

Description of the Metamorphosed Virginia Formation at the Peter Mitchell Mine, Babbitt, Minnesota

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Introduction

At Northshore Mining Company's Peter Mitchell mine in northeastern Minnesota (Fig. 1) mining of the Biwabik Iron Formation has become complicated by the need to strip overlying bedrock as well as the glacial drift in order to expose the ore. The waste rock, sediments of the Virginia Formation metamorphosed by the Duluth Complex, is a hornfels composed of quartz-biotite-cordierite-orthopyroxene-feldspar in varying proportions. One member of the Virginia Formation hornfels consists of a suite of sulfide-rich, graphite-bearing rocks informally known as the "bedded pyrrhotite unit" (Zanko et. al., 1994) which contains 5 – 10% pyrrhotite. These sulfide-rich rocks pose a potential acid drainage problem if stockpiled. The Virginia Formation section has been inflated by the intrusion of several sills; one of these, informally called the Virginia Sill (Severson, 1996) is up to 75 feet thick (Fig. 3a, 3b; Appendix II). Fourteen drill cores and several drill logs from the vicinity of proposed mining were examined, as well as outcrops along the southeast pit wall, in order to determine the areal extent of the bedded pyrrhotite and its stratigraphic position within the Virginia Formation package, especially in relation to the Massive Grey/Virginia Sill rocks.

Massive Grey and Virginia Sill Units

The "Massive Grey" is an enigmatic rock unit associated with the Virginia Sill. When first observed by NRRI staff it was described as a massive greywacke (Zanko, 1994; Severson, 1996). In many instances it has the appearance of a meta-sediment, being faintly banded. However, this could be flow banding within the sill (Severson, 1996). The upper contact with the Virginia Formation and the lower contact with either Biwabik Iron Formation or other Virginia Formation rocks is sharp. Biotite flakes or hornblende "clots" often give it a spotted appearance. The Virginia Sill is almost always entirely contained within the Massive Grey rocks.

The Virginia Sill is a dark grey-green to black, fine to medium-grained rock with variable amounts of orthopyroxene, hornblende, olivine and plagioclase. It may be magnetic, and in some cores is rich in mafic minerals (hornblende, olivine, orthopyroxene). One interval in DDH 67048 has a sharp contact between the plagioclase-orthopyroxene-olivine rock and the more mafic-rich portion. This sill contains elevated amounts of chromium and is interpreted to be pre- to early Duluth Complex in age (Severson, 1996). It often exhibits a granoblastic texture resulting from metamorphism by the Duluth Complex, as do the Virginia Formation and other rocks in the vicinity.

Sulfides occur (excepting the bedded pyrrhotite unit) along fractures, as small masses or disseminations within any of the Virginia Formations rocks or the Virginia Sill but are generally a small or non-existent proportion of the minerals examined visually.

Methodology

All cores were examined with the aid of a ten power hand lens; thin sections and chemistry were not available. Rock nomenclature was adapted from Zanko et. al., 1994. Magnetic susceptibility measurements were taken on portions of three cores to determine whether the Virginia Sill has a distinct magnetic signature. Results were inconclusive; the bedded pyrrhotite was very distinctive (Fig. 3a), but the Virginia Sill is magnetic over some intervals and not others.

Note: See Appendix II for an explanation of abbreviations used on figures 3a and 3b.

Outcrops in the northeast portion of the mine were examined by the author; no bedded pyrrhotite was observed. The Virginia Sill is well exposed.

Results & Discussion of Drill Core Observations

Many of the cores drilled by Reserve Mining Co. (RMC) were lost during the hiatus between the bankruptcy of RMC and the subsequent start up by Cypress-Northshore Mining Co.; information is lacking in some key areas. Descriptive logs do exist for several of the missing cores in the area of interest. One of these logs, DDH 64060 (Fig. 2), noted pyrrhotite bands in a one foot interval at 72 – 73 feet. This is near the outcrop extension of the Serpentine deposit at the south edge of the mine pit (Fig. 2).

Three of the fourteen drill cores examined contained sections of the bedded pyrrhotite member (Fig. 2); from southwest to northeast, drill cores 64048 (42 feet thick), 65223 (9 feet thick), and 67042 (52 feet thick) while eleven cores have no bedded pyrrhotite intervals. No continuity between cores exists, although DDH 65223 and DDH 67042, just over 200 feet apart, are adjacent. As noted above, the thicknesses are dramatically different. From DDH 67042 northeast to DDH 70162 the bedded pyrrhotite disappears from the cores; very little or no Virginia Formation is present in the upper portions of the cores northeast of DDH 67042; two of the three are collared in the Virginia Sill (Fig. 3a). Non-deposition/erosion and/or structural controls may be responsible; not enough evidence for any mechanism is present in the cores described for this study.

