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GEOLOGY AND STRUCTURE OF A PORTION OF THE PARTRIDGE RIVER INTRUSION: A PROGRESS REPORT

By

Mark J. Severson

September 1988
Technical Report
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Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth, MN 55811-1442

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

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

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Natural Resources Research Institute
University of Minnesota, Duluth
3151 Miller Trunk Highway
Duluth, Minnesota 55811

ABSTRACT

Studies of the basal contact of the Partridge River intrusion, as deduced by compilation of all drill hole data and relogging of 37 drill holes, has indicated more structure than previously recognized. Structure contour maps of the footwall rocks have been prepared showing the nature of the basal contact, the top of the Biwabik Iron-Formation, and the thickness of the Virginia Formation beneath the Partridge River intrusion. These data indicate that pre-existing folds in the basement rocks at both Minnamax and Dunka Road exerted a strong control over the form of the base of the intrusion. Several northeast-trending normal faults and northwest-trending strike-slip(?) faults were also delineated in this study which supports the half-graben model proposed by Weiblen and Morey (1980). A northeast-trending pre-Keweenawan fault has also been located in the Wetlegs area. Along this fault an inferred window of Biwabik Iron Formation is in direct contact with the Partridge River intrusion. Three oxide-bearing ultramafic bodies (Longnose, Longear, and Section 17) are exposed at the surface along this zone. The spatial location of oxide-bearing ultramafics to areas where the iron formation is in direct contact with the Duluth Complex suggests that they may be genetically related.

At least five major units within the basal portion of the Partridge River intrusion have been delineated for the Wetlegs area. They are present in 23 drill holes at Wetlegs and extend northeast into the Dunka Road Cu-Ni deposit and southwest into the Wyman Creek Cu-Ni deposit. From the base up, these units are characterized by: sulfide-bearing augite troctolite (175-1570 ft. thick); troctolite with abundant layers of picrite (melatroctolite), peridotite and dunite (450 ft. thick); a 250 ft. thick, fine-grained, mottled-textured

troctolitic anorthosite ("marker bed" for the area); augite troctolite (400 ft. thick); and augite-bearing anorthositic troctolite (250 ft. thick). To the northeast and southwest of Wetlegs, most of these units are present but the omission of particular units in either direction indicates an irregular stacked pattern. Establishment of an internal stratigraphy has provided an excellent opportunity to: 1) study the nature of any structural discontinuities present within the intrusion, 2) determine the extent and variability of intrusive lithologic units, 3) more fully understand any background geochemical variations that may be present within and between the lithologic units, and 4) better understand the origin of the Partridge River intrusion, the various Cu-Ni, Cu-Ni-Ti and Fe-Ti deposits and their relationship to the origin of the Duluth Complex.

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INTRODUCTION

Several studies have been conducted on the various subeconomic mineral deposits (Cu-Ni and Fe-Ti±Cu) located within the Partridge River troctolite (PRT) of the Duluth Complex. However, to date there has been little attempt to correlate these works. Only a limited amount of geochemical data pertinent to unmineralized rocks of the PRT are available and even these are not representative of the wide variety of rock types present. The goal of this project is to: 1) establish background geochemical values for the variety of mineralized rock types within and surrounding the various mineral deposits to aid mineral companies in future exploration campaigns, 2) establish an internal stratigraphy for the PRT along with respective geochemical values, and 3) provide any additional data in the form of lithologic drill hole correlations, cross-sections, outcrop maps, and structural data to aid in understanding the Duluth Complex and its related mineral deposits.

Geologic Setting

The Duluth Complex (Complex) is a series of multiple, predominantly mafic intrusions of Keweenawan age (1.1 b.y.) that formed with associated basaltic volcanism along a portion of the Midcontinent Rift. The Complex is sporadically exposed in an arcuate belt extending from Duluth, Minnesota, north toward Ely and from there east-northeast toward Hovland, Minnesota (Figure 1). Along its western edge, from Duluth to Babbitt, the base of the Complex is in sharp contact with shallow dipping Middle Precambrian (1.7 b.y.) metasediments of the Virginia/Thomson Formations, and at some localities the underlying Biwabik Iron-Formation. Northeast from Babbitt to the Gunflint Trail, the footwall rocks of

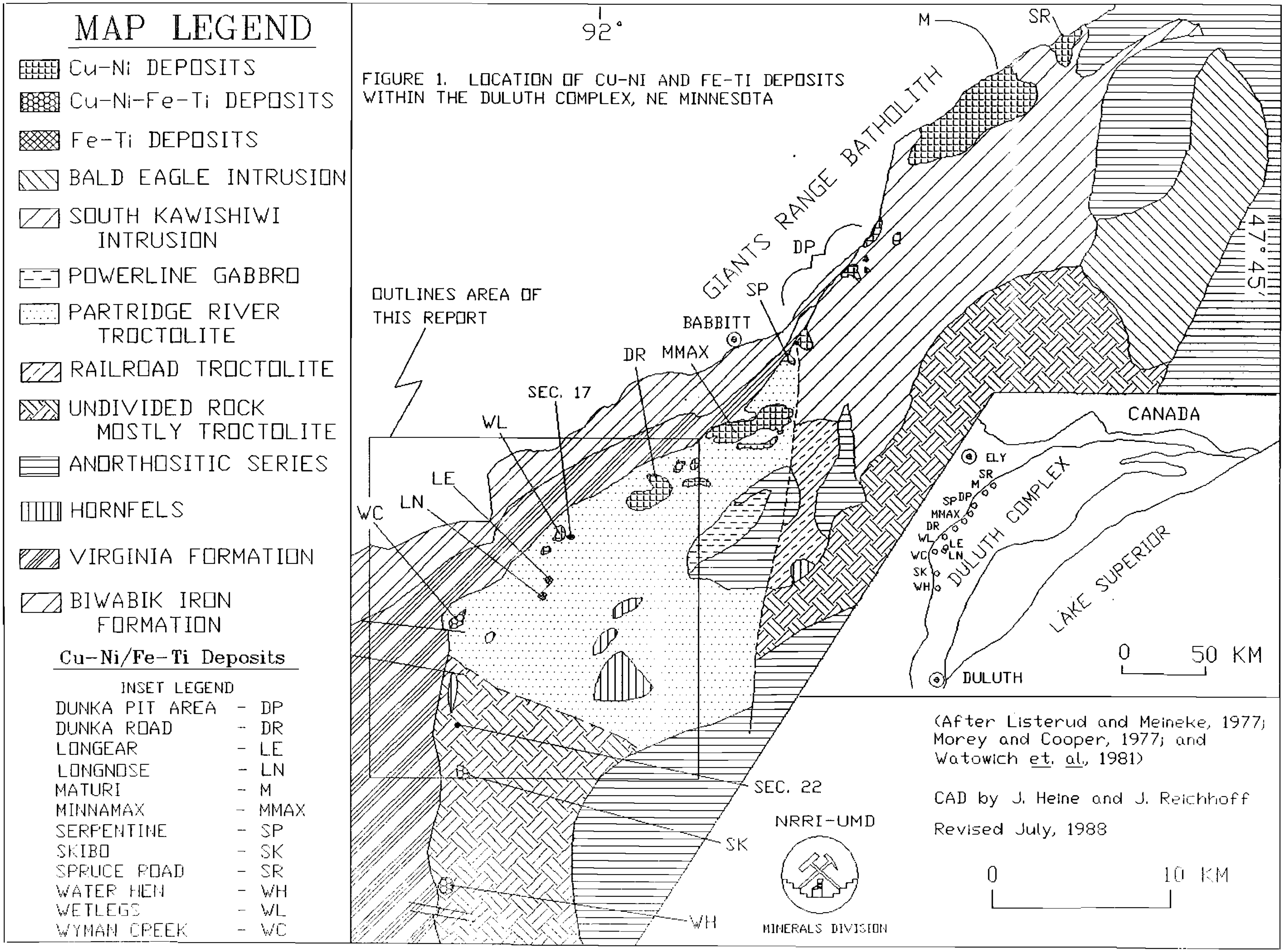


FIGURE 1. LOCATION OF CU-NI AND FE-TI DEPOSITS WITHIN THE DULUTH COMPLEX, NE MINNESOTA

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

CAD by J. Heine and J. Reichhoff

Revised July, 1988

the Complex consist of Archean (2.7 b.y.) granites and greenstones. East from the Gunflint Trail, at the basal contact are the Middle Precambrian metasediments of the Rove Formation. At the eastern upper contact of the Duluth Complex are the mafic volcanics of the North Shore Volcanic Group; however, since gradations between the two are often present, the "upper contact" of the Complex is arbitrarily chosen in places (Weiblen and Morey, 1975).

Rocks of the Duluth Complex are varied, but in general can be divided into an early Anorthositic Series (Davidson, 1972) and a later Troctolitic Series (Bonnichsen, 1972). Within a portion of the Complex near Babbitt, Minnesota, the Troctolitic Series has been further subdivided into at least three intrusive bodies which have been given the informal names of: South Kawishiwi intrusion, Partridge River intrusion, and Bald Eagle intrusion (Foose and Weiblen, 1986). Within this region, several large, though subeconomic, Cu-Ni deposits have been delineated along the base of the South Kawishiwi and Partridge River intrusions. From north to south these deposits are: Spruce Road, Maturi, Dunka Pit, Serpentine, Minnamax (also known as Babbitt), Dunka Road, Wetlegs, and Wyman Creek (Figure 1). Oxide-bearing ultramafic bodies (Fe-Ti) are also present within the PRT and include: Section 17 (Wetlegs), Longear, Longnose, "Section 22", Skibo, and Water Hen to the south. The Skibo and Water Hen deposits also contain Cu-Ni mineralization. Primary and secondary PGE mineralization have been documented in several drill holes located in both the South Kawishiwi and Partridge River intrusions (Ryan and Weiblen, 1984; Sabelin, et al., 1986; Dahlberg, 1987; Morton and Hauck, 1987).

Emplacement of the Duluth Complex occurred during an episode of extensional tectonism which produced what is now referred to as the Midcontinent Rift. Weiblen and Morey (1975, 1980) have presented a half-graben model for the overall structural geometry of the Complex in which they envision a step and riser configuration of the basal contact due to steep, southeast-dipping, northeast-trending normal faults underlying the Complex. According to the model, magma was injected into foundered, fault-bounded voids formed during rifting to produce the multiple intrusions that make up the Complex (Foose and Weiblen, 1986). They also suggest that these northeast-trending faults may be offset by a series of northwest-trending strike-slip (transform) faults. This model is consistent with the two fault directions recognized in a lineament study conducted by Cooper (1978). The abundance of faults within this postulated half-graben geometry may have been important in localizing the Cu-Ni mineralization. However, "Green (1982, 1983) has pointed out a number of problems with the model and suggests an alternative model of subsiding sequences of plateau lavas." (Holst, et al., 1986, p. I-3).

Recent studies of faulting in the Middle Precambrian basement rocks of the Hoyt Lakes - Kawishiwi area (Holst, et al., 1986) have delineated several north-south and northwest-trending faults in open pit mines of the Mesabi Range to the north of the Complex. However, no evidence within the pit walls was found for any northeast-trending faults as suggested by the half-graben model. In fact, most of the structural irregularities present within the iron formation are suggestive of a pre-Keweenawan age, and some are apparently Animikian in age (Holst, et al., 1986). Only one fault (NW-trending) was located within the Complex itself during a cursory examination. Small scale detachment faults, of apparently Keweenawan age, were located in the Dunka Pit area and could be interpreted as having resulted from extensional stresses at the time of Duluth Complex emplacement (Holst, et al., 1986). Studies of the basal contact in the Minnamax area indicate that pre-Keweenawan structures in the footwall rocks exerted a major control over the form of the base of the Duluth Complex and possibly over localization of the Cu-Ni deposits (Holst, et al., 1986). No northeast-trending faults were readily apparent on contoured maps of the basal contact for the entire Hoyt Lakes-Kawishiwi area. Overall, the study conducted by Holst, et al., (1986) failed to locate any of the half-graben rift faults (NE-trending) within the Animikian sediments immediately adjacent to the Duluth Complex. However, both NE-trending and NW-trending faults have been located within the South Kawishiwi intrusion (Foose and Cooper, 1981).

This report is concerned chiefly with rocks of the Partridge River troctolite (PRT) exposed within T.58-59 N., R.13-14 W. Rock types present within the PRT consist predominantly of augite troctolite and troctolite with lesser amounts of olivine gabbro, anorthositic troctolite, and picrite (melatroctolite), and minor peridotite, dunite, melagabbro and anorthosite. Due to a fairly extensive cover of glacial material, most of the detailed rock descriptions of the PRT have been conducted on various drill holes and include: Hardyman (1969; 1 hole - Minnamax); Boucher (1975; 1 hole - Minnamax); Molling (1979; 1 hole - Minnamax); Tyson (1979; 4 holes - Minnamax); Rao (1981; 7 holes - Dunka Road); Al-Alawi (1985; portions of 18 holes - Minnamax); Chalokwu (1985; 1 hole - Minnamax); and Linscheid (in prep; 4 holes - Longnose). Due to the spacing between these drill holes and a general lack of recognizable marker beds, no correlations between these author's works have been attempted. However, despite any recognized internal stratigraphy, the PRT has been divided into various magmatic units on the basis of textural, modal, and chemical differences. Within the Minnamax area, Grant and Molling (1981) divided the PRT into 3 major units on the basis of trace element chemistry; Tyson and Chang (1984) described 5 different units; Ripley and Alawi (1986) divide the PRT into 3 units; and Chalokwu and Grant (1987) divide it into 4 units. Within the Dunka Road deposit area, located within 2 miles to the southeast, Rao and Ripley (1983) subdivided the PRT into at least 3 major units. To date, no attempt has been made to correlate these various subunits of the PRT and to extend the divisions into other drilled areas.

Present Investigation

This progress report is a summary of activities conducted from January to July, 1988. Since new information is constantly added to the data base, the maps, cross-sections and observations included in this report are still preliminary in nature. Core logging has been initiated for selected holes out of a possible 244 holes (274,228 ft.) located within the confines of the study area (Table 1). To date, 37 holes totaling 32,490 feet have been logged and include: 23 holes from the Wetlegs Cu-Ni deposit, 5 holes from the Section 17 Fe-Ti deposit, 3 holes from the Longear Fe-Ti deposit, 3 holes from the Wyman Creek Cu-Ni deposit, and 3 holes from outlying areas. All known holes, and corresponding company lithologic logs, have been compiled and are plotted on Plate I. Structural contour maps of the basal contact, top of the Biwabik Iron Formation, and an isopach map of the Virginia Formation have also been compiled and are plotted on Plates II, III, and IV, respectively. Lithologic data for these maps are included in tables A1 through A7 in Appendix A. Collection of known geochemical values and microprobe data for rocks within the study area have been initiated and are presented in tables A8 and A9 in Appendix A, respectively. Detailed logging and correlation of drill holes for the Wetlegs area has indicated the presence of at least 5 major lithologic units which are portrayed in Plate V. Preliminary cross-sections illustrating the faulted nature of the basal contact in the Wetlegs area have been completed and are shown in Figures 6 through 9. Polished thin section samples (85) have been collected for microprobe work from Wyman Creek, Section 17 and Longear areas.

Table 1

Summary Table of Drill Holes in the Partridge River Intrusion

Deposit Name	No. of Drill Holes	No. of Feet Drilled
Minnamax (Babbitt)	467	569,676
Allen	17	12,990
Dunka Road	122	145,509
Longnose/Longear	15	10,361
Wetlegs	49	53,136
Wyman Creek	27	35,462
Skibo	14	16,770
TOTAL	711	843,904

Though no geochemical samples have been collected yet, 26 representative samples of "unmineralized" rocks have been selected for the Wetlegs area. The rock classification scheme for this study is provided in Appendix B.

Acknowledgements

This project has been funded through the Minerals Diversification Plan of the Minerals Coordinating Committee. Special thanks are extended to Mr. Cedric Iverson (USX), Mr. William Ulland (American Shield Corp.), Mr. Roger Andrews (Kennecott Corp.), and Mr. Douglas Carlson (Reserve Mining) for allowing access to private company records and/or permitting drill core to be logged and sampled. Drill logs and drill core for about one quarter of the holes are located at the Department of Natural Resources, Minerals Division, Hibbing, Minnesota. The general geology of the Hoyt Lakes - Kawishiwi area was obtained from maps and publications of the Minnesota Geological Survey. Discussions with Steven Hauck (NRRI) proved valuable in unraveling some of the complexities inherent within the Duluth Complex. Thanks are also extended to Jayne Reichhoff (NRRI) for aid in completing the figures, tables, and plates of this report.

FOOTWALL STRUCTURE OF THE PARTRIDGE RIVER INTRUSION

Stratigraphic picks from company logs for all drill holes within the study area, including the Minnamax area to the north, have been compiled and are listed in tables A1 - A7 in Appendix A. These picks include the basal contact, the top of the Biwabik Iron-Formation (BIF), and top of the Pokegama Quartzite and Giants Range Granite when encountered. All data were plotted, hand contoured, and computer drafted to produce the following plates: I - drill hole location map, II - basal contact, III - top of BIF, and IV - isopach of the Virginia Formation. The plates exhibit several irregularities that are present in both the basal contact and top of the BIF which indicate more structure than previously recognized (Holst, et al., 1986). Footwall rocks at both the Minnamax and Dunka Road deposits exhibit fold axes that exerted a major control on the basal contact of the Complex and possibly the location of Cu-Ni mineralization. Northeast-trending normal faults (downthrown to the east) and northwest-trending strike slip(?) faults are also indicated in the footwall rocks and support Weiblen and Morey's (1980) half-graben model. The basal structure for each area is described below.

