogging, several correlatable mineralized horizons have been delineated (Fig. 2). Mineralized horizons are herein defined by the presence of one or more sampled intervals (5-10 feet) with >0.5% Cu and/or >800 ppb Pt+Pd. However, this does not mean that if a drill hole interval did not meet this cut-off that there was not any mineralization. Thus, this arbitrary cut-off was used only to illustrate the higher grade stratabound nature of these horizons. These mineralized horizons are defined as "enriched" with respect to the rest of the prospect. Because assay results represent samples of 5 and 10 foot intervals of core, it is important to note that the true grade of these horizons is not portrayed, rather the average grade of each interval that makes up the horizon.

In general, the mineralized horizons can be consistently traced laterally throughout most of the prospect, but can vary greatly in thickness (ranging from 5 to 140 feet thick). Because it is difficult to trace local or specific individual rock types from hole to hole, it is uncertain whether or not mineralized horizons cross-cut stratigraphy. A difference in the host rock type of a particular horizon, from one drill hole to an adjacent hole, may only be the result of a few varying modal percents of olivine or pyroxene. For this reason, it is difficult to predict whether the host rock (and the assigned rock type name) has changed laterally, or the mineralized horizon has cross-cut stratigraphy.

Mineralized horizons may be internally controlled by and related to specific lithologies. In the southwest half of the prospect, these horizons occur at the same relative position with respect to internal ultramafic subunits. The ultramafic subunits may have acted as redox barriers to locally migrating Cu PGE-enriched fluids. The presence of individual mineralized horizons within Unit I may be evidence that the placement of Unit I as a whole was, in fact, the result of multiple pulses of magma. Fracturing of the troctolites and ultramafic subunits prior to the secondary mineralization provided the pathways for the migrating fluids. The alteration assemblage, secondary sulfide mineralization, and fracturing are similar to the paragenetic sequence at the South Filson Creek Cu-Ni deposit (Kuhns et al., 1990). Kuhns et al. (1990) described redox boundaries as being important to precipitating secondary mineralization.

The absence of a particular mineralized horizon in a drill hole may represent a "pinch-out" of the host rock. Host rock types range from anorthositic troctolite to augite troctolite. Although cross-cutting veinlets and included sulfides are common, the most predominant texture is interstitial sulfides to a dominant plagioclase framework. Sulfide mineralization occurring with the horizons is thought to be primary, with the exception of minor secondary enriched copper sulfides as cross-cutting veinlets. The sulfide mineralization (averaging 5%) can be characterized by medium- to coarse-grained (3-10 mm) chalcopyrite, cubanite, pyrrhotite, and pentlandite, with minor bornite. Three distinct mineralized horizons have been identified within Unit I (Table 1). They are described in detail in descending order through the unit.

Table 1. Mineralized horizons

Mineralized Horizon	Percentage of Holes	Number of Assays	Average Thickness	Average Cu %	Average Pt+Pd ppb
RED Horizon	87%	241	32.5'	0.57	986
ORANGE Horizon	63%	227	35.7'	0.61	768
YELLOW Horizon	45%	140	34.2'	0.62	737
MAGENTA Horizon	27%	15	25.8'	0.72	1488
Background values				0.26	256

Note: Background values represent an average value of assayed mineralized samples that are not a part of the mineralized horizons.

RED Horizon

The RED Horizon is the most continuous mineralized horizon within Unit I and is present in 87% of the drill holes. This horizon is located approximately 450 feet above the basal contact, directly beneath the basal ultramafic subunit II(a). It can, however, be present at the top of Unit I even when subunit II(a) is absent. Therefore, it is not quite understood whether or not the RED

Horizon is stratigraphically controlled by ultramafic subunit II(a) or some other mechanism. The horizon has an average thickness of 32.5 feet and can range from 5 feet to 100 feet thick. Anorthositic troctolite is the predominant host rock type. Overall, average values for the RED Horizon are 0.57% Cu and 986 ppb Pt+Pd (Table 1).

ORANGE Horizon

The second most continuous mineralized horizon is the ORANGE Horizon. The ORANGE Horizon is present in 63% of the drill holes and is located approximately 300 to 350 feet above the basal contact. It is located beneath internal ultramafic subunit I(b) (when present) in the southwest half of the property. This horizon varies greatly in thickness and can range from as thin as 5 feet to as thick as 140 feet. It has an average thickness of 36 feet. The most predominant host rock type is anorthositic troctolite, although the presence of augite troctolite is not uncommon. Overall, the average grade for the ORANGE Horizon is 0.61% Cu and 768 ppb Pt+Pd (Table 1).

YELLOW Horizon

The lowermost mineralized horizon delineated within Unit I is the YELLOW Horizon. Yellow Horizon is the least continuous horizon, occurring in only 45% of the drill holes. The location of this horizon is the most variable within Unit I. In the southwestern third of the prospect, the horizon is located approximately 200 to 250 feet above the basal contact, directly beneath the ultramafic subunit I(a), when present. In the remaining two thirds of the prospect, the YELLOW Horizon is located just above the basal contact. This horizon has an average thickness of 34 feet and can range from 5 to 140 feet thick. In contrast with the other mineralized horizons, augite troctolite is the most prominent host rock type for the YELLOW Horizon. Overall, the average grade for the YELLOW Horizon is 0.62% Cu and 737 ppb Pt+Pd (Table 1).

MAGENTA Horizon

Only one mineralized horizon has been delineated outside of Unit I and occurs in Unit VI. Although it has only been detected in six drill holes, the MAGENTA Horizon contains some of the highest values of Cu and PGE mineralization. The average grade for the MAGENTA Horizon is 0.72% Cu and 1488 ppb Pt+Pd (Table 1). The MAGENTA Horizon is located in drill holes 26080, 26090, 26121, 26122, 26142, and 26143. These holes form a linear trend in the southwest half of the prospect. The horizon is located roughly in the middle of Unit VI, approximately 1,800 feet above the basal contact of the Complex. It has an average thickness of 26 feet and ranges from 6 to 40 feet thick.

ALTERATION/FRACTURING

Although the majority of rock within the Dunka Road prospect is unaltered, it has been estimated that approximately 20% of the rock is affected by alteration. The majority of alteration generally occurs as deuterically altered zones (few inches to tens of feet) that can be present within all rock lithologies and major rock units of the prospect. The alteration occurs as weak to moderate serpentinization/chloritization, saussuritization, and uralitization. In many of these zones, pyroxene has been uralitized. However, it is not uncommon to have adjoining altered and unaltered pyroxenes. Varying degrees of uralitization are characterized by an amorphous, light green, relatively soft replacement or as radiating prismatic clusters. The saussuritization of plagioclase also varies greatly within these zones, occurring as slight to highly bleached laths. Serpentinization can also be associated with these altered zones, but is not limited to them. Varying amounts of serpentine ± chlorite occur along fractures. These fractures can vary greatly in number and in orientation within the core. Serpentine ± magnetite is also associated with ultramafic occurrences/subunits, forming thin foliations of altered and unaltered olivine. A notably higher degree of serpentinization/chloritization is present around the perimeter of hornfels inclusions.

A few local occurrences of intensely altered core have been observed (few feet to tens of feet of core), consisting of highly bleached/pitted rock. Some of the cavities within these zones contain calcite, quartz, and minor unidentified zeolite minerals. Overall, these zones are uncommon and cannot be traced to surrounding drill holes. These highly altered zones may represent the near vertical movement of late-stage fluids along fractures/faults.

The alteration zones have also been observed to overprint mineralized horizons in some locations, but it has not yet been determined whether or not these zones have any relationship with higher grades of sulfides or PGEs. They do, however, suggest local movement and, in some cases, local enrichment of copper sulfides. This is most commonly observed as veinlets of chalcopyrite ± bornite. These zones may also represent a later-stage fluid movement along fractures. The measured dip of fractures within the altered mineralized zones is extremely complex and variable (core angles of 5E to 85E). Alteration is concentrated along the fractures. Although difficult to observe in core, minor amounts of microfracturing are also present. It is along these microfractures that the majority of chalcopyrite veinlets and bornite are found. The microfracturing appears to be most abundant in zones that contain uralite and bleached plagioclase. It is important to note, however, that not all uralitized zones contain sulfide mineralization. This alteration assemblage and fracture arrangement has also been observed at the South Filson Creek Cu-Ni prospect in Lake County (Kuhns et al., 1990).

GEOCHEMISTRY

A total of 1,773 U.S. Steel pulps were re-assayed by Fleck Resources Ltd. during the first phase of the Dunka Road project (Geerts et al., 1990). These pulps represented previously split and assayed core (10-ft. intervals). During this same time, 118 samples (Appendix B) from previously unsplit sulfide-bearing zones were also assayed. These core intervals ranged in thickness from 1 to 5 feet.

An additional 298 samples (both unsplit and previously split) were assayed during this study by Fleck Resources Ltd., Nerco Exploration Company, and the NRRI. These samples represent both split and unsplit sulfide-bearing zones that were suspected of being correlative with the recently delineated mineralized horizons, e.g., RED Horizon, etc. Sample sizes included pulps representing 10-foot core intervals for previously split core, and core intervals from 1 to 5 feet for unsplit core. Both sample sets were assayed at Acme Labs in Vancouver, B.C., for 28 elements as well as Cu-Ni-Au-Ag-Pt-Pd-Rh (Appendix B). Cu-Ni-Fe-S data from the U.S. Steel drilling program is also provided in Appendix B. All past and present geochemical data on the Dunka Road prospect is provided in Appendix B, and duplicate assays have been composited.