Significantly, the bedded pyrrhotite unit always occurs above the Virginia Sill in the cores described. This is also the case at the Serpentine deposit as defined by Zanko, et. al (1994).

The Virginia Sill occurs near the base of the Virginia Formation just above the contact with the Biwabik Iron Formation in the cores described (Fig. 3b). Near the Grano fault it bifurcates and thickens (Fig. 3a). This fault is thought to be a "feeder" for magmas of the Duluth Complex and associated mineralization in the vicinity (Severson, pers. comm.), such as the Serpentine deposit.

Refer to Zanko et. al. (1994; pp. 16 - 18) for a discussion of the structural setting of the Serpentine deposit area and its influence on the emplacement and mineralization of the Duluth Complex rocks in the area.

Results & Discussion of Chemical Analysis

Sulfur and carbon characterization of the Virginia Formation, by North Shore Mining Co. and the Cleveland Cliffs Lab at Ishpeming, MI, is in progress. This preliminary analysis includes data from several drill cores, from an adjacent non-state lease, not described in this report. Descriptive statistics for individual drill cores (at least six samples) and by described rock type are summarized in Tables 1 & 2, respectively. Preliminary data indicates overall mean sulfur values from a minimum of 0.07% (DDH 71003; 6 samples) - to a maximum of 0.25% (DDH 65200; 8 samples). The remaining cores sampled had means ranging from 0.19% to 0.22% (Table 1).

However, for individual Virginia Formation lithologies, the means drop to 0.14% to 0.18% (Table 2) with the exception of a unit with "disrupted bedding" which has a mean of 0.23%. The number of samples per drill core/lithology is low (6 to 21) so comparisons are tenuous at best.

The bedded pyrrhotite unit sulfur values range from 3.4% to 4.24% (3 samples; DDH 67042). Two additional cores with bedded pyrrhotite have not been sampled to date.

Assays are presented in Appendix I.

Conclusions/Recommendations

The Virginia Sill can be used as a marker between the Biwabik Iron Formation and the bedded pyrrhotite unit. Mine stripping to the top of the Virginia Sill should avoid any disturbance of the sulfide-rich rocks of the bedded pyrrhotite unit.

Electromagnetic/magnetic geophysical techniques on lines normal to the contacts between the Duluth Complex, Virginia Formation and the Biwabik Iron Formation should detect the bedded pyrrhotite unit. These lines should be run starting from near DDH 67042 and continue to the northeast limit of the area to be stripped. Core drilling between DDH 67042 and DDH 70162 to the northeast may be necessary to confirm geophysical results.

Down-hole geophysics in blast holes may also aid in determining the presence of the bedded pyrrhotite unit.