Minnamax (Figure 2)

Several investigators have recognized that pre-existing structural conditions in the footwall rocks of the Minnamax (Babbitt) area strongly influenced the basal contact of the Duluth Complex (Mancuso and Dolence, 1970; Watowich, 1978; Holst, et al., 1986). Irregularities of the basal contact are generally related to folds in the country rock indicating that the intrusion proceeded more or less along bedding planes (Holst, et al., 1986). This is readily expressed by a major EW-trending trough and ridge in the basal contact

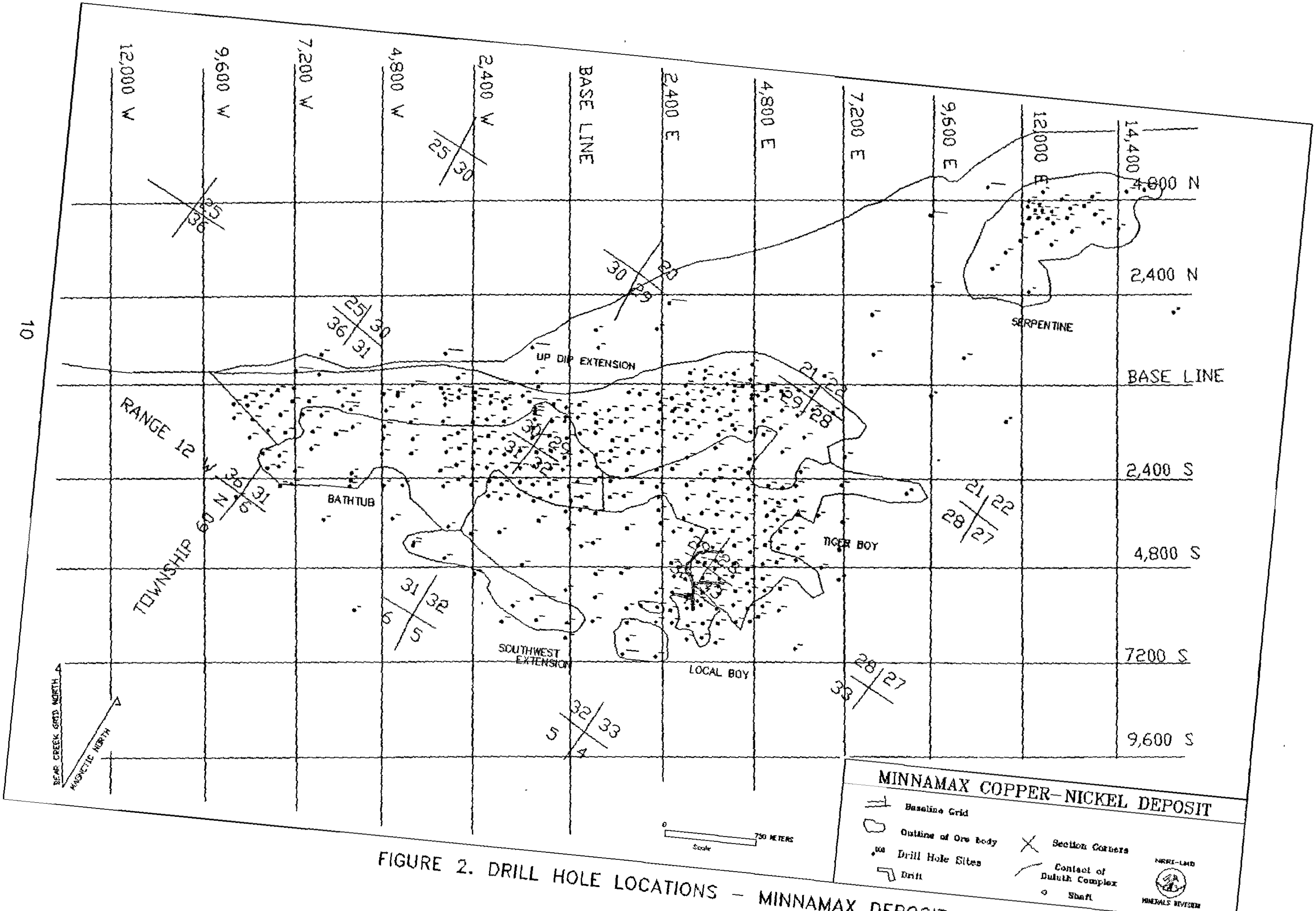


FIGURE 2. DRILL HOLE LOCATIONS – MINNAMAX DEPOSIT

that coincides exactly with a syncline-anticline within the underlying BIF (Plates II and III). Along the northwestern edge of the Minnamax area, the basal contact exhibits steep dips of 30-60°. Within the interior of the Minnamax deposit, the basal contact flattens to near horizontal at the trough and ridge feature. The underlying BIF mimics this morphology in that 25-35° dips are present at the northwestern edge of the Minnamax area and a near horizontal surface is present in the corresponding anticline-syncline which plunges at 2-5° to N 75°E. The thickness of preserved Virginia Fm. (Plate IV) along this trough and ridge feature is variable due to the amount of material assimilated and/or rafted by the Complex. This is indicated by a thinning of the Virginia Fm. "cap" down to 10 ft. in the trough due to a higher degree of assimilation/rafting, and a thickening to over 200 ft. along the ridge. Along the northern edge of the Minnamax area, the amount of Virginia Fm. "cap" present exhibits a drastic increase in thickness of up to 400 ft. due to the steeper dip of the basal contact (30-60°) relative to dips in the underlying BIF (25-35°). Several smaller folds are also present in the footwall rocks of the Minnamax area and include: 1) bifurcation of the EW-trending anticline-syncline in the high-grade Minnamax shaft area which resulted in a highly irregular basal topography resembling lense-shaped domes and basins (Holst, et al., 1986), and 2) several N 40-60°W trending folds in the SW 1/4 of section 29.

Throughout the Minnamax area the footwall rocks are generally pelites, graphitic argillites and calc-silicate units of the Virginia Formation. However, review of drill logs to the east of the shaft area indicates that the Complex is in direct contact with the BIF in eight drill holes (Plate II). Within this area the iron formation has been variably assimilated by the Complex as indicated by the presence of only 15 ft., 45 ft., and 50 ft. of BIF in drill holes BA-2, BI-128, and BI-122, respectively. Several oxide-bearing ultramafic bodies are also reported in holes drilled in this area and an oxide-bearing peridotite has been mapped at the surface in the SW-SW-SW 33-60N-12W. The presence of oxide-bearing ultramafic bodies wherever the Duluth Complex is in contact with the BIF indicates that the two may be genetically related due to massive iron assimilation at the basal contact. Part of a recent proposal submitted to the Minerals Coordinating Committee by personnel from the NRRI and the UMD Geology Department is directed at studying this relationship.

The morphology of the basal contact (Plate II) indicates that at least two major faults are present within the Minnamax area: a northeast-trending reverse(?) fault (north side down) and a north-trending normal fault (east side down). The north-trending fault (fault B-22 in Holst, et al., 1986) has an indicated offset of several tens of feet within the Mesabi Range (Bonnichsen, 1968) but up to 500 ft. of offset is evident in the Minnamax area. This fault bisects an area where the Duluth Complex is in direct contact with the BIF (described above). Since the BIF/Duluth Complex relationship occurs on both sides of the fault, the faults' age is, therefore, presumed to be syn- to post-Complex emplacement. Also, this north-trending fault is the dividing line between the South Kawishiwi and Partridge River intrusions (Morey and Cooper, 1977). A northeast-trending reverse(?) fault extends from the southwest edge of the Minnamax area northeast through the Serpentine deposit. Based on the morphology of the basal contact (this study), the fault may also be inferred to be a right lateral fault with 2500 ft. of movement. In a study conducted by Holst, et al., (1986), the offsets of this fault were explained as being the result of two faults: a north-trending normal fault (DC-3) and a sinuous northeast-trending fault (DC-2) with 200-300 ft. of offset - down to the northwest. However, recontouring of the basal contact (this study) indicates that most of the offset can be explained by one linear NE-trending fault with an offshoot in section 29 (Plate II). Interestingly, several drill holes with "anomalous" PGE values (Morton and Hauck, 1987) are situated along the northeast-trending fault. This situation, however, may be more a function of where Amax conducted a more detailed sampling campaign.

Dunka Road

As at Minnamax, pre-existing structures in the footwall rocks at Dunka Road played an important role in the topography of the base of the Duluth Complex. Structure contours of both the basal contact and top of the BIF delineate a N 30°E trending monocline with apparent offsets by northwest-trending faults (Plates II and III). Dips of the basal contact are around 22-35° along the northwest edge of the deposit but exhibit a dramatic steepening to 45-60° within the interior of the deposit and then a flattening to 18-19° dip along the southeast edge of the deposit (Figure 3 and Plate II). Structure contours of the top of the BIF (Plate III) also indicate a nearly coincident monocline that is located slightly south (200-300 ft.) of the steeply dipping portion of the basal contact. Dips of the BIF top (Figure 4) vary from 18-23° along the edge of the Complex to 40-55° along the monoclinal axis to 16-22° at the southern edge of the deposit (the general dip of the BIF within the eastern Mesabi Range is approximately 5-15°; Grout and Broderick, 1919). Bedding plane angles of the BIF in drill holes within the Dunka Road deposit also confirm a monocline in that measured dip angles are 5-30° along the edge of the Complex, 30-65° along the axis, and 5-25° at the southern edge of the deposit. However, steep BIF bedding planes (30-90°) are also present along the southern edge of the deposit in the NW-SW of section 10 indicating that local folding is present. Whether any NE-trending faults are also present within the Dunka Road monocline cannot be ascertained at this time. The monocline at Dunka Road strikes into the paired

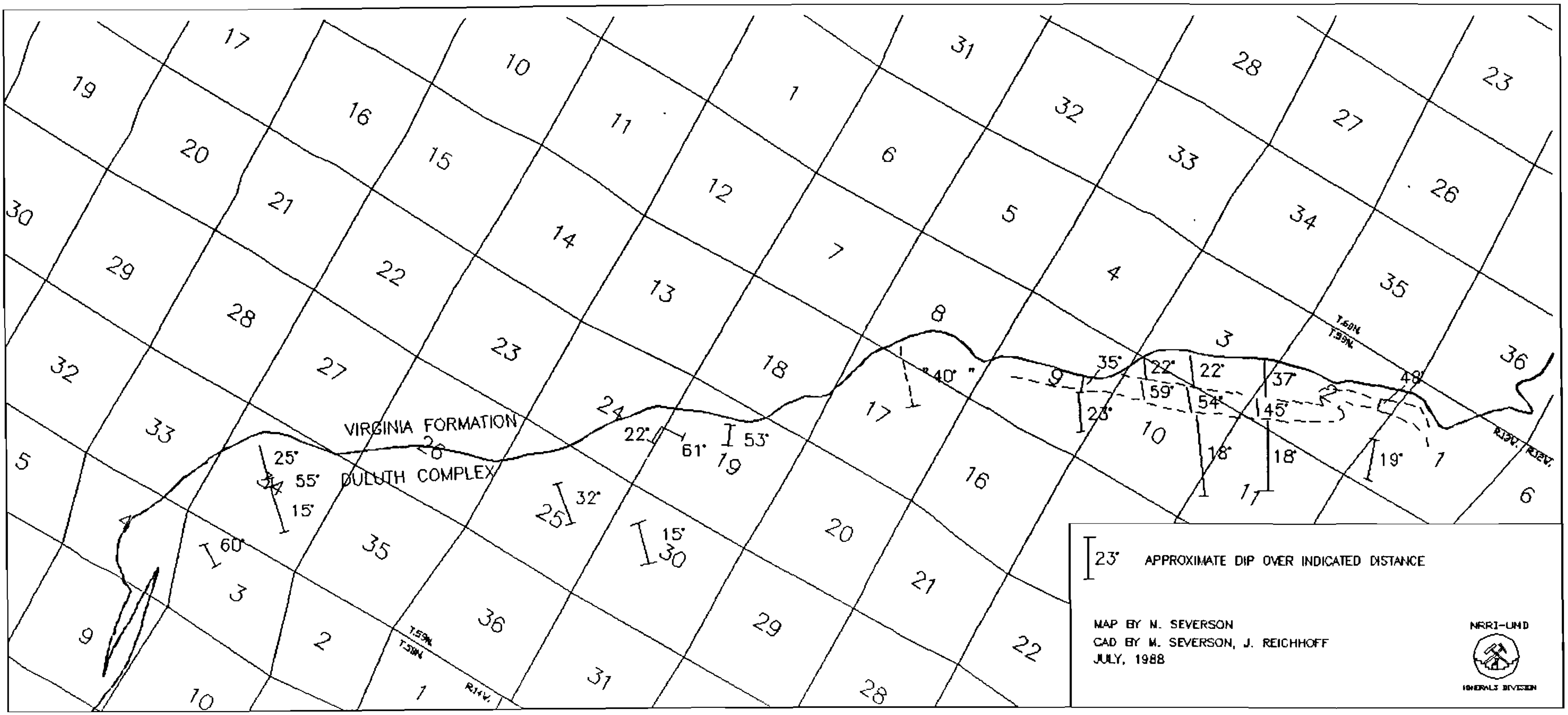


FIGURE 3. BASAL CONTACT DIPS – PARTRIDGE RIVER TROCTOLITE

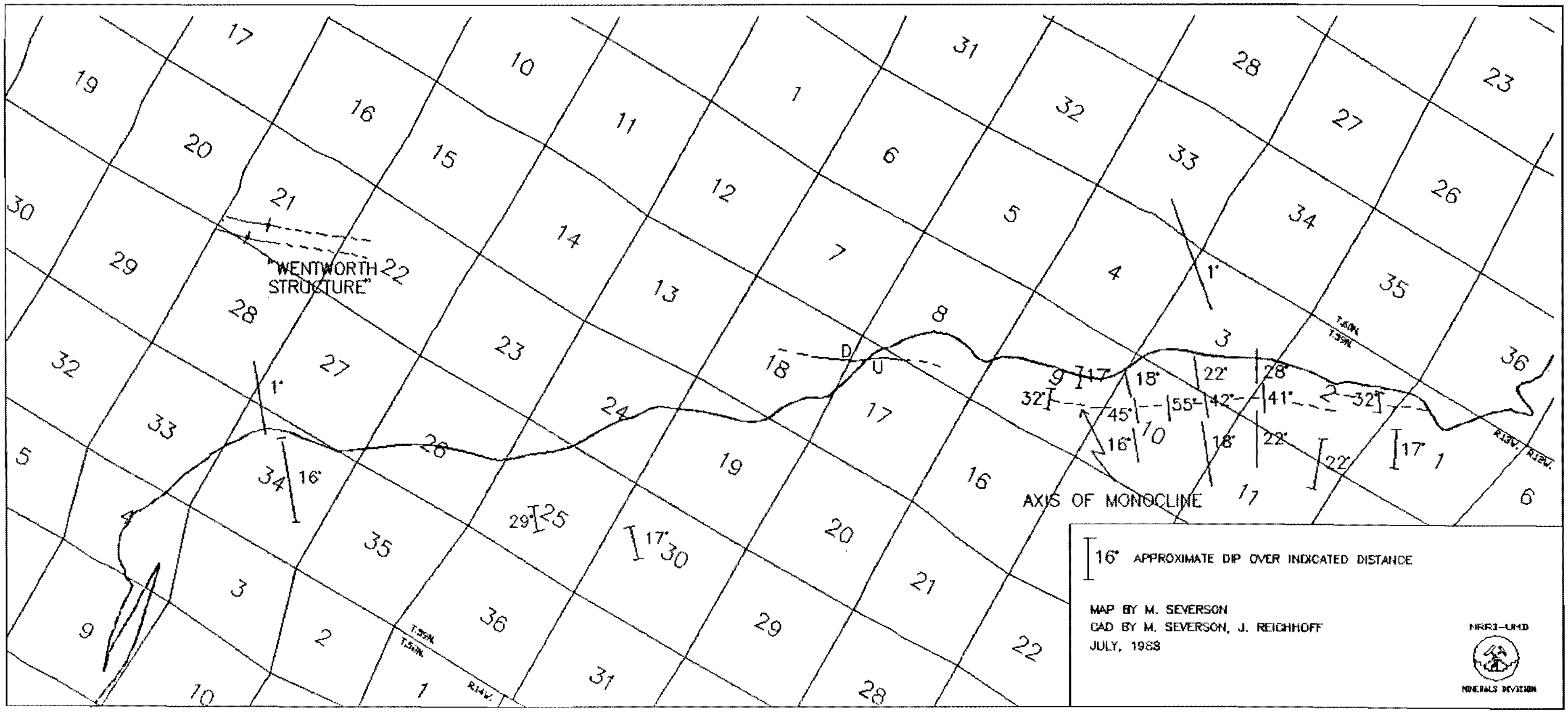
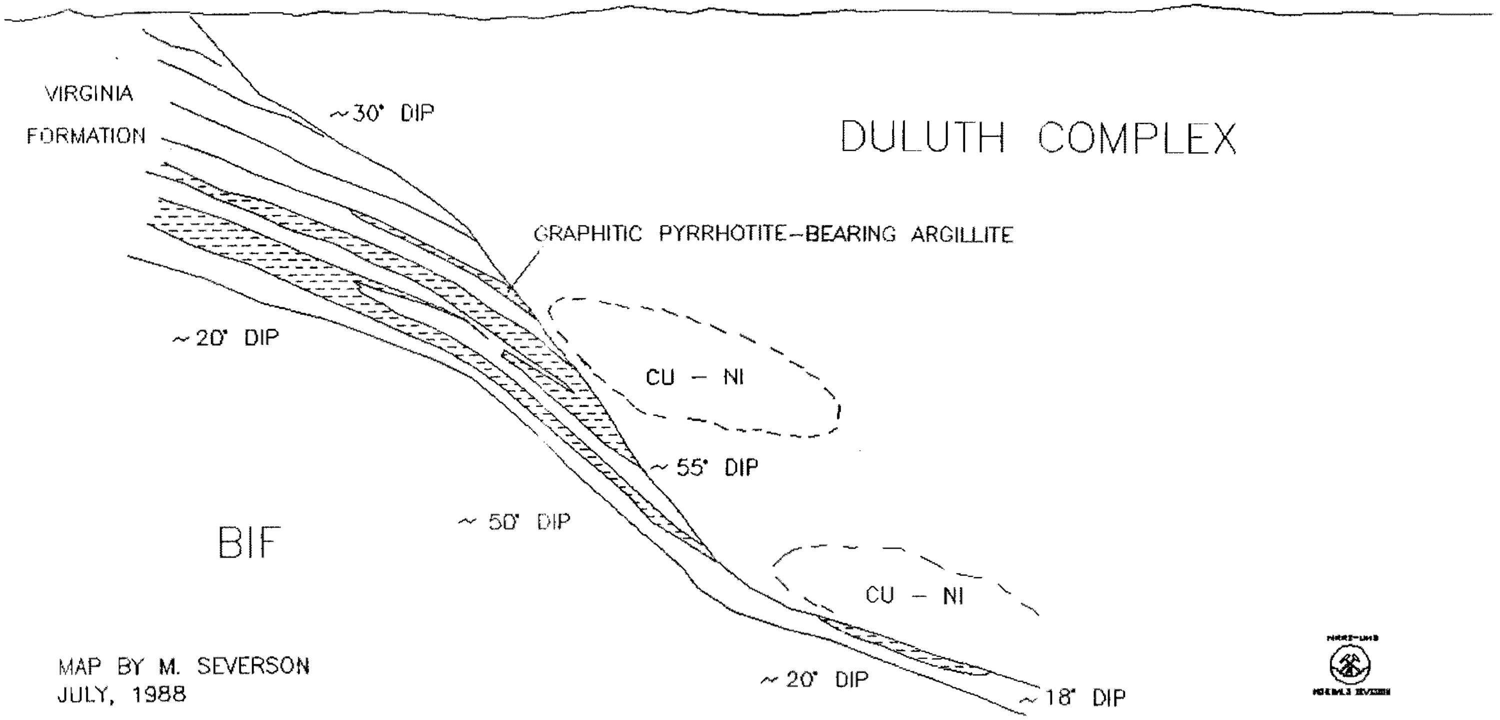