A number of interesting correlations were made between Au-Ag-Cu-Ni-S and associated PGEs (Pt-Pd-Rh) in Geerts et al. (1990). Table 2 contains the correlation coefficients for several elements from Geerts et al. (1990).

As seen by these coefficients, some generalizations can be made about the relationship of PGEs and the other elements. The relationship between Pd and Pt is fairly consistent throughout the study area, with a ratio of 3:1, respectively, and a correlation coefficient of 0.5805. There is also a strong correlation between Pd, Au, and Ag with that of Cu. Because

Table 2. Correlation coefficients

	Pt	Pd	Pt+Pd	Au	Ag
Pt		0.5805		0.4572	
Rh	0.4946	0.6840	0.6974	0.5951	
Au	0.4572	0.8073			
Cu		0.7803		0.6690	0.7990
S			0.1825	0.2280	

n = number of paired values in calculating correlation coefficient.
n = 1643 in correlation coefficient involving Rh.
n = 1890 in all other correlation coefficients.

the correlation of sulfur with that of Pd, Au, and Ag is relatively poor, this would indicate that the majority of these elements occur with copper-rich mineralization, rather than copper-poor mineralization. Thus, high copper values as associated with the mineralized horizons, e.g., RED Horizon, etc., are also associated with higher PGE values. The occurrence of Rh can also be related to that of Pt and Pd, with a correlation coefficient of 0.6974 to Pt+Pd. However, when correlated separately, there is a closer relationship of Rh with Pd (0.6840) than with Pt (0.4946).

Because the Dunka Road geochemical data file contains both USX values (total Ni) and Fleck values (soluble Ni), it is possible to compare the Ni occurring in sulfides with that of the entire Ni content. There is a strong correlation coefficient of 0.7802 calculated with 1,512 pairs of values. The calculated slope of total Ni and soluble Ni is 0.7657, with a ratio of total Ni to soluble Ni of 3:2, respectively.

SPIDER DIAGRAMS

Eight of the 298 geochemistry samples were assayed separately at X-Ray Assay Laboratories in Don Mills, Ontario, for 14 whole rock analyses and 56 elemental analyses (Appendix C). This sample set includes: 3 mineralized samples from the RED Horizon; 1 unmineralized sample unrelated to the mineralized horizons; 3 basal ultramafic subunit samples from II(a); and 1 internal ultramafic subunit sample from I(b). The rock chondrite data from this set have been compared to diagrams representing unmineralized samples from Severson and Hauck (1990). It is important to note that the sample set of Severson and Hauck (1990) contains samples taken throughout the Partridge River Troctolitic Series, including samples from areas other than Dunka Road. The three samples from the RED Horizon are compared with ten samples taken from the upper half of Unit I (Fig. 4). The shaded area represents predominantly unmineralized samples. Thus, as expected, the mineralized samples from the RED Horizon are consistently higher in rare earth elements (REEs), P, Zr, and Y. In Figure 5, the three basal ultramafic samples are compared with six peridotite samples from Unit II (shaded area, from Severson and Hauck, 1990). These samples (shaded area) also include samples taken outside of Dunka Road and from ultramafics other than II(a). One of the three ultramafic samples (sample 26064, 760-765) compares well with that of the shaded area (Fig. 5).

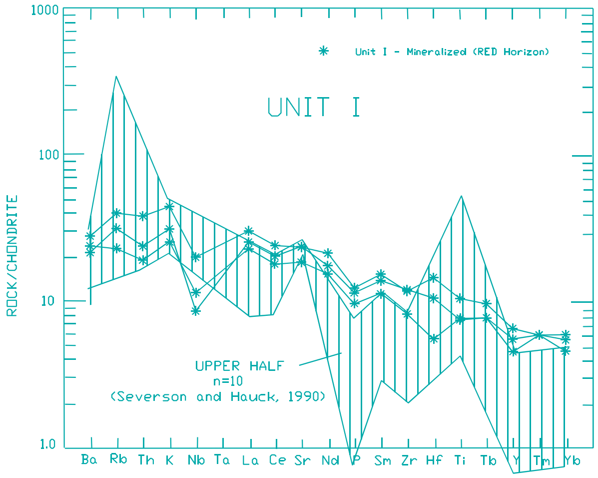

Figure 4. Spider diagram comparing the mineralized RED Horizon with the upper half of Unit I, Partridge River Troctolitic Series.

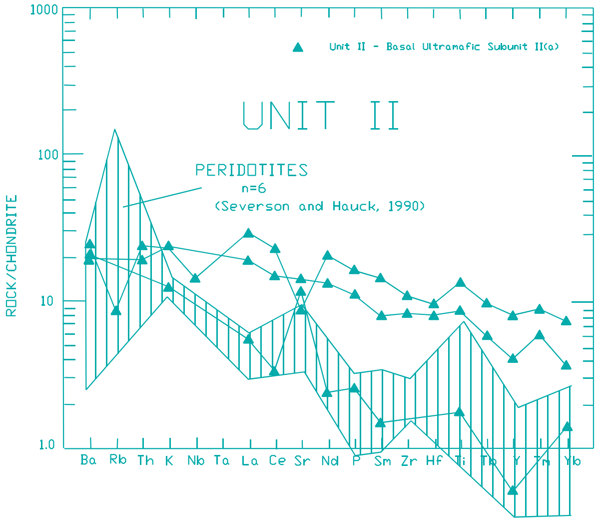

Figure 5. Spider diagram comparing ultramafic subunit II(a) with Unit II peridotites of the Partridge River Troctolitic Series.

RARE EARTH CHONDRITE PLOTS

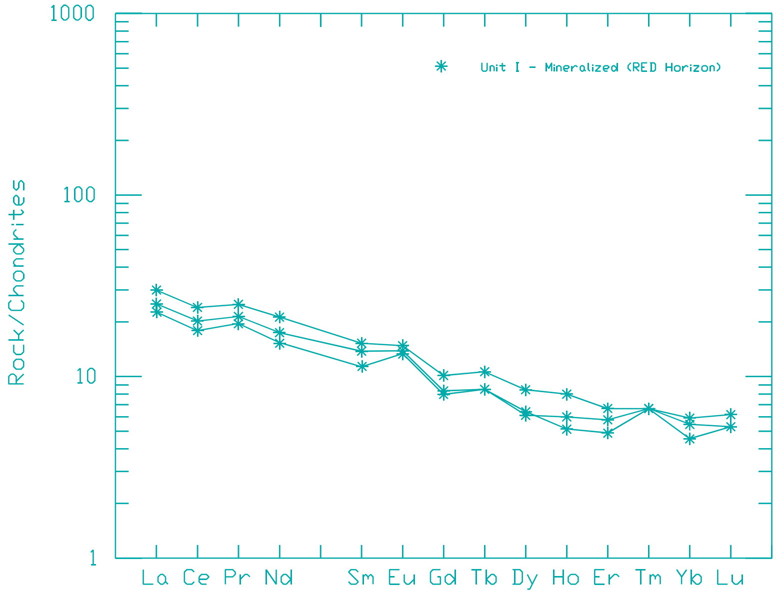

Figure 6. Rare earth rock chondrite plots for the RED Horizon.

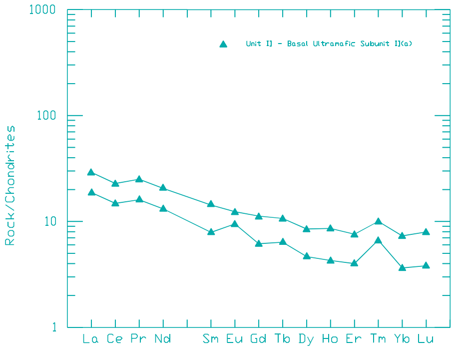

Figure 7. Rare earth rock chondrite plots for the basal ultramafic subunit II(a).

Figures 6 and 7 contain REE/chondrite plots of the mineralized RED Horizon and the basal ultramafic subunit II(a). Both plots contain slightly higher values of light REEs as compared to the heavy REEs. This results in a fairly low La/Lu ratio that is typical of continental tholeiites and their associated intrusive complexes. As expected for mafic and ultramafic rocks, the plots have little or no Eu anomaly. There is a strong correlation between the REEs in the three samples of the RED Horizon (Fig. 6). This adds to the evidence that similar process(es) are responsible for the formation of the laterally extensive "enriched" mineralized horizons. A total lateral distance of approximately 8,000 feet (trending northeast-southwest) is represented by these three samples. Likewise, there is a fairly good correlation between the basal ultramafic subunit II(a) samples (Fig. 7).

