OBSERVATIONS ON Cu-Ni MINERALIZATION IN THE GIANTS RANGE BATHOLITH FOOTWALL TO THE SOUTH KAWISHIWI INTRUSION, DULUTH COMPLEX, NORTHEASTERN MINNESOTA

By

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INTRODUCTION

The intent of this study is to take a focused look at known mineralization within rocks of the Giants Range Batholith (GRB) where they compose the footwall to the South Kawishiwi intrusion (SKI) of the Duluth Complex (Complex), and attempt to localize new areas of footwall mineral potential. This study has been accomplished by compiling the existing literature on the subject, logging drill core from representative holes that penetrated the GRB footwall below the SKI, making thin sections from this core, and looking at the spatial relationships of the footwall and SKI mineralization. The following is a description of the occurrence and characteristics of this mineralization in the granitic footwall to the SKI.

REGIONAL GEOLOGY OVERVIEW

The Archean Giants Range Batholith is located in the Wawa subprovince of the Superior Province in northern Minnesota. In size it ranges from 8-40 kilometers wide, 240 kilometers long, and trends northeast (Miller et al., 2002). The GRB is a "composite intrusion of granite, monozonite, granodiorite, monzodiorite, and gneissic equivalents" that contain aplite and pegmatite dikes (Sims and Viswanathan, 1972; Miller et al., 2002). Isotope age dates give a crystallization age of about 2,700 m.y. (Prince and Hanson, 1972).

Proterozoic rocks of the Animikie Group lie south of the GRB. In stratigraphic order they are the Pokegama Quartzite, the Biwabik Iron Formation, and the Virginia Formation. The Pokegama Quartzite is a thin sandstone unit that unconformably overlies Archean rocks and is only present locally (Miller et al., 2002). Above this unit is the Biwabik Iron Formation, a thick sequence of interlayered iron formation-types that skirts the southern margin of the GRB and is known geographically as the Mesabi Range (Miller et al., 2002). The overlying Virginia Formation is a sedimentary package composed of argillites, siltstones, and greywackes. It is broken into two members, the lower unit being primarily carbonaceous argillites and the upper unit composed of argillite and greywacke (Miller et al., 2002). Rocks of this Animikie Basin generally strike northeast, dip 5-15 degrees to the southeast (Morey, 1972) and contain minor structures and small folds (Miller et al., 2002). The intrusion of the Duluth Complex on the eastern edge of the Animikie Group has caused dips of 20-35 degrees to the south and strong contact metamorphism of the Biwabik and Virginia Formations (Miller et al., 2002).

The Duluth Complex is a large composite mafic intrusion emplaced into the base of the Keweenawan (1.1 Ga) Mid-Continent Rift. flood basalts. The South Kawishiwi intrusion lies along the western margin of the Duluth Complex and is a 19 mile long, layered mafic sub-intrusion of the Duluth Complex located approximately 15 miles south of Ely, Minnesota (Severson, 1994) (Fig. 1). The footwall contact between the GRB and SKI dips approximately 25 degrees southward and trends northeast. The SKI and the Partridge River intrusion to the south host several low grade Cu-Ni occurrences that have been the target of sporadically intense mineral exploration activity in the last half of the 20th century.

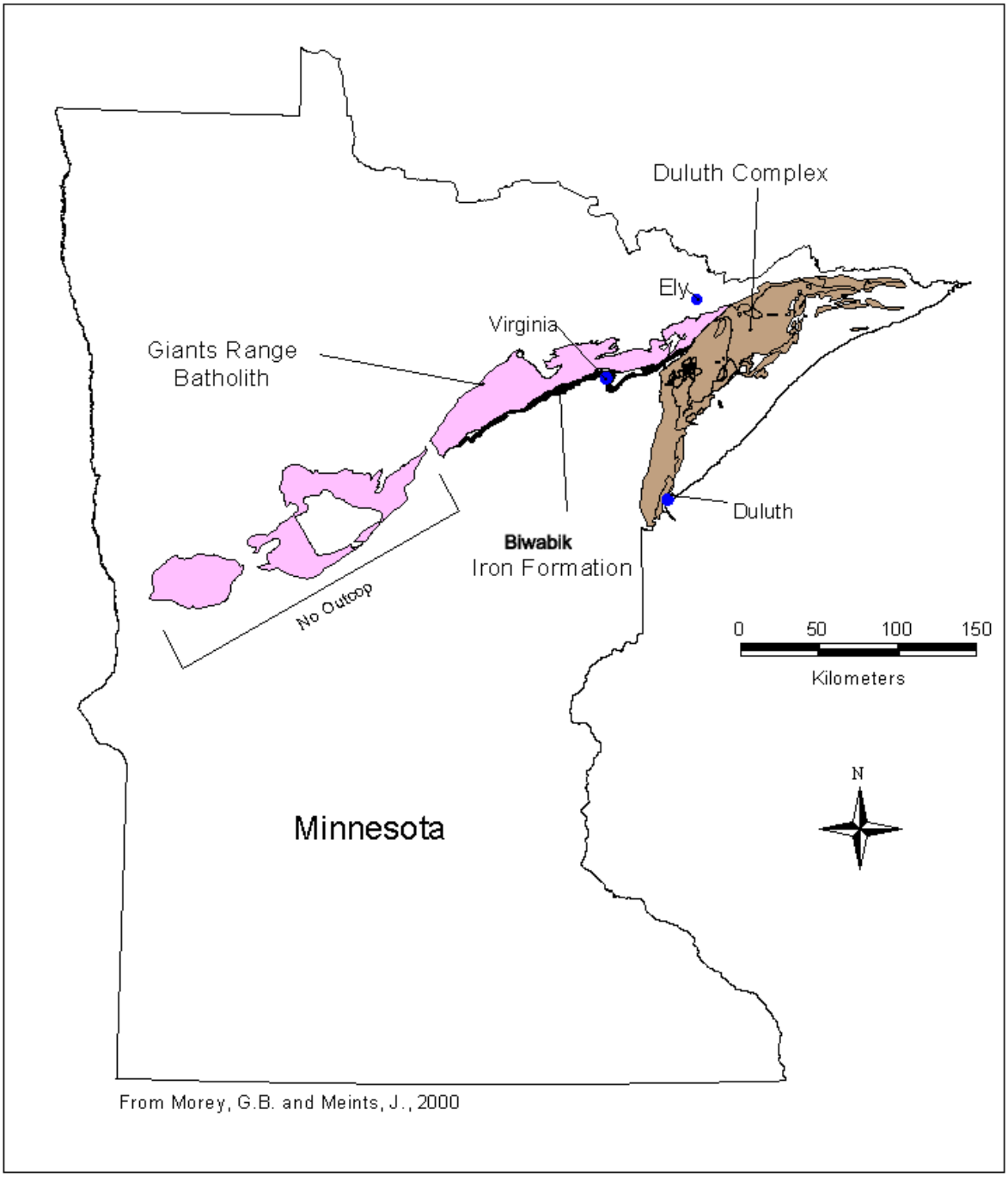

Figure 1. Regional extent of the Giants Range Batholith and the Duluth Complex.

PREVIOUS WORK ON THE GIANTS RANGE BATHOLITH

Since the Giants Range Batholith was formally named more than 100 years ago, it has been described and mapped by many geologists. The following description is a brief compilation of past work done on the eastern part of the GRB.

According to Sims and Viswanathan (1972) the GRB is a variably porphyritic, medium- to coarse-grained, hornblende-bearing composite intrusion that ranges from quartz monzonite to diorite compositions, but is primarily quartz monzonite to granodiorite.

Many of the common GRB rock types are described as pink to pinkish grey in hand sample with lower quartz content (+/- 10%) than in normal granitic rocks (Sims and Viswanathan, 1972). The pluton is heterogeneous and 'compositionally complex'; having gradational contacts between phases (Sims and Viswanathan, 1972). Several northeast-trending faults in the eastern part of the batholith have 'conspicuous red alteration' and are filled with milky quartz veinlets. The wallrock of these veins have been cataclastically deformed without being recrystallized (Sims and Viswanathan, 1972).

In mapping the GRB, Green (1970) described metamorphic effects from the Duluth Complex as producing a recrystallized texture and observed common perthite, antiperthite, and mymerkite in feldspars. The ferromagnesian mineral assemblage in the metamorphic aureole is hornblende + clinopyroxene + orthopyroxene + biotite + magnetite with retrograde reactions altering orthopyroxene to biotite + actinolite. Metamorphic facies in the contact aureole are complex and are transitional between amphibolite/hornblende hornfels and pyroxene hornfels. Bonichsen (1972) made similar observations about GRB drill core from beneath the Duluth Complex, noting that most portions of the GRB appeared to be recrystallized and partially melted as indicated by the removal of K-feldspar and the addition of orthopyroxene. He described the rocks as similar in appearance to the expected quartz monzonite and granodiorite of other parts of the GRB, but dioritic in composition. Bonnichsen et al. (1980) in a study of a single drill core described dikes of noritic composition in the footwall and speculated that they may be derived from the basal layer of the SKI.

Sawyer (2002) recently completed a detailed petrographic analysis on a single drill core of GRB from beneath the Spruce Road deposit. He describes products of contact metamorphism in the form of recrystallization and partial melting of the rock with accompanying deformation. He believes that temperatures may have been as high as 800ºC and described textures that suggest that both silicate and sulfide melt may have existed contemporaneously. He also found SKI derived noritic rocks within the GRB. For photomicrographs of metamorphic textures in the GRB see Sawyer (2002).

Sulfide Mineralization

Sulfide mineralization in the GRB is believed to be derived from the overlying South Kawishiwi intrusion were it contains significant volumes of low grade Cu-Ni mineralization. The SKI includes the Dunka Pit, Birch Lake, Maturi, Serpentine, and Spruce Road mineral deposits, which have been extensively drilled in search of economically viable Cu-Ni-Pt-Pd concentrations. Miller et al., (2002) outlines a detailed history of mineral exploration industry and academic work on the Duluth Complex. Serious mineral exploration of the Complex began in 1948, near the present Spruce Road deposit with the discovery of Cu sulfide mineralization in outcrop. Since then, more than 1,700 drill holes have been completed along the western margin of the Complex (Miller et al., 2002).

The intrusion of sulfide-bearing mafic magma of the SKI has resulted in the formation of several types of mineral concentrations within the SKI and it's footwall. These include:

- Disseminated Cu-Ni sulfide mineralization, the most common style of sulfide accumulation in the SKI. Estimates suggest that several billions of tons of low grade Cu-Ni ore are present (Peterson, 1997; Miller et al., 2002).
- Thin massive sulfide lenses and veins along the footwall contact and within the GRB itself (Severson, 1994; Bonnichsen, 1972).
- Epigenetic disseminated Cu mineralization found to 300+ foot depths below the footwall contact within the GRB (Bonnichsen, 1972; Severson, 1994; Peterson, 1997).
- Stratigraphically controlled PGE mineralization associated with ultramafic horizons in the SKI (Severson, 1994).

Disseminated, secondary sulfides are common in the GRB for approximately 100 meters below the footwall contact. In core, the sulfides are dominantly chalcopyrite with minor bornite, often occur in net textured stringers, and have higher Cu:Ni ratios than disseminated mineralization in the SKI (Bonnichsen et al., 1980). Pyrrhotite is seen only in the top 12-14 meters of the granite (Bonnichsen et al., 1980). Green (1970) observed secondary Cu sulfides in outcrop north of Spruce Road and attributed them to the once overlying Duluth Complex.

Massive sulfide and semi massive sulfide accumulations are found along the footwall contact. The thickest occurrences are in non-GRB footwall downdip from pyrrhotite-rich Virginia Formation on the far southwestern end of the SKI where the massive sulfide is structurally controlled by faults or folds (Miller et al., 2002). In the GRB footwall, massive sulfide veins and pods are found in two northeast trending 'belts' also believed to be structurally controlled. One of these aligns with the Birch Lake Fault (Severson, 1994). The massive sulfides appear to have been formed by downward injection of the sulfide melt into the footwall (Bonnichsen et al., 1980; Severson, 1994). To date, none of these occurrences have proved economically viable for mining.