FIGURE 4. DIPS OF THE TOP OF THE BIWABIK IRON-FORMATION – PARTRIDGE RIVER TROCTOLITE

syncline-anticline feature at Minnamax; however, the data are not sufficient to join the two at present.

Isopachs of the Virginia Fm. thickness beneath the Duluth Complex (Plate IV) also indicate that the monoclinal axis within the BIF does not coincide exactly with the steep portion of the basal contact. This is indicated by a thick portion of Virginia Fm. "cap" (200 - 400 ft. thick) located along the northern flank of the monoclinal axis; this relationship is schematically represented in Figure 5. All these data (Plates II, III, IV) indicate that in the Dunka Road area the base of the Duluth Complex was controlled by bedding planes within the Virginia Formation. However, in the vicinity of the monocline, the Complex cross-cut the bedding planes and, thus, encountered a thicker stratigraphic section of the Virginia Fm., i.e., more pyrrhotite-bearing graphitic argillite horizons. Interestingly, a preliminary review of Cu-Ni grades indicates that most of the basal and "cloud" mineralized zones (>0.5% Cu over 50-100 consecutive feet) are situated along the steep portion of the basal contact. Along this zone, an increased local availability of sulfur from graphitic horizons of the Virginia Fm. may be inferred. Other mineralized zones, apparently not directly related to the steep portion of the basal contact, are present in the NE 1/4 of section 10 (basal mineralization south of the monocline) and higher grade Cu-Ni zones are adjacent to NW-trending faults.

Several northwest-trending faults are also evident within the Dunka Road area. These faults trend N 20-40°W and are located in sections 1 and 2 and section 10 (2 parallel faults). They are recognizable as offsets in the steep basal portion of the basal contact (Plate II) and offsets in the monoclinal axis at the top of the BIF (Plate III). The fault in sections 1 and 2 appears to be a left lateral fault with approximately 1500 ft. of movement whereas the southern fault in section 10 appears to be a right lateral fault with approximately 700



MAP BY M. SEVERSON
JULY, 1988

FIGURE 5. SCHEMATIC CROSS-SECTION (N-S) OF THE DUNKA ROAD AREA (NO SCALE IMPLIED)

ft. of movement. The northern fault in section 10 (indicated motion of northeast side up) does not exhibit any appreciable strike-slip movement. These faults are apparently syn-Complex in age as both the BIF and basal contacts are affected; corresponding offsets within troctolitic rocks of the Complex have yet to be demonstrated. Interestingly, high grade copper zones (>1.2% Cu for >20 ft.) occur sporadically around the two NW-trending faults in section 10. Studies of structures within the Mesabi Range to the north (Holst, et al., 1986) failed to locate any continuations of the NW-trending faults inferred to be present in the Dunka Road area (this study).

Wetlegs

Structure contours of the basal contact (Plate II) and the top of BIF (Plate III) do not readily indicate any northeast-trending faults within the Wetlegs area. However, recognition of offset intrusive units within the Complex (to be described later) indicates that several northeast-trending normal faults are present. A northwest-trending fault (northeast side down) is readily apparent in the top of the BIF and basal contact. This fault strikes toward fault B-17 (Holst, et al., 1986); however, they are not the same fault as the relative sense of motion in B-17 is opposite of the Wetlegs area fault (fault 4 in Figures 6 - 9).

The northern NE-trending fault (north side down) in sections 17 and 18 (Plate III and fault 5 in Figures 6 - 9) is based on a projection of the BIF. By projecting the BIF top to the northwest from Wetlegs drill hole intercepts, (using a BIF dip of approximately 20° SE, which is the average bedding plane dip of the BIF in the Wetlegs drill core) the BIF should be exposed within 1600-3200 feet northwest of the exposed Duluth Complex contact. However, the southern edge of the Mesabi Range is actually exposed 9000 ft. northwest of the contact

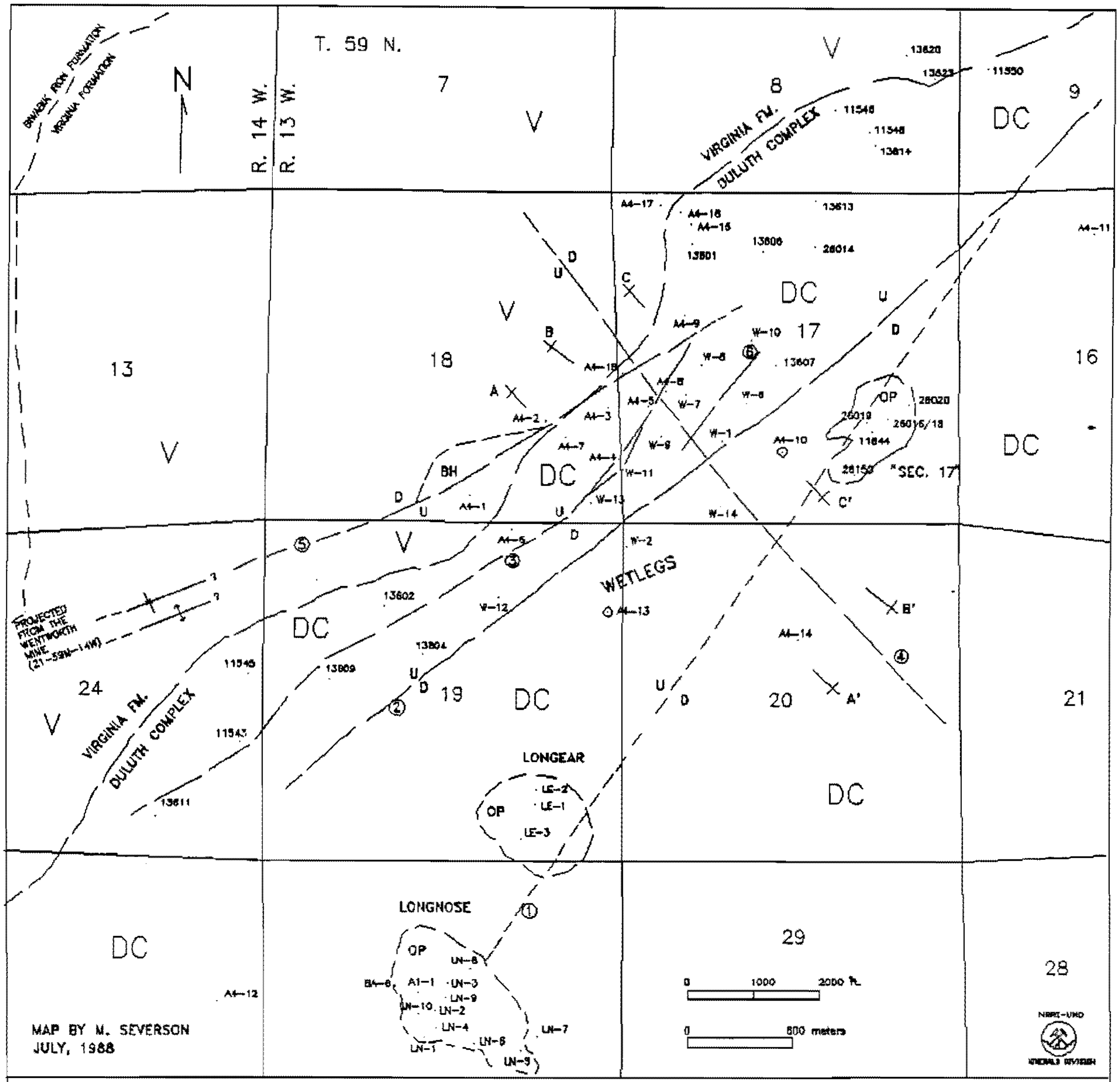


FIGURE 6. WETLEGS AND SURROUNDING AREA (T. 59 N., R. 13 W.)

ROCK UNITS

BH	BASALTIC HORNFELS
OP	PEGMATITIC OXIDE PYROXENITE – PERIDOTITE
DC	DULUTH COMPLEX
V	VIRGINIA FORMATION

SYMBOLS

· 13609	DRILL HOLE AND NUMBER
⊙ A4-13	DRILL HOLE WHERE THE DULUTH COMPLEX IS IN DIRECT CONTACT WITH THE BIWABIK I.F.
——U/D——	INFERRED FAULT WITH INDICATED MOTION (SYN TO POST – DULUTH COMPLEX)
– – U/D – –	INFERRED FAULT WITH INDICATED MOTION (PRE – DULUTH COMPLEX?)
A ⟵ ⟶ A'	LOCATION OF CROSS-SECTION

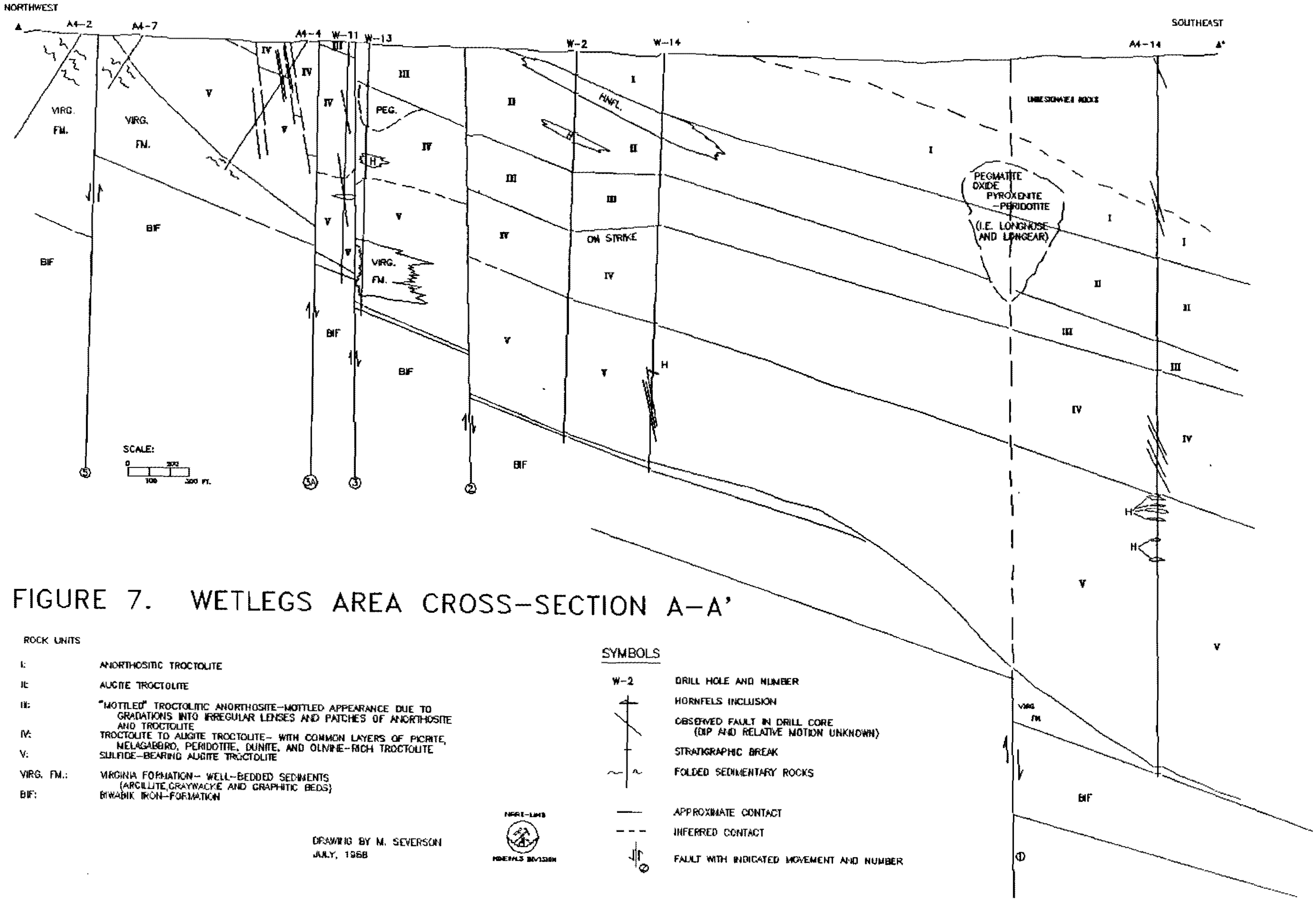


FIGURE 7. WETLEGS AREA CROSS-SECTION A-A'

ROCK UNITS

I:	ANORTHOSITIC TROCTOLITE
II:	AUGITE TROCTOLITE
III:	"MOTTLED" TROCTOLITIC ANORTHOSITE–MOTTLED APPEARANCE DUE TO GRADATIONS INTO IRREGULAR LENSES AND PATCHES OF ANORTHOSITE AND TROCTOLITE
IV:	TROCTOLITE TO AUGITE TROCTOLITE– WITH COMMON LAYERS OF PICRITE, MELAGABBRO, PERIDOTITE, DUNITE, AND OLIVINE-RICH TROCTOLITE
V:	SULFIDE-BEARING AUGITE TROCTOLITE
VIRG. FM.:	VIRGINIA FORMATION– WELL-BEDDED SEDIMENTS (ARGILLITE, GRAYWACKE AND GRAPHITIC BEDS)
BIF:	BIWABIK IRON-FORMATION

SYMBOLS

W-2	DRILL HOLE AND NUMBER
┼	HORNFELS INCLUSION
╲	OBSERVED FAULT IN DRILL CORE (DIP AND RELATIVE MOTION UNKNOWN)
┼	STRATIGRAPHIC BREAK
~ | ~	FOLDED SEDIMENTARY ROCKS
——	APPROXIMATE CONTACT
- - -	INFERRED CONTACT
⇅ ②	FAULT WITH INDICATED MOVEMENT AND NUMBER