Figure 1. Location of Peter Mitchell Mine and Area of Interest

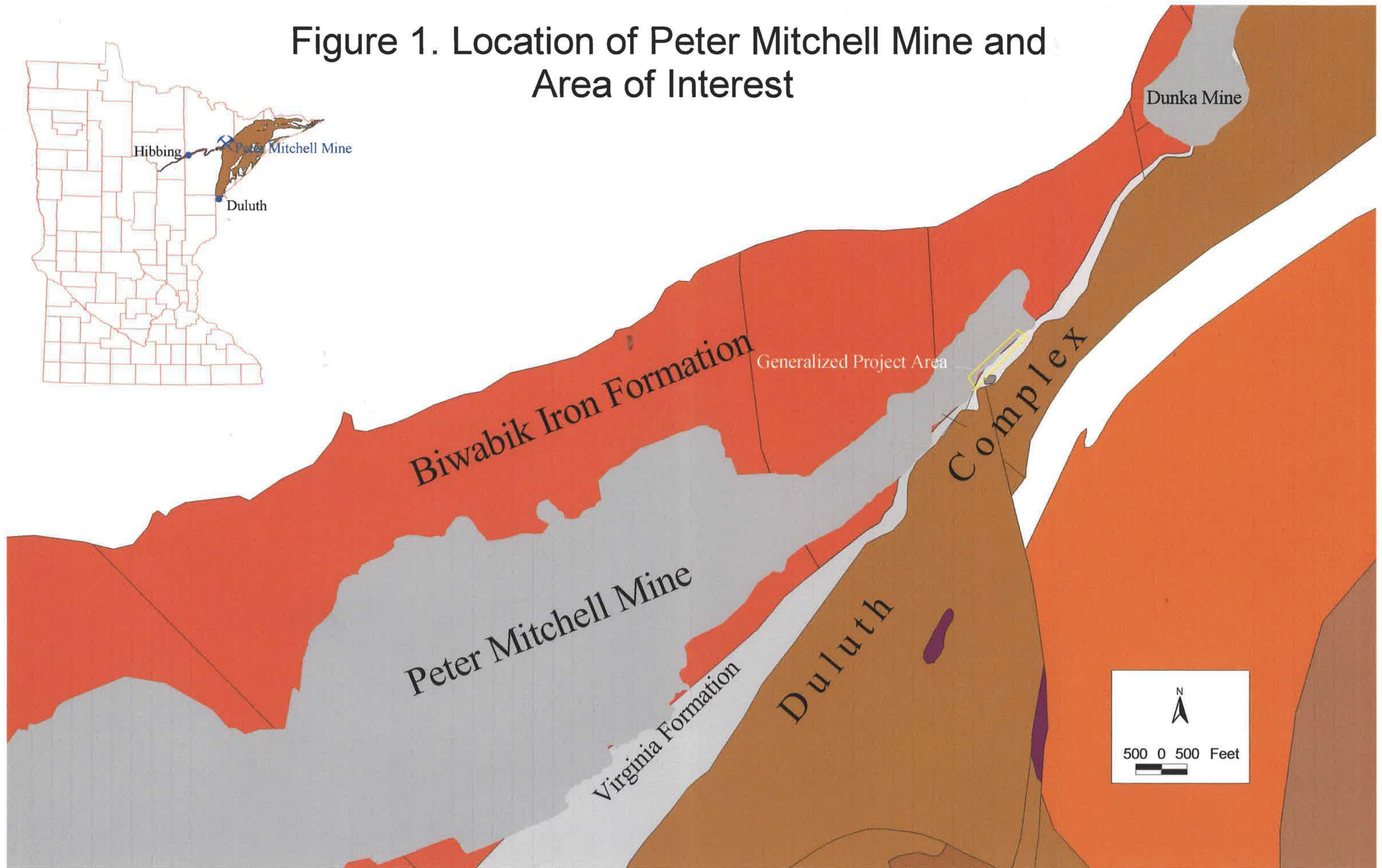


Figure 2.
N E portion of Peter Mitchell Mine
Drill Hole Locations and Serpentine Deposit