X-Y PLOTS

Various X-Y scatter plots are presented in Figures 8 through 13. By comparing the two sets of data, similarities may be revealed between particular rock units at Dunka Road and the rest of the Partridge River Troctolite Series. These plots compare the Dunka Road whole rock data of this investigation to whole rock data collected for the Partridge River Troctolite Series by Severson and Hauck (1990). The later data set represents samples taken throughout the Partridge River Troctolitic Series, including samples outside of the Dunka Road area. Both sets of data were plotted using IGPET II (Carr, 1987) that normalized the major oxides to 100% on a water-free basis; trace element values were not normalized by the same factor. To simplify the plots, only the related fields of whole rock data from Severson and Hauck (1990) were used in the comparison. Figures 8 through 11 include X-Y plots of wt. % MgO versus: wt. % CaO, wt. % SiO_2, total wt. % FeO, and wt. % Al_2O_3. There is a close correlation of the Dunka Road whole rock data to that of the general whole rock data of the Partridge River Troctolite Series. The Dunka Road samples generally fall into the respective sample fields ("Units I and II" field, and "peridotite" field) delineated by Severson and Hauck (1990). Two additional plots were included, plotting MG number versus wt. % Al_2O_3 (Fig. 12), and Y versus Zr (Fig. 13). Again, in most cases the Dunka Road whole rock data fall into the respective fields. This would indicate that particular rock units within the Dunka Road prospect are related to similar rock types throughout the Partridge River Troctolite Series, or are the result of similar processes.

PGE SCANS

Sixteen samples were selected from the sample set that was previously assayed by Acme Analytical Labs in Vancouver, B.C. for S-Cu-Ni-Au and Pt-Pd-Rh (Table 3). The 16 sample set contains 13 samples from the laterally continuous mineralized horizons and 3 samples from

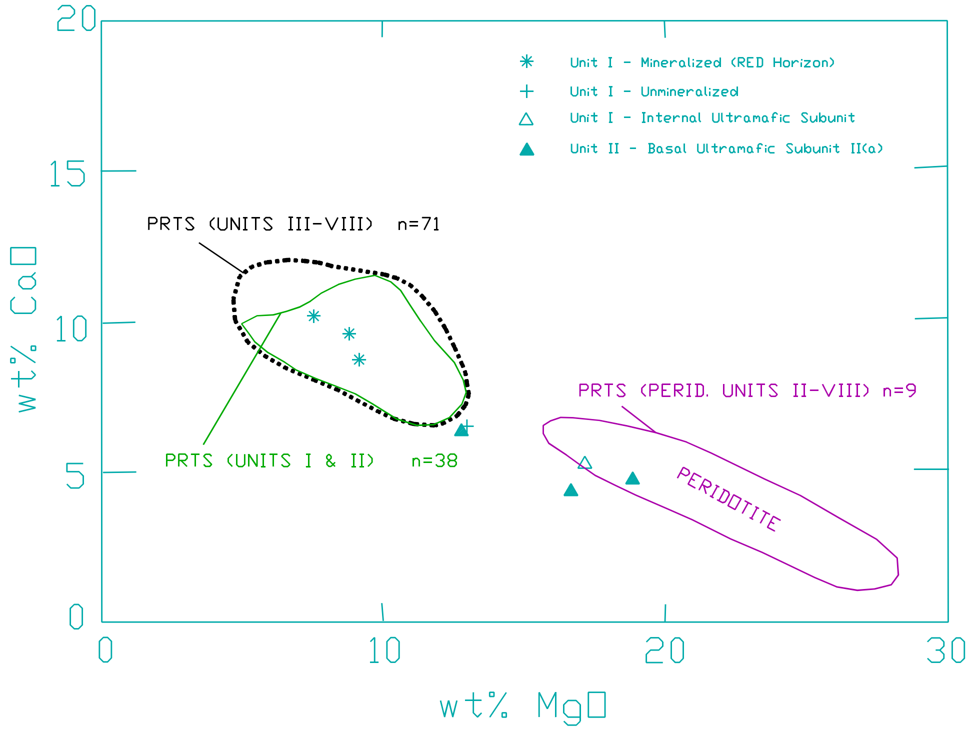

Figure 8. MgO versus CaO, Dunka Road whole rock compared with Partridge River Troctolitic Series.

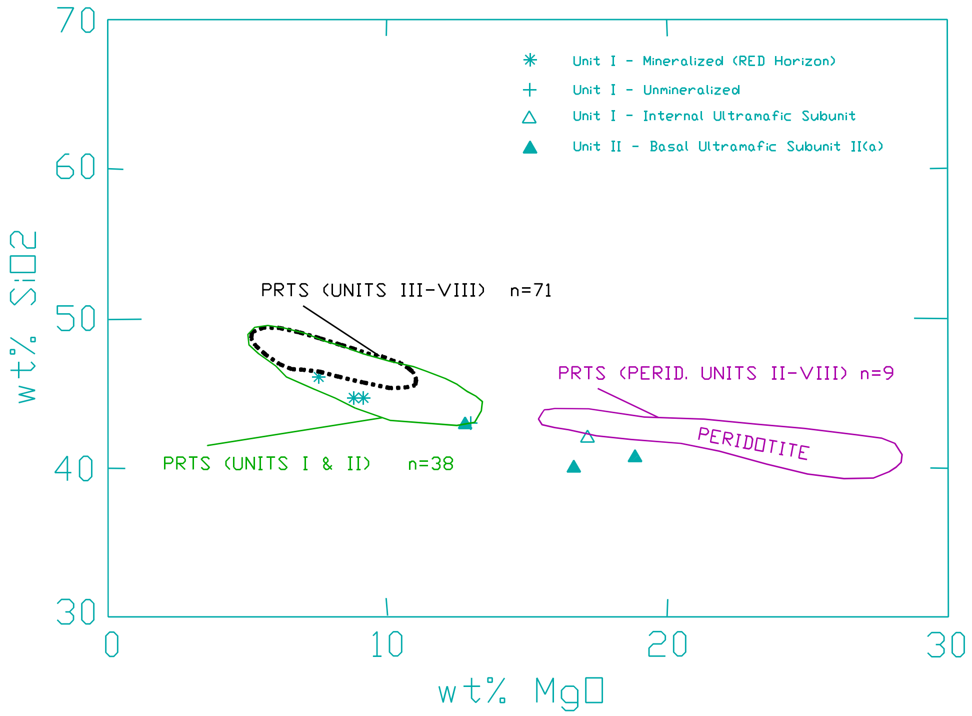

Figure 9. MgO versus SiO_2, Dunka Road whole rock compared with Partridge River Troctolitic Series.

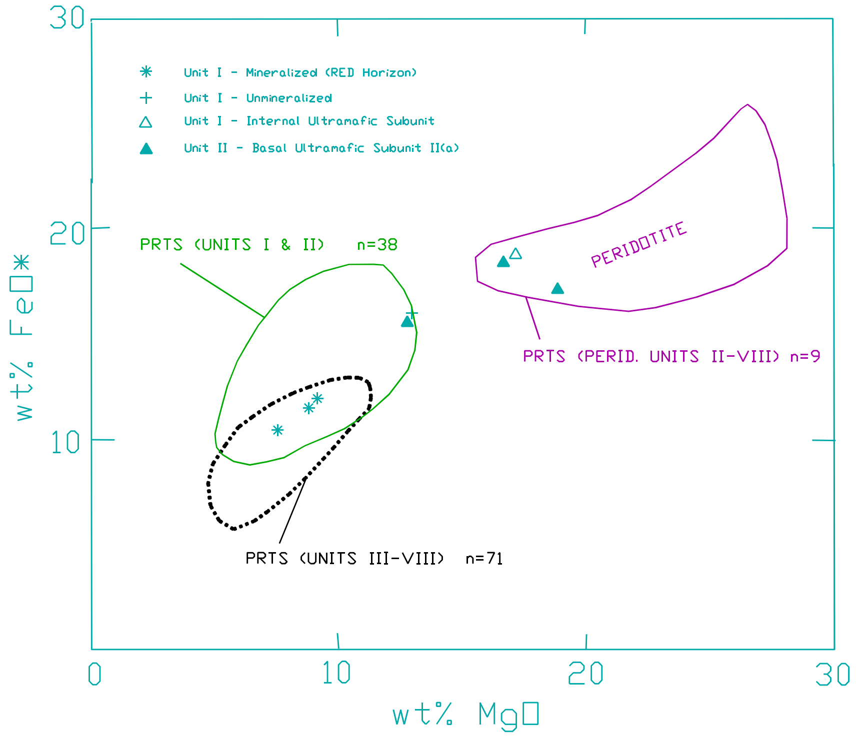

Figure 10. MgO versus FeO*, Dunka Road whole rock compared with Partridge River Troctolitic Series. (FeO* = FeO + 0.8998 Fe_2O_3)

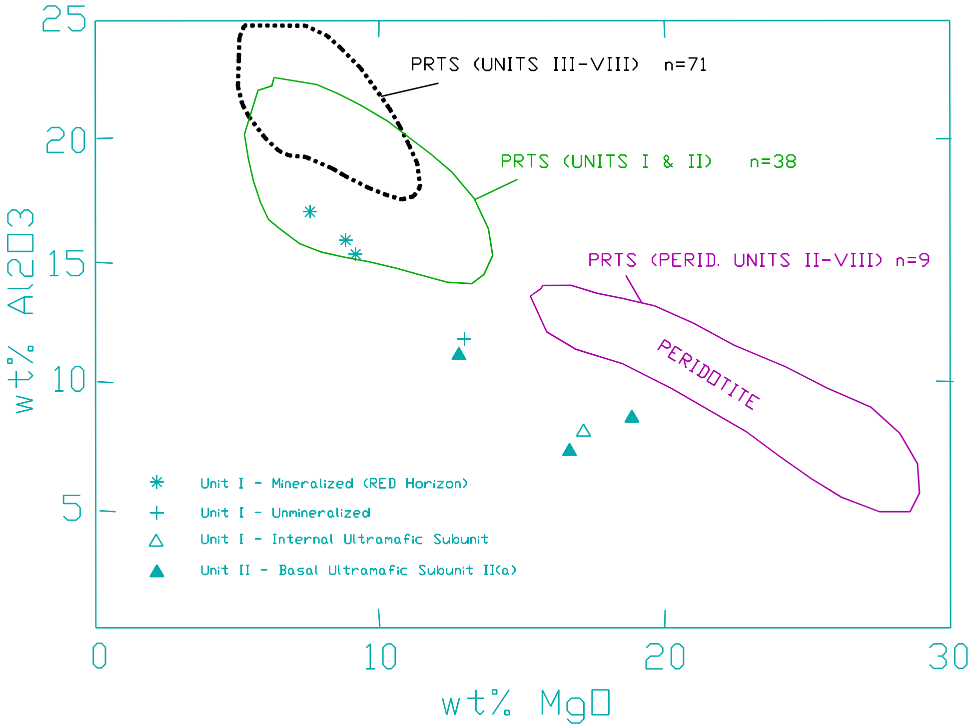

Figure 11. MgO versus Al_2O_3, Dunka Road whole rock compared with Partridge River Troctolitic Series.