Peterson (1997) compiled most (~95%) of the available assay data from drill holes in the SKI into a single database that he used to model depletion and addition of Cu within a 500 foot thick basal zone of the SKI. He suggested that areas of the SKI depleted in Cu have corresponding zones of Cu enrichment in the footwall below. This approach appears to have

worked well in areas with high densities of Cu assays, particularly the Spruce Road deposit. Here Cu depletion in the SKI corresponds to >1% Cu assays in the immediate footwall.

Taking another approach, Peterson (2002) modeled Cu and Ni assay values at Spruce Road in thirty 50-foot thick layers above the basal contact (0-1500 feet). A composite Cu and Ni value was calculated from drill hole assays for each layer, and these data were gridded and imaged to give a 2D map of individual zones. Further data manipulation allowed grades and tonnages of known mineralization to be calculated. This study did not look at footwall mineralization, but did interpret several possible magma conduits that may have fed the SKI and Spruce Road deposit from a larger magma channel to the south that may have influenced sulfide movement into the footwall.

PGE Mineralization

Two hundred fifty nine PGE assays from the GRB footwall to the SKI are found in Severson's and Hauck's (in press) PGE database. The bulk of these data are from the Birch Lake, Dunka Pit, and Maturi deposits. Platinum values range from below detection to 760 ppb. Only 29 intervals have values above 100 ppb Pt. These high values occur with elevated to high grade Cu assays. PGE values are generally near background value in the GRB footwall.

NEW WORK

This study was intended to find vectors to mineralization by considering existing data and attempting to compile it in ways that emphasize footwall mineralization potential. A large portion of the following work is based on the geochemical database compiled by Peterson (1997, 2002) for several studies he has completed. The database consists of ~95% of the known assays of drill core from holes collared in the SKI. It is important to note that the vast majority of these assays are from rocks of the SKI. The database contains 257 drill holes that penetrate the GRB an average of 193 feet below the basal contact, with a total of approximately 49,400 feet of core from the granite footwall (Fig. 2). Of this group, 198 drill holes have assays of GRB rocks. There are 1,648 assay intervals from the granite footwall that total 14,547 feet. This footage is likely a slightly low number because it was calculated by subtracting the footwall contact footage from the total depth of a given hole where the contact footage is a calculated number rather than being taken from drill logs. Angled holes will have more core footage than this number shows. Therefore, approximately 34,900 feet of granitic footwall core has not been sampled. Undoubtedly, much of this rock is barren; however it would have been easy for a sampler focused on mineralization in the SKI to have missed significant intervals of disseminated chalcopyrite in the GRB. Many drill cores from the footwall have not been sampled or may have only short, sporadic sample intervals, leaving much of the rock unanalyzed.

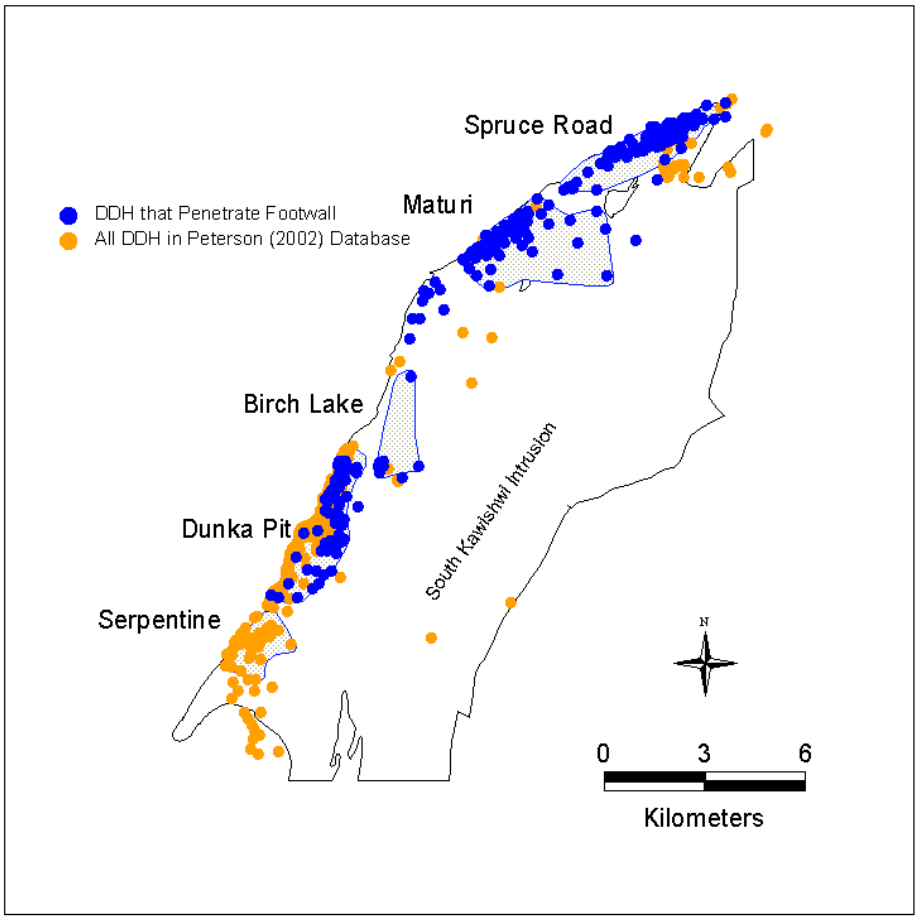

Figure 2. Drill holes in the South Kawishiwi Intrusion (SKI). Those in blue intersect the granitic footwall.

Work consisted of relogging eleven drill cores from the Dunka Pit and Maturi mineral deposits (Fig. 3; Appendix I). The cores are located in the Minnesota Department of Natural Resources (MDNR) Core Repository in Hibbing, Minnesota. Drill cores to be logged were selected primarily on the basis of footwall assay values and depth of penetration into the footwall. Holes with both high and low Cu-Ni values were chosen for comparison. Unfortunately, no footwall core from the Spruce Road deposit is available for study. Only holes on the eastern margin of the Dunka Pit deposit were selected because the Biwabik Iron Formation underlies the western portion of the deposit. Little core from the Birch Lake deposit was studied because much of it is not yet in the public domain.

Single and doubly polished thin sections were made from core samples. Thirty-one thin sections and forty-five polished thin sections made from drill core were studied (Appendix 1). The majority of thin sections were made from core of the GRB. Most thin sections were made from samples collected by the author, but several were from studies done by previous workers and archived at the Natural Resources Research Institute (see Appendix II for petrographic descriptions of individual thin sections). The following rock description is drawn from the author's observations made from core and thin sections.

GRB LITHOLOGIC DESCRIPTION

The Giants Range Batholith immediately below the South Kawishiwi intrusion is a heterogeneous mix of rock types ranging from diorite to granite. Compositional changes result from primary lithologic variations and contact metamorphism. Changes may occur on the scale of only several feet and generally have gradational contacts. The core has a distinct recrystallized character and often appears 'bleached'. The dominant mineral assemblage is K-feldspar + hornblende + biotite + orthopyroxene + plagioclase with varying amounts of chlorite, tremolite/actinolite, and clay + sericite alteration products. Dark grey to black, mafic, amphibole-altered xenoliths from 1 centimeter to +/- 1 meter are typical. Larger xenoliths may appear as amphibole schist in core. Pink, fine-grained, granular aplite dikes from 1 centimeter to 2+ meters are common throughout the drill core. White granodiorite dikes with up to 5% dark minerals, 2 centimeter to 2+ meters thick are less common, but not unusual.

Primary and secondary textures are present in these rocks. The rocks can be fine- to medium-grained equidimensional, fine- to medium-grained weakly porphyritic, and fine- to medium-grained strongly porphyritic. Phenocrysts of white and/or pink K-feldspar range in size from 1 millimeter to 3+ centimeter, with typical phenocryst sizes 1-10 millimeter. The larger phenocrysts are rare and only found at depth beneath the footwall contact. Brown metamorphic orthopyroxene to 1 millimeter is commonly disseminated in the rock within 200 feet of the contact.

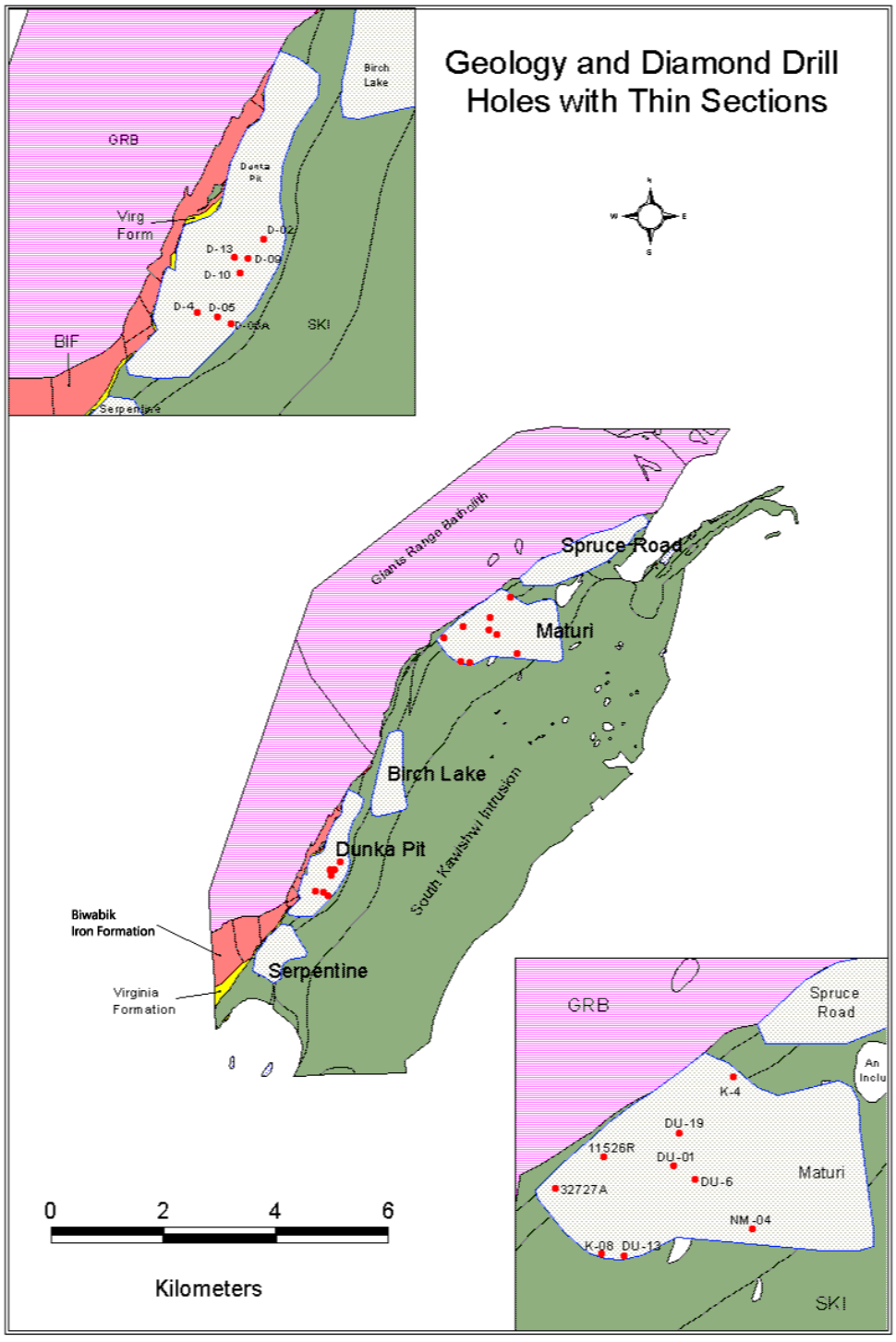

Figure 3. Diamond drill holes logged for this study. Some map data from Peterson (2002).

K-feldspar phenocrysts in thin section are subhedral with ragged, recrystallized edges and may have a boundary of fine, recrystallized 'mortar' textured K-feldspar. Most phenocrysts and much of the ground mass have strong undulose extinction in polarized light indicative of strain (Sawyer, 2002). Also common are phenocrysts that appear broken with many irregular internal dislocations. Groundmass is composed of sub-equigranular feldspar +/- quartz with polygonal grain shapes and common triple junction grain boundaries. Rare angular aggregates of K-feldspar +/- quartz + amphibole + biotite are believed to be partial melt pockets (Sawyer, 2002). All of these characteristics result from metamorphism with probable partial melting (Sawyer, 2002). Most thin sections within 200 feet of the SKI contact have 5-40% orthopyroxene as </= 1 millimeter euhedral to subhedral grains in groundmass. Greater than 200 feet below the contact metamorphic pyroxene is considerably less common.