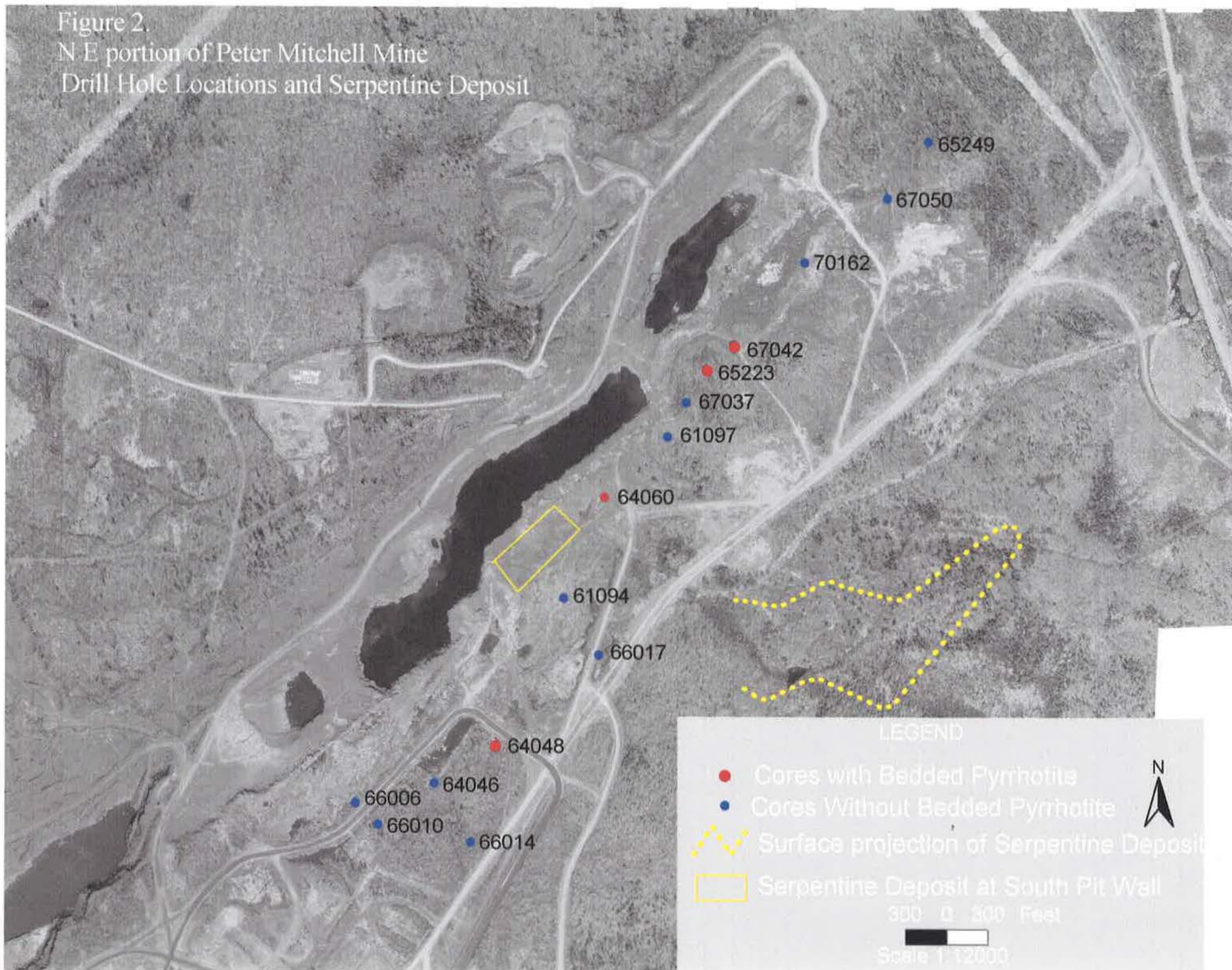


Table 1 - Descriptive Statistics for 8 Cores

237		65200		67037		67042 (Exc Bedded Po)		67042 (With Bedded Po)	
Mean	0.205	Mean	0.251	Mean	0.193	Mean	0.263	Mean	1.31
Standard Error	0.035	Standard Error	0.031	Standard Error	0.04	Standard Error	0.048	Standard Error	0.54
Median	0.211	Median	0.243	Median	0.154	Median	0.231	Median	0.27
Mode	#N/A	Mode	#N/A	Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.1	Standard Deviation	0.089	Standard Deviation	0.106	Standard Deviation	0.127	Standard Deviation	1.7
Sample Variance	0.01	Sample Variance	0.008	Sample Variance	0.011	Sample Variance	0.016	Sample Variance	2.9
Range	0.274	Range	0.236	Range	0.317	Range	0.388	Range	4.1
Minimum	0.088	Minimum	0.135	Minimum	0.111	Minimum	0.141	Minimum	0.14
Maximum	0.362	Maximum	0.371	Maximum	0.428	Maximum	0.529	Maximum	4.24
Sum	1.644	Sum	2.01	Sum	1.354	Sum	1.84	Sum	13.1
Count	8	Count	8	Count	7	Count	7	Count	10

65237		66042		71003		79078	
Mean	0.197	Mean	0.193	Mean	0.075	Mean	0.194
Standard Error	0.032	Standard Error	0.035	Standard Error	0.014	Standard Error	0.023
Median	0.182	Median	0.143	Median	0.076	Median	0.161
Mode	#N/A	Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.092	Standard Deviation	0.092	Standard Deviation	0.033	Standard Deviation	0.084
Sample Variance	0.008	Sample Variance	0.008	Sample Variance	0.001	Sample Variance	0.007
Range	0.256	Range	0.218	Range	0.095	Range	0.289
Minimum	0.092	Minimum	0.097	Minimum	0.016	Minimum	0.078
Maximum	0.349	Maximum	0.316	Maximum	0.112	Maximum	0.367
Sum	1.576	Sum	1.351	Sum	0.448	Sum	2.526
Count	8	Count	7	Count	6	Count	13

Table 2 - Descriptive Statistics by Lithology

Bedded Hornfels		Va Sill		Va Sill + Inclusions		Va Sill All	
Mean	0.183	Mean	0.15	Mean	0.154	Mean	0.152
Standard Error	0.027	Standard Error	0.023	Standard Error	0.027	Standard Error	0.018
Median	0.135	Median	0.115	Median	0.131	Median	0.118
Mode	#N/A	Mode	#N/A	Mode	#N/A	Mode	#N/A
Standard Deviation	0.126	Standard Deviation	0.106	Standard Deviation	0.09	Standard Deviation	0.1
Sample Variance	0.016	Sample Variance	0.011	Sample Variance	0.008	Sample Variance	0.01
Kurtosis	1.788	Kurtosis	5	Kurtosis	-0.69	Kurtosis	3.539
Skewness	1.649	Skewness	1.98	Skewness	0.768	Skewness	1.653
Range	0.442	Range	0.484	Range	0.26	Range	0.484
Minimum	0.064	Minimum	0.016	Minimum	0.043	Minimum	0.016
Maximum	0.506	Maximum	0.5	Maximum	0.303	Maximum	0.5
Sum	3.847	Sum	3.156	Sum	1.694	Sum	4.851
Count	21	Count	21	Count	11	Count	32
MG + Inclusions		MG All		Rxtl		All Rock Types	
Mean	0.172	Mean	0.154	Mean	0.18	Mean	0.262
Standard Error	0.021	Standard Error	0.016	Standard Error	0.022	Standard Error	0.051
Median	0.171	Median	0.145	Median	0.163	Median	0.147
Mode	#N/A	Mode	#N/A	Mode	#N/A	Mode	0.127
Standard Deviation	0.063	Standard Deviation	0.08	Standard Deviation	0.062	Standard Deviation	0.567
Sample Variance	0.004	Sample Variance	0.006	Sample Variance	0.004	Sample Variance	0.322
Kurtosis	1.89	Kurtosis	1.179	Kurtosis	0.243	Kurtosis	36.37
Skewness	-1.15	Skewness	0.843	Skewness	1.044	Skewness	6
Range	0.21	Range	0.348	Range	0.184	Range	4.231
Minimum	0.038	Minimum	0.013	Minimum	0.107	Minimum	0.013
Maximum	0.247	Maximum	0.362	Maximum	0.291	Maximum	4.244
Sum	1.547	Sum	3.691	Sum	1.437	Sum	32.23
Count	9	Count	24	Count	8	Count	123