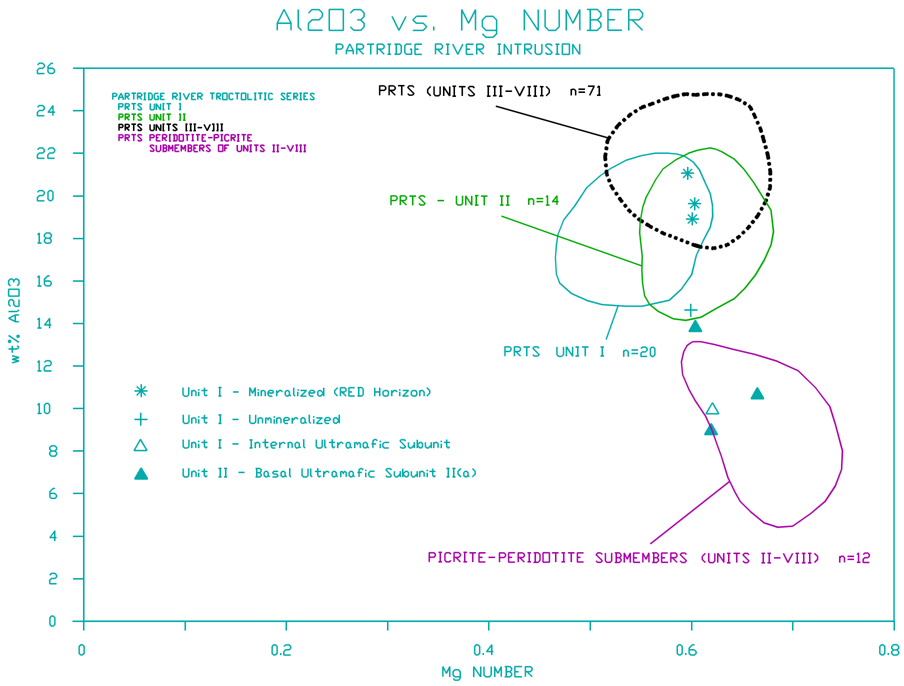

Figure 12. Mg number versus Al_2O_3, Dunka Road whole rock compared with Partridge River Troctolitic Series.

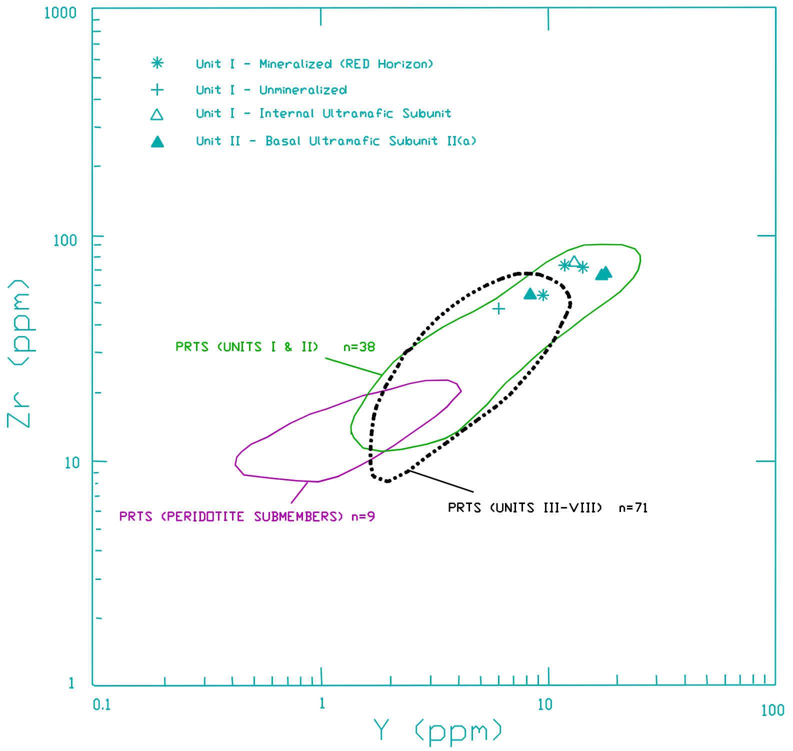

Figure 13. Y versus Zr, Dunka Road whole rock compared with Partridge River Troctolitic Series.

Table 3. Sample descriptions and Acme assay results

Hole	Interval	Description	%Cu	%Ni	%S	Pd	Pt	Rh	Au
26010	115.5-118.5	Massive sulfide lense, Unit I	5.64	0.62	11.99	10386	96	151	1926
26017	585-593	Dissem. sulf. in cpx troctolite, ORANGE horizon, Unit I	0.63	0.11	1.16	1130	305	11	113
26034	1058-1068	Dissem. sulf. in anorth. troct., RED horizon, Unit I	0.74	0.18	1.17	868	412	15	78
26060	109-119	Dissem. sulf. in anorth. troct., RED horizon, Unit I	1.03	0.31	1.42	2026	329	22	442
26073	1697-1707	Dissem. sulf. in anorth. troct., RED horizon, Unit I	0.67	0.16	1.02	1358	199	12	62
26073	1717-1727	Dissem. sulf. in anorth. troct., RED horizon, Unit I	0.49	0.10	0.82	922	283	9	75
26086	463-473	Dissem. sulf. in troct. anorth., YELLOW horizon, Unit I	0.79	0.25	1.38	1237	377	25	67
26098	428-438	Dissem. sulf. in troct. anorth., YELLOW horizon, Unit I	0.51	0.11	0.64	648	115	15	38
26098	438-448	Dissem. sulf. in troct. anorth., YELLOW horizon, Unit I	0.67	0.13	0.89	1787	443	15	95
26107	2110-2115	Unmineralized cpx troct., top of Unit I	0.11	0.06	0.19	260	80	?	36
26121	313-323	Dissem. sulf. in troct. anorth., MAGENTA horizon, Unit VI	0.96	0.18	1.38	1181	396	13	48
26125	2141-2151	Dissem. sulf. in anorth. troct., ORANGE horizon, Unit I	0.59	0.13	0.90	1306	218	13	48
26125	2151-2161	Dissem. sulf. in anorth. troct., ORANGE horizon, Unit I	0.75	0.16	1.09	1024	158	26	41
26142	252-262	Dissem. sulf. in troctolite, MAGENTA horizon, Unit I	0.75	0.17	1.10	1506	585	13	222
26143	1435-1440	Unmineralized cpx troct., below RED horizon, Unit I	0.02	0.03	0.44	5	15	?	3
26143	1680-1685	Unmineralized cpx troct., below RED horizon, Unit I	0.01	0.02	0.11	10	15	?	2

unmineralized rocks for comparison. The 16 samples were then sent to the University of Quebec, Chicoutimi, Quebec to be analyzed for PGEs by Dr. Sarah-Jane Barnes. The purpose of the PGE scans was to determine the accuracy of the prior results and to also test for previously untested PGEs, e.g., Os, Ir, Ru, and Re. The analysis was conducted using analytical procedures by Barnes and Giovenazzo (1990). In summary, the procedure involved the pre-concentration of PGEs in a Ni-sulfide bead that was then dissolved, and the noble metals were collected on filter paper. The sample was irradiated and concentrations of noble metals were determined by instrumental neutron-activation analysis (INAA). The test results from Dr. Barnes showed similar values for both Pt and Pd, but were systematically higher in Rh than the Acme results (Tables 3 and 4). The reason for this is probably due to an extra cupellation step performed by Acme, involving the loss of Rh due to oxidation (S.-J. Barnes, pers. comm., 1991). Results for Os, Ir, and Ru by Dr. Barnes appear to be normal for this type of sample (Table 4).