Color variation in the core is noticeable. Most rocks near the contact are light grey to white. Porphyritic rocks commonly have a grey groundmass with white feldspar phenocrysts. However, as distance below the SKI increases, so does the predominance of pink colored rock as a result of pink K-feldspar. Five to ten percent pink K-feldspar gives the rock a distinct pink color and is not seen less than 45 feet below the contact, except as thin, sporadic occurrences. The K feldspar may be confined primarily to the groundmass or the phenocrysts, or occur in both locations.

Structure

There is little evidence of well developed faulting within the GRB in these drill cores. NM-4 has <1 – 2 millimeter, white amphibole (tremolite or actinolite ?) +/- K-feldspar +/- quartz veinlets with strong pink alteration over 1-15 millimeter of the wall rock. The pink alteration may also occur along open fractures. This very intense, pervasive alteration of the rock is clay + sericite +/- hematite(?) replacing up to 95% of the feldspar within the alteration halo. Quartz veining is rare, but a 2 foot zone of strong quartz replacement is seen in D-10. Overall, there are generally very few fractures, faults or veinlets seen in the +/- 400 foot maximum depth below the SKI that is reached in some of these holes. The best evidence of fracturing in the GRB is seen near the SKI contact where thin massive sulfide veins are sometimes found. Weak foliation is observed in some core and thin sections. Sawyer (2002) pointed out a sub-vertical foliation and possible proto-mylonites in his study of drill core WM-1.

Two fine-grained mafic dikes containing olivine were found in the drill core, but were only recognized a ft.er thin section analysis. These are in drill holes at the Dunka Pit (D-5) and Maturi (32727A) in thin sections D5-1790 and 32727A-697. Section 332723A-697 (ft.) contains 35% subhedral olivine, and D5-1790 (ft.) has 15% subhedral olivine. Both have well-developed poikilitic plagioclase.

Disseminated Mineralization

The most common type of mineralization in the footwall is disseminated chalcopyrite and pyrrhotite. This style of mineralization may be found in both uniformly disseminated continuous intervals or as irregular thin patches 1 - 60 centimeter thick. Significant pyrrhotite occurs only within approximately 30 feet of the basal contact. Chalcopyrite is the dominant sulfide, and often is associated with lesser quantities of pyrrhotite and oxides. Chalcopyrite zones run to an estimated 3% by volume in core, and may assay >1% Cu for fine disseminated chalcopyrite over 10 foot intervals. Drill hole NM-4 has 30 feet grading over 1.4% Cu. Petrographic work shows that these sulfides are interstitial and often net-textured to semi-net textured around subhedral to anhedral feldspar, quartz, and/or pyroxene grains. Magnetite may be associated with chalcopyrite. Composite grains of coarse chalcopyrite with finer pyrrhotite, pentlandite, or sphalerite are common. Chalcopyrite also occurs in composite grains with bornite and millerite and one occurrence of violarite (?). The millerite and violarite were positively verified by electron microprobe analysis by Peter McSwiggen of McSwiggen and Associates, St. Anthony Falls, Minnesota (Table 2). Small amounts of millerite are common throughout the core studied, but it is not identifiable in hand sample. Bornite is often found exsolving out of chalcopyrite grains, but may also occur as fine, individual grains. Pentlandite is rare and occurs as exsolution lamellae in pyrrhotite. In NM-4 and D-13, chalcopyrite also occurs in 5-10 millimeter clots with little disseminated sulfide in the remaining rock. These clots consist of concentrations of interstitial sulfide among feldspar and pyroxene grains with sulfide >> silicate. A 1 millimeter tremolite vein cuts a sulfide clot in polished thin section DMP01-81 and has chalcopyrite interfingering with feathery tremolite along cleavage planes. The vein contains angular chips of chalcopyrite. This interfingering of chalcopyrite with amphibole is a common texture in the disseminated sulfides, occurring with amphibole alteration that is disseminated throughout the rock. More rarely, chalcopyrite may invade feldspar grains along cleavage planes. Two polished thin sections from cores D-5 and D-9 (D5-1777 and D9-1314) have <1 millimeter, discontinuous fractures filled with chalcopyrite + pyrrhotite. Core D-6A is barren of sulfide within the footwall, except for a 15 centimeter interval above a small amphibole altered mafic inclusion where 1-2% chalcopyrite is concentrated along the inclusion margin. Note in Table 2 the occurrence of trace metals, i.e., Ag, Bi, Pb, Sb, Sn, Te in the various sulfides. Severson and Hauck (in press) report similar elevated amounts of these metals in sulfides from various Cu-Ni deposits, and they note these trace metals commonly from platinum-group minerals in these deposits.

Massive Mineralization

Of the eleven drill cores logged, six have a massive sulfide occurrence in the GRB (Table 1). These range in thickness from 2-4 centimeter veins in DU-13 and DU-1 to 10+ feet in D-5. Core D-9 has one foot of massive sulfide at the footwall contact, but all other holes have massive sulfide veins from seven to 31 feet below the SKI contact. Veins are narrow, 2-30 centimeter, and have sharp contacts with diffuse, pyrrhotite-rich sulfide in the wallrock. Irregular 1-3 centimeter blebs of sulfide also occur. These massive sulfides are always pyrrhotite dominant and contain pentlandite and chalcopyrite, often with traces of sphalerite that can only be seen microscopically. Pentlandite may be coarse enough to distinguish in hand sample. Hole D-5 has 5-10 centimeter chalcopyrite-rich zones within the massive sulfide. One 0.5 foot interval runs 18% Cu. Thirty percent disseminated sulfide may occur in close proximity to massive sulfide veins.

DDH	From (ft.)	To (ft.)	Depth (ft.) below footwall	Description	Grades	Cu:Ni
D-2	1588	1589	-7.5	1 ft. 92% po, 8% ccp, +/- brn	11 ft. 1% Cu, 0.52% Ni;	2.04
D-5	1609	1621	-14	Massive po+pn+ccp with 4% ccp rich zones, 5-10mm pn grains	12 ft. 3.5% Cu, 2.95% Ni, 1 ft. 760 ppb Pt, 0.5 ft. 470 ppb Pt	1.19
D-9	1296	1297.3	0	Massive po at contact	2 ft. 0.46 Cu, 0.55 Ni	0.83
DU-1	2676.5	2683.7	-31	Three 5 cm massive veins, po>>>ccp	9 ft. 0.94 Cu, 1.40% Ni	0.67
DU-13	3541	3541.2	-6	4 cm massive vein po+pn+ccp	5 ft. 1% Cu, 1.57% Ni, 51ppb Pt	0.65
K-8	3340	3342	-5.5	blebby massive po>>ccp	2 ft. 0.2% Cu, 1.30% Ni, 148ppb Pt	0.15

Table 1. Diamond drill holes with massive sulfide logged by the author. Po = pyrrhotite, pn = pentlandite, ccp = chalcopyrite, brn = bornite.

Average	Average	Average	Average	Average	Average	Average
# Analyses	4 Analyses	5 Analyses	2 Analyses	4 Analyses	2 Analyses	2 Analyses
Weight %	Bornite	Chalcopyrite	Covellite	Millerite	Sphalerite	Violarite
S	25.96	34.91	31.79	34.63	32.70	40.96
Fe	11.34	30.45	0.97	0.16	2.85	14.70
Ni	0.23	0.06	0.99	60.75	0.00	28.07
Zn	0.00	0.00	0.00	0.00	60.45	0.00
Co	0.06	0.06	0.18	4.22	0.01	7.24
Pb	0.00	0.02	0.03	0.06	0.02	0.12
Cd	0.00	0.00	0.00	0.00	0.22	0.00
As	0.00	0.00	0.00	0.00	0.00	0.00
Cu	61.47	33.33	65.71	0.00	3.10	8.67
Ag	0.05	0.03	0.24	0.03	0.01	0.03
Au	0.04	0.01	0.07	0.03	0.00	0.06
Bi	0.00	0.04	0.00	0.04	0.04	0.15
Pt	0.00	0.00	0.00	0.00	0.00	0.00
Pd	0.00	0.00	0.00	0.00	0.00	0.00
Ir	0.00	0.00	0.00	0.00	0.00	0.00
Os	0.00	0.00	0.00	0.00	0.00	0.00
Ru	0.00	0.00	0.00	0.00	0.00	0.00
Rh	0.00	0.00	0.00	0.00	0.00	0.00
Sb	0.00	0.00	0.01	0.03	0.02	0.00
Te	0.04	0.00	0.00	0.00	0.00	0.00
Sn	0.01	0.01	0.00	0.00	0.02	0.00
Re	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.20	98.86	100.00	99.95	99.43	100.00
* Includes normalized data		*	*			*

Table 2. Microprobe data of sulfides in outcrop sample (DMP-85-01.

SPRUCE ROAD FOOTWALL GRADE MAPS

Following Peterson's (2002) method, composite Cu and Ni values were calculated for a 50 foot thick sheet of GRB immediately below the basal contact at the Spruce Road deposit, and new grade maps were generated. This was done by taking assay values in each drill hole for the 50 feet below the contact and combining them into a single Cu and Ni grade value for that hole. To composite the assays, individual assays in each drill hole were multiplied by sample length, the values summed, and then divided by the thickness of the composite sheet (50 feet). Core that had not been assayed was assumed to have 0% metal content. The composite data were then gridded in Golden Software's Surfer program and color imaged into a footwall grade map of the Spruce Road area, duplicating Peterson's (2002) parameters as nearly as possible. Peterson's SKI Cu and Ni composite data for the 50 feet above the basal contact was then contoured and overlaid on the new color imaged GRB grade map (Figs. 4, 5). This allowed patterns of high-grade zones in the SKI to be spatially compared to high-grade zones in the top portion of the GRB footwall. Finally, contours of the basal contact of the SKI and mapped surface faults, both generated by Peterson (2002), were overlaid on the GRB Cu and Ni grade maps (Figs. 6, 7). These maps show how mineralization relates to the 'topography' of the footwall contact and how it lines up with local faults.

The highest composite values in the map grid for the GRB are approximately 0.22% Ni and 0.54% Cu, while the highest SKI values are about 0.57% Ni and 0.75% Cu. The SKI has higher grades for two reasons. First, the Spruce Road deposit contains uniform, relatively high grades across much of its thickness (Peterson, 2002). Second, there is a limited number of assays in the footwall, with some drill cores having only 5-10 feet of footwall core sampled. Compositing these assays with 30-40 feet of 0% metal causes high metal values over short intervals to be washed out to relatively low numbers. Whereas sampling of the SKI core in the 50 feet above the contact is continuous in nearly all cases.

The new maps show several patterns:

- Low grade zones in the SKI often overlay metal enriched granite footwall.
- High grade zones in the SKI often overlay areas of low metal content in the footwall.
- High-grade footwall zones often occur beneath irregularities in the footwall contact surface.
- Surface sub-vertical faults appear to line up with some footwall Ni mineralization.

DISCUSSION

The degree of permeability and 'topography' of the footwall contact appear to have controlled the extent of footwall mineralization by the sulfide melt carried in the SKI. Sulfide melt that accumulated in footwall surface irregularities at the base of the SKI has migrated into variably permeable zones created by faulting and partial melting of the GRB.