Table 2 - Descriptive Statistics by Lithology (continued)

Disrupted Bedding		MG		All Exc. Bedded Po		All Exc. Bedded Po & Disrupted	
Mean	0.238	Mean	0.143	Mean	0.175	Mean	0.166
Standard Error	0.027	Standard Error	0.023	Standard Error	0.01	Standard Error	0.01
Median	0.253	Median	0.127	Median	0.142	Median	0.136
Mode	#N/A	Mode	#N/A	Mode	0.127	Mode	0.127
Standard Deviation	0.1	Standard Deviation	0.089	Standard Deviation	0.108	Standard Deviation	0.107
Sample Variance	0.01	Sample Variance	0.008	Sample Variance	0.012	Sample Variance	0.011
Kurtosis	-1.53	Kurtosis	2.361	Kurtosis	1.274	Kurtosis	2.198
Skewness	-0.17	Skewness	1.484	Skewness	1.198	Skewness	1.443
Range	0.292	Range	0.348	Range	0.516	Range	0.516
Minimum	0.078	Minimum	0.013	Minimum	0.013	Minimum	0.013
Maximum	0.371	Maximum	0.362	Maximum	0.529	Maximum	0.529
Sum	3.337	Sum	2.144	Sum	20.96	Sum	17.62
Count	14	Count	15	Count	120	Count	106

Appendix I - Drill Core Sulfur and Carbon Analysis

Hole No.	From	To	Sulfur	Total Carbon	Description
237	36	56	0.16876	0.79176	Rxtl
237	56	68	0.29146	0.2001	Rxtl
237	68	80.4	0.2528	0.14363	Rxtl
237	80.4	95	0.13226	0.08565	Disrupted Bedded
237	95	117	0.36186	0.11666	MG
237	117	129	0.25643	0.1768	DB Sill & Calc-silicate
237	129	140	0.08806	0.1802	DB Sill
237	140	156.5	0.09215	0.2866	DB Sill
65200	32.8	55	0.3292	1.01	Disrupted Bedded
65200	55	75	0.3325	0.4323	Disrupted Bedded
65200	75	95	0.2794	0.3045	Disrupted Bedded
65200	95	115	0.3705	0.2072	Disrupted Bedded
65200	115	135	0.2061	0.06849	Rxtl & MG
65200	135	154.5	0.205	0.145	MG & Bedded Hornfels
65200	154.5	171	0.1518	0.1358	DB Sill
65200	171	175.1	0.135	0.1871	Bedded Hornfels
65225	39.8	55	0.1482	0.05691	DB Sill & Bedded Hornfels
65225	55	59	0.1584	0.08127	Bedded Hornfels
65237	37	57	0.2451	0.2737	Bedded Hornfels
65237	57	61.5	0.3485	0.2405	Bedded Hornfels w/ Po
65237	61.5	75	0.1367	0.02823	Rxtl
65237	75	86.5	0.1472	0.0303	Rxtl
65237	86.5	95	0.2175	0.3068	Bedded Hornfels
65237	95	104.5	0.2837	0.07826	Bedded Hornfels w/ Po
65237	104.5	122	0.1047	0.02787	DB Sill
65237	122	125	0.09236	0.03316	Bedded Hornfels
65381	29	45.1	0.20346	0.20313	DB Sill
65381	45.1	60.3	0.13073	0.04451	DB Sill w interbedded chert
66042	16.9	18.3	0.09726	0.04496	Bedded Hornfels
66042	18.3	25.2	0.26836	0.14123	DB Sill
66042	25.2	35.1	0.1356	0.07874	Disrupted Bedded
66042	35.1	45.5	0.31573	0.45356	MG
66042	45.5	50.9	0.28203	0.10616	Calc-silicate
66042	50.9	67.3	0.10923	0.06317	DB Sill
66042	67.3	72	0.143	0.1511	Bedded Hornfels
66046	17.9	27.7	0.2151	0.09913	MG & Bedded Hornfels& DB Sill
66046	27.7	44.3	0.08818	0.03714	MG
66046	44.3	48.6	0.04165	0.0852	Bedded Hornfels & Calc-silicate
66051	32.9	56	0.1789	0.056	MG
66051	56	62	0.427	0.09235	Bedded Hornfels
66051	62	84	0.1542	0.02381	MG & Bedded Hornfels
67037	45.2	65	0.1881	0.11316	Cordierite
67037	65	85	0.15436	0.0957	Cordierite
67037	85	99	0.4276	0.44796	Cordierite
67037	99	115	0.1535	0.0364	MG
67037	115	133	0.17113	0.05106	MG & DB Sill
67037	133	158	0.1106	0.06488	DB Sill & Chert
67037	158	170	0.149	0.02876	MG & Hornfels
67042	12.6	30	3.443	1.787	Bedded Po
67042	30	50	4.24433	2.02966	Bedded Po