The most important point, from a prospecting point of view, is determining if and when sulfide segregation took place. Sulfides are one determining factor of a PGE deposit. If a PGE deposit is going to be generated, sulfides should not be retained in the mantle, and sulfides should not be segregated from the magma prior to reaching the site of intrusion (Barnes et al., 1990). The results of the PGE scans best illustrate this by plotting Pd (ppb) versus Cu/Pd (Fig. 14). The ratio of Cu to Pd for uncontaminated magma from the mantle is approximately 6,300 (Barnes et al., 1990). Twelve of the sixteen samples had values of around 6,300 for Cu/Pd (Fig. 14). Therefore, the original magma must have contained all of the dissolved sulfides and PGEs, until final emplacement. One reason for the absence of any PGE reefs at Dunka Road may be the low concentration of PGEs in the original mantle melt. The low back-

Table 4. Results of PGE scan

Sample	Os ppb	Ir	Ru	Rh	Pt	Pd	Au^{x}	Re*	Ni	Cu	S
26010	5.3^{+}	11.82^{+}	25^{+}	63^{+}	83^{+}	10380^{+}	582.7	40	0.62	5.64	11.99
26017	2.2	3.53	18	17.3	141	889	40.1	3.9	0.11	0.63	1.16
26034	2.5	4.45	23	19.8	341	1010	31.5	4.8	0.18	0.74	1.17
26060	5.3	5.92	29	38.8	315	2153	166.8	4.4	0.31	1.03	1.42
26073/07	4.6	5.15	22	22.2	161	963	29.4	5.6	0.16	0.67	1.02
26073/17	4.0	4.13	21	18.6	239	937	80.6	5.6	0.10	0.49	0.82
26086	2.2	6.03	24	18.0	339	1286	50.4	4.5	0.25	0.79	1.38
26098/28	1.1	2.46	17	11.5	124	599	38.9	3.3	0.11	0.51	0.64
26098/38	2.5	3.28	15	16.6	384	1903	56.2	4.5	0.13	0.67	0.89
26107	1.0	0.81	16	13.7	60	313	11.2	11	0.06	0.11	0.19
26121	6.3	9.44	31	26.8	382	1435	73.8	4.3	0.18	0.96	1.38
26125/45	1.8	5.69	19	21.3	257	862	23.8	4.6	0.13	0.59	0.90
26125/51	3.8	7.21	21	21.7	360	988	153.9	3.0	0.16	0.75	1.09
26142	2.5	3.51	20	17.5	183	1055	35.1	4.7	0.17	0.75	1.10
26143/35	<1	0.16	<5	<0.5	6	6	0.78	1.4	0.03	0.02	0.44
26143/80	<1	0.25	<5	1.5	14	15	1.27	0.39	0.02	0.01	0.11

^{x} = lack of agreement between your Au and these Au values is still being investigated.
$^{+}$ = high dead time, therefore the counting errors are large.
* = Re results are experimental, there is some question as to whether Re is fully collected in the Ni-bead. (S.-J. Barnes, pers. comm., 1991)

ground values of PGEs in unmineralized rock (Severson and Hauck, 1990) also supports this conclusion. Background values of PGEs for unmineralized rock in Unit I are generally less than 15 ppb Pt+Pd. In comparison, background values for mineralized rock, not including any of the delineated mineralized horizons, are approximately 150 ppb Pt+Pd. Four of the samples fall into the depleted range of values, having had values greater than 10,000 (Fig. 14). These four samples may have high Cu/Pd ratios because: 1) Pd has been removed by a previous sulfide segregation; 2) Cu was added to the magma through contamination of the magma by assimilation of sediments; or 3) they may be high due to Cu redistribution by hydrothermal fluids (S.-J. Barnes, pers. comm., 1991).

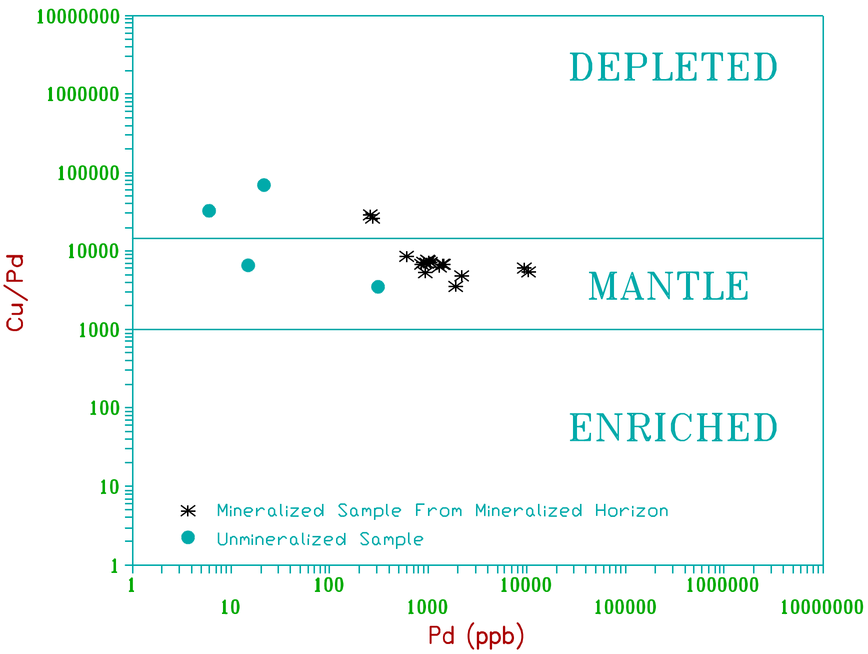

Figure 14. Pd versus Cu/Pd diagram (from S.-J. Barnes, 1990).

CONCLUSIONS

Although Dunka Road represents only a small fraction of the entire Duluth Complex, the knowledge gained by this study should prove useful in understanding and exploring for other Cu-Ni-PGE-Au-Ag occurrences within the Duluth Complex. The rock units delineated by Severson (1988) and Severson and Hauck (1990) are useful in constructing a detailed understanding of the igneous stratigraphy in the Dunka Road area. It is evident from the study at Dunka Road that the igneous stratigraphy can be worked out, and that it conforms nicely to that delineated by Severson and Hauck (1990). Also, by further subdividing individual rock units, a new set of ore controls, e.g., the basal/internal ultramafic subunits and the laterally extensive "enriched" mineralized horizons, can be more clearly defined, and they, in turn, are useful for understanding the PGE and Cu-Ni mineralization.

Generally, each troctolitic rock unit is characterized by a dominant rock type. However, due to the complexity in each unit and the small volume and area represented by core, rock types often vary from hole to hole, as in Unit I, due to slight lateral changes in the modal percentage of olivine, pyroxene, or plagioclase. Thus, correlation of the troctolitic rocks may be hampered by a few percent variation in the modal percentages of minerals. However, correlation of basal and internal ultramafic subunits laterally throughout the prospect provides a more consistent internal framework that can be used as a stratigraphic guide in correlating other troctolitic rock types between drill holes.

Changes in the relative percentage of chalcopyrite and pyrrhotite seem to be related to the distance from hornfels inclusions and/or the basal contact. There is a definite increase in the pyrrhotite to chalcopyrite ratio toward the contact of hornfels inclusions and with the basal contact of the Virginia Formation. Also, mineralized horizons may be internally controlled by and related to specific lithologies or internal ultramafic subunits within Unit I. A preliminary hypothesis is that the elevated Cu and PGE mineralization found within the laterally continuous horizons, e.g., RED Horizon, is predominantly primary and directly related to the crystallization of late stage residual melt, rather than the local secondary copper-enrichment by post-crystallization residual fluids. This hypothesis is supported by the results of the PGE scans. The majority of samples reflect "mantle" derived values of PGEs. Any secondary copper-enrichment would have resulted in "depleted" values of PGEs with respect to Cu mineralization. The presence of multiple mineralized horizons is most probably the result of multiple pulses of magma comprising Unit I.

BENEFITS

1. The upper limit of sulfide mineralization is defined by the base of subunit II(a).
2. The basal ultramafic subunit II(a) and internal ultramafic subunits within Unit I may be important controls on secondary mineralization enrichment, i.e., redox barriers.
3. Ultramafic subunits and mineralized horizons are regional in extent and can be identifiable horizons for exploration drilling and/or mining.
4. Cu-Ni and PGE mineralization occurs laterally over significant distances (mineralized horizons, e.g., RED Horizon) and may be an important economic contribution to the economic value of the prospect.

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APPENDIX A

THICKNESS (FT.) AND ELEVATION OF IGNEOUS UNITS

T - Hole tops out in that particular unit.

B - Hole bottoms out in that particular unit.