DRAWING BY M. SEVERSON
JULY, 1988

NRRI-UMD
MINERALS DIVISION

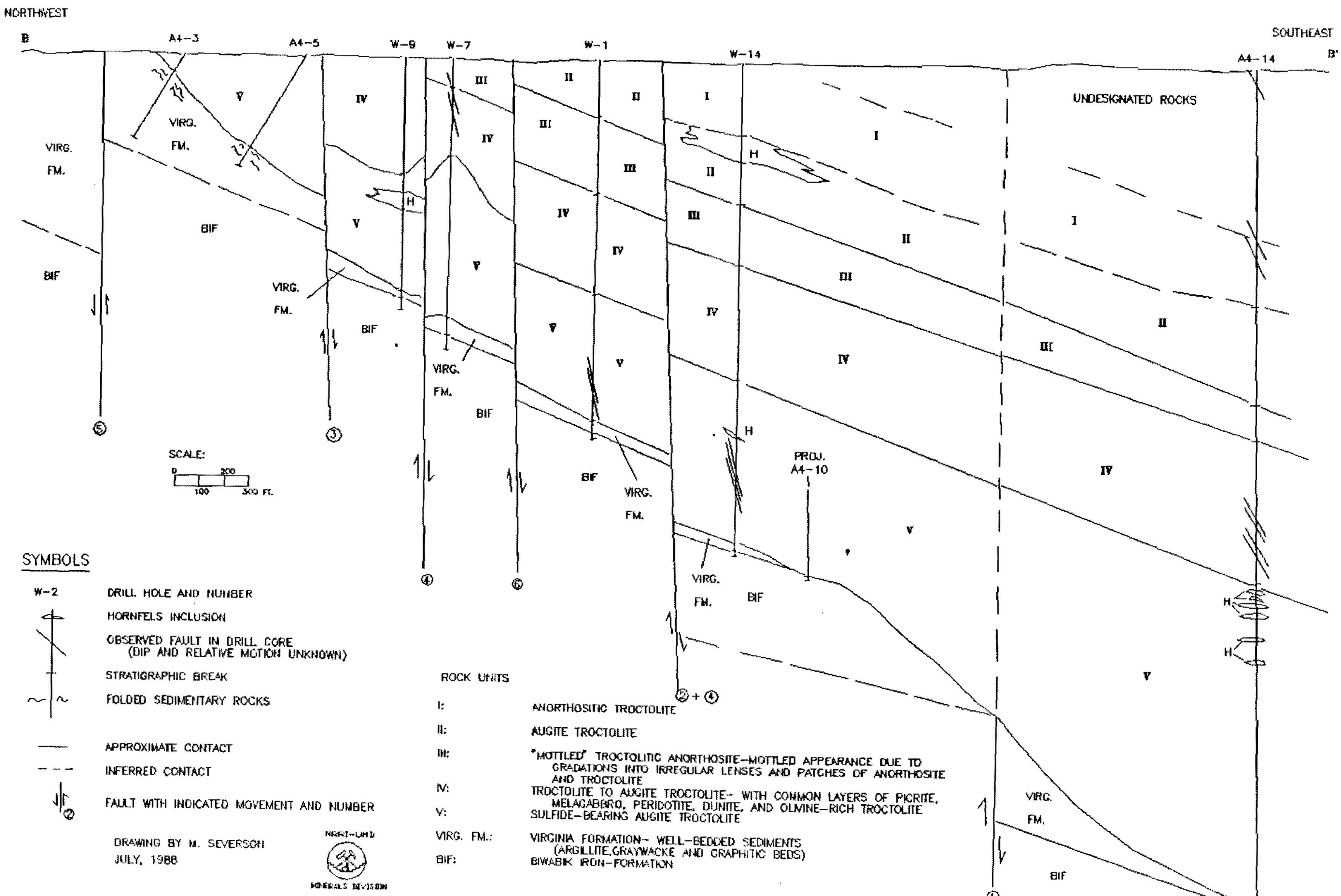
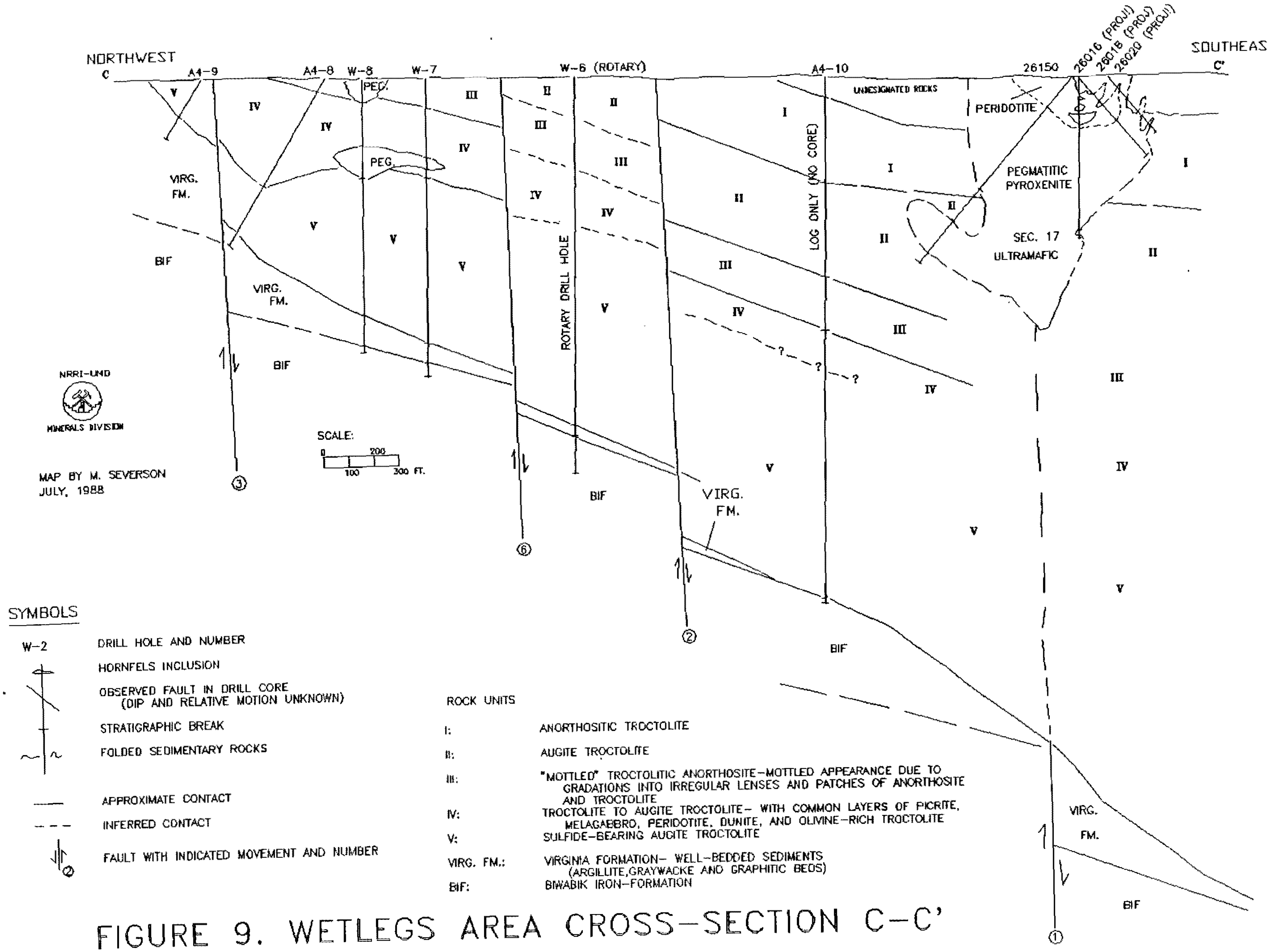


FIGURE 8. WETLEGS AREA CROSS-SECTION B-B'



MAP BY M. SEVERSON
JULY, 1988

SYMBOLS

W-2	DRILL HOLE AND NUMBER
	HORNFELS INCLUSION
	OBSERVED FAULT IN DRILL CORE (DIP AND RELATIVE MOTION UNKNOWN)
	STRATIGRAPHIC BREAK
	FOLDED SEDIMENTARY ROCKS
——	APPROXIMATE CONTACT
- - -	INFERRED CONTACT
②	FAULT WITH INDICATED MOVEMENT AND NUMBER

ROCK UNITS

I:	ANORTHOSITIC TROCTOLITE
II:	AUGITE TROCTOLITE
III:	"MOTTLED" TROCTOLITIC ANORTHOSITE-MOTTLED APPEARANCE DUE TO GRADATIONS INTO IRREGULAR LENSES AND PATCHES OF ANORTHOSITE AND TROCTOLITE
IV:	TROCTOLITE TO AUGITE TROCTOLITE- WITH COMMON LAYERS OF PICRITE, MELAGABBRO, PERIDOTITE, DUNITE, AND OLIVINE-RICH TROCTOLITE
V:	SULFIDE-BEARING AUGITE TROCTOLITE
VIRG. FM.:	VIRGINIA FORMATION- WELL-BEDDED SEDIMENTS (ARGILLITE,GRAYWACKE AND GRAPHITIC BEDS)
BIF:	BIWABIK IRON-FORMATION

FIGURE 9. WETLEGS AREA CROSS-SECTION C-C'

indicating that some form of structural discontinuity is necessary to produce a downdropped BIF to the northwest of Wetlegs. This discontinuity is also substantiated by the fact that A4-2 was drilled into the equivalent of 520 vertical feet of the Virginia Fm. and did not encounter any iron formation. This would be expected by projecting the BIF to the northwest from drill holes W-11 and W-13 (see cross sections - Figure 7). The necessary downdropping of the BIF is depicted as resulting from a fault (north side down) in the maps and cross-sections of this report; however, this structural discontinuity is also on trend with a N 10°E striking paired anticline-syncline exposed 4 miles to the west in the Wentworth Mine (Figure 4). To the east of Wetlegs, this same discontinuity is down strike of the Dunka Road monocline (Figure 4). All three may be the same structure. The presence of a wedge of hornfelsed basalt (North Shore Volcanic Group?) in section 18 at Wetlegs (Tyson, 1976) may also be related to the discontinuity.

Of particular interest in the Wetlegs area is a northeast-trending fault of presumably pre-Keweenawan age (fault 1 on Figures 6 - 9). An indicated offset of 800 ft. down to the southeast is indicated by assuming an average 20° dip in the BIF between drill holes A4-10, A4-14, W-2 and W-14 (see cross-sections - Figures 6 - 9).. However, overlying intrusive units within the troctolitic series (to be described later) do not appear to have been appreciably offset within this area, thus establishing a pre-Keweenawan age. Also suggestive of a pre-Keweenawan age is the inferred presence of a window of BIF in direct contact with the Complex that is reported in drill holes A4-10 and A4-13 (no core available for inspection). This inferred window indicates that as the Duluth Complex magmas intruded along bedding planes and across the fault, the magmas effectively removed/assimilated the Virginia Fm. "cap" and some of the BIF on the upthrown side (northwest) of this structure. Interestingly, the oxide-bearing pyroxenites and peridotites exposed at the surface in the Section 17, Longear and Longnose Fe-Ti deposits correspond to this inferred window (Figure 6). The genetic relationship between assimilated BIF and oxide-bearing ultramafics present in the Minnamax area appears to also be present in the Wetlegs area.

The Siphon fault is located approximately 1.5-2.0 miles to the west within the Mesabi Range (Plates II and III). The fault is apparently Animikian in age based on a decrease in stratigraphic thickness in BIF that occurs from west to east across the Siphon fault (Holst, et al., 1986). Meager data does not justify extending the fault into the Duluth Complex.

Wyman Creek

Chandler (Holst, et al., 1986) has inferred the existence of several northwest-trending faults in the Wyman Creek area on the basis of second-derivative aeromagnetic lineaments. Structure contours of the basal contact (Plate II) and top of the BIF (Plate III) at Wyman Creek are not indicative of any faults with appreciable movement. The basal contact exhibits a dip of approximately 25° along the northern edge of the Complex. The dip then steepens to over 50° between drill holes 26144 and 26132 and then flattens to approximately 15° in the southeastern half of Wyman Creek. The top of the BIF exhibits a uniform 16° dip throughout the Wyman Creek area (Figure 4).

At the southwestern edge of Wyman Creek, the Duluth Complex contact exhibits a rapid change from a northeasterly trend to a nearly north-south trend south to Duluth, Minnesota. Drill hole data at this point of inflection indicate that the basal contact of the Complex is approximately 60° or greater (Figure 3).

Allen Area

Drill holes within the Allen area (sections 3, 10, 15, and 22) are too sparse or not deep enough to reveal much about the basal contact. Several large north-trending rafts of hornfelsed Virginia Fm. have been encountered within the area (see Plate I) which further complicate studies of the basal contact. A fault (DC-1) which occurs along the projected strike of the northwest-trending Dark Lake/Biwabik fault (B-1) has been located within the troctolitic series in section 14 (Holst, et al., 1986). The Denora fault (B-3) has been projected into the Complex as a synformal trough by Holst, et al., (1986). However, extensive faulted and brecciated zones have been reported in the Virginia Fm. in drill hole A2-7 (section 9). This hole is located along the projected strike of the Denora fault indicating that the fault may be continuous into the Complex. An oxide-bearing ultramafic body was encountered in drill hole A-4 located in the SW 1/4 of section 22.

Skibo (Section 34, T.58 N., R.14 W.)

Several drill holes were put down by INCO to test an oxide-bearing ultramafic body situated within the SW 1/4 of section 34. These holes indicated that the basal contact of the Complex dips approximately 35° to the east; no BIF was encountered. A drill hole put down by USS (27016) represents the only core preserved for this area and is currently being investigated by J. Seitz at Washington University - St. Louis, Missouri, with geochemistry support from the NRRI.

Summary

To date, data on the basal contact indicate that pre-existing structures within the Animikian footwall rocks exerted strong control over the topography of the base of the Duluth Complex in the Hoyt Lakes area. This is especially evident in the Minnamax and Dunka Road deposits where fold axes in the underlying footwall rocks closely correspond to NE-trending irregularities in the basal contact. Both NE- and NW-trending faults are apparently present in the Dunka Road and Wetlegs areas and support the half-graben model proposed by Weiblen and Morey (1980). Oxide-bearing ultramafic bodies appear to be spatially related to areas where the Duluth Complex is in direct contact with the underlying Biwabik Iron-Formation. A mechanism of massive iron assimilation by the Complex may partially explain their origin. Data for the Wyman Creek area does not indicate any major structural discontinuities although NW-trending aeromagnetic lineaments have been reported (Holst, et. al., 1986).

LITHOLOGIC DESCRIPTIONS OF INTRUSIVE UNITS WITHIN THE PARTRIDGE RIVER INTRUSION

Detailed relogging of core in the Wetlegs area has culminated in the recognition of 5 major lithologic units within the basal 2000 ft.-2700 ft. of the Partridge River intrusion. Most of these units are present in 26 holes over a 6 square mile area extending from just west of the Dunka Road deposit to just east of the Wyman Creek deposit. Igneous rock names are based on estimated modal percentages of plagioclase, olivine and pyroxene and are depicted in Appendix B. No petrographic descriptions have been completed and the rock descriptions included herein are generalized and megascopic in nature.

Wetlegs Area

All drill holes available for inspection from the Wetlegs area have been relogged. The deepest holes are plotted on Plate V which is arranged in a general SW to NE direction across the Wetlegs area. Note that all holes have been "hung" on the basis of the contact between units III and IV which is the most persistent and easiest to recognize. Unit III was the most important in terms of recognition and acted as a "marker" bed in unraveling the multitude of "troctolitic" rocks present in all the other units. Generalized descriptions of the 5 major units, starting from the basal unit (V) and working upward follows. Sedimentary inclusions, pegmatitic bodies with both sharp and gradational contacts, and faults characterized by brecciated and slickensided serpentine-chlorite zones are present throughout the entire section at Wetlegs.

Unit V - Sulfide-Bearing Augite Troctolite

The lowest unit of the Partridge River intrusion in the Wetlegs area consists dominantly of sulfide-bearing augite troctolite with lesser amounts of augite-bearing troctolite, troctolite, and minor anorthosite troctolite (all sulfide-bearing) and rare picrite/peridotite layers. Grain size is extremely variable, from fine to pegmatitic, but overall the troctolitic rocks are medium to coarse grained. Numerous internal "contacts" are present among the various troctolitic rocks in unit V due to changes in grain size and/or modal percentages of minerals. These contacts range from sharp to gradational (over distances of <1 ft. to tens of feet) and divide unit V into several subunits that are not correlatable from drill hole to drill hole. Thus, unit V is a conglomeration of various troctolitic subunits, all or most of which contain augite and interstitial sulfides. The thickness of unit V is also highly variable (175-1570 ft. thick) due to a nearly horizontal but undulating top and a southeast deepening base that is in contact with the footwall rocks. The top "contact" of unit V is defined by a general decrease in sulfide content (<1%) and/or the appearance of picritic layers characteristic of the overlying unit (IV). However, in some instances the upper contact of unit V is arbitrarily chosen due to the presence of >1% sulfides in unit IV, lack of abundant picrite layers at the base of unit IV, and/or presence of picrite/peridotite layers in the top portion of unit V (Plate IV - drill holes W-7, W-14, A4-4).