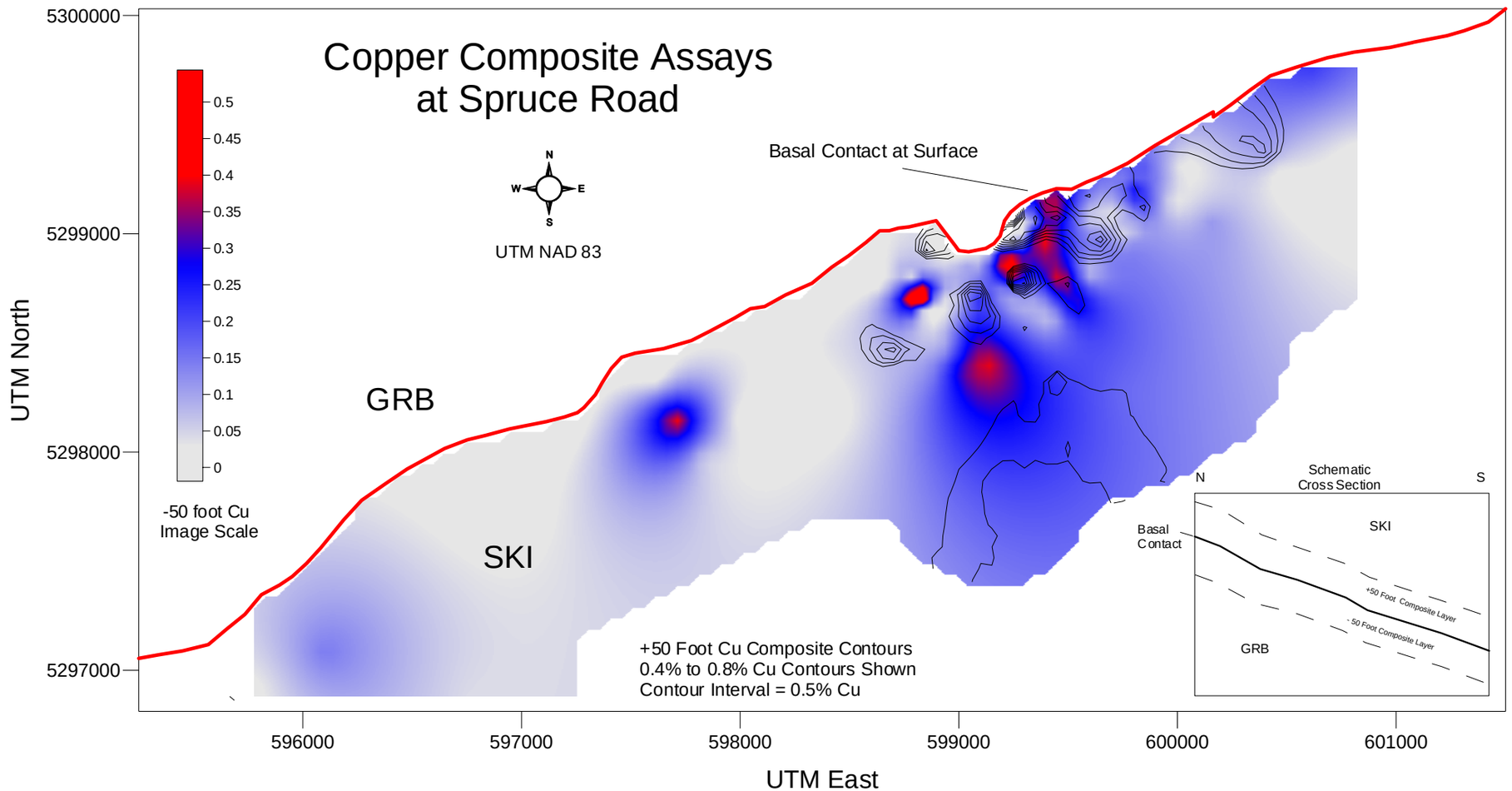

Figure 4. Spruce Road Cu grade map showing black Cu contours for the 50 foot thick SKI composite sheet above the footwall contact (Peterson, 2002) overlaid on a color image of Cu assays for the 50 foot thick GRB composite sheet below the basal contact.

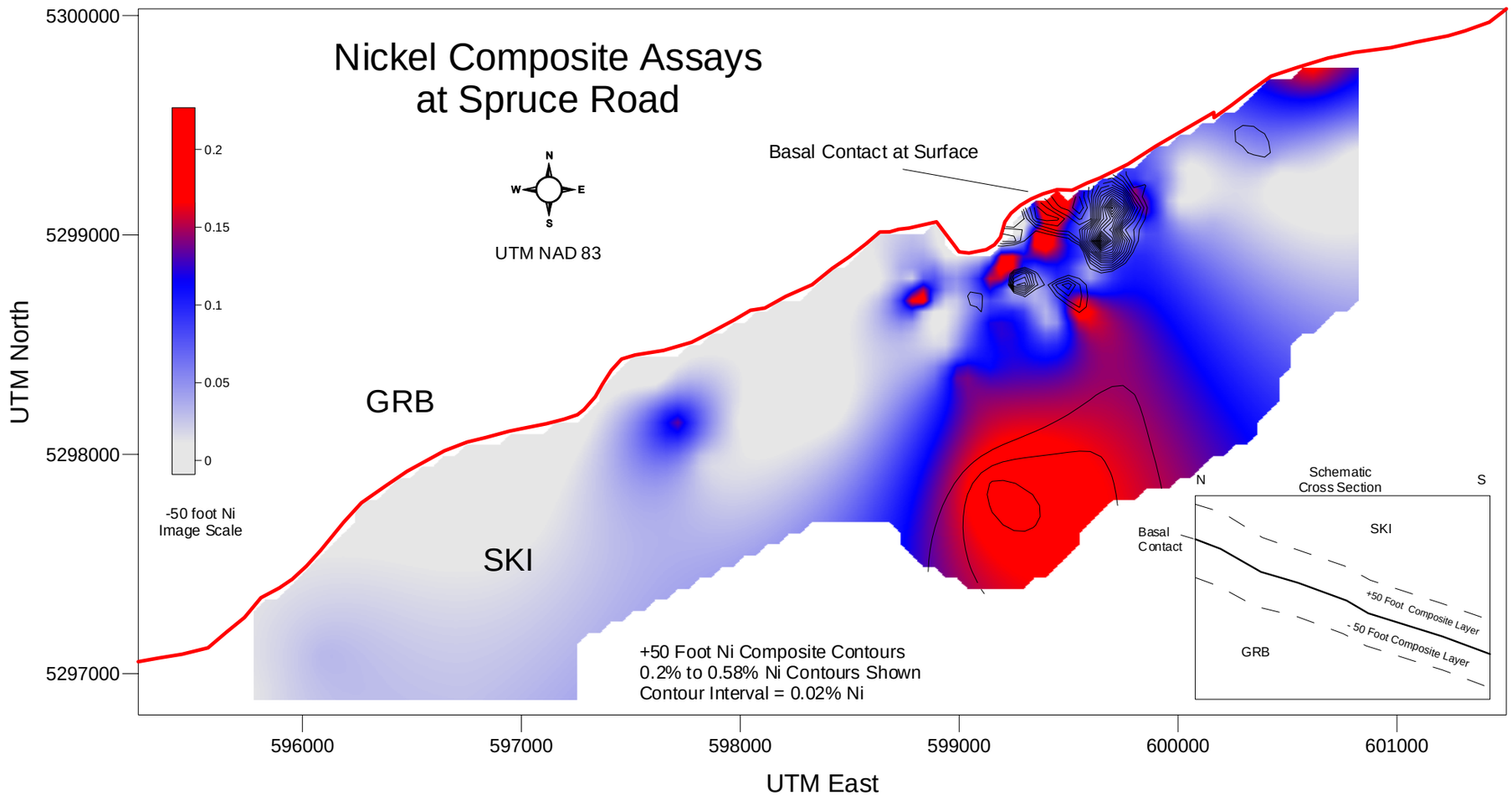

Figure 5. Spruce Road Ni grade map showing black Ni contours for the 50 foot thick SKI composite sheet above the footwall contact (Peterson, 2002) overlaid on a color image of Ni assays for the 50 foot thick GRB composite sheet below the basal contact.

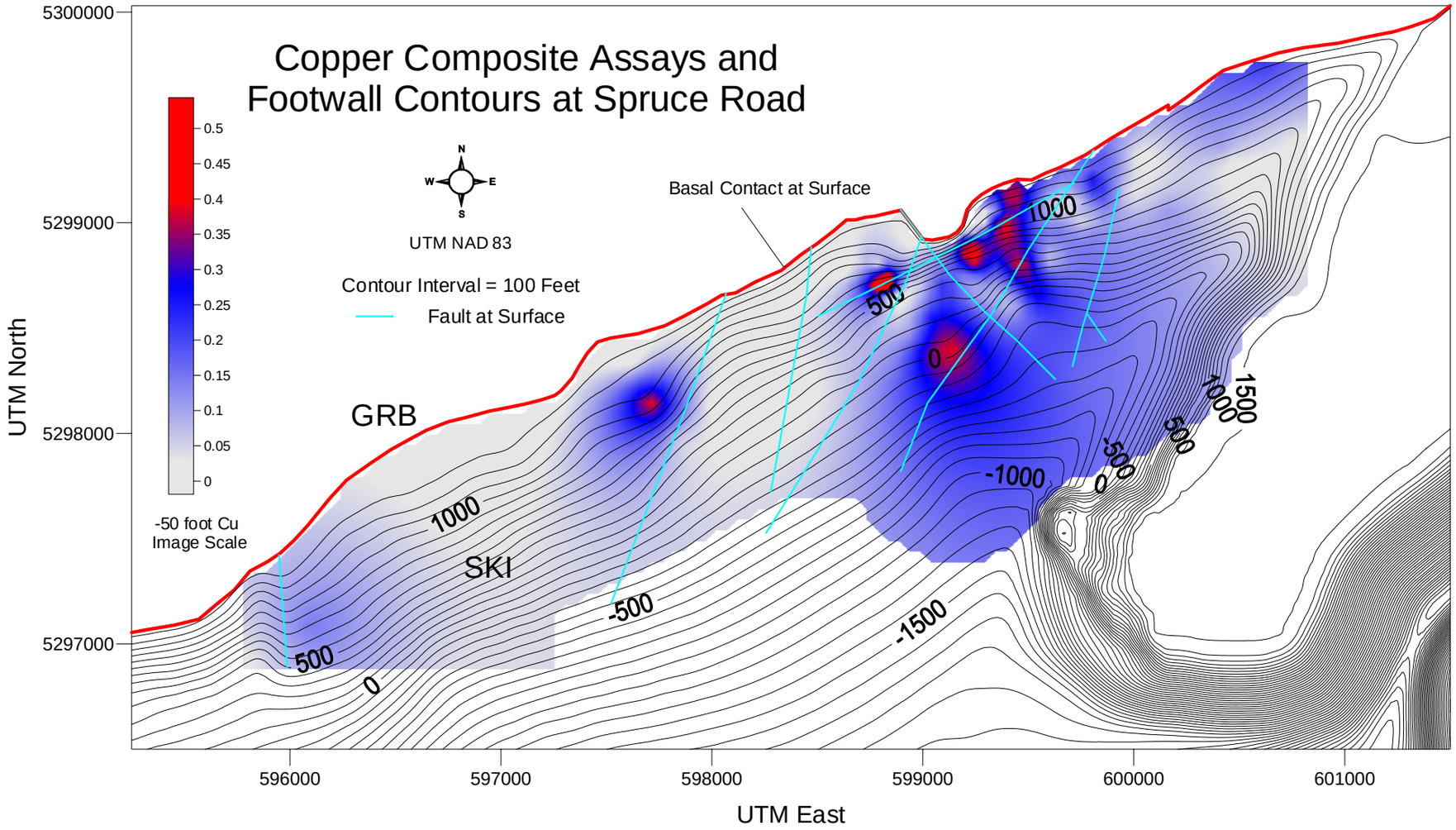

Figure 6. Contoured SKI basal contact (Peterson, 2002) overlaid on the color image of the 50 foot Cu GRB composite sheet below the contact. Surface faults in blue.