VF - Virginia Formation

Drill Hole #	Collar Elev. (Ft.)	Hole Angle (Deg.)	T.D. (Ft.)	Base of Complex (Ft.)	Elev. (Ft.)	Top of Pokegama (Ft.)	Elev. (Ft.)	Top of Biwabik Fe Form (Ft.)	Elev. (Ft.)	Thick. of Biwabik (Ft.)	Top of Virginia Form (Ft.)	Elev. (Ft.)	Thick. of Virginia (Ft.)
26010	1602	50NW	620	415	1284						415	1284	>157
26011	1602		455	445	1157						445	1157	>10
26013	1610	60NW	740	533	1148			738	971	>2	533	1148	179
26015	1605	50NW	893	595	1149			885	927	>6	595	1149	228
26017	1605		861	793	812						793	812	>68
26021	1605		608	B-1							T-1		
26022	1605		606	484.5	1120.5						484.5	1120.5	>121.5
26023	1605		725	597	1008						597	1008	>128
26024	1605		586	T-VF							T-VF		>586
26025	1613		1042	1017	596						1017	596	>25
26026	1614		715	692	922						692	922	>23
26027	1606		910	878	728						878	728	>32
26028	1600	50NW	381	330	1347						330	1347	>39
26029	1620		1181	1081	539						1081	539	>100
26030	1622		1094	1030	592						1030	592	>64
26031	1599		1116	1059	540						1059	540	>57
26032	1611		690	598	1013						598	1013	>92
26033	1614		1104	1032	582			1096	518	>8	1032	582	64
26034	1600		1375	1341	259			1343	257	>32	1341	259	2
26035	1600		915	T-VF				854	746	>61	T-VF		>854
26036	1596		1237	1140	456			1208	388	>29	T-VF		>1208
26037	1605	45NW	301	83	1546						83	1546	>154
26038	1613		405	281	1332						281	1332	>124

Drill Hole #	Collar Elev. (Ft.)	Hole Angle (Deg.)	T.D. (Ft.)	Base of Complex (Ft.)	Elev. (Ft.)	Top of Pokegama (Ft.)	Elev. (Ft.)	Top of Biwabik Fe Form (Ft.)	Elev. (Ft.)	Thick. of Biwabik (Ft.)	Top of Virginia Form (Ft.)	Elev. (Ft.)	Thick. of Virginia (Ft.)
26039	1606		956	802	804						802	804	>154
26040	1596		679	T-VF							T-VF		>679
26041	1613		387	306	1307						306	1307	>81
26042	1595		1946	1873	-278			1911	-316	>35	1873	-278	38
26043	1606		1559	1553	53						1553	53	>6
26044	1612		205	B-1							T-1		
26045	1598		926	808	790						808	790	>118
26046	1603		945	888	715						888	715	>57
26047	1609		800	736	873						736	873	>64
26048	1590		1902	1835	-245			1896	-306	>6	1835	-245	61
26049	1608		1207	1161	447			1176	432	>31	1161	447	15
26050	1599		2005	1946	-347			1964	-365	>41	1946	-347	18
26051	1600		1454	1397	203			1432	168	>22	1397	203	35
26052	1593		1866	1806	-213			1828	-235	>38	1806	-213	22
26053	1595		1018	1004	591						1004	591	>14
26054	1598		776	652	946						652	946	>124
26055	1595		1672	1616	-21			1656	-61	>16	1616	-21	40
26056	1592		1693	1652.5	-60.5						1652.5	-60.5	>40.5
26057	1599		608	555	1044						555	1044	>53
26058	1612		817	754.5	857.5						754.5	857.5	>62.5
26059	1603		608	497.5	1105.5						497.5	1105.5	>110.5
26060	1610		812	592	1018			719	891	>93	592	1018	127
26061	1602		1277	1273	329						1273	329	>4

Drill Hole #	Collar Elev. (Ft.)	Hole Angle (Deg.)	T.D. (Ft.)	Base of Complex (Ft.)	Elev. (Ft.)	Top of Pokegama (Ft.)	Elev. (Ft.)	Top of Biwabik Fe Form (Ft.)	Elev. (Ft.)	Thick. of Biwabik (Ft.)	Top of Virginia Form (Ft.)	Elev. (Ft.)	Thick. of Virginia (Ft.)
26062	1593		1477	1426	167			1456	137	>21	1426	167	30
26063	1594		1957	1897	-303						1897	-303	>60
26064	1595		1496	1472	123			1481	114	>15	1472	123	9
26065	1592		2466	2334.5	-742.5			2397	-805	>69	2334.5	-742.5	62.5
26066	1604		1677	1607	-3			1646	-42	>31	1607	-3	39
26067	1598		2147	2053	-455			2142	-544	>5	2053	-455	89
26068	1601		1458	1450	151						1450	151	>8
26069	1604		2006	1969	-365			1982	-378	>24	1969	-365	13
26073	1603		2494	2378	-775			2408	-805	>86	2378	-775	30
26074	1598		2095	2030	-432			2041	-443	>54	2030	-432	11
26075	1597		2505	2467	-870			2489	-892	>16	2467	-870	22
26076	1610		1180	456	1154	1163	447	712	898	468	456	1154	256
26077	1609		374	171	1438						171	1438	>203
26078	1613		904	864.5	748.5			888	725	>16	864.5	748.5	23.5
26079	1597		864	778	819			841	756	>23	778	819	63
26080	1597		1925	1514	83			1906	-309	>19	1514	83	392
26081	1578		2345	2242.5	-664.5			2300.5	-722.5	>44.5	2242.5	664.5	58
26082	1607		935	599	1008			906	701	>29	599	1008	307
26083	1607		644	570	1037						570	1037	>74
26084	1613		1354	626	987	1271	342	877	736	394	626	987	251
26085	1606		535	479	1127						479	1127	>56
26086	1617		574	498	1119						498	1119	>76
26087	1595		1675	1646	-51			1663	-68	>12	1646	-51	17

Drill Hole #	Collar Elev. (Ft.)	Hole Angle (Deg.)	T.D. (Ft.)	Base of Complex (Ft.)	Elev. (Ft.)	Top of Pokegama (Ft.)	Elev. (Ft.)	Top of Biwabik Fe Form (Ft.)	Elev. (Ft.)	Thick. of Biwabik (Ft.)	Top of Virginia Form (Ft.)	Elev. (Ft.)	Thick. of Virginia (Ft.)
26088	1610		885	T-VF							T-VF		>885
26089	1605		837	T-VF							T-VF		>837
26090	1595		1775	1743	-148			1775	-160	>20	1743	-148	12
26091	1609		231	156	1453						156	1453	>75
26092	1613		376	283.5	1329.5						283.5	1329.5	>92.5
26093	1613		1085	1013	600						1013	600	72
26094	1582		2515	2468	-886			2483	-901	>32	2468	-886	15
26095	1605		425	249.5	1355.5						249.5	1355.5	>175.5
26096	1625		883	795	830						795	830	>88
26097	1606		787	729	877						729	877	>58
26098	1604		755	702	902			738	866	>17	702	902	36
26099	1623		565	488	1135						488	1135	>77
26100	1613		465	412.5	1200.5						412.5	1200.5	>52.5
26101	1607		655	601	1006						601	1006	>54
26102	1598		1112	T-VF				1087	657	>25	T-VF		>1087
26103	1612		965	909	703						909	703	>56
26104	1612		2445	2423	-811			2435	-823	>10	2423	-811	12
26105	1617	45NW	212	85	1557						85	1557	>90
26106	1601		1875	1796	-195			1830.5	-229.5	>44.5	1796	-195	34.5
26107	1579		2431	2374	-795			2424.5	-845.5	>6.5	2374	-795	50.5
26108	1617	45NW	167	99	1547						99	1547	>48
26109	1612	45NW	242	216	1459						216	1396	>18
27110	1621	45NW	162	B-1							T-1		

Drill Hole #	Collar Elev. (Ft.)	Hole Angle (Deg.)	T.D. (Ft.)	Base of Complex (Ft.)	Elev. (Ft.)	Top of Pokegama (Ft.)	Elev. (Ft.)	Top of Biwabik Fe Form (Ft.)	Elev. (Ft.)	Thick. of Biwabik (Ft.)	Top of Virginia Form (Ft.)	Elev. (Ft.)	Thick. of Virginia (Ft.)
26111	1613	45NW	162	B-1							T-1		
26112	1614	45NW	222	209	1466						209	1466	>9
26113	1621	45NW	214	194	1484						194	1484	>14
26114	1617	40NW	293	271	1443						271	1443	>14
26115	1592		2180	2112	-520			2141	-549	>39	2112	-520	29
26116	1610	2245	T-1								T-1		
26117	1586		2594	2566	-980			2580	-994	>14	2566	-980	14
26118	1618		1145	1101	517			1128	490	>17	1101	517	27
26119	1568		2647	2557	-989			2577	-1009	>70	2557	-989	20
26120	1597		1080	600	997			1064	533	>16	600	997	464
26121	1594		2151	2116	-522			2125	-531	>26	2116	-522	9
26122	1607		2242	2191	-584			2207	-600	>35	2191	-584	16
26123	1597		2253	2188	-591			2217	-620	>36	2188	-591	29
26124	1593		2415	2353	-760			2395	-802	>20	2353	-760	42
26125	1597		2504	2480	-883			2496	-899	>8	2480	-883	16
26127	1629		918	B-1							T-1		
26128	1632		1008	834	798			947	685	>61	834	798	113
26141	1592		1585	1432	160			1568	24	>17	1432	160	136
26142	1593		2118	2088	-495			2110	-517	>8	2088	-495	22
26143	1592		2125	2107	-513			2114	-522	>11	2107	-513	7