Sulfide-"rich" zones (>1%) in unit V are portrayed on Plate V and exhibit a variable distribution from hole to hole. In some drill holes, almost the entire section of unit V is sulfide-"rich", whereas a spotted distribution is present in other holes. The sulfides present include pyrrhotite, chalcopyrite and pentlandite which occur as interstitial grains ranging from <1 mm to 1.5 cm across. The sulfides generally average ~1.0-3.0% but sections with up to 3-5% sulfides, and sections with only trace-0.5% sulfides are also common throughout; local zones (<3 ft.) with up to 10% sulfides may also be present locally. Local sulfide enrichment at the basal contact or around hornfels inclusions may be present in some drill holes but no consistent trend is apparent. A two pyroxene (opx and cpx) olivine gabbro grading to fine grained norite is usually present at the basal contact.

Within unit V is an olivine-rich subzone (Va) which is present in about one half of the Wetlegs drill holes (see Plate IV). This subzone is 7-170 ft. thick and is located about 100-300 ft. above the basal contact in drill holes W-2, W-9, W-11, W-12, A4-4, and A4-5 and 780 ft. above the basal contact in A4-14. The subzone is also characterized by an increase in olivine content manifested by: 1) olivine-rich troctolite or troctolite or augite troctolite grading into abundant picritic patches, 2) picrite grading into olivine-rich troctolite, and/or 3) picrite/peridotite layers. The picrite/peridotite layers are fine to medium grained, vary from 7-13 ft. thick and exhibit sharp tops and bottoms.

Inclusions of Virginia Fm. are common within unit V and vary from over 275 ft. thick (W-13) down to 6 inches thick. A zone of abundant Virginia Fm. inclusions is present approximately 50-550 ft. above the basal contact in drill holes W-9, W-11, W-12, and W-13 and 950-1350 ft. above the basal contact in A4-14. The distribution of this hornfels-rich zone implies that the inclusions were relatively in their original position as the lowest portion of unit V was intruded sill-like into the Virginia Fm. Bedding planes of the inclusions within this zone vary from highly contorted to 30-50° (most common) indicating that some rotation of the sedimentary rafts occurred during emplacement of the Partridge River intrusion. Massive floatation of individual blocks of hornfels, as has been suggested by several authors, does not appear to be the cause for this hornfels-rich zone.

Several laterally discontinuous picrite/peridotite layers (up to 4 horizons in A4-4) are occasionally encountered near the top of unit V (see Plate V).

These layers vary from 1-13 ft. thick and exhibit gradational to sharp tops and sharp bases. These rocks are commonly serpentinized which has imparted a strong foliation with dips of 80°.

Unit IV

Unit IV averages approximately 450 ft. thick (150-620 ft. range) and is characterized by abundant picrite-peridotite-dunite layers and minor melagabbro layers within medium grained troctolite and/or augite troctolite. These layers (picrite and peridotite dominant) are fine to medium grained and vary from 8 in. to 36 ft. thick, although most of the layers average either 5-18 ft. or 1-2 ft. thick. They often exhibit internal banding (alternating olivine and plagioclase-rich laminae down to 1 cm thick) and/or a serpentinized foliation with dips of approximately 5-20° (range of 5-40°). Sharp bases are always present and tops exhibit both sharp and gradational contacts with the enclosing troctolitic rocks. Some of the layers exhibit modal grading characterized by picritic tops and dunite bases. The layers are laterally discontinuous and rarely can any one layer be correlated with other layers in more than 2 drill holes. The amount of picrite/peridotite layers in individual drill holes is also extremely variable due to their discontinuous nature (note: only one picrite layer in W-13). Also present within unit IV are abundant <2 ft. thick patches of picrite grading into the troctolitic rocks. Rocks in which the picrite and peridotite layers are enclosed are generally medium grained troctolite but augite troctolite is more common in some of the holes. Sulfide-"rich" (>1%) zones are sporadically distributed throughout both the troctolitic rocks and picrite-peridotite-melagabbro layers. Hornfels inclusions are also sporadically distributed throughout unit IV; sulfide enriched zones show a crude correlation with hornfels inclusions.

The lowest portion of unit IV (unit IVa on Plate V) is characterized by either: 1) a thick picrite horizon, 2) a thick olivine-rich troctolite horizon plus or minus gradational picritic patches, 3) an augite troctolite with picritic layers and/or gradational picritic patches, and 4) several closely spaced picrite and/or peridotite layers within troctolite and/or augite troctolite. Unit IVa varies from 7-190 ft. thick and is not present in some drill holes (see Plate V) due to a laterally discontinuous nature.

Near the top of unit IV a pegmatitic anorthositic troctolite is present in some drill holes. The extreme top of unit IV is characterized by a persistent peridotite layer that averages 5 ft. thick (6 in. - 11 ft. range). This was encountered in all but 2 drill holes that intersected a complete section. In some holes, this layer exhibits modal grading from picrite through dunite, and in a few holes the layer is characterized by either picrite, dunite or melagabbro. The peridotite layer is commonly serpentinized/foliated with dips of 10-30° (20° average).

Unit III

Unit III is the major "marker bed" in the Wetlegs area due to an unusual texture that is immediately recognizable in drill core. This texture is characterized by a fine grained troctolitic anorthosite that constantly grades into irregular patches (<1 ft.) of anorthosite, anorthositic troctolite, troctolite, and picrite giving the rock an overall mottled appearance. The distribution of olivine is highly irregular and occurs as interstitial material and oikocrysts up to 3 cm across within a plagioclase-rich rock. Plagioclase is generally lath-shaped and arranged in a decussate texture. Locally, pyroxene and oxides occur as oikocrysts. Since the distribution of olivine is so erratic, the core has to be "looked at from a distance" in order to assign an overall rock name of troctolitic anorthosite.

Unit III averages about 250 ft. thick (135-450 ft. range) and commonly grades down into medium to coarse grained troctolitic anorthosite and/or augite troctolite in several holes (see Plate V). The base of unit III is in sharp contact with the persistent peridotite layer of unit IV in all but 2 holes. The top of unit III is in sharp contact with unit II; a picrite, peridotite and melagabbro layer is present in 3 holes at the base of unit II. Hornfels inclusions within unit III are present in several holes. Sulfide mineralization is rare within unit III (except in the top of 26014).

Unit II

Unit II is characterized by a medium to coarse grained augite troctolite with abundant thick sedimentary hornfels inclusions in W-2, W-14. The rock is relatively uniform in texture and modal proportions although gradations to olivine gabbro and thin pegmatitic zones may be locally present, i.e., W-2. Sulfides are present but are generally rare throughout this unit. Pegmatitic bodies with sharp contacts are present in 2 holes. Unit II has been intersected in 5 Wetlegs area drill holes and averages about 400 ft. thick (300 - 465 ft. range). Unit II is not present in drill hole W-1 possibly due to a fault offset (fault zone noted in drill core about 20 ft. above unit III - see Plate V). The base of unit II is in sharp contact with unit III - an ultramafic layer is present at the base in 3 drill holes. The top contact with unit I is generally sharp.

Unit I

Unit I has only been intersected by 6 holes and averages about 250 ft. thick (200 - 350 ft. range). This unit is characterized by a medium to coarse grained (locally pegmatitic) augite-bearing anorthositic troctolite that locally grades to olivine gabbro and troctolitic anorthosite. Rare thin sedimentary hornfels inclusions and rare sulfide-bearing (> 1%) zones are present in drill holes W-1 and W-14, respectively.

Troctolitic series rocks above unit I have only been intersected in two holes in the Wetlegs area and thus no correlations can be made at this time. In drill hole A4-14, 750 ft. of rock has been intersected above unit I and consists of troctolite grading to augite troctolite with 3 picrite and 2 peridotite horizons. Troctolite with lesser amounts of gabbroic anorthosite was intersected in the top 400 ft. of hole A4-11. Within the top half of A4-11, abundant basaltic hornfels inclusions are also present with a combined thickness of 96 ft. In the lower half of A4-11, abundant picrite layers are intermixed with troctolite and gabbroic anorthosite.

Footwall Rocks

Within the Wetlegs area, the lowest 400 ft. of Virginia Fm. has been intersected in several holes. The rock is generally well bedded and is characterized by graphitic argillites, argillites, and siltstone with minor recrystallized biotite schist, graywacke, calc-silicate beds, massive cordierite-bearing argillite and chert. The graphitic argillites commonly exhibit weakly to highly contorted bedding planes and contain up to 5 - 10% very finely disseminated and bedded pyrrhotite. Planar to ptygmatic pyrrhotite beds averaging 1 - 2 mm thick (up to 1 cm) are also present in some graphitic argillite horizons. Planar "undeformed" beds in the argillites and graphitic argillites commonly exhibit dips ranging from 20-45°. Interestingly, the planar bedding planes in the large hornfels inclusions exhibit the same range - rarely are near vertical beds encountered. Recrystallized biotitic argillite with decussate arranged biotite flakes/plates are commonly intermixed with the argillites. Primary bedding is occasionally preserved (planar to highly contorted) but these recrystallized sediments commonly exhibit a massive decussate texture. Inclusions of highly contorted bedded siltstones with sharp contacts with the surrounding rock are commonly found in the recrystallized biotitic argillite indicating a mobile partial melt nature. Partial melt granites ranging from irregular-shaped wisps (<1 cm thick) to 10-20 ft. thick bodies (rare) are present within the Virginia Fm. The contact with the underlying Biwabik Iron-Formation is generally sharp.

The upper slatey member of the Biwabik Iron Formation (BIF) was intersected in 13 Wetlegs drill holes. Submembers present within the BIF (after Gundersen and Schwartz, 1959) include: submembers: A - coarse grained bedded to massive marble (present in 7 out of 13 holes), B - layered diopside-chert taconite, and C - thinly laminated quartz taconite with ferrohypersthene, fayalite and magnetite. Bedding plane dips within the core are generally 10-30°; however, steeper dips (35-70°) are present in a NE-trending belt which includes drill holes W-9, W-11, W-12, W-13, and W-14.

Miscellaneous

Numerous pegmatitic bodies in sharp contact with the troctolitic rocks are present in all 5 units of the Wetlegs area. They are extremely variable in rock type ranging from anorthosite and troctolitic anorthosite to olivine gabbro; anorthositic troctolite (excepting drill hole A4-8), troctolite and augite-troctolite are generally rare. Their size is also extremely variable ranging from 1 ft. thick to larger bodies measured in tens of feet (see Plate V). Some of the pegmatite bodies contain abundant sulfides whereas others are barren - there is no clear-cut distinction between rock type and presence of sulfides. Oxide-bearing (>10%) pegmatitic olivine gabbros are also dispersed throughout the 5 units (at least seven >5 ft. thick bodies were intercepted in the drill holes).

Numerous fault zones were also intersected by several holes. They are characterized by a brecciated to crumbly slickensided chlorite-serpentine mixture plus or minus calcite-plagioclase-quartz veins and veinlets. Contacts with the surrounding rocks exhibit both a gradational (into altered country rock) and sharp nature.

Inclusions of Virginia Fm. are present throughout the entire section at Wetlegs. Rock types are the same as described earlier for the footwall rocks. There is no 1:1 correlation of sulfide content to hornfels content at Wetlegs.

Structural Correlations - Wetlegs Area

Division of the Partridge River intrusion into major units provides an excellent opportunity to examine any fault offsets present in both the footwall and troctolitic rocks of the Wetlegs area. Cross-sections (Figures 6 - 9) were prepared utilizing the major units and assuming that they dip around 20°. Two marker beds were instrumental in locating fault offsets and include: 1) the top of the BIF (average dip of approximately 20°), and 2) the persistent peridotite bed at the top of unit IV (average foliation/banding of approximately 20°). Major faults that offset both marker beds are portrayed in Figures 6 - 9. Faults directly observed in drill core are also shown on the cross-sections but they are not extended to the basement as their trend and dip are unknown.

The pattern that emerges for the Wetlegs area is a series of NE-trending normal faults based on correlation of faults within and between the 3 parallel cross-sections (A-A’, B-B’, and C-C’; Figures 7 - 9). All of these faults exhibit a pronounced offset in both BIF and top of unit IV (that is when using an assumed 20° dip). Fault #1 is distinctly different from the other NE-trending faults in that an offset of about 500 ft. in the BIF is indicated but no appreciable movement is present in the overlying troctolitic units - from these relationships this fault is inferred to be pre- or early-Keweenawan. On the upthrown NW side of fault #1, two drill hole logs (A4-10, A4-13) indicate that the Duluth Complex directly overlies the BIF - thus a window of BIF is inferred to exist within the Wetlegs area. Corresponding to this window are 3 oxide-bearing ultramafic bodies (Section 17, Longear, Longnose) also arranged in a NE-trending pattern. Note that the offset within the basement along fault #1 may also be shown as being due to a NE-trending monoclinal structure.

Fault #4 is the only major NW-trending fault within the Wetlegs area. This fault is readily apparent in the contoured basal contact (Plate II) and strikes toward faults B-17 and B-18 (Holst, et al., 1986) exposed within the open pits of the Mesabi Range. Fault #5 is based on inferred downdropping of the BIF necessary to explain why no iron formation was encountered in drill hole A4-1, and why the Mesabi Range is not exposed closer to the Wetlegs area (as would be expected by projecting the BIF to the surface from Wetlegs drill hole intercepts). This structure may also be explained by NE-trending folds that may be correlative with a paired anticline-syncline in the Wentworth Mine area (located 4 miles downstrike to the west) and/or the Dunka Road monocline (located 1.5 miles downstrike to the east - Figure 4).

All of the NE-trending faults of the Wetlegs area correspond to NE-trending topographic lows. Even fault #1, which is inferred to be pre-Keweenawan, is closely aligned with the NE-trending portion of Wetlegs Creek and a large swamp located southwest of the creek toward the Longear ultramafic body. This suggests that fault #1 may have been reactivated while the Partridge River intrusion was still a crystal mush and provided a structural weakness along which the Section 17, Longear and Longnose bodies were intruded.

Correlation of Wetlegs Units to Outside Areas

Several holes located between Wetlegs and Wyman Creek (southwest), and Dunka Road (northeast), have been logged and indicate that most of the Wetlegs units are present. Toward Wyman Creek (holes A4-12, BA-6, W-3, and 26152) units I, II, IV, and V were intercepted but unit III is missing. A cursory review of drill hole A-5 (Allen area) indicates that unit III is again present to the south of Wyman Creek. Review of USS drill logs indicates that units I, II, IV, and V are present in the Wyman Creek area.

Unit V contains a few sporadic sulfide-bearing (> 1%) zones between Wetlegs and Wyman Creek but thicker sulfide-bearing zones are again present at Wyman Creek. Several large sedimentary rafts are also present between units IV and V in the Wyman Creek area (review of USS logs). Unit Va is present in all 4 holes located between Wetlegs and Wyman Creek.

Toward the northeast (holes A4-11 and 26014) units I, II, III and V are present. However, unit IV is missing in A4-11 and may not be present in 26014 (only one picrite horizon). The persistent peridotite horizon at the top of unit IV is missing in 26014 and thins to a <1 ft. thick picrite in A4-11.

The lateral distribution and pinch out of certain Wetlegs units, to both the west and northeast of the Wetlegs area, suggests an irregular stacked pattern of intrusive pulses. Continued logging of core will aid in the further delineation of major intrusive units of the Partridge River troctolite and their spacial relationships. This will also aid in locating faults that are not readily evident in the contoured maps of the basal contact.

Summary

An internal stratigraphy that is correlatable between 26 drill holes has been established for the Wetlegs and outside areas. Recognition of these units has provided a basis for interpreting structural offsets within the troctolitic rocks. Several NE-trending normal faults have been located, which supports the half-graben model of Weiblen and Morey (1980). A pre-Keweenawan fault may be present in the area along which a window of Biwabik Iron-Formation is in direct contact with the Duluth Complex. The correspondence of several oxide-bearing ultramafic bodies to this inferred window suggests that the two may be genetically related due to massive iron assimilation by the Complex.

Division of the Wetlegs area troctolitic rocks into 5 major units has provided an internal stratigraphy upon which drill holes in outlying areas may be correlated. An irregular overlapping relationship of these units is apparent due to pinching out of certain units away from the Wetlegs area. After a complete internal stratigraphy of the Partridge River intrusion is established, background geochemical values, yet to be obtained, from the major units (and their subunits) should prove more meaningful if any geochemical signatures are present. Additional faults, not clearly recognizable as offsets in the basal contact, may also be delineated, as has been done in the Wetlegs area.

GENERAL DESCRIPTION OF OXIDE-BEARING ULTRAMAFICS - PARTRIDGE RIVER INTRUSION

Three oxide-bearing ultramafic bodies are located to the east and southwest of the Wetlegs area (see Plate I). They are arranged in a NE-trending pattern that coincides with an inferred window of BIF at the basal contact of the Partridge River intrusion. A general description of these bodies progressing from NE to SW follows.

Section 17

Five holes put down by USS (26106, 26018, 26019, 26020, 26150) into the Section 17 oxide-bearing ultramafic have been logged (T.59 N., R.13 W.). The rock type that is the most dominant in Section 17 is a very coarse grained to pegmatitic oxide-bearing pyroxenite containing about 0.5-5% plagioclase, 5-15% olivine (overall percent), 60-80% pyroxene (titanaugite >> augite), 5-20% oxides, and rare-3% sulfides. Olivine content is highly variable as the rock commonly grades into 2 in.-2 ft. peridotite patches throughout. Thick horizons (5-30 ft. thick) of coarse grained oxide-bearing peridotite (40-70% olivine, 15-25% pyroxene, 10-15% oxides) are present in a few holes (top 130 ft. of 26150 and 50% of the top 1/2 of 26018) and exhibit gradational contacts with the surrounding pyroxenites. The general distribution of these thick peridotite horizons indicates that they are more common in the core of this body.