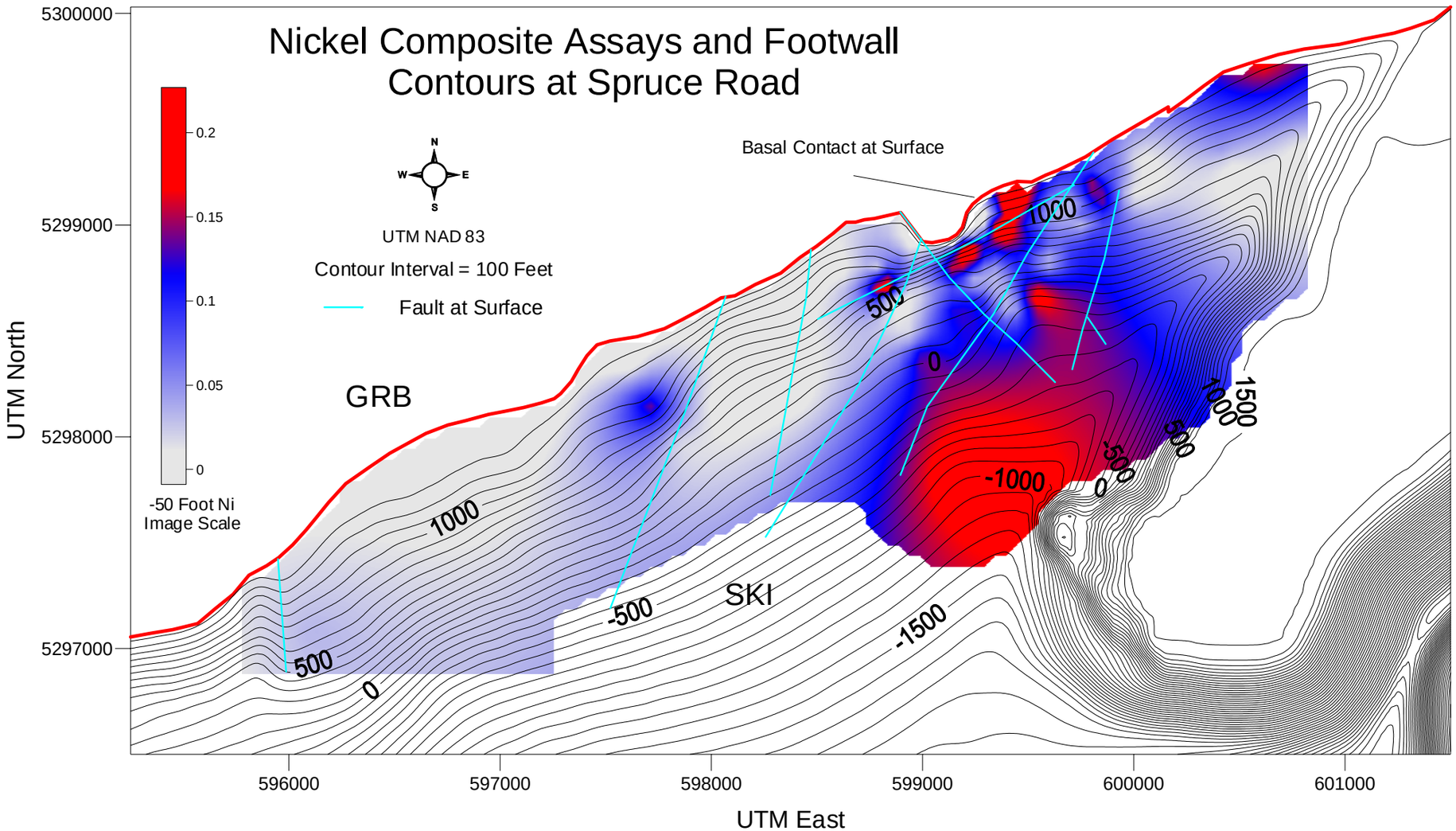

Figure 7. Contoured SKI basal contact (Peterson, 2002) overlaid on the color image of the 50 foot Ni GRB composite sheet below the contact. Surface faults in blue.

Massive sulfide veins have formed in narrow fractures in the granite and seldom penetrate more than 40 feet into the footwall. The sharp contacts of the massive sulfides and their dominantly pyrrhotite (Ni-rich) composition suggest that the melt was quickly drained into preexisting fractures in the granite soon after the melt settled onto the intrusion floor. Had the melt had time to fractionate in the magma chamber before draining, the massive sulfide veins would be expected to contain a large percentage of chalcopyrite. The narrow width of these veins and their shallow depth beneath the contact suggest two limits to massive sulfide accumulation. First, an extensively developed fracture system was not present in the footwall. Second, there were not sufficient quantities of sulfide melt available to widen and deepen the existing fracture network. The presence of mafic dikes derived from the SKI in the granite footwall suggest that there were structural weaknesses in the footwall that could have been used by sulfide melt, had there been a large quantity available.

Disseminated footwall mineralization occurs to significant depths beneath the SKI, and typically has a semi-net- to net-textured character. All of the rocks studied in both core and thin section have been recrystallized and often show evidence of partial melting as described by Sawyer (2002). The sulfide melt settling onto the floor of the intrusion was probably able to move into the footwall as small discrete melt drops and migrate downward into the footwall by its greater density, using the space created by the net-like melt films on the boundaries of still solid mineral grains. This condition would explain the commonly seen texture of sulfides enclosing rounded feldspar and quartz grains. Sawyer (2002) first noted that disseminated sulfides in the footwall may have moved in this manner. The sulfide zoning seen beneath the contact where pyrrhotite + pentlandite quickly grades into a dominantly chalcopyrite assemblage suggests that this process occurred relatively slowly, giving the melt time to fractionate as it moved away from the intrusion and into cooler country rock. The presence of disseminated sulfide on the margins of massive sulfide veins, and small clots of discontinuous massive sulfide suggest that the sulfide movement process was a continuum.

The Cu-Ni composite grade maps of the Spruce Road deposit show a locally inverse relationship between mineralization in the 50 feet above the basal contact and mineralization in the 50 below the contact. Peterson (1997, 2002) has speculated that high metal tenor in the footwall occurs where large volumes of melt were available and had time to penetrate the footwall. This situation would occur beneath a magma conduit that is streaming continuous sulfide rich melt over a specific footwall area for an extended time period. This idea means that if significant volumes of sulfide melt settle onto the partially melted and permeable footwall contact and reside there for an extended time, they should begin to move into the footwall leaving relatively unmineralized SKI behind. Why the basal sulfide melt was not replenished in some areas of the SKI before it crystallized is unknown. Conversely, high-grade zones immediately above the contact in the SKI seem to have solidified before much melt was able to drain into the footwall because permeability was low.

The greatest permeability came from fracture zones in the footwall. Evidence for this is found in the alignment of a semi-linear, high-grade footwall mineralization with a mapped surface fault (Fig. 7). The fault may have been active in the GRB before intrusion of the SKI, creating space for sulfide accumulation. Figure 7 also shows that high grade Ni zones do not

often align with contact irregularities (flats or channels). High Ni assays come from pyrrhotite dominant massive sulfide veins that would require structural ground preparation (high permeability) to form and would not require pooling at the contact surface. Core from these holes is not available, but original drill logs record thin massive sulfide veins along the fault trace and disseminated chalcopyrite elsewhere. Severson (1994) noted a similar linear trend of massive sulfide intersections along the Birch Lake Fault.

Another potentially important factor in footwall mineralization is the 'topography' of the basal contact itself. Peterson's (2002) report showed that high-grade mineralization above the basal contact often corresponds with flat spots and channelways in the contact where sulfide melt appears to have pooled. Figure 6 shows that several areas of high-grade Cu footwall mineralization lie beneath irregularities in the contact surface where melt could easily been trapped and then drained downward. This process would probably create disseminated chalcopyrite mineralization due to slow seepage and fractionation into partially melted rocks.

The primary mechanism controlling mineralization of the GRB beneath the SKI seems to have been the permeability of the footwall. The disseminated nature of the Cu-rich mineralization corresponds to the moderate permeability created by partial melting of the granite. Also, the massive nature of Ni-rich vein mineralization results from highly permeable structural preparation of the footwall. Footwall that has sporadic or no mineralization (common) may result from sulfide melt having passed through the rock without crystallizing, or from a lack of extensive partial melting in these areas. Targets for new mineralization are difficult to define. Any Archean age fault intersecting the basal contact would be of interest. However, the lack of large, presently known occurrences of massive sulfide at the basal contact does not lend encouragement to the prospect of locating large bodies of high-grade massive sulfide mineralization in the footwall.

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Appendix I

Drill holes with thin sections

DDH	Deposit	UTM East NAD83	UTM North NAD83	ELEV (feet)	Total Depth (feet)	Azimuth (degrees)	DIP (degrees)	Footwall Contact (feet below surface)
D-02	Dunka Pit	587889	5284883	1475.0	1665	0	-90	1580.5
D-04	Dunka Pit	586787	5283649	1520.0	1447	0	-90	1215
D-05	Dunka Pit	587120	5283586	1510.0	1873	0	-90	1595
D-09	Dunka Pit	587642	5284552	1490.0	1477	0	-90	1440
D-10	Dunka Pit	587498	5284319	1485.0	1684	0	-90	1621
D-13	Dunka Pit	587410	5284583	1490.0	1002	0	-90	887
D-06A	Dunka Pit	587351	5283462	1521	2125	0	-90	2016
DU-01	Maturi	594207	5294849	1500	2895	0	-90	2643
DU-06	Maturi Ex	594547	5294639	1470	3005	0	-90	2977
DU-13	Maturi	593412	5293419	1450	NA	0	-90	3536
DU-19	Maturi	594282	5295364	1485	1830	0	-90	1757
NM-04	Maturi Ex	595443	5293844	1504	5045	0	-90	4614
K-04	Maturi	595148	5296248	1500	1697	0	-85	1627
K-08	Maturi Ex	593065	5293460	1430	3420	0	-90	3335
11526R	Maturi	593094	5294991	1458	1163	325	-72	976
32727A	Maturi	592332	5294485	1462	925	328	-90	651

Appendix II

Thin Section Descriptions

Descriptions listed in order of distance in feet from the footwall contact beginning above the contact. P = polished section; T = thin section.

DMP01-76 (P, +33.5 ft.)- 70% feathery amphibole (tremolite?) + chlorite + serpentine alteration; 20% clay + sericite altered feldspar; 3% quartz; 2-3% biotite.

5% chalcopyrite>pentlandite>pyrrhotite. Trace sphalerite with very fine chalcopyrite inclusions. Chalcopyrite is very ragged and interfingered with feathery amphibole. Strong amphibole alteration. Many fine, disseminated individual pentlandite grains.

D2-1577 (P, +3.5 ft.)- 50% orthopyroxene; 40% clinopyroxene; 25% plagioclase; 2-3% biotite; 1-2% quartz. 5-20 millimeter orthopyroxene and clinopyroxene oikocrysts. All plagioclase is interstitial, some poikilitic. Poikilitic orthopyroxene encloses orthopyroxene and plagioclase.

1% fine chalcopyrite + trace pyrrhotite. Several 1 millimeter chalcopyrite with fine pyrrhotite on margins.

Du1-2646 (P, -1 ft.)- 40% plagioclase, 20% potassium feldspar, 20% orthopyroxene + clinopyroxene; 5% biotite; 1-2% interstitial quartz; trace amphibole (tremolite?). All feldspar is strained, some with internal dislocations. Some plagioclase with internal potassium feldspar grains. 4-5 millimeter plagioclase phenocrysts, groundmass is <0.5-a millimeter plagioclase + potassium feldspar. Orthopyroxene completely replacing some plagioclase lathes. Orthopyroxene in groundmass is anhedral. Biotite rims on some sulfide. Biotite growing around orthopyroxene in groundmass.

1-2% semi-net textured chalcopyrite + pyrrhotite composite grains. Minor, coarse pentlandite adjacent to pyrrhotite. Very fine chalcopyrite +/- pyrrhotite grains disseminated throughout. Minor oxides.

W010120-1028 (P, -1 ft.)- 55% potassium feldspar; 25% </=1 millimeter; 15% clinopyroxene; 5% 0.5-1 millimeter biotite, sometimes poikilitic; 1-2% tremolite (?); trace plagioclase. 5-8% ragged, strained, potassium feldspar phenocrysts in orthopyroxene + clinopyroxene + potassium feldspar + biotite groundmass. Orthopyroxene clustering around potassium feldspar phenocrysts.

2% interstitial chalcopyrite + pyrrhotite + trace pentlandite. Pentlandite exsolving from pyrrhotite. Several chalcopyrite grains with lathes of cubanite (?). Remainder of slide has very, very fine disseminated chalcopyrite +/- pyrrhotite. Larger chalcopyrite grains sometimes interfingering with feathery amphibole. Trace fine oxides.

D2-1582 (P, -1.5 ft.)- Dike or xenolith- 70-75% orthopyroxene + clinopyroxene, 15% plagioclase, 10% potassium feldspar, trace quartz, trace biotite. Much orthopyroxene and clinopyroxene altering directly out of feldspar along cleavage planes (90% alteration).