Drill Hole #	Top of Unit I (Ft.)	Elev. (Ft.)	Thick. of Unit I (Ft.)	Top of Unit II (Ft.)	Elev. (Ft.)	Thick of Unit II (Ft.)	Top of Unit III (Ft.)	Elev. (Ft.)	Thick. of Unit III (Ft.)	Top of Unit IV (Ft.)	Elev. (Ft.)	Thick. of Unit IV (Ft.)	Top of Unit V	Elev. (Ft.)	Thick. of Unit V (Ft.)	Top of Unit VI	Elev. (Ft.)	Thick. of Unit VI (Ft.)	Top of Unit VII (Ft.)	Elev. (Ft.)	Thick of Unit VII (Ft.)
26010	T-1		>415																		
26011	T-1		>445																		
26013	83	1538	>450	T-2		>83															
26015	256	1409	339	58	1560	198	T-3		>58												
26017	319	1286	474	70	1535	249	T-3		>70												
26021	81.5	1523.5	>526.5	T-2		>81.5															
26022	124	1481	360.5	T-2		>124															
26023	189	1416	408	T-2		>189															
26025	91	1540	926	58	1555	33	T-3		>58												
26026	310	1304	382	84	1530	226	T-3		>84												
26027	186	1420	692	86	1520	100	T-3		>86												
26028	T-1		>330																		
26029	527	1093	554	324	1296	203	T-3		>324												
26030	380	1242	650	315	1307	65	204	1418	111	T-4		>204									
26031	715	884	344	552	1047	163	296	1303	256	T-4		>296									
26032	217	1394	381	8	1603	209	T-3		>8												
26033	531	1083	501	421	1193	110	240.5	1373.5	180.5	T-4		>240.5									
26034	1018	582	323	851	749	167	411	1189	440	T-4		>411									
26036	870	726	270	625	971	245															
26037	T-1		>83																		
26038	T-1		>281																		
26039	323	1283	479	105.5	1500.5	217.5	T-3		>105.5												
26041	T-1		>306																		
26042	1315	280	558	1122	473	193	926	669	196	624	971	302	330	1265	294	T-6		>330			

Drill Hole #	Top of Unit I (Ft.)	Elev. (Ft.)	Thick. of Unit I (Ft.)	Top of Unit II (Ft.)	Elev. (Ft.)	Thick of Unit II (Ft.)	Top of Unit III (Ft.)	Elev. (Ft.)	Thick. of Unit III (Ft.)	Top of Unit IV (Ft.)	Elev. (Ft.)	Thick. of Unit IV (Ft.)	Top of Unit V	Elev. (Ft.)	Thick. of Unit V (Ft.)	Top of Unit VI	Elev. (Ft.)	Thick. of Unit VI (Ft.)	Top of Unit VII (Ft.)	Elev. (Ft.)	Thick of Unit VII (Ft.)
26043	1144.5	461.5	408.5	1053	553	91.5	836	770	217	554	1052	282	46	1560	508	T-6		>46			
26044	T-1		>205																		
26045	369	1229	439	152	1446	217	T-3		>152												
26046	466	1137	402	276	1327	190	61	1542	215	T-4		>61									
26047	202	1407	534	69	1540	133	T-3		>69												
26048	1425	165	410	1338	252	87	1083	507	255	819	771	264	385	1205	434	T-6	>385				
26049	752.5	855.5	408.5	570	1038	182.5	234	1374	336	T-4		>234									
26050	1694	-95	252	1482	117	212	1141	458	341	898	701	243	454	1145	444	T-6		>454			
26051	966	634	431	891	709	75	595	1005	296	241	1359	354	T-5		>241						
26052	1354	239	452	1286	307	68	1038	555	248	650	943	388	444	1149	206	T-6		>444			
26053	706	889	298	390	1205	316	146	1449	244	T-4		>146									
26054	372	1226	280	295	1303	77	146	1452	149	T-4		>146									
26055	1090	505	526	745	850	345	559	1036	186	435	1160	124	140	1455	295	T-6		>140			
26056	837	755	815.5	780	812	57	581.5	1010.5	198.5	183	1409	398.5	66	1526	117	T-6		>66			
26057	91	1508	464	T-2		>91															
26058	524	1088	230.5	226	1386	298	55	1557	171	T-4		>55									
26059	T-1		>497.5																		
26060	99	1511	493	T-2		>99															
26061	862	740	411	718	884	144	507	1095	211	237	1365	270	T-5		>237						
26062	719	874	707	637	956	82	430	1163	207	201	1392	229	T-5		>201						
26063	1533	61	364	1394	200	139	1081	513	313	751	843	330	372	1222	379	T-6		>372			
26064	766	829	706	613	982	153	453	1142	160	T-4		>453									
26065	2033	-441	301.5	1857	-265	176	1378	214	479	1010	582	368	816	776	194	294	1298	522	T-7		>294
26066	1191	413	416	1045	559	146	813	791	232	470	1134	343	256	1348	214	T-6		>256			

Drill Hole #	Top of Unit I (Ft.)	Elev. (Ft.)	Thick. of Unit I (Ft.)	Top of Unit II (Ft.)	Elev. (Ft.)	Thick of Unit II (Ft.)	Top of Unit III (Ft.)	Elev. (Ft.)	Thick. of Unit III (Ft.)	Top of Unit IV (Ft.)	Elev. (Ft.)	Thick. of Unit IV (Ft.)	Top of Unit V	Elev. (Ft.)	Thick. of Unit V (Ft.)	Top of Unit VI	Elev. (Ft.)	Thick. of Unit VI (Ft.)	Top of Unit VII (Ft.)	Elev. (Ft.)	Thick of Unit VII (Ft.)
26067	1845	-247	208	1763	-165	82	1467	131	296	917	681	550	669	929	248	293	1305	376	T-7		>293
26068	1100	501	350	995	606	105	870	731	125	482	1119	388	261	1340	221	T-6		>261			
26069	1691	-87	278	1606	-2	85	1262.5	341.5	343.5	690	914	572.5	484	1120	206	171	1433	313	T-7		>171
26073	1687	-84	691	1521	82	166	1312	291	209	1052	551	260	825	778	227	302	1301	523	T-7		>302
26074	1739	-141	291	1605	-7	134	1411	187	194	1141	457	270	668	930	473	153	1445	515	T-7		>153
26075	2200	-603	267	1846	-249	354	1581	16	265	1195	402	386	870	727	325	280	1317	590	T-7		>280
26076	94	1516	368	T-2		>94															
26077	T-1		>171																		
26078	428	1185	436.5	130	1483	298	T-3		>130												
26079	472	1125	306	179	1418	184	T-3		>179												
26080	1117	480	397	1045	552	72	845	752	200	655	942	190	433	1164	222	164	1433	269	T-7		>164
26081	1757	-179	485.5	1470	108	287	1095	483	375	840	738	255	710	868	130	291	1287	419	T-7		>291
26082	T-1		>599																		
26083	T-1		>570																		
26084	T-1		>626																		
26085	T-1		>479																		
26086	117	1443	324	T-2		>174															
26087	1404	191	242	1155	440	249	843	752	312	380	1215	463	T-5		>380						
26090	1212	383	531	955	640	257	465	1130	490	1305	175	210	1385	80	T-6		>210				
26091	T-1		>156																		
26092	T-1		>283.5																		
26093	330	1283	683	242	1371	88	16	1597	226	T-4		>16									
26094	1421	161	1047	1211	371	210	1075	507	136	1020	562	55	681	901	339	326	1256	355	T-7		>326
26095	T-1		>249.5																		

Drill Hole #	Top of Unit I (Ft.)	Elev. (Ft.)	Thick. of Unit I (Ft.)	Top of Unit II (Ft.)	Elev. (Ft.)	Thick of Unit II (Ft.)	Top of Unit III (Ft.)	Elev. (Ft.)	Thick. of Unit III (Ft.)	Top of Unit IV (Ft.)	Elev. (Ft.)	Thick. of Unit IV (Ft.)	Top of Unit V	Elev. (Ft.)	Thick. of Unit V (Ft.)	Top of Unit VI	Elev. (Ft.)	Thick. of Unit VI (Ft.)	Top of Unit VII (Ft.)	Elev. (Ft.)	Thick of Unit VII (Ft.)
26096	526	1099	269	265	1360	261	50	1575	215	T-4		>50									
26097	T-1		>729																		
26098	154	1450	548	T-2		>154															
26099	206	1417	282	T-2		>206															
26100	T-1		>412.5																		
26101	135	1472	466	85	1522	50	T-3		>85												
26103	547	1065	362	265	1347	282	T-3		>265												
26104	1979	-367	444	1679	-67	300	1432	180	247	1150	462	282	806	806	344	275	1337	531	T-7		>275
26105	T-1		>85																		
26106	1507	94	289	1438	163	69	1233	368	205	655	946	578	455	1146	200	233	1368	222	T-7		>225
26107	2034	-455	340	1880	-301	154	1475	104	405	1094	485	381	832	747	262	427	1152	405	T-7		>427
26108	T-1		>99																		
26109	T-1		>216																		
26110	T-1		>162																		
26111	T-1		>162																		
26112	T-1		>209																		
26113	T-1		>194																		
26114	T-1		>271																		
26115	1542	50	570	1350	242	192	1115	477	235	875	717	240	530	1062	345	T-6		>530			
26116	1690	-80	>555	1560	50	130	1276	334	284	887	723	389	639	971	248	231	1379	408	T-7		>231
26117	1993	-407	573	1871	-285	122	1660	-74	211	1382	204	278	1084.5	501.5	297.5	507	1079	577.5	T-7		>507
26118	640.5	977.5	460.5	450	1168	190.5	245	1373	205	T-4		>245									
26119	2190	-622	367	1862	-294	328	1572	-4	290	1400	168	172	1010	558	390	419	1149	591	T-7		>419
26120	395	1202	205	138	1459	257	T-3		>138												