Hole No.	From	To	Sulfur	Total Carbon	Description
67042	50	64.2	3.579	2.60933	Bedded Po
67042	64.2	76	0.5291	0.42296	Hornfels w/ Po & graphite
67042	76	84.9	0.176	0.04754	Rxtl
67042	84.9	100	0.23136	0.09031	DB Sill
67042	100	112	0.2887	0.17673	DB Sill
67042	112	131	0.24743	0.16533	MG & DB Sill
67042	131	148.8	0.1414	0.05814	MG & DB Sill & Calc-Silicate
67042	148.8	160.5	0.2261	0.03708	MG & DB Sill
67042	160.5	173	0.05979	0.13473	BIF A
67042	173	179.9	0.1338	1.451	BIF B
70124	10.7	20.3	0.1312	0.01732	MG
70124	20.3	22.5	0.01954	0.1263	Calc-Silicate
70124	22.5	27	0.01342	0.03708	MG
70124	27	36	0.04293	2.263	DB Sill & A-B
70125	31	54	0.07878	0.02511	Bedded Hornfels & DB Sill
70170	7.2	14	0.50036	0.31963	DB Sill
70170	14	23.2	0.21206	0.10222	DB Sill
70170	23.2	27	0.5055	0.1518	Bedded Hornfels
71002	8.3	24.8	0.12566	0.07117	DB Sill
71002	24.8	29.5	0.23276	0.24866	Bedded Hornfels
71003	21.7	29.8	0.01648	0.07289	DB Sill
71003	29.8	32.1	0.1017	0.07965	DB Sill
71003	32.1	33.9	0.07394	0.04248	DB Sill
71003	33.9	34.5	0.07839	0.04361	Bedded Hornfels
71003	34.5	39	0.06614	0.03206	DB Sill
71003	39	45	0.1115	0.04314	Bedded Hornfels
71004	23.5	25.3	0.12263	0.02462	Bedded Hornfels
71004	25.3	40.8	0.11463	0.04083	DB Sill
71004	40.8	44.7	0.09009	0.03716	Bedded Hornfels
71005	29.4	48	0.07857	0.05216	DB Sill
71005	48	53	0.1273	0.0706	Bedded Hornfels
71006	14.5	31	0.07979	0.07513	DB Sill
71006	31	39	0.07637	0.4301	Bedded Hornfels & Calc-silicate
71007	10.3	22.5	0.1273	0.01917	DB Sill
71007	22.5	30.5	0.1157	0.05312	Calc-Silicate & Bedded Hornfels
71008	18	24	0.4457	0.02953	Bedded Hornfels
71008	24	41.5	0.09549	0.03749	MG
71008	41.5	45.2	0.0212	0.07327	Calc-Silicate & Bedded Hornfels
71013	14	36	0.03778	0.03154	MG & Bedded Hornfels
79023	7.3	22.4	0.122	0.02759	DB Sill
79023	22.4	25.5	0.1144	0.04355	DB Sill & Bedded Hornfels
79026	55	71.5	0.2795	0.2961	Bedded Hornfels & Cordierite & Calc-silicate
79026	71.5	81	0.1568	0.6644	Rxtl
79026	81	84	0.06484	0.1083	Cordierite
79026	84	92.5	0.1074	0.1012	Rxtl
79026	92.5	105.3	0.13065	0.07893	DB Sill & Bedded Hornfels
79031	14	23	0.1056	0.0442	Bedded Hornfels
79037	23	34	0.1061	0.06807	DB Sill & Bedded Hornfels
79041	14	33	0.09018	0.04263	MG
79041	33	48	0.06375	0.3755	Bedded Hornfels
79052	25	31	0.05723	0.2094	DB Sill & Bedded Hornfels
79078	29	49	0.2035	0.08647	Disrupted Bedded
79078	49	69	0.1242	0.05777	Disrupted Bedded
79078	68	89	0.1547	0.1761	Disrupted Bedded