Wallrock- 80% moderately clay + sericite altered feldspar; 10% plagioclase; 3-5% quartz; 5% orthopyroxene; 1% biotite. Feldspar is strained and recrystallized.

0.5-1.0% interstitial composite grains of chalcopyrite>pyrrhotite and pyrrhotite>chalcopyrite. Individual grains of both pyrrhotite and chalcopyrite also present. Minor pentlandite flames in pyrrhotite. Possible violarite.

D6A-2033 (P, -3 ft.)- 75% clay + sericite altered potassium feldspar; 10-15% quartz; 2-3% tremolite (?) + biotite; 2% fine orthopyroxene; trace plagioclase. 1 millimeter potassium feldspar grains with mortar texture on margins. 10 millimeter clot of biotite + amphibole flakes with minor potassium feldspar and 2-3% sulfide. Appears to be a small inclusion.

1% chalcopyrite + pyrrhotite primarily located on the margin of a 1-2 centimeter mafic inclusion. Chalcopyrite surrounding rounded quartz grains, commonly with thin opaque (isotropic in transmitted light) rims that are not reflective, but appear to be silicate (??). Large arsenopyrite (?) grain surrounded by biotite + amphibole + quartz with one euhedral, faceted quartz grain with amphibole terminating against it. Indicates open space. Very fine, white-silver-grey amoeboid unknown within arsenopyrite (?). Disseminated oxide throughout inclusion and host rock.

32727A-657.5 (P, -3.5 ft.)- 78% 1-2 millimeter, ragged, strained potassium feldspar some with internal dislocations. 10-15% chlorite in </=1-2 millimeter clots with tremolite and sulfide; 1-2% tremolite; trace orthopyroxene. 10% clay + sericite alteration most intense near chlorite clots. Very weak mortar texture.

2-3% disseminated pyrrhotite and chalcopyrite. Relatively few composite grains. Trace exsolved pentlandite. Ragged sulfide grains. Some chalcopyrite interfingered along cleavage in amphibole. Some very, very fine disseminated chalcopyrite.

D2-1584 (P, -3.5 ft.)- 80% polygonal, ragged, weakly clay + sericite alteration potassium feldspar; 10% orthopyroxene; 5% plagioclase; <1% biotite + chlorite as alteration of orthopyroxene; trace quartz. Weakly recrystallized.

4% disseminated, fine chalcopyrite + pyrrhotite; 1% magnetite + ilmenite; trace sphalerite (?).

D5-1599 (T, -4 ft.)- 75%, 0.5-2 millimeter, euhedral, randomly oriented, plagioclase lathes; 15% 1-2 millimeter clinopyroxene; 5%, 1-2 millimeter relict clinopyroxene phenocrysts replaced by tremolite; 1-2% poikilitic hornblende; 1-2% magnetite. 15% clay + sericite alteration of plagioclase.

DMP01-78 (T, -5 ft.)- Contact with inclusion. Inclusion = 45% potassium feldspar; 30-35%, 0.5 millimeter orthopyroxene + clinopyroxene; 15%, 1 millimeter plagioclase; 3% biotite; 1% magnetite. Some zonation of biotite (weak foliation). Plagioclase is subhedral and the potassium feldspar is anhedral. Generally equigranular.

Rock = 90% potassium feldspar; 5% orthopyroxene; 3-5% plagioclase; 0.5% tremolite; 0.5% biotite. Groundmass is +/- 1 millimeter and weakly recrystallized.

DU19-1762.5 (P, -5.5 ft.)- 60% strained, weakly recrystallized potassium feldspar; 30% granular, <0.5-1 millimeter orthopyroxene + clinopyroxene; 5% disseminated biotite; 3-5% plagioclase; 1% fibrous amphibole (tremolite?). All equidimensional.

Trace very, very fine disseminated chalcopyrite. Minor disseminated oxides.

D10-1625.5 (T, -6.5 ft.) - 88% potassium feldspar, 5% quartz; 3% biotite; 2-3% orthopyroxene; 1-2% hornblende; 0.5% magnetite; trace plagioclase. 2 millimeter, weakly sericitized potassium feldspar with ragged edges, locally with weak mermekitic texture, minor Carlsbad twins. With finer 0.5-1 millimeter, intergranular quartz. Mortar texture along boundaries of larger grains. Biotite + tremolite + orthopyroxene is intergranular, 0.5 millimeter; orthopyroxene partially altered to amphibole.

K8-3341.8 (P, -7 ft.)- Contact between host rock and massive sulfide bleb (40% sulfide). Rock = 55% fibrous, foliated amphibole (tremolite?); 30% potassium feldspar becoming more clay altered toward massive sulfide (MS) contact; 10% <0.5 millimeter plagioclase; 2-3% biotite; 2-3% quartz; <1% chlorite. Very equidimensional texture. Disseminated sulfide increasing toward MS contact. Massive sulfide- Rounded, dissolved (??) plagioclase +/- potassium feldspar floating in sulfide. Larger phenocrysts have amoeboid, wormy inclusions of sulfide. Minor clay alteration in feldspar. 5-10% fibrous amphibole (tremolite?) + serpentine.

55% pyrrhotite + pentlandite +/- chalcopyrite net-textured massive sulfide (35% pyrrhotite, 20% pentlandite). Several large pentlandite grains. Pyrrhotite has variable anisotropy possibly from being strained. MS has hairline cracks filled with very fine amphibole or serpentine.

D2-1588 (P, -7.5 ft.)- 2% rounded feldspar + quartz grains in massive sulfide. Fine cracks in MS filled with very fine, fibrous amphibole (?) + serpentine (?).

85% 3-10 millimeter pyrrhotite; 10% 3-6 millimeter chalcopyrite, 2% pentlandite as exsolved flames in pyrrhotite; trace sphalerite; 3% 1-5 millimeter magnetite + ilmenite.

DU13-3543 (P, -8 ft.)- 50% potassium feldspar; 20% uniformly distributed orthopyroxene; 5-10% plagioclase; 3% clinopyroxene, much with sulfide; 2% red biotite; 1% amphibole (tremolite?) +/- chlorite (?) clots. 0.5-1 millimeter, equidimensional, very uniform feldspar + orthopyroxene. 1.5 centimeter sulfide bleb has orthopyroxene + clinopyroxene + potassium feldspar +/- quartz grains suspended in it.

Massive sulfide bleb of net-textured pyrrhotite>pentlandite>chalcopyrite. Pentlandite is found on pyrrhotite margins and as exsolving flame structures within pyrrhotite. Many fine slivers of chalcopyrite interfingering with, or included in silicates. Margins of some pyrrhotite grains have very fine ‘dogs teeth’ of chalcopyrite projecting into adjacent silicate grains. ‘Dogs teeth’ may begin at cracks within silicates, also.

K4-1635 (P, -9 ft.)- 85% equidimensional, weak-moderate clay + sericite altered potassium feldspar; 5-8% interstitial quartz; 5-6% subhedral to anhedral <1 millimeter biotite; 1% chlorite sometimes altering from biotite. No strong recrystallization. 0.5% fine disseminated oxides.

DU6-2986 (T, -9 ft.)- 50-55% potassium feldspar; 25-30% <1 millimeter orthopyroxene; 5-10% plagioclase; 3-5% quartz; 2% tremolite + biotite + hornblende; 1% clinopyroxene. <5% potassium feldspar phenocrysts, undulose extinction, moderate to strong clay + sericite alteration in potassium feldspar.

W01012-1038 (P, -11 ft.)- 40% potassium feldspar; 30% orthopyroxene; 20% clinopyroxene; 3-5% <0.5-1 millimeter biotite; trace plagioclase; trace quartz. Granular orthopyroxene + clinopyroxene in 2-4 millimeter clots associated with sulfide. Weakly foliated with 5% 2 millimeter, ragged strained potassium feldspar phenocrysts in potassium feldspar + pyroxene groundmass. Granular orthopyroxene clustered on margin of phenocrysts. 1 millimeter elongate clots of fine biotite + orthopyroxene.

5% semi-net textured chalcopyrite + pyrrhotite + pentlandite. Typically composite grains. Minor pentlandite. Chalcopyrite grain margins interfinger w/ feathery amphibole. Unknown dark grey mineral.

D10-1633.5 (P, -14.5 ft.)- 5%, 3-4 millimeter, strained, ragged potassium feldspar phenocrysts; 15-20%, subhedral orthopyroxene, defining weak foliation; 2-3% plagioclase; 3-5% biotite; 1-2% quartz; 75% potassium feldspar groundmass. Thin, quartz + biotite (?) rims on orthopyroxene grains within sulfide pockets. Mortar texture at boundaries of larger grains. Potassium feldspar is interstitial to larger orthopyroxene grains.

1-2% chalcopyrite + bornite in semi-net textured patches. Some chalcopyrite grains have pale yellow/white blebs of arsenopyrite (?). Very fine disseminated magnetite with exsolving ilmenite. Minor coarse magnetite grains. Sulfides occur within patches of magnetite + amphibole.

D4-1230 (P, -15 ft.)- 85% weakly clay + sericite altered, porphyritic potassium feldspar; 10% fibrous amphibole (tremolite?); 2% orthopyroxene; 2% biotite + hornblende; 1% quartz. Undulose extinction, internal dislocations, and mortar texture in potassium feldspar. Subangular hornblende + biotite + tremolite (?) clots.

1% magnetite + ilmenite; trace disseminated chalcopyrite +/-pyrrhotite, usually as composite grains with magnetite.

D5-1610.5 (P, -15.5 ft.)- Massive sulfide 83% pyrrhotite; 10% chalcopyrite; 2% pentlandite; trace sphalerite; trace magnetite + ilmenite; 3% clinopyroxene +/- orthopyroxene; 1% amphibole (tremolite?); trace potassium feldspar. Coarse, 3-15 millimeter pyrrhotite with pentlandite exsolution flames. Very fine sphalerite grains within chalcopyrite. 2-10 millimeter grains chalcopyrite.

D9-1314 (P, -17.5 ft.)- 55% potassium feldspar; 15-20% orthopyroxene + clinopyroxene; 10% plagioclase; 2-3% dark red biotite rims on sulfide. Weak clay + sericite alteration. Possibly some microcline. 3-5 millimeter, sub-equigranular, well-rounded orthopyroxene grains within sulfide clots.

10% pyrrhotite + chalcopyrite + pentlandite in one massive sulfide clot. Pentlandite exsolving as fine lamellae within pyrrhotite grains. Chalcopyrite clots as rims on and included in pyrrhotite grains. MS has significant proportion of oxide. Sulfide and oxide grains to 4 millimeter. No coarse pentlandite. Several disseminated, <<1 millimeter, well-rounded pyrrhotite +/- chalcopyrite composite drops. Pyrrhotite + chalcopyrite following hairline cracks through silicates. Much interstitial skeletal magnetite + ilmenite.

D6A-2048 (T, -18 ft.)- 90%, 2-4 millimeter, ragged potassium feldspar grains with mortar texture rims; 3-4% orthopyroxene; 3% quartz; 2% hornblende + biotite in groundmass.

D13-913 (P, -23 ft.)- (Slide mislabeled by lab, actually 910 ft.) Chalcopyrite surrounding rounded, unstrained quartz grains enclosed by grains of potassium feldspar with unstrained edges, which are rimmed with tremolite. Chalcopyrite blebs edged by biotite grains that are growing into a large potassium feldspar grain, probably along cleavage.

3-5% net-texture of composite chalcopyrite + arsenopyrite (?) surrounding well-rounded, 'dissolved' feldspar grains. Fine oxides disseminated throughout. Small pinkish-grey unknown on margin of chalcopyrite grain.

D4-1238 (P, -23 ft.)- 90% anhedral potassium feldspar phenocrysts in polygonal matrix with well developed mortar texture. 5% hornblende + biotite, 5% interstitial quartz; 3% plagioclase; 2% tremolite, trace chlorite; trace magnetite. Potassium feldspar variably altered to clay + sericite, some show strain (undulose extinction).

DU6-3001 (T, -24 ft.)- 87% 4-8 millimeter, moderately clay + sericite altered potassium feldspar; 5-8% fine, <<0.5 millimeter, o ft.en graphic quartz; 3-4% biotite + hornblende +/- chlorite +/- tremolite; 0.5% plagioclase.