Drill Hole #	Top of Unit I (Ft.)	Elev. (Ft.)	Thick. of Unit I (Ft.)	Top of Unit II (Ft.)	Elev. (Ft.)	Thick of Unit II (Ft.)	Top of Unit III (Ft.)	Elev. (Ft.)	Thick. of Unit III (Ft.)	Top of Unit IV (Ft.)	Elev. (Ft.)	Thick. of Unit IV (Ft.)	Top of Unit V	Elev. (Ft.)	Thick. of Unit V (Ft.)	Top of Unit VI	Elev. (Ft.)	Thick. of Unit VI (Ft.)	Top of Unit VII (Ft.)	Elev. (Ft.)	Thick of Unit VII (Ft.)
26121	1442	152	674	1375	219	67	752	842	623	690	904	62	505	1089	185	135	1459	370	T-7		>135
26122	1871	-264	320	1635	-28	236	1441	166	194	1004	603	437	672	935	332	166	1441	506	T-7		>166
26123	1370	227	818	1155	442	215	946	651	209	825	772	121	509	1088	316	156	1441	353	T-7		>156
26124	1401	192	952	1135	458	266	854	739	281	755	838	99	490	1103	265	130	1463	360	T-7		>130
26125	2053	-456	427	1866	-269	187	1553	44	313	1234	363	319	860	737	374	288	1309	572	T-7		>288
26127	230	1399	404	111	1518	119	T-3		>111												
26128	549	1083	285	309	1323	240	T-3		>309												
26141	652	940	780	543	1049	109	467	1125	76	145	1447	322	T-5		>145						
26142	1115	478	973	1054	539	61	887	706	167	641	952	246	462	1131	179	111	1482	351	T-7		>111
26143	1122	470	985	1093	499	29	961	631	132	819	773	142	445	1147	374	184	1408	261	T-7		>184

APPENDIX B

DUNKA ROAD GEOCHEMICAL AND ASSAY DATA

This data base contains the geochemical assay values for all Dunka Road samples. The file is located on a 1.44 MB floppy diskette. Other formats are available on request from the Minerals Division or Library at the NRRI. The data are in QUATTRO PRO format and have been composited for intervals with more than one assay.

Column designations are listed on the following page. Columns J through M contain values from U.S. Steel assays, while columns N through AO represent values of assays and re-assays by ACME Analytical Labs. Blanks indicate a lack of data. Asterisk indicates sample digested with 3 ml 3-1-2 $HCl\text{-}HNO_3\text{-}H_2O$ at 95E C for one hour and is diluted to 10 ml with water, and therefore, the leach is only partial for these elements.

Name of file: Dnktot11.wq1 (back pocket)

Geochemical Assay Columns

A - Sort Number	AA - ACME Soluble Fe (wt. %)*	BA - TiO_2 (wt. %)	CA - Cl (ppm)	DA - Sc (ppm)
B - Drill Hole Number	AB - ACME As (ppm)	BB - Fe^{++} (wt. %)	CB - Cr (ppm)	DB - Se (ppm)
C - Collar Elevation	AC - ACME Sr (ppm)*	BC - TFe_2O_3 (wt. %)	CC - Co (ppm)	DC - Sr (ppm)
D - Footage (from)	AD - ACME Bi (ppm)	BD - Fe_2O_3 (wt. %)	CD - Cs (ppm)	DD - Ta (ppm)
E - Footage (to)	AE - ACME V (ppm)	BE - TFeO (wt. %)	CE - Dy (ppm)	DE - Te (ppm)
F - Interval Thickness	AF - ACME Ca (wt. %)*	BF - FeO (wt. %)	CF - Er (ppm)	DF - Tb (ppm)
G - Rock Unit	AG - ACME P (wt. %)*	BG - CaO (wt. %)	CG - Eu (ppm)	DG - Th (ppm)
H - Mineralized Horizon	AH - ACME La (ppm)*	BH - MgO (wt. %)	CH - F (ppm)	DH - Tl (ppm)
I - Rock Type	AI - ACME Cr (ppm)*	BI - MnO (wt. %)	CI - Ga (ppm)	DI - Tm (ppm)
J - USS Cu (wt. %)	AJ - ACME Ba (ppm)*	BJ - Na_2O (wt. %)	CJ - Ge (ppm)	DJ - Sn (ppm)
K - USS Total Ni (wt. %)	AK - ACME Ti (wt. %)*	BK - K_2O (wt. %)	CK - Gd (ppm)	DK - U (ppm)
L - USS S (wt. %)	AL - ACME Al (wt. %)*	BL - P_2O_5 (wt. %)	CL - Hf (ppm)	DL - V (ppm)
M - USS Total Fe (wt. %)	AM - ACME Na (wt. %)*	BM - Cr_2O_3 (wt. %)	CM - Ho (ppm)	DM - W (ppm)
N - ACME Cu (wt. %)	AN - ACME K (wt. %)*	BN - LOI (wt. %)	CN - In (ppm)	DN - Yb (ppm)
O - Acme Soluble Ni (wt. %)	AO - ACME W (ppm)*	BO - CO_2 (wt. %)	CO - La (ppm)	DO - Y (ppm)
P - Acme Ag (ppm)	AP - Cu/Ni (ppm)	BP - H_2O (wt. %)	CP - Pb (ppm)	DP - Zn (ppm)
Q - ACME Au (ppb)	AQ - Cu (ppm)	BQ - Total LOI	CQ - Li (ppm)	DQ - Zr (ppm)
R - ACME Pt (ppb)	AR - Ni (ppm)	BR - Sb (ppm)	CR - Lu (ppm)	DR - USX
S - ACME Pd (ppb)	AS - S (wt. %)	BS - As (ppm)	CS - Hg (ppb)	DS - ACME
T - ACME Rh (ppb)	AT - Fe (wt. %)	BT - B (ppm)	CT - Mo (ppm)	DT - Bondar Clegg
U - Pt+Pd (ppb)	AU - Ag (ppm)	BU - Ba (ppm)	CU - Nb (ppm)	DU - XRAL
V - Cu/Pd (ppm/ppb)	AV - Au (ppb)	BV - Be (ppm)	CV - Nd (ppm)	DV - IN UNIV.
X - ACME Pb (ppm)	AW - Pt (ppb)	BW - Bi (ppm)	CW - P (ppm)	DW - Reference
Y - ACME Zn (ppm)	AX - Pd (ppb)	BX - Cd (ppm)	CX - Pr (ppm)	
Z - ACME Co (ppm)	AY - SiO_2 (wt. %)	BY - C (ppm)	CY - Rb (ppm)	
	AZ - Al_2O_3 (wt. %)	BZ - Ce (ppm)	CZ - Sm (ppm)	

APPENDIX C

DUNKA ROAD WHOLE ROCK ASSAY DATA

This data base contains the whole rock analyses for Dunka Road. The file is located on a 1.44 MB floppy diskette. Other formats are available on request from the Minerals Division or Library at the NRRI. The data are in LOTUS 1-2-3 format - column designations are listed on the following page. Trace elements are arranged alphabetically by name (not symbol). Blanks indicate lack of data.

Name of file: Drwr.wk1 (back pocket)

Whole Rock Columns

A - Sample Number	AA - B (ppm)	BA - Ni (ppm)	CA - Blank
B - Rock Unit	AB - Cd (ppm)	BB - Nb (ppm)	CB - Cu/Pd (ppm/ppb)
C - Rock Type	AC - C (graph)	BC - Pr (ppm)	CC - MgO (cat. %)
D - SiO_2 (wt. %)	AD - Ce (ppm)	BD - Rb (ppm)	CD - TFE_2O_3 (cat. %)
E - Al_2O_3 (wt. %)	AE - Cs (ppm)	BE - Sm (ppm)	CE - Mg Number
F - TiO_2 (wt. %)	AF - Cl (ppm)	BF - Sc (ppm)	
G - TFE_2O_3 (wt. %)	AG - Cr (ppm)	BG - Se (ppm)	
H - Fe_2O_3 (wt. %)	AH - Co (ppm)	BH - Ag (ppm)	
I - FeO (wt. %)	AI - Cu (ppm)	BI - Sr (ppm)	
J - CaO (wt. %)	AJ - Dy (ppm)	BJ - Ta (ppm)	
K - MgO (wt. %)	AK - Er (ppm)	BK - Te (ppm)	
L - MnO (wt. %)	AL - Eu (ppm)	BL - Tb (ppm)	
M - Na_2O (wt. %)	AM - F (ppm)	BM - Tl (ppm)	
N - K_2O (wt. %)	AN - Gd (ppm)	BN - Th (ppm)	
O - P_2O_5 (wt. %)	AO - Ga (ppm)	BO - Tm (ppm)	
P - P (ppm)	AP - Ge (ppm)	BP - Sn (ppm)	
Q - LOI (wt. %)	AQ - Au (ppb)	BQ - W (ppm)	
R - CO_2 (wt. %)	AR - Hf (ppm)	BR - U (ppm)	
S - H_2O^+ (wt. %)	AS - Ho (ppm)	BS - V (ppm)	
T - S (wt. %)	AT - La (ppm)	BT - Yb (ppm)	
U - Total (wt. %)	AU - Pb (ppm)	BU - Y (ppm)	
V - Sb (ppm)	AV - Li (ppm)	BV - Zn (ppm)	
W - As (ppm)	AW - Lu (ppm)	BW - Zr (ppm)	
X - Ba (ppm)	AX - Hg (ppb)	BX - Pt (ppb)	
Y - Be (ppm)	AY - Mo (ppm)	BY - Pd (ppb)	
Z - Bi (ppm)	AZ - Nd (ppm)	BZ - In (ppm)	