Alternating bands of peridotite and pyroxenite were noted in two zones within 26018 and exhibit a dip of 0-20°. Also within 26018 is a zone in which peridotite and pyroxenite are intricately mixed with highly irregular contacts between the two rock types - whenever planar contacts are present within this zone they exhibit subhorizontal dips. Often present within the peridotites and other olivine-rich zones (all drill holes) are closely spaced hairline to 1.0

mm wide serpentine-chlorite filled planar fractures that dip around 0-20°. Whenever one of these fractures crosses a pyroxene crystal it thins dramatically to hairline width.

Within the pyroxenites, and occasionally the peridotites, are some semi-massive (50-80%) oxide horizons up to 7 ft. thick containing subzones of massive-oxides (>80%) up to 1 ft. thick. These oxide enriched zones are generally uncorrelatable between holes. The oxides in both the enriched horizons and the pegmatitic pyroxenite occur as either equant cumulus grains (<1.5 cm) often concentrated in clusters and crude bands (rare), or as interstitial, irregular grains and blades between pyroxene crystals. Ilmenite content is generally greater than titanomagnetite (visual estimate).

Sulfide content generally ranges from trace to 3% (locally 3 - 5%) in the tops of some holes, but exhibits a downward decrease in all 5 holes to rare-trace amounts. Pyrrhotite is by far the most dominant sulfide (>95%) and occurs as both <1 mm round droplets within pyroxene and olivine, and as interstitial grains (up to 5 mm) adjacent to oxides and pyroxene. Chalcopyrite, and rare bornite, almost always occur on the periphery of pyrrhotite. In general, sulfide content increases whenever olivine and/or oxide content increases but there are numerous exceptions to this statement. Two occurrences of massive pyrrhotite patches (<1.5 in.) were noted.

The pegmatitic pyroxenite body of Section 17 is in sharp contact with the troctolitic series rocks and is clearly younger. This is demonstrated in drill core by: 1) near vertical sharp contacts, 2) abundant small lenses of pegmatitic pyroxenite within the troctolitic rocks adjacent to the larger body of pyroxenite, and 3) a moderately developed foliation present within the troctolitic rocks (intersected in drill hole 26020) which is cross-cut by a sharp pegmatitic pyroxenite contact - the pyroxenite itself is not foliated or fractured. Troctolitic "country" rocks were intersected in three holes (26016, 26020, and 26150). The troctolitic rocks encountered correspond to Wetlegs units I, II and a portion of the troctolitic rocks overlying unit I. The spatial relationship of the pegmatitic pyroxenite to the Wetlegs units for the three drill holes is portrayed in cross-section C-C' (Figure 9).

Longear

The Longear prospect is located 1.5 miles southwest of the Section 17 prospect. Three angle holes (LE-1, LE-2, LE-3) were put into this near-surface ultramafic body by American Shield Corporation of Duluth, Minnesota. Longear is characterized by alternating coarse grained and pegmatitic oxide-bearing pyroxenites exhibiting both abrupt and sharp contacts between the two rock types (multiple pulses). Overall, rock types are similar to Section 17 except that only minor thin peridotite horizons were intersected in the three drill holes at Longear. The pyroxenites contain about 0.5-10% plagioclase, 0.5-10% olivine, 60-90% titanaugite, and 5-25% oxides (excepting oxide enriched zones which contain up to 95% oxides at the expense of cpx). Sulfides are present as trace amounts to 0.5% in the top half of all three drill holes but sulfide content decreases to rare amounts with depth. The highest percentages of sulfides are generally associated with olivine-rich and/or oxide-rich zones. In the middle of LE-3 the sulfide content increases to 1-3% in a 50 ft. zone between two peridotite horizons. Chalcopyrite is generally present in greater amounts than pyrrhotite.

The oxides exhibit a variable nature characterized by: 1) skeletal blebs, 2) interstitial grains, 3) round "cumulate" grains (2 mm - 1 cm) that are often concentrated in patches, 4) long slender blades adjacent to pyroxene crystals, and 5) oxides poikilitically enclosed in pyroxene. Semi-massive oxide (50-80%)

and massive oxide (>80%) zones up to 10 ft. thick are more commonly intersected in the Longear holes than at Section 17. Some of the >50% oxide zones at Longear can be correlated between drill holes. Ilmenite is generally present in much greater amounts than titanomagnetite in the pyroxenites and semi-massive oxide zones but the reverse is true of massive oxide zones at depth.

Troctolitic series "country" rocks, with abundant small lenses of pegmatitic oxide-bearing pyroxenite, were encountered in all three Longear drill holes. Both the lenses and main pyroxenite body exhibit sharp contacts with the enclosing troctolitic rocks and in one case, the pyroxenite contained troctolitic inclusions (bottom of LE-3). Unit II (augite troctolite of Wetlegs area) was intersected at the bottom of all three holes. Unit I (anorthositic troctolite) was intersected near the top of LE-1. The top 32 ft. of LE-3 consists of layered troctolite and dunite (dips of 10°) correlative with rocks above unit I, i.e., equivalent of the 248-284 ft. zone in drill hole A4-11(?).

The drilled portions of both Longear and Section 17 are similar in that: 1) pegmatitic pyroxenite is the dominant rock type, 2) sulfide content decreases to rare to trace amounts with depth, and 3) troctolitic "country" rocks correspond to Wetlegs units I, II and rocks higher up in the stratigraphic sequence. Major differences between the two include: 1) gradational peridotite patches and horizons are more common in the "core" of Section 17, 2) overall oxide content is higher at Longear which also contains more semi-massive and massive oxide zones, and 3) although sulfide content is generally lower at Longear, chalcopyrite is dominant over pyrrhotite.

Longnose

Twelve holes have been put down into the Longnose prospect which is located 1/2 miles southwest of Longear. A review of four holes by Linscheid (in prep) indicates this oxide-bearing ultramafic body is intrusive into the Partridge

River troctolite. The ultramafic body is crudely concentrically zoned with a dunite core grading outward and downward through peridotite and pegmatitic pyroxenite. Several massive to semi-massive oxide zones (3-4) are present within the core dunite and apparently can be correlated between drill holes. Sulfides are a minor constituent at Longear, occurring in amounts of trace - 2%, and chalcopyrite accounts for about 99% of the sulfides (Linscheid, in prep). A cursory review of LN-5 and LN-6 by the author indicates that the rock types are similar to the Longear and Section 17 prospects except that dunite and peridotite are more dominant at Longnose.

Summary

All three oxide ultramafic bodies are intrusive into the Partridge River intrusion and are arranged in a NE-trending fashion that coincides with an inferred window of BIF in the footwall rocks. Massive assimilation of iron by the Partridge River intrusion may have produced these late stage intrusives. However, the source of titanium is unknown (a recent proposal by the NRRI is aimed at resolving these questions). Many similarities and differences occur in all three ultramafic bodies. Section 17 and Longear are similar in that pyroxenite is the dominant rock type and sulfide content decreases with depth. Longnose is dominantly dunite and peridotite with a pyroxenite "rind", but gradations to peridotite are also common within the "core" of Section 17. Though the dominant rock types are different in Longnose and Longear prospects, both contain several massive to semi-massive oxide zones and chalcopyrite is the dominant sulfide. Section 17 contains more sulfides but pyrrhotite is the dominant sulfide. The overall chalcopyrite content is approximately the same for all three prospects. Geochemical sampling and future microprobe and petrographical studies will be aimed at the similarities and differences between the pyroxenites and peridotites.

CONCLUSIONS

All data collected to date have added immensely to an understanding of the Duluth Complex and its related ore deposits. Contouring of the basal contact of the Complex and top of the Biwabik Iron Formation has indicated more structure within the Partridge River intrusion than previously recognized. Northeast to east-trending fold axes have been recognized at both Minnamax and Dunka Road. These structures exerted a strong control over the topography of the base of the Duluth Complex and possibly the location of the Cu-Ni deposits. Numerous NE-trending normal faults and northwest-trending strike slip faults are also indicated as offsets in the basal contact and underlying Biwabik Iron- Formation. Though not readily apparent in the contoured basal contact at Wetlegs, several NE-trending normal faults have been delineated by utilizing offsets of both the Biwabik Iron-Formation and internal units of the troctolitic rocks (that is when an assumed 20° average dip is used in projecting units between the drill holes). The pattern that emerges from this study is that both NE-trending and NW-trending faults are present within the Partridge River intrusion which supports the half-graben model proposed by Weiblen and Morey (1980). Mineralization appears to be related to some of these fault systems. "Anomalous" PGE values occur along a NE-trending fault at Minnamax and thin high-grade copper zones occur along a NW-trending fault at Dunka Road, but their relationships are, as yet, unknown and more data are needed.

Studies of the basal contact have also indicated that oxide-bearing ultramafics are commonly associated with areas where the Partridge River troctolite is in direct contact with the Biwabik Iron-Formation rather than the Virginia Formation. This suggests that the origin of the ultramafic bodies may be related to massive iron assimilation at the basal contact followed by redeposition in late stage intrusives. Three such late stage pegmatitic bodies are present in the Wetlegs vicinity and are arranged in a NE-trending fashion that closely corresponds to an inferred window of BIF at the basal contact. The window is apparently related to a pre-Keweenawan fault that may have been reactivated during intrusion of the PRT. Each of the ultramafic bodies is different when viewed separately but gross similarities are collectively present.

Division of the troctolitic rocks at Wetlegs has provided a convenient data base on which to "hang" drill holes of the Partridge River troctolite. As more data are added in the form of relogged core, a lateral and vertical stratigraphy of overlapping units may be established for the entire basal portion of the PRT. This type of control has long been lacking for the area, and previous studies of one or two drill holes have remained floating in a sea of troctolite. Once an internal stratigraphy is established, background geochemical values for a variety of rock types may be more fully understood. The geochemistry will help in understanding the origin of the PRT and its relationship to the emplacement of the Duluth Complex. Also, the geochemistry on the unmineralized rocks of the PRT may provide further insights into the origin and emplacement of the Cu-Ni-Ti mineralization. Additional faults not readily apparent as offsets in the basal contact may be recognized, as has been done at Wetlegs.

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APPENDICES

Appendix A1

Minnamax (Babbitt) Cu-Ni Deposit
Drill Hole Lithologic Breaks

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
RMC 67034	1602.1			54	1548	130	1472					76	
RMC 67037	1609.1			48	1561	171	1438					123	
RMC 67042	1602.0			VF*		167	1435					>167	170+
RMC 67046	1573.2			18	1555	111	1462					93	208+
RMC 59029	1600.0			108	1492	452	1148					344	
RMC 66225	1600.1		1340	1101	499	1169	431			1318	282	68	149
RMC 59033	1600.0			VF		194	1406					>194	
RMC 61094	1611.9			124	1488	185	1427					61	
RMC 61097	1611.3			87	1524	193	1418					106	
RMC 64040	1630.4			225	1405	433	1197					208	
RMC 64046	1603.1			127	1476	175	1428					>48	
RMC 64048	1601.5			101	1500	214	1388					>113	
RMC 64052	1606.7			37	1570	105	1502					68	
RMC 64060	1592.6			75	1518	163	1430					88	
RMC 65011	1599.9			VF		94	1506					>94	
RMC 65246	1598.3			VF		364	1234					>364	
RMC 65223	1609.2			123	1486	199	1410					76	
RMC 65249	1546.4			VF		93	1453					>93	
RMC 65260	1599.3			VF		357	1242					>357	
RMC 66010	1607.6			95	1513	159	1449					64	
RMC 66012	1612.4			25	1587	95	1517					70	
RMC 66014	1608.1			390	1218	437	1171					47	
RMC 66017	1595.8			285	1311	340	1256					55	
RMC 66305	1586.9			204	1383	621	966					417	
RMC 66313	1587.7			1002	586	1002	586					0	
BA-1	1595.0		3130	3023	-1428	3060	-1465					37	
1	1620.9	60	520	172	1449								
2	1553.0	60	906	623	930								
3	1565.0	45	932	211	1354								
4	1544.0	60	1018	751	793								
5	1528.0	60	795	385	1143								
6	1584.8	60	700	223	1361								
7	1545.0	60	1004	776	769								
8	1535.5		756	645	891								
9	1531.4		465	419	1112								
10	1542.3		692	641	902								
11	1575.3		275	71	1504								
12	1557.2		486	366	1191								
13	1573.7		456	300	1274								
14	1578.2		566	404	1175								
15	1579.6		126		1580								
16	1585.7		93		1586								
17	1585.9		576	534	1052								
18	1583.9		685	648	936								
19	1612.3		512	472	1140								
20	1608.8		249	218	1391								
21	1613.9		831	632	982								
22	1608.8		1055	904	705	1030	579					126	
23	1592.2		977	704	888	920	672					216	
24	1590.4		1590	1503	87	1583	8					80	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
25	1606.5		512	405	1202								
26	1617.0		434	342	1275								
27	1543.4		1186	1095	448								
28	1608.5		1234	1104	505	1206	403					102	
29	1591.9		1703	1652	-60	1672	-80					20	
30	1563.2		1248	1007	556								
31	1607.0	45	608	151	1456								
32	1630.0	60	589	412	1218								
33	1567.2		1726	1652	-85	1689	-122					37	
34	1597.9	55	1921	1509	89	1524	74					15	
35	1529.5		800		1530								
36	1548.0	41	929										
37	1556.0	45	600										
38	1528.0	75	1103										
39	1593.1		1800	1585	8	1619	-26					34	
40	1604.2		1226	1179	425	1198	406					19	
41	1599.4		1606	1518	81	1530	69					12	
42	1598.0		1649	1332	266	1591	7					259	
43	1531.0		1043	989	542								
44	1530.0	50	308	207	1323								
45	1540.0		351	244	1296								
46	1558.0	50	474										
47	1538.0	50	348										
48	1538.7	45	350										
49	1535.4	50	350										
50	1528.8	55	350										
51	1624.0	50	893	575	1050								
52	1609.0	50	165	25	1584								
53	1606.0	50	101										
54	1602.0	50	405	288	1314								
55	1600.0	45	479	301	1299								
56	1602.0		1430	1223	379	1384	218					161	
57	1596.0		964	681	915	932	664					251	
58	1596.0		1962	1507	89	1552	44	1950	-354	1960	-364	45	398
59	1613.0		794	677	936	772	841					95	
60	1601.0		1851	1735	-134	1812	-211					77	
61	1589.0		2088	1899	-310	2052	-463					153	
62	1557.0		634	578	979	593	964					15	
63	1537.0		997	896	641	947	590					51	
64	1531.0		2083										
65	1547.1		2320	2240	-693	2240	-693					0	
66	1600.0		2344	2272	-672	2327	-727					55	
67	1543.0		835	815	728	826	717					11	
68	1553.0		2534	2354	-801								
69	1609.0		2024	1965	-356	2006	-397					41	
70	1561.0		674	536	1025	646	915					110	
71	1540.0		674	605	935	664	876					59	
72	1540.0		722	587	953	694	846					107	
73	1595.3		1675	1590	5	1645	-50					55	
73A	1595.3	85		1571	24	1637	-41					66	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
74	1589.0		505	454	1135								
75	1557.0		554	488	1069	502	1055					14	
76	1552.0		1214	1122	430	1167	385					45	
77	1544.0		724	551	993	668	876					117	
78	1592.5		1675	1614	-22	1667	-75					53	
78A	1592.5			1611	-19	1651	-59					40	
79	1550.0		582	468	1082	562	988					94	
80	1550.0		685	561	989	651	899					90	
81	1601.0		1436	1367	234	1406	195					39	
81A	1601.0												
82	1591.8		1701	1645	-53	1695	-103					50	
83	1565.0		605	567	998	592							
84	1567.0		515	312	1255	491	1076					179	
85	1597.7		1676	1618	-20	1672	-74					54	
86	1560.0		605	563	997	587	973					24	
87	1542.0		635	604	938	604	938					0	
88	1593.1		1437	1394	199	1394	199					0	
89	1549.0		715	637	912	686	863					49	
90	1591.1		1680	1627	-36	1669	-78					42	
91	1601.5		1609	1586	16	1600	2					14	
92	1591.9		1678	1575	17	1671	-79					96	
93	1553.0		662	557	996	653	900					96	
94	1601.5		1625	1543	59	1622	-21					79	
95	1597.0		1535	1387	210								
96	1597.3		1635	1470	127	1606	-9					136	
97	1594.9		1675	1616	-21								
98	1595.2		1317	1299	296	1305	290					6	
99	1604.6		1465	1321	284	1454	151					133	
100	1589.0		1785	1761	-172	1773	-184					12	
100A	1589.0		1785	1772	-183								
100B	1589.0			1751	-162								
101	1597.9		1595	1528	70	1592	6					64	
102	1609.4		1685	1497	112	1683	-74					186	
103	1611.2		1617	1569	-150	1612	-162					12	
104	1597.0		2181	2142	-545	2155	-558					13	
105	1611.0		1921	1861	-250	1904	-293					43	
106	1603.0		1301	1290	313	1299	304					9	
107	1535.0	60	232	122	1413								
108	1535.0	55	423	87	1448								
109	1581.0		1525	1447	134	1495	86					48	
110	1533.0	60	354	185	1348								
111	1557.0	50	573	385	1172								
112	1590.0		1197	1145	445	1195	395					50	
113	1531.0	50	973	592	939								
114	1551.4	50	1163	487	1064	882	670					394	
115	1588.8	60	933	512	1077	773	816					261	
116	1604.0		1805	1721	-117	1775	-171					54	
117	1598.0		1837	1788	-190	1835	-237					47	
118	1613.0		1817										
118A	1613.0												