Hole No.	From	To	Sulfur	Total Carbon	Description
79078	89	109	0.2949	0.2214	Disrupted Bedded
79078	109	129	0.367	0.4195	Disrupted Bedded
79078	129	149	0.07814	0.7086	Disrupted Bedded
79078	149	169	0.2272	0.4352	Disrupted Bedded
79078	169	188	0.3081	0.1067	Disrupted Bedded
79078	188	200	0.132	0.256	MG
79078	200	223	0.1529	0.154	Bedded Hornfels & MG
79078	223	230	0.1271	0.06202	MG
79078	230	233	0.1952	0.03229	Tuff?
79078	233	244	0.1611	0.06054	Bedded Hornfels
79081	35	58	0.1198	0.05859	MG
79081	58	80.5	0.1044	0.0262	MG
79081	80.5	88	0.2941	0.1367	DB Sill & Bedded Hornfels
99013	99	113	0.1126	0.04016	Bedded Hornfels
99013	113	124.5	0.1744	0.1166	Bedded Hornfels
99013	124.5	140.1	0.1561	0.1921	MG
99013	140.1	152	0.07637	0.4961	MG
99013	152	162.4	0.3031	0.1291	DB Sill & Bedded Hornfels
71006A	14.4	32.3	0.1368	0.04536	Bedded Hornfels& DB Sill & Calc-Silicate

Appendix II - Abbreviations Used on Sections – Figures 3a and 3b

Virginia Formation

Va hnfls	= Virginia Formation hornfels
Va hnfls bdd	= Virginia Formation hornfels with distinct bedding (inclusions)
Va hnfls sulfides	=Sulfide-bearing Virginia Formation
MG	=Massive Grey unit; enigmatic as it may appear to be a metasediment in some cores and a fine-grained portion of the Virginia sill in others
Rxtl	= Recrystallized Virginia Formation
Disrupt	= Disrupted bedding in Virginia Formation
Bedd Po	= "Bedded pyrrhotite" of Virginia Formation
cord	= Cordierite-rich hornfels of Virginia Formation
biot	= Biotite-rich
grph	= Graphite-rich portions of core
CSW	= Calc-silicate; generally, some combination of calcite, diopside, quartz (chert) and/or wollastonite; idocrase observed in one small section
chert	= chert

Duluth Complex / Volcanics

nor	= Norite; orthopyroxene-rich rock; may be meta Virginia Formation or of igneous origin
BAS	= Basaltic hornfels
Va Sill	= Sill intrusive to Virginia Formation; Pre- or syn- Duluth complex
Logan	= "Logan type" sill
DC	= Duluth Complex rocks, undivided

Miscellaneous

ovbdn	=Glacial debris
bcr	= Broken core/rubble
grano	= Granophyre/granitic zones; orthoclase-quartz-(hornblende-biotite- muscovite) rock most often with graphic textures.
trans	= "Transitional" rocks; mixed and hybrid zones between Duluth Complex and Virginia Formation rocks; gradational contact between Virginia Formation and Biwabik Iron Formation unit "A"
vein	=Minor vein of quartz, calcite
volc	=Volcanic-appearing (tuffaceous?) beds in Virginia hornfels
lamp	=Lamprophyric-appearing "vein" or small dike

Light and dark purple colors represent the Massive Grey and Virginia Sill units, respectively.

Contacts are often gradational within the Massive Grey/Virginia Sill rocks.

Datum for the sections is the top of the BIF.

Appendix III - Drill Core Descriptions

Description of Northshore Mining Co. DDH 66006 June, 2002 R. W. Ruhanen

Collar elevation 1601.9

From	To	Lithology/Mineralogy/Comments
0	27	Glacial debris.
27	36	Va Sill; Fine grained, 60% grey, cloudy plagioclase (some twinned), hornblende-biotite 35%, orthopyroxene. Becomes hornblende-rich 28.5-36.
36	39	Massive Grey (MG); Very fine grained, plagioclase-orthopyroxene-hornblende-biotite; trace pyrite; finer grained above and below "quartzite". @ 36-36.3 Quartzite; medium grained; 1% biotite as irregular masses, flakes.
39	40	Chert; core broken up.
40	41	Transition rocks. Fine grained, granular, "sugary", porous, light grey-white, biotite ("peppery"), w/wisps of quartz.
41	50	Biwabik "A"
50	63	Biwabik "B"
63	74.6	Missing.
74.6	74.7	Biwabik "C"
74.7	90	Sill; Logan type? Fine grained plagioclase-clinopyroxene-biotite. Slightly magnetic at top.

Description of Northshore Mining Co. DDH 66010 June, 2002 R. W. Ruhanen

Collar elevation 1607.6

From	To	Lithology/Mineralogy/Comments
0	9.7	Glacial debris.