DU6-3005 (T, -28 ft.)- Hand sample is strongly altered along 1-2 millimeter veins. 1-2 millimeter veinlet- sericite blocks, minor elongate chlorite, trace quartz in cross cutting vein, much open space.

Wall rock- 95% 1-2 millimeter, ragged, intensely clay altered potassium feldspar; 3-5% 0.5 millimeter chlorite clots; 3% fine quartz; trace amphibole (tremolite?); Likely some hematite alteration with clay.

D2-1611 (T, -30.5 ft.)- 82%, <0.5 millimeter, equigranular potassium feldspar; 10-15% tremolite + chlorite; 2%, fine-grained quartz; 1% hornblende + biotite; trace magnetite. Moderate sericite alteration of feldspar.

D5-1627 (P, -32 ft.)- 45-50% sericite +/- clay altered plagioclase; 30-40%, subhedral, weakly altered plagioclase, 2-3% potassium feldspar; 3-4% clinopyroxene (?); 1-2% biotite; 1-2% amphibole.

<1% chalcopyrite>pyrrhotite composite grains and irregular masses. Trace pentlandite or possibly violarite. Large grains of magnetite, some associated with chalcopyrite. Oxide >> sulfide.

D10-1653 (T, -34 ft.)- 82% potassium feldspar; 3-5% biotite + hornblende; 3-5% quartz; 3-5% plagioclase phenocrysts and groundmass; 2% orthopyroxene; <1% magnetite. Potassium feldspar phenocrysts (porphyroblasts) within fine-grained recrystallized potassium feldspar with polygonal grain boundaries. Phenocrysts have ragged edges, some with mermykite. Granular, intergrown masses of biotite + hornblende + orthopyroxene. Some potassium feldspar phenocrysts and large biotite flakes are slightly bent. Clearly metamorphosed.

DU1-2680 (P, -35 ft.)- Contact with massive Sulfide vein. 45% potassium feldspar; 25% sulfide; 15-20% orthopyroxene; 5% plagioclase; 1% biotite; 1% amphibole (tremolite?). Feldspars are strained and have internal dislocations. Some feldspar phenocrysts are strongly replaced with fine, rounded orthopyroxene grains and minor, elongate tremolite. Several 5-10 millimeter clots of amphibole (tremolite?) + feldspar within massive sulfide appears to be clasts (xenoliths) from near the Duluth Complex contact. Massive sulfide has rounded plagioclase and potassium feldspar grains, some contain amoeboid inclusions of sulfide. Also, rounded orthopyroxene grains suspended in sulfide.

70% pyrrhotite>pentlandite>chalcopyrite semi-massive sulfide of well developed net-texture surrounding feldspars. Pyrrhotite with coarse veins and rims of pentlandite, minor pentlandite flames within pyrrhotite. Pentlandite has very fine, high interference color alteration flecks. Pyrrhotite grains have variable anisotropy possibly resulting from strain (?). Minor slivers of chalcopyrite within pyrrhotite.

NM4-4678 (T, -36 ft.)- 95% 0.5-2 millimeter, ragged, strongly clay altered potassium feldspar; 2-3% 0.5-1 millimeter disseminated tremolite; 1-2% 0.5-1 millimeter quartz; 0.5% oxides; <0.5% plagioclase. Vein of 95% randomly oriented needles of amphibole (tremolite + actinolite??) with 5% quartz on vein wall. Some open space.

D5-1634 (P, -39 ft.)- 60% weakly sericite altered, interlocking, equidimensional, euhedral plagioclase; 15% orthopyroxene interstitial to and embaying plagioclase; 5% biotite + chlorite +/- tremolite; 5% interstitial hornblende.

<0.5% very, very fine, disseminated chalcopyrite; 0.5% 0.5 millimeter disseminated magnetite.

D6A-2072 (P, -42 ft.)- 55% potassium feldspar; 30% plagioclase; 10% orthopyroxene; 2-3% biotite + chlorite; 1% disseminated magnetite. Porphyritic feldspar with some grains having internal dislocations, undulose extinction. Good recrystallized texture in groundmass. Fine orthopyroxene sometimes rims feldspars.

D9-1339 (P, -42.5 ft.)- 50% moderately clay + sericite altered potassium feldspar; 40% 0.5-2 millimeter orthopyroxene; 3% <0.5 millimeter, dark red biotite; 2% plagioclase. Finer orthopyroxene is replacing feldspar along cleavage.

5% interstitial pyrrhotite>chalcopyrite>pentlandite. Pentlandite grains similar size to pyrrhotite (</=5 millimeter), both on pyrrhotite margins and interior, also as lamellae. Possible violarite. Disseminated magnetite.

32727A-697 (P, -43 ft.)- 45% orthopyroxene + clinopyroxene; 35% 1-1.5 millimeter, subhedral olivine; 15% poikilitic plagioclase; 3% biotite. Brown alteration product of orthopyroxene??? Minor, very fine fibrous alteration stringers of amphibole (?) throughout slide. Cracks in olivine have fine magnetite stringers with iddingsite (?). Mafic dike.

0.5% disseminated oxides. Two very, very fine composite pyrrhotite + chalcopyrite grains.

D6A-2073.5 (T, -43.5 ft.)- 40% potassium feldspar; 40% plagioclase; 15%, <0.5-1 millimeter, orthopyroxene; 2-3%, <0.5-1 millimeter hornblende + biotite + tremolite interstitial with orthopyroxene; trace magnetite. Some plagioclase phenocrysts slightly bent. Overall equidimensional.

D5-1641 (P, -46 ft.)- 70% subhedral orthopyroxene; 10% poikilitic hornblende; 5-8% biotite; 5-10% poikilitic plagioclase; 2-3% feathery amphibole (tremolite?); trace quartz. All equidimensional. Trace chalcopyrite.

D13-935 (T, -48 ft.)- 75% potassium feldspar; 15% quartz; 3-5% biotite + hornblende; 1-2% plagioclase; 0.5% sericite; trace magnetite. Equigranular potassium feldspar groundmass with 2-3% ragged, sericite altered potassium feldspar phenocrysts. Groundmass has triple junctions. 1 millimeter, ragged quartz grains. Some 1.5 millimeter biotite + hornblende clots are clearly filling gaps between potassium feldspar grains. Mortar texture common.

D2-1635 (T, -54.5 ft.)- 88% potassium feldspar with 10%, 1-3 millimeter, ragged phenocrysts in equigranular groundmass; 5-10% quartz in groundmass; 3-5%, fine orthopyroxene with tremolite or chlorite rims; 3-5%, fine tremolite +/- hornblende; 0.5%, fine magnetite. Groundmass </=1 millimeter.

DMP01-81 (P, -57 ft.)- 82% potassium feldspar (60% clay + sericite altered); 5-8% quartz; 3-5% feathery amphibole; 3% orthopyroxene. 1-3 millimeter potassium feldspar is sub-equigranular with undulose extinction. Minor graphic potassium feldspar phenocrysts.

Vein (<1 millimeter)- 40%, feathery, acicular amphibole (tremolite, act??); minor cc; minor potassium feldspar; 30% open space. Veins cut sulfide blebs and some chips of sulfide are suspended in vein.

<1% net-textured chalcopyrite with exsolving bornite altering to covellite in 6 millimeter clot. Some magnetite rimming chalcopyrite. Bornite has very fine 'cloth'-like exsolution texture. Amphibole veinlet cross-cuts sulfide bleb. Chalcopyrite interfingering with feathery amphibole along cleavage. Remainder of slide has very, very fine disseminated chalcopyrite.

D13-949 (P, -62 ft.)- 68% potassium feldspar, weakly clay + sericite alteration, rare potassium feldspar phenocrysts; 15% quartz; 5% biotite; 2-3% amphibole (tremolite?); <1% plagioclase. 1-3 millimeter, sub-equidimensional, small pockets of interstitial sulfide. Less well-developed mortar texture. Most potassium feldspar has undulose extinction.

1% 1 centimeter zone of primarily net-textured chalcopyrite +/- magnetite. Some magnetite grains have crystal faces. Minor bornite exsolving within chalcopyrite and as individual grains. Minor covellite altering from bornite. Some magnetite +/- ilmenite is net texture around feldspar. Some chalcopyrite enclosing magnetite. Minor arsenopyrite (?).

D10-1683 (T, -64 ft.)- 92% potassium feldspar; 5% orthopyroxene; 2% plagioclase; 2% quartz; 2% hornblende + biotite; 0.5% tremolite; trace magnetite. 0.5-1 millimeter granular potassium feldspar with 2-3%, 1-2 millimeter, ragged potassium feldspar phenocrysts, weakly clay + sericite altered. Many triple junctions in groundmass. Possibly some partial melt pockets outlined by quartz. Minor <1 millimeter euhedral plagioclase in groundmass and 2 millimeter subhedral plagioclase phenocrysts. Orthopyroxene is 1 millimeter subhedral grains uniformly distributed in groundmass. Minor tremolite alteration.

DMP01-82 (P, -65 ft.)- 85% potassium feldspar (15-20% clay + sericite alteration); 5% quartz; 2-3% amphibole (tremolite?); 1-2% biotite; 1-2% fine grain orthopyroxene; 1% plagioclase. Some orthopyroxene with amphibole rims. 1-2 millimeter, sub-equidimensional potassium feldspar with moderate mortar texture and strained grains. Graphic potassium feldspar. Some 'pebbly', broken potassium feldspar grains with messy extinction, many dislocations. Many holes from 'plucked' grains that are filled with cement.

One 4-5 millimeter clot of interstitial chalcopyrite with exsolved bornite altering to trace covellite. Trace fine, disseminated chalcopyrite + sphalerite composite grains.

DU13- 3602 (T, -67 ft.)- 90% potassium feldspar; 5% chlorite + biotite + hornblende; 5% quartz; trace opaques. 3-4 millimeter potassium feldspar grains, weakly clay + sericite altered. Mortar texture. Strong undulose extinction in potassium feldspar. Some potassium feldspar phenocrysts have strong internal dislocations.

D5-1665 (T, -70 ft.)- 45%, 0.5-1 millimeter, plagioclase; 40% 1-3 millimeter hornblende; 10%, <0.5 millimeter clinopyroxene + orthopyroxene; 2% tremolite alteration of hornblende; 2% fine grain potassium feldspar; 2-3% magnetite. Hornblende poikilitic with plagioclase. Clinopyroxene uniformly disseminated. Weak, local foliation.

D2-1663 (T, -82.5 ft.)- 85% potassium feldspar; 5-10% quartz; 3-4% biotite + hornblende + tremolite; 2% orthopyroxene; <0.5% magnetite. Sub-equigranular, 2-3 millimeter, ragged, potassium feldspar grains with finer 0.5-1 millimeter potassium feldspar. No discrete phenocrysts. Weak sericite alteration of potassium feldspar.

K8-3420 (T, -85.5 ft.)- 90% sub-equidimensional, ragged potassium feldspar; 5% 0.5-1.5 millimeter hornblende + chlorite + biotite + oxide; 2-3% 1-2 millimeter quartz; 2% plagioclase. Not strongly recrystallized.

D5-1683 (P, -88 ft.)- 75% equidimensional, interlocking, embayed, randomly oriented plagioclase; 15% anhedral, rounded orthopyroxene; 5-8% hornblende; 1% biotite. Orthopyroxene is slightly coarser than plagioclase. One 3 millimeter orthopyroxene oikocryst. Hornblende concentrated in small zones.

5% skeletal magnetite + ilmenite with trace very fine chalcopyrite.

D9-1388.5 (P, -92 ft.)- 92% strongly clay + sericite altered potassium feldspar; 3-5% orthopyroxene; 2% quartz; 2% amphibole (tremolite?); 1% biotite. Some clots of sericite. Feldspar sub-equidimensional with several 4 millimeter phenocrysts.

1% interstitial chalcopyrite + pyrrhotite + pentlandite + arsenopyrite + trace sphalerite. Clusters of very, very fine disseminated chalcopyrite throughout. Skeletal oxides.

D6A-2123 (T, -93 ft.)- 80%, subequigranular, ragged potassium feldspar; 10% plagioclase; 5% 0.5 millimeter hornblende + biotite; 2%, <0.5 millimeter orthopyroxene; trace magnetite. Weak sericite alteration of potassium feldspar.