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
119	1588.0		2043	1958	-370	2015	-427					57	
120	1624.0		2095	1927	-303	2057	-433					130	
121	1589.0		1844	1776	-187	1826	-237					50	
122	1564.0		2525	2427	-863	2427	-863			2479	-915	0	52
123	1597.0		930	866	731	909	688					43	
124	1590.0		1934	1851	-261	1891	-301					40	
125	1596.0		981	539	1057	953	643					414	
126	1600.0		1054	655	945	1025	575					370	
127	1602.0		1895	1790	-188	1870	-268					80	
128	1586.0		2995	2880	-1294	2937	-1351			2983	-1397	0	46
129	1615.0		1985	1909	-294	1961	-346					52	
130	1605.0		1827	1637	-32	1816	-211					179	
131	1606.0		1945	1729	-123	1920	-314					191	
132	1602.0		1820	1595	7	1789	-187					194	
133	1596.6		1813	1667	-70	1767	-170					100	
134	1616.0		1906	1744	-128	1895	-279					151	
135	1601.0		1779	1453	148	1758	-157					305	
136	1602.0		1855	1633	-31	1843	-241					210	
137	1610.0		1996	1935	-325	1977	-367					42	
138	1587.0		1843	1743	-156	1837	-250					94	
139	1605.0		1828	1651	-46	1819	-214					168	
140	1621.0		1993	1819	-198	1975	-354					156	
141	1613.0		1997	1865	-252	1996	-383					131	
142	1587.0		1765	1664	-77	1763	-176					99	
143	1574.0		2082	1994	-420	2056	-482					62	
144	1588.2		1825	1738	-150	1793	-205					55	
145	1566.0		2105	2045	-479	2085	-519					40	
146	1585.0		1949	1855	-270	1992	-407					137	
147	1585.0		1931	1873	-288	1909	-324					36	
148	1584.1		2016	1954	-370	2011	-427					57	
149	1584.0		2055	1941	-357	2013	-429					72	
151	1597.2		1945	1893	-296	1930	-333					37	
152	1594.2		2008	1787	-193	1977	-383					190	
150	1577.7		1985	1883	-305	1982	-404					99	
153	1599.0		1975	1895	-296	1968	-369					73	
154	1589.0		1939	1779	-190	1919	-330					140	
155	1579.6		2085	2038	-458	2051	-471					13	
156	1586.0		1875	1685	-99	1835	-249					150	
157	1586.0		2203	2145	-559	2145	-559					0	
158	1584.0		1907	1801	-217	1891	-307					90	
159	1584.0		1955	1903	-319	1928	-344					25	
160	1604.0		1875	1675	-71	1851	-247					176	
161	1594.8		1795	1702	-107	1769	-174					67	
162	1588.9		1782	1673	-84	1766	-177					93	
163	1633.0		2050	1888	-255	2040	-407					152	
164	1595.5		1125	1071	525	1121	475					50	
165	1603.6		1010	692	912	991	613					299	
166	1604.9		46										
167	1596.0		831	505	1091	778	818					273	
168	1576.0		1080	986	590	1050	526					64	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
169	1532.5		1185	1091	442	1146	387					55	
170	1554.0		675	490	1064	612	942					122	
171	1566.0		654	596	970	624	942					28	
172	1560.0		592	394	1166	536	1024					142	
173	1602.9		2028	1750	-147	2007	-404					257	
174	1554.0		654	597	957	607	947					10	
175	1566.0		617	585	981	589	977					4	
176	1574.0		556	469	1105	538	1036					69	
177	1562.0		758	708	854	732	830					24	
178	1562.0		586	407	1155	538	1024					131	
179	1561.0		802	724	837	751	810					27	
180	1593.1		1710	1465	128	1665	-72					200	
181	1536.0		771	722	814	730	806					8	
182	1542.0		836	559	983	720	822					161	
183	1597.8		2113	2034	-436	2083	-485					49	
184	1617.2		1780	1906	-289	1956	-339					50	
185	1551.0		831	752	799	765	786					13	
186	1529.5		1111	333	1197	1047	483					714	
187	1611.0		586	365	1246	536	1075					171	
188	1618.0		611	190	1428	592	1026					402	
189	1588.5		2115	2062	-474	2108	-520					46	
190	1606.0		156	67	1539								
191	1621.0		1066	998	623	1047	574					49	
192	1610.0		730	568	1042	710	900					142	
193	1604.0		895	863	741	887	717					24	
194	1569.3		1641	1579	-10	1610	-41					31	
195	1578.0		1415	1350	228	1406	172					56	
196	1598.0		1266	1225	373	1259	339					34	
197	1586.5		1920	1825	-239	1913	-327					88	
198	1619.0		691	268	1351	678	941					410	
199	1602.0		1259	1130	472	1202	400					72	
200	1599.2		317	197	1402								
201	1599.6		580	36	1564	574	1026					538	
202	1599.7		1516	1381	219	1480	120					99	
203	1609.2		1908	1832	-223	1902	-293					70	
204	1596.0		640										
205	1589.1		1207	1150	439	1164	425					14	
206	1528.2		1356	1194	334	1312	216					118	
207	1581.4		1505	1440	141	1475	106					35	
208	1584.7		1531	1301	284	1510	75					209	
209	1586.3		1965	1901	-315	1945	-359					44	
210	1563.4		1456	1283	280	1434	129					151	
211	1586.6		2085	2073	-486	2076	-489					3	
212	1589.5		1845	1793	-204	1827	-238					34	
213	1562.5		1507	1344	219	1495	68					151	
214	1586.0		1995	1905	-319	1982	-396					77	
215	1568.9		2005	1930	-361	1995	-426					65	
216	1590.6		1795	1726	-135	1761	-170					35	
217	1595.1		2028	1997	-402	2009	-414					12	
218	1580.9		1645	1558	23	1635	-54					77	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
219	1595.0		2035	1935	-340	2005	-410					70	
220	1594.0		1775	1674	-80	1747	-153					73	
221	1588.0		1734	1655	-67	1703	-115					48	
222	1590.0		2062	1950	-360	2037	-447					87	
223	1589.0		2065	2009	-420	2039	-450					30	
224	1566.0		1479	1306	260	1459	107					153	
225	1579.6		2095	2052	-472	2063	-483					11	
226	1573.0		1814	1725	-152	1796	-223					71	
227	1597.0		2125	2060	-463	2114	-517					54	
228	1586.0		1778	1666	-80	1756	-170					90	
229	1581.0		2276	2257	-676	2257	-676					0	
230	1587.0		1952	1821	-234	1946	-359					125	
231	1599.0		1994	1882	-283	1974	-375					92	
232	1559.0		2695	2665	-1106	2665	-1106					0	
233	1590.0		2005	1863	-273	1987	-397					124	
234	1594.0		1994	1937	-343	1993	-399					56	
235	1586.0		2055	1912	-326	2044	-458					132	
236	1588.0		2135	2040	-452	2120	-532					80	
237	1583.1		1598	1548	35	1563	20					15	
238	1598.0		2095	2043	-445	2068	-470					25	
239	1598.0		2025	1955	-357	2019	-421					64	
240	1589.0		2035	1893	-304	2006	-417					113	
241	1589.0		1963	1703	-114	1942	-353					239	
242	1591.8		2023	1901	-309	2004	-412					103	
243	1596.0		2038	1997	-401	2029	-433					32	
244	1595.9		2106	2029	-433	2078	-482					49	
245	1580.0		1910	1715	-135	1895	-315					180	
246	1601.8		2016	1877	-275	1997	-395					120	
247	1585.0		1995	1869	-284	1975	-390					106	
248	1575.0		1933	1885	-310	1913	-338					28	
249	1591.0		2125	2032	-441	2094	-503					62	
250	1596.0		2005										
251	1576.0		1745	1728	-152	1744	-168					16	
252	1572.4		2082	2046	-474	2046	-474					0	
253	1590.1		1955	1855	-265	1931	-341					76	
254	1586.9		2031	1915	-328	2017	-430					102	
255	1593.8		1809	1547	47	1787	-193					240	
256	1589.5		640	378	1212								
257	1574.1		1885	1798	-224	1843	-269					45	
258	1589.2		755	690	899								
259	1660.4		1936	1831	-171	1918	-258					87	
260	1598.1		955	855	743	935	663					80	
261	1586.6		2034	1966	-379	2022	-435					56	
262	1571.8		2132	1969	-397	2103	-531					134	
263	1599.3		1240	993	606	1238	361					245	
264	1581.4		766	477	1104	746	835					269	
265	1610.1		755	570	1040	752	858					182	
266	1602.9		1415	1201	402								
267	1589.9		1225	1042	548	1205	385					163	
268	1588.7		2101	2043	-454	2091	-502					48	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
269	1595.5		1678	1596	-1	1675	-80					79	
270	1579.0		553	465	1114								
271	1586.0		1075	790	796	1046	540					256	
272	1587.1		1940	1837	-250	1917	-330					80	
273	1576.5		1189	1098	479	1160	417					62	
274	1583.5		425	279	1305								
275	1588.8		543										
276	1588.8		1435	1327	262	1418	171					91	
277	1570.8		1831	1773	-202	1805	-234					32	
278	1570.0		997	832	738	986	584					154	
279	1599.5		1635	1510	90	1627	-28					117	
280	1579.6		1315	1191	389	1301	279					110	
281	1611.2		2155	2075	-464	2132	-521					57	
282	1609.5		529	259	1351	509	1101					250	
283	1610.1	45	572	272	1339								
284	1610.8		535	305	1306								
285	1593.0		1080	1000	593	1070	523					70	
286	1564.7		932	712	853	923	642					211	
287	1609.7	38	580	96	1514								
288	1589.8		1780	1710	-120	1760	-170					50	
289	1609.7		1485	1468	142	1478	132					10	
290	1604.7		925	847	758	917	688					70	
291	1583.2		1550	1440	143	1530	53					90	
292	1560.1		1127	1021	539	1121	439					100	
293	1596.6		2050	1990	-393	2035	-438					45	
294	1603.3		935	663	940	929	674					266	
295	1606.9		2315	2231	-624	2285	-678					54	
296	1591.5		1715	1704	-113	1710	-119					6	
297	1604.4		1748	1692	-88	1744	-140					52	
298	1602.4		1611	1264	338	1561	41					>152	
299	1584.5		2068	1980	-396	2060	-476					80	
300	1594.6		1860	1830	-235	1850	-255					20	
301	1590.5		1812	1740	-150	1785	-195					45	
302	1608.0		2066	1973	-365	2044	-436					71	
303	1592.1		1874	1790	-198	1865	-273					75	
304	1610.0		1725	1638	-28	1702	-92					64	
305	1595.4		1525	1159	436	1262	333					103	227
306	1591.5		1664	1630	-39	1655	-64					25	
307	1606.4		1685	1571	35	1679	-73					108	
308	1574.7		1820	1560	15	1800	-225					240	
309	1579.7		1395	1258	322	1375	205					117	
310	1610.7		517	243	1368	493	1118					250	
311	1583.3		780	310	1273	765	818					455	
312	1577.3		1281	1210	367	1275	302					65	
313	1611.8	45	413	125	1487								
314	1571.0		900	790	781	890	681					100	
315	1607.0		1786	1634	-27	1734	-127					100	
316	1592.7		1655	1572	21	1648	-55					76	
317	1586.6		758	481	1106	757	830					276	
318	1550.6		1180	1010	541	1155	396					145	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
319	1562.7		1375	1245	318	1364	199					119	
320	1608.7		2150	1992	-383	2095	-486					103	
321	1564.8		411	117	1448								
322	1553.9		795	648	906								
323	1584.2		825	480	1104	819	765					339	
324	1589.7		1796	1663	-73	1775	-185					112	
325	1553.4		1211	1059	494	1200	353					141	
326	1545.8	45	593	327	1219								
327	1633.3		2341	2224	-591	2301	-668					77	
328	1589.0		425	352	1237								
329	1568.6	50	747	491	1078								
330	1607.7		2287	2234	-626	2277	-669					43	
331	1578.1		955	737	841	937	641					200	
332	1588.2	60	447	248	1341								
333	1529.8		805	686	844								
334	1571.3		1185	1017	554	1173	398					156	
335	1613.7	75	575	397	1217								
336	1591.5		415										
337	1548.8		697	559	990								
338	1584.8		829	384	1201	803	782					419	
339	1612.3	45	403	128	1484								
340	1545.7		599	478	1068								
341	1566.1	50	843	603	963								
342	1562.4		965	637	925	743	819					106	
343	1619.8	55	363	188	1431								
344	1536.1		866	647	889								
345	1531.2	60	874	334	1197								
346	1609.6	50	513	234	1375								
347	1530.5		385	354	1177								
348	1530.7		1023	911	620								
349	1531.8	50	331	96	1436								
350	1609.7		785	450	1160	744	866					294	
351	1531.8	60	364	204	1327								
352	1529.0	60	843	596	933								
353	1603.0		815	403	1200	773	830					370	
354	1528.5	60	455	272	1257								
355	1567.3		1865	1825	-258	1855	-288					30	
356	1596.3		1845	1745	-149	1815	-219					70	
357	1597.4		1712	1617	-20	1688	-91					71	
358	1590.4		1831	1715	-125	1821	-231					106	
359	1595.6		2055	1932	-336	2032	-436					100	
360	1597.6		1735	1659	-61	1713	-115					54	
361	1595.1		2158	2091	-496	2154	-559					63	
362	1597.8		1911	1883	-285	1895	-297					12	
363	1592.0		1723	1691	-99	1701	-109					10	
364	1594.5		1705	1620	-26	1689	-95					69	
365	1608.7		625	466	1143	612	997					146	
366	1608.2	80	626	413	1195	588	1020					175	
367	1590.4		1661	1645	-55	1651	-61					6	
368	1598.6		1873	1857	-258	1866	-267					9	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
369	1590.4		1583	1532	58	1575	15					43	
370	1609.0	45	282	49	1560								
371	1599.5		2154	2020	-421	2092	-493					72	
372	1610.3		1371	1196	414	1359	251					163	
373	1600.8		795	667	934								
374	1605.0		445	284	1321								
375	1565.6		365										
376	1573.3		825	797	776								
377	1560.8		815	446	1115								
378	1565.2		965	851	714								
379	1543.1		1100	1010	533								
380	1573.8		1361	1280	294	1346	228					66	
381	1552.2		1113	1065	487								
382	1558.7		945	783	776								
383	1560.3		1195	1031	529	1169	391					138	
384	1550.5		1273	1222	329								
385	1555.8		1485	1384	172	1443	113					59	
386	1576.2		1292	1215	361	1285	291					70	
387	1532.3		965	786	746								
388	1533.8		1214	1057	477	1198	336					141	
389	1590.0		1434	1159	431	1420	170					261	
390	1542.8		1420	1330	213	1411	132					81	
391	1555.6		1238	1174	382	1224	332					50	
392	1578.4		1471	1305	273	1465	113					160	
393	1541.4		1079	825	716	1071	470					246	
394	1583.4		1795	1553	30	1769	-186					216	
395	1532.9		1285	1149	384	1268	265					119	
396	1554.6		1294	1056	499	1283	272					227	
397	1559.2		1347	1230	329								
398	1528.3		1211	1088	440	1208	320					120	
399	1579.4		1355	1288	291	1341	238					53	
400	1623.1		1018	944	679	1014	609					70	
401	1619.7		983	950	670	979	641					29	
402	1535.2		1275	1185	350	1259	276					74	
403	1623.2		595	539	1084								
404	1602.0		1099	1041	561	1093	509					52	
405	1602.3		1223	1136	466	1211	391					75	
406	1535.9		1247	1203	333	1229	307					26	
407	1623.1		977	864	759	955	668					91	
408	1612.5		1305	1235	378	1297	316					62	
409	1619.0		1969	1697	-78	1955	-336					258	
410	1621.2		759	609	1012	742	879					133	
411	1626.9		465	398	1229								
412	1607.4		1300	1140	467	1293	314					153	
413	1610.3		525	416	1194								
414	1561.9		2065										
415	1608.5		245	105	1504								
416	1594.1		365										
417	1603.6		215										
418	1618.5		235										

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)++	ELEV. (FT.)	TOP FE FM. (FT.)++	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
419	1596.8		758			750	847					750	
420	1562.5		1732	1722	-160	1722	-160					0	
421	1611.2		1935	1836	-225	1928	-317					92	
422			43										
423			55										
424			62										
425			62										
426			62										
427			51										
428	1557.4		1168	1065	492	1161	396					96	
429	1538.6		1466	1306	233	1541	-2					235	
430	1572.8		2041										
431	1527.3		1519										
432	1547.5		1955										
34873	1590.0		2954	2849	-1259	2914	-1324					65	
59029	1602.6		630	108	1495	462	1141					354	
BA-2	1550.0		3574	3395	-1845	3395	-1845			3410	-1860	0	
TOTALS					431		342		3		7	342	9

TOTAL NO. DDH - 467

TOTAL NO. FEET DRILLED - 569,676 FT.

Appendix A2

Dunka Road Cu-Ni Deposit
Drill Hole Lithologic Breaks

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
25400	1610		1180	455	1155	710	900					255	
25401	1613		1354	616	997	877	736	1275-1354				261	
25402	1609		885	10		426	1183	858-885				>416	
25403	1605		837	8		386	1219	776-837				>378	
25415	1614		465			14		438-453					
25416	1610		446	2		7	1603	411-435					
25417	1609		495	29		45	1564	435-485					
25418	1609		485	5		72	1537	476-481					
25420	1605		518	0		67	1538	484-510					
25421	1600		465	10		190	1410					>180	
26010	1602	50	620	415	1284							>157	
26011	1602		455	445	1157							>10	
26015	1605	50	893	595	1149	678	927					63	
26021	1606		608										
26022	1605		606	485	1120							>121	
26023	1605		725	597	1008							>128	
26024	1605		586	40								>546	
26025	1613		1042	968	645							>74	
26026	1614		715	692	522							>23	
26027	1606		910	878	728							>32	
26028	1600	50	381	330	1347							>39	
26029	1620		1181	1083	537	1178	442					95	
26030	1622		1094	1034	588							>60	
26031	1599		1116	999	600							>117	
26032	1611		690	598	1013							>92	
26033	1614		1104	1032	579	1096	518					64	
26034	1600		1375	1190	410	1343	257					153	
26035	1600		915	572	1028	854	746					282	
26036	1596		1237	1136	460	1208	388					72	
26037	1605	45	301	115	1524							>132	
26038	1613		405	260	1553							>145	
26039	1606		956	769	837							>187	
26040	1596		679	40								>639	
26041	1613		387	301	1312							>86	
26042	1595		1946	1870	-275	1910	-315					40	
26043	1606		1559	1491	115							>68	
26044	1612		205										
26045	1598		926	760	838							>166	
26046	1603		945	868	735							>77	
26047	1609		800	735	874							>65	
26048	1590		1902	1835	-245	1896	-306					61	
26049	1608		1207	1114	494	1176	432					62	
26050	1599		2005	1905	-306	1967	-368					62	
26051	1600		1454	1389	211	1433	167					44	
26052	1593		1866	1806	-213	1828	-235					22	
26053	1595		1018	955	640							>63	
26054	1598		776	652	946							>124	
26055	1595		1672	1616	-21	1657	-62					41	
26056	1592		1693	1652	-60							>41	
26057	1599		608	559	1000							>49	

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
26058	1612		817	704	908							>113	
26059	1603		608	494	1109							>114	
26060	1610		812	592	1018	719	891					127	
26061	1602		1277	1212	390							>65	
26062	1593		1477	1386	207	1456	137					70	
26063	1594		1957	1897	-303							>60	
26064	1595		1496	1454	141	1484	111					30	
26065	1592		2466	2335	-743	2407	-815					72	
26066	1604		1677	1599	5	1645	-41					46	
26067	1598		2147	2046	-448							>101	
26068	1601		1458	1403	198							>55	
26069	1604		2006	1841	-237	1977	-373					136	
26073	1603		2494	2378	-775	2412	-809					34	
26074	1598		2095	2005	-407	2041	-443					36	
26075	1597		2505	2463	-866	2490	-893					27	
26076	1610		1180	455	1155	712	898	1163-1180				257	
26077	1609		374	169	1440							>205	
26078	1613		904	857	756	888	725					31	
26079	1597		864	777	820	842	755					65	
26080	1597		1925	1514	83	1906	-309					392	
26081	1578		2345	2243	-665	2301	-723					58	
26082	1607		935	599	1008	906	701					307	
26083	1607		644	530	1077							114	
26084	1613		1354	616	997	877	736	1271-1275				261	
26085	1606		535	479	1127							>56	
26086	1617		574	499	1118							>75	
26087	1595		1675	1646	-51	1663	-68					17	
26088	1610		885	10		426	1184	859-885				>416	
26089	1605		837	8		386	1219	776-837				>378	
26090	1595		1775	1743	-148	1755	-160	1775				12	
26091	1609		231	157	1452							>74	
26092	1613		376	281	1332							>95	
26093	1613		1085	1013	600							>72	
26094	1582		2515	2466	-884	2485	-903					19	
26095	1605		425	244	1361							>181	
26096	1625		883	795	830							>88	
26097	1606		787	704	902							>83	
26098	1604		755	701	903	738	866					37	
26099	1623		564	488	1135							>76	
26100	1613		465	412	1201							>53	
26101	1607		655	600	1007							>55	
26102	1598	60	1112	39		1087	657					>902	
26103	1612		965	911	701							>54	
26104	1612		2445	2402	-790	2435	-823					33	
26105	1617	45	212	85	1557							>90	
26106	1601		1875	1784	-183	1831	-230					47	
26107	1579		2431	2402	-823	2425	-846					23	
26108	1617	45	167	99	1547							>48	
26109	1612	45	242	218	1458							>17	
26110	1621	45	162										

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
26111	1613	45	162										
26112	1614	45	222	209	1466							>9	
26113	1621	45	214	95	1554							>84	
26114	1617	40	293	271	1443							>14	
26115	1592		2180	2123	-531	2140	-548					17	
26116	1610		2245	2218	-608							>27	
26117	1586		2594	2566	-980	2580	-994					14	
26118	1618		1145	1101	517	1136	482					35	
26119	1568		2647	2562	-994	2579	-1011					17	
26120	1597		1080	590	1007	1064	533					474	
26121	1594		2151	2116	-522	2126	-532					10	
26122	1607		2242	2196	-589	2207	-600					11	
26123	1597		2253	2190	-593	2217	-620					27	
26124	1593		2415	2351	-758	2395	-802					44	
26125	1597		2504	2467	-870	2496	-899					29	
26127	1629		918										
26128	1632		1008	834	798	950	682					116	
26141	1592		1585	1434	158	1560	32					126	
26142	1593		2118	2075	-482	2110	-517					35	
26143	1592		2125	2106	-515	2114	-522					8	
BA-3	1550		3588										
BA-4	1565		2677	2573	-1008	2627	-1062					54	
TOTALS					103		63		0		0	111	0

TOTAL NO. DDH - 122

TOTAL NO. FEET DRILLED - 145,509 FT.

Appendix A3

Wetlegs Cu-Ni Deposit
Drill Hole Lithologic Breaks

DRILL HOLE NO.	ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
A4-1	1572	60	565	29								>489	
A4-2	1593	60	600	22								>520	
A4-3	1593	60	400	82	1522							>275	
A4-4	1580	60	733	695	978							>33	
A4-5	1580	60	533	443	1196							>78	
A4-6	1580	60	385	195	1411							>333	
A4-7	1590	60	304	120	1486							>159	
A4-8	1570	60	775	710	955							>56	
A4-9	1590	60	279	165	1447							>99	
A4-10	1570		2113	NONE		2093	-523					0	
A4-11	1610		2214	2176	-566	2188	-578					12	
A4-12	1590		2655	2604	-1014	2619	-1029					15	
A4-13	1560		2465	NONE		2431	-871					0	
A4-14	1555		3467	3425	-1870	3451	-1896					26	
W-1	1580		1559	1482	98	1527	53					45	
W-2	1570		1893	1848	-278	1854	-284					6	
W-3	1550		1708	1591	-41	1694	-144					103	
W-6	1575		1491	1390	185	1438	137					48	
W-7	1585		1199	1062	523	1139	446					77	
W-8	1585		1102	1026	559	1076	509					50	
W-9	1590		1041	967	623	992	598					25	
W-10	1590		1135	987	609	1094	496					107	
W-11	1580		1161	1075	505	1115	465					40	
W-12	1580		1425	1369	211	1391	189					22	
W-13	1580		1315	1276	304	1284	296					8	
W-14	1575		2030	1974	-399	2008	-433					34	
11543	1555	70	896	805	799							>86	
11544	1578	60	709										
11545	1570	60	400	328	1286							>62	
11546	1630	60	676	376	1304							>259	
11548	1660	60	576	176	1508							>347	
11550	1628	70	449	249	1394							>188	
13601	1600		722	185	1415	692	908					507	
13602	1560		870	101	1459	810	750					709	
13604	1570		1384	1320	250	1335	235					15	
13606	1595		934	785	810							>149	
13607	1580		1430	1310	270	1402	178					92	
13609	1560		1182	1095	465							>87	
13611	1550		1455	1332	218							>123	

DRILL HOLE NO.	ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
13613	1610		895	850	760	881	729					31	
13614	1690		890	818	872	831	859					13	
13620	1670		646	50								>596	
13623	1680		920	40		870	810					>830	
26014	1590	57	894										
26016	1580		645										
26018	1580	50	418										
26019	1580	50	351										
26020	1590	50	293										
26150	1580	50	954										
TOTALS					36		24		0		0	42	0

TOTAL NO. DDH - 49

TOTAL NO. FEET DRILLED - 53,136 FT.

Appendix A4

Longnose-Longear Fe-Ti Deposits
Drill Hole Lithologic Breaks

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
A1-1	1530		416										
BA-6	1540		3085	2995	-1455	3031	-1491					36	
LN-1	1525	45	634										
LN-2	1525	45	570										
LN-3	1525	45	502										
LN-4	1525	45	612										
LN-5	1525	45	602										
LN-6	1525	45	595										
LN-7	1525	45	602										
LN-8	1525	45	402										
LN-9	1525	45	400										
LN-10	1525	45	330										
LE-1	1540	45	610										
LE-2	1540	45	502										
LE-3	1540	45	499										
TOTALS					1		1		0		0	1	0

TOTAL NO. DDH - 15

TOTAL NO. FEET DRILLED - 10,361 FT.

Appendix A5

Wyman Creek Cu-Ni-Ti Deposit
Drill Hole Lithologic Breaks

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
W-4	1470		3114										
W-5	1480		1634	706	774	1574	-94					868	
W-15	1495		2545										
B-3	1570		2477										
17700	1531		1210	223	1308	708	823	1148-1210				485	
17703	1521		151	134	1387							>17	
26126	1490		1393	1330	160	1342	148					12	
26130	1485		1555	1515	-30	1527	-42					12	
26131	1506		1505	1443	63	1467	39					24	
26132	1496		1165	1154	342	1160	336					6	
26133	1478		1646	1589	-111	1605	-127					16	
26134	1500		1240	1167	333	1233	267					66	
26135	1511		1325	1278	233	1293	218					15	
26136	1504		1105	779	725	1075	429					296	
26137	1511		1535	1483	28	1507	4					24	
26138	1491		1353	1305	186	1338	153					33	
26139	1500		475										
26140	1501		535										
26144	1496		1095	842	654	1089	407					247	
26145	1505		500										
26146	1502		1075	738	764	1046	456					308	
26147	1508		525										
26148	1513		500										
26149	1501		1337	1283	218	1316	185					33	
26151	1498		1297	1188	310	1285	213					97	
26152	1515		1725	1685	170	1707	-192					22	
26153	1483		1445	1395	88	1437	46					42	
TOTALS					19		18		0		0	19	0

TOTAL NO. DDH - 27

TOTAL NO. FEET DRILLED - 35,462 FT.

Appendix A6

Allen Area
Drill Hole Lithologic Breaks

DRILL HOLE NO.	COLLAR ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
A-1	1510	60	563	432	1136							>114	
A-2	1611	60	1611	1559	261							>45	
A-3	1530		405	(279)									
A-4	1525		829										
A-5	1530		509										
A2-1	1470	63	232	20								>212	
A2-2	1470		304	36	1437							>268	
A2-3	1470		1231										
A2-4	1488	60	593	520	1038							>64	
A2-5	1480	60	324	192	1314							>115	
A2-6	1460	45	2570	2508	-313							>44	
A2-7	1448	45	1224										
A3-1	1440	60	300	33								>226	
A3-2	1440	60	345	38								>260	
A3-3	1475	45	115	10								>74	
A3-4	1500	60	514	328	1216							>161	
A3-5	1480	85	1321	1230	250	1300	185					70	
TOTALS					8		1		0		0	12	0

TOTAL NO. DDH - 17

TOTAL NO. FEET DRILLED - 12,990 FT.

Appendix A7

Skibo Cu-Ni-Ti Deposit
Drill Hole Lithologic Breaks

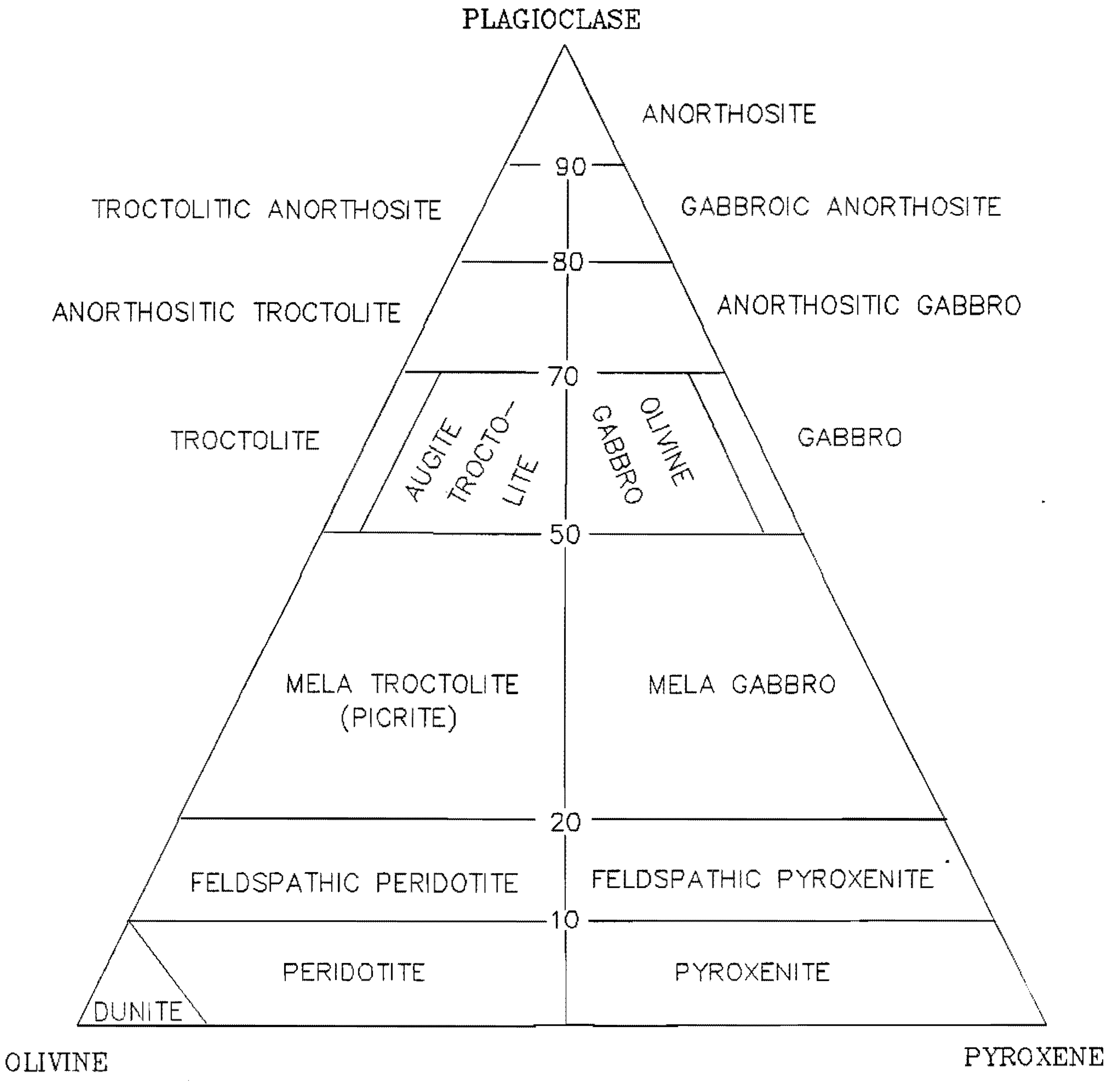
DRILL HOLE NO.	ELEV. (FT.)	HOLE ANGLE (DEG.)	T.D. (FT.)	BASE COMPLEX (FT.)	ELEV. (FT.)	TOP OF FE FM. (FT.)	ELEV. (FT.)	TOP OF POKEGAMA (FT.)	ELEV. (FT.)	TOP OF GIANTS RANGE (FT.)	ELEV. (FT.)	THICK. VA. FM. (FT.)	THICK. FE FM. (FT.)
11547	1510	60	485										
13605	1510		6953	794	716							>159	
13608	1510	45	744	660	1043								
13612	1510		1054	888	622							>166	
13615	1510		1450	1237	273							>213	
13618	1510		1585	1530	-20							>50	
13619	1520		1209	1084	436							>25	
13621	1520		1185	1125	395							>60	
13624	1500		389										
13625	1490		2295	2236	-746							>59	
27016	1510		1605	1581	-71							>24	
34898	1510		1475	1415	95							>60	
40901	1510	80	1141										
DDH-3	1540		1200	1090	450							>110	
TOTALS					11		0		0		0	10	0

TOTAL NO. DDH - 14

TOTAL NO. FEET DRILLED - 16,770 FT.

Appendix B

Rock Classification Scheme



ROCK CLASSIFICATION DIAGRAM