9.7	16	Basaltic hornfels; "Colvin Creek type" (M. J. Severson, 1992)
16	92	Duluth Complex rocks; augite troctolite. @ 59-64 Poikiloblastic cordierite hornfels.
92	94.5	Hybrid contact zone; mix of textures, mineralogy. @93.4-93.5 Vein; quartz-diopside-garnet-chalcopyrite.
94.5	97	Va hornfels; bedded.
97	101	Recrystallized (Rxtl) Va
101	122.5	Massive Grey (MG); Very fine grained, massive, grey-buff color. Orthopyroxene? Rock is biotite-rich @ 105.5-106.2, 107-107.2, 112.6-114.2. @112.6-114.8 Core broken up.
122.5	130	Va Sill; Very fine grained, grey-buff, plagioclase-orthopyroxene-hornblende(?) -clinopyroxene-biotite. Plagioclase as laths, grey-milky, blocky crystals, surrounded by blocky, black clinopyroxene.
130	133	MG. As above exc. no biotite-rich intervals.
133	153	Va Sill; as above. @140-141 MG. @ 140-150 core broken up, rubbly.
153	165	Biwabik "A"
165	177	Biwabik "B"
177	187	Biwabik "C"
187	200	Sill; Logan type. End of hole.

Description of Northshore Mining Co. DDH 64046 June, 2002 R. W. Ruhanen

Collar elevation 1603.1

From	To	Lithology/Mineralogy/Comments
0	15	Glacial debris.
15	136	Duluth Complex rocks; troctolite, anorthositic troctolite. Va hornfels @ 61-65, 69.8-79, 86-91.2, 88-88.5 (Bedded Po?) 117-118, 126.2-132.5.
136	145	Massive Grey (MG). Appearance of Massive Greywacke/Va sill.
145	149	Va Sill.
149	153.5	MG.
153.5	158	Chert, bedded.
(Note: Footage run blocks off)		@ 156-157 Broken core/rubble.
158	161	MG.
161	165	Va Sill.
165	166	MG.
166	172	Va Sill.
172	175	Transitional zone; Cherty; "dirty" cherts, massive to bedded.

E. O. H.

Description of Northshore Mining Co. DDH 64048 R. W. Ruhanen July, 2002

Collar elevation 1601.5

From	To	Lithology/Mineralogy/Comments
0	25	Glacial debris.
25	110	Duluth Complex rocks.

110	121	Va hornfels.
121	163	Bedded pyrrhotite (Po), siltstone in part w/wispy and disseminated Po, blebs occasionally; magnetic. @ 140 2 inch massive Po. @ 159-161 Cordierite-rich.
163	165	Massive Grey (MG).
165	168	Va Sill.
168	173	MG.
173	176.5	Va Sill.
176.5	191.5	MG. @ 187 Va Sill?
191.5	193	Chert, recrystallized, bedded.
193	205	Va Sill, plagioclase, olivine, biotite, (clinopyroxene); becomes hornblende-rich 196.5-205, with sharp contact. E.O.H. @ 205.

Description of Northshore Mining Co DDH 66014 June, 2002 R. W. Ruhanen

Collar elevation 1608.1

Note: Descriptors from surface to 390 feet, 434-470 feet adapted from L. Zanko, 1992. This core not included in sections.

From	To	Lithology/Mineralogy/Comments
0	2.2	Glacial debris.
2.2	390	Duluth Complex rocks. Basaltic hornfels @ 30-37, 46-52, 57-60, 64-70.
390	392	Va hornfels.

@ 390-391.2 Transition – contact hornfels.
@ 391.5 Bedding.

392	408	Massive Grey (MG) – Massive greywacke/v fn gn sill?
408	412.5	Va Sill.
412.5	416	MG.
416	416.2	Va Sill.
416.2	416.5	Va hornfels – bedded.
416.5	419	MG.
419	421	Va Sill.
421	423	MG.
423	424	Calc-silicate w/wollastonite.
424	424.5	Va Sill.
424.5	425.2	MG.
425.2	434.5	Va Sill.

Core broken up @ 429.7-430, 434.5-434.9.

434.5	437.3	Biwabik “A”; chert, marble.
437.3	455	Biwabik “B”.

@ 443-443.2 Sill?

@ 446 Granophyre; orthoclase-quartz.

455	463	Biwabik “C”.
463	470	Sill – Logan type.

Collar elevation 1595.8

From	To	Lithology/Mineralogy/Comments
0	25	Glacial debris.
25	265	Duluth Complex rocks. @ 100-101 Basaltic hornfels. @ 185-203 Va hornfels.
265	288	Norite. @ 285-288 Transition rocks, mixed "gabbroic" and Va hornfels.
288	295	Cordierite hornfels.
295	299.5	Va Sill.
299.5	306	MG, Va hornfels inclusions.
306	319.5	Va Sill.
319.5	321.5	MG.
321.5	323	Calc-silicate; chert, wollastonite.
323	336	Va Sill. @ 326.5-327 Chert. @ 334-335 Graphic textured orthoclase-quartz-hornblende(?).
336	341	Transition rocks; "dirty" cherts, calc-silicate?
341	344.8	Biwabik "A", marble.
344.8	362.8	Biwabik "B