DMP01-84 (T, -95 ft.)- 87% potassium feldspar; 5%, <0.5 millimeter orthopyroxene; 3-5% plagioclase; 2% hornblende; 2% biotite; 0.5% oxides. 0.5-1.5 millimeter, sub-equigranular, ragged potassium feldspar grains. Potassium feldspar has internal dislocations. Potassium feldspar embays interstitial biotite. Biotite and hornblende have small zircon inclusions with dark brown halos. Orthopyroxene being replaced by a light green mineral that may be stilpnomelane (??).

D13-983.5 (T, -96.5 ft.)- With mafic inclusion. Host rock: 85%, fine grained, equigranular potassium feldspar groundmass with 1-2% weakly sericite altered phenocrysts; 5% orthopyroxene; 2% biotite + hornblende; trace magnetite; trace quartz. Inclusion: 55% amphibole (tremolite + hornblende); 35% anhedral potassium feldspar; 2-3% biotite; 2% plagioclase; 1% magnetite. Relict potassium feldspar phenocrysts in amphibole groundmass.

D13-997 (T, -110 ft.)- 85% potassium feldspar with 40% 3-4 millimeter ragged potassium feldspar and composite quartz phenocrysts in <1 millimeter potassium feldspar + quartz groundmass; 10% quartz; 2-3% biotite + hornblende + tremolite; trace plagioclase, 0.5% magnetite.

DU1-2756 (T, -111 ft.)- 60% potassium feldspar; 30% hornblende; 5% biotite; 2% plagioclase; 2% orthopyroxene. 3-10 millimeter potassium feldspar phenocrysts in amphibole (hornblende?) rich groundmass.

DMP01-85 (P, -113 ft.)- 85% potassium feldspar; 7-8% orthopyroxene; 3% biotite; </= amphibole; trace plagioclase. Rounded orthopyroxene with thin quartz rims surrounded by sulfide. Biotite flakes protruding into both sulfide grains and orthopyroxene grains. 1-5 millimeter potassium feldspar grain size continuum. Moderate mortar texture, ragged, and strained potassium feldspar grains. Sulfide runs with orthopyroxene.

5% interstitial chalcopyrite with exsolving bornite altering to trace covellite. Trace sphalerite with very, very fine chalcopyrite inclusions. Two large composite grains of chalcopyrite + millerite + bornite + covellite + pentlandite (?) + violarite (?). Skeletal oxides (see Table 2 for sulfide microprobe analyses).

DU13-3658 (P, -123 ft.)- 60% moderately clay + sericite altered potassium feldspar; 10-15% quartz; 5-8%, 1-2 millimeter patches of fibrous, relatively coarse serpentine (?) with some chlorite; 5% plagioclase. 5%, irregular, 2-10 millimeter potassium feldspar phenocrysts in </=1 millimeter potassium feldspar + quartz groundmass. Large potassium feldspar phenocrysts have broken plagioclase inclusions. Many, rounded, up to 4 millimeter holes in slide with rims of fine, granular brown alteration. <0.5%, </=0.25 millimeter, single, anhedral grains of epidote (?).

5% interstitial chalcopyrite + bornite (60% chalcopyrite, 40% bornite). Some large grains with bornite >chalcopyrite. Trace, very fine oxides. Sulfide runs along margin of strong amphibole +/- quartz alteration.

32727A-777 (P, -123 ft.)- 65% equigranular, strained, weakly recrystallized, weakly clay + sericite altered feldspar. 35% 1-2 millimeter orthopyroxene + biotite + tremolite (?) clots. Two types of biotite: anhedral dark red and euhedral light brown.

0.5% fine, disseminated oxides.

DMP01-88 (T, -137.3 ft.)- 92% potassium feldspar; 2-3% plagioclase; 2-3% hornblende; 1% tremolite; 1% biotite; <0.5% sericite; trace oxides. Large 5-10 millimeter potassium feldspar clots with moderate sericite alteration, minor mermykite in sub-equidimensional, ragged grain groundmass. Pockets of completely recrystallized potassium feldspar. Some biotite altering to magnetite.

DU1-2786 (T, -141 ft.)- 88% potassium feldspar; 5% biotite; 3-4% hornblende; 2% plagioclase; 2% orthopyroxene. 3-10 millimeter potassium feldspar phenocrysts in groundmass of <0.5-1 millimeter potassium feldspar + biotite + hornblende + orthopyroxene. Weakly recrystallized texture.

D5-1738 (P, -143 ft.)- 65-70% 1-2 millimeter, weakly clay + sericite altered, subhedral, randomly oriented, often embayed plagioclase; 10% </=1 millimeter, equidimensional, disseminated orthopyroxene; 10% hornblende; 1-2% biotite.

5% skeletal magnetite + ilmenite; trace fine chalcopyrite.

D5-1750 (T, -155 ft.)- 30-40%, 0.5-1 millimeter interstitial hornblende; 32% subhedral, 0.5-1.5 millimeter plagioclase lathes; 25%, 0.5 millimeter, interstitial orthopyroxene +/- clinopyroxene; 1 % potassium feldspar. Some triple junctions among orthopyroxene. Plagioclase may enclose clinopyroxene. Ragged boundaries between plagioclase and hornblende. Groundmass is mostly with hornblende + orthopyroxene with orthopyroxene-only patches.

D9-1452 (T, -155.5 ft.)- 90% potassium feldspar +/- plagioclase; 5%, <0.5 millimeter orthopyroxene; 2% 0.5 millimeter biotite flakes and clots; <1%, <0.5 millimeter tremolite + hornblende; trace magnetite. 60%, 2-5 millimeter, ragged phenocrysts in 0.5-1 millimeter granular potassium feldspar + biotite + hornblende groundmass. Slightly less metamorphosed.

D9-1465 (T, -168.5 ft.)- 96% potassium feldspar; 1-2% fine-grained orthopyroxene; 1% fine biotite + tremolite; 1% plagioclase; 0.5% magnetite. Large 2-5 millimeter, ragged plagioclase phenocrysts enclosing </=1 millimeter potassium feldspar grains. Some phenocrysts slightly bent.

DMP01-90 (P, -169.2 ft.)- Very similar to DMP01-85. 88% potassium feldspar; 5% orthopyroxene; 1-2% quartz; <1% red biotite. Rounded orthopyroxene grains with quartz rims partially suspended in sulfide. Weakly porphyritic with 3-4 millimeter ragged potassium feldspar in 0.5-1 millimeter potassium feldspar with mortar texture and strained grains. Quartz disseminated and rimming orthopyroxene. Sulfide + orthopyroxene clots seem to be weakly connected as stringer zones across slide. Strong, very fine orthopyroxene (?) in irregularly shaped zones.

2% semi-net-textured chalcopyrite with rare exsolving bornite altering to covellite. Composite chalcopyrite + arsenopyrite grains. Bornite inclusions (?) or exsolution (?) in arsenopyrite (maybe cubanite?) Fine anhedral grains of sphalerite with very fine chalcopyrite inclusions. Coarse and fine disseminated, skeletal magnetite + ilmenite. Opaque rims on quartz.

D9-1467 (P, -171.5 ft.)- 85% sub-equidimensional, medium-coarse, potassium feldspar with weakly developed recrystallization in finer fraction; 5% plagioclase; 5% strongly amphibole altered orthopyroxene, 1-2% hornblende +/- chlorite, trace quartz; 3% disseminated magnetite.

D9-1472 (P, -176.5 ft.)- 85% porphyritic, moderately clay + sericite altered potassium feldspar with well-developed mortar texture; 3-5% plagioclase in groundmass; 3-5% orthopyroxene; 2% biotite + tremolite; trace quartz. Orthopyroxene moderately altering to amphibole (?).

1% magnetite + ilmenite; 0.5% <1 millimeter chalcopyrite + bornite.

D5-1777 (P, -182 ft.)- 60% plagioclase; 20-25% orthopyroxene +/- clinopyroxene; 5% hornblende; 2-3% biotite; 1% potassium feldspar. Plagioclase is randomly oriented, weakly sericite altered, some with undulose extinction. Orthopyroxene often has biotite rims. Amphibole + sericite or chlorite rims on sulfide where it contacts plagioclase.

5-6% chalcopyrite>pyrrhotite>pentlandite + magnetite interstitial blebs. Chalcopyrite sometimes rimming pyrrhotite grains. Hairline fractures filled with pyrrhotite + chalcopyrite. Very fine tremolite (?) or sericite (?) in fine cracks within massive pyrrhotite and chalcopyrite grains. Some fine pyrrhotite replacing skeletal oxide grains and along cleavage plans of fibrous amphibole. Larger chalcopyrite grains along cleavage plains of biotite altering to amphibole. Strong, coarse oxide, some surrounded with chalcopyrite.

D5-1790 (P, -195 ft.)- 55% subhedral, equidimensional, sometimes poikilitic orthopyroxene + clinopyroxene; 10-15% olivine; 20% poikilitic plagioclase; 10% biotite, typically poikilitic around orthopyroxene and clinopyroxene. This is a mafic dike.

3-4% semi-net-textured composite pyrrhotite + chalcopyrite grains. Pentlandite exsolution flames in pyrrhotite. Chalcopyrite grains have rare, fine cubanite (?) and common fine sphalerite. Ilmenite sometimes composite with chalcopyrite + pyrrhotite. Also very, very fine chalcopyrite + pyrrhotite disseminated throughout.

DMP01-92 (P, -207 ft.)- 88% potassium feldspar; 5% orthopyroxene; 2-3% biotite; 1% quartz; trace plagioclase. Ragged, 2-5 millimeter phenocrysts of potassium feldspar (one plagioclase) in 0.5-1 millimeter groundmass with mortar texture and strongly strained grains. Angular pockets of biotite flakes and fine potassium feldspar. Some biotite growing into boundary of potassium feldspar grains. Melt pocket?? Rounded orthopyroxene with quartz rims and potassium feldspar +/- biotite suspended in sulfide.

2-3% semi-net-textured chalcopyrite with exsolving bornite altering to covellite (84% chalcopyrite, 15% bornite, 1% covellite). Minor composite chalcopyrite + arsenopyrite grains. Trace sphalerite with chalcopyrite inside bornite. Semi-net texture and disseminated, coarse and fine magnetite. Fine chalcopyrite in core of altered orthopyroxene. Bornite within arsenopyrite (?).

D5-1809 (P, -214 ft.)- 45% weakly sericite altered, subhedral potassium feldspar; 40% equidimensional, subhedral, randomly oriented plagioclase; 8-10% orthopyroxene; 4% hornblende + biotite. 15% slightly coarser feldspar in polygonal feldspar matrix. 5-10 millimeter clots of fine-grained orthopyroxene + biotite + hornblende + sulfide.

3% disseminated magnetite + ilmenite.

DU13-3775 (T, -240 ft.)- 55% weakly clay + sericite altered potassium feldspar, 30% plagioclase; 8-10% quartz; 3% hornblende + biotite + chlorite + oxide; 5%, 4-8 millimeter potassium feldspar phenocrysts; 35%, 1-4 millimeter potassium feldspar; 25%, <1 millimeter recrystallized potassium feldspar. Biotite altering to chlorite. Undulose potassium feldspar extinction.

DU1-2894 (T, -249 ft.)- 85% potassium feldspar; 8-10% quartz; 3-4% hornblende + biotite; <1% plagioclase; trace chlorite. 3-5 millimeter composite quartz grains in 1-8 millimeter, weakly sericite-altered potassium feldspar. Minor orthopyroxene (?) replaced by tremolite + chlorite. Mortar texture along larger grains.

D5-1872 (T, -277 ft.)- 70% strongly clay + sericite altered potassium feldspar; 20% interstitial, ragged quartz; 2% biotite altering to chlorite with minor discrete chlorite; 1% hornblende. Generally equigranular.

DMP01-97 (T, -360 ft.)- 92% potassium feldspar (25% 5-10 millimeter phenocrysts); 3-4% biotite; 2% plagioclase; 1% hornblende; 0.5% orthopyroxene; trace quartz; trace magnetite. Biotite flakes + hornblende as clots within fine-grained potassium feldspar+ plagioclase + biotite + hornblende +/-orthopyroxene groundmass. One 2 millimeter quartz bleb. Potassium feldspar phenocrysts are embayed by <0.5 millimeter potassium feldspar grains. Phenocrysts show some partial internal recrystallization(??)

DMP01-98 (T, -388 ft.)- Nearly identical to DMP01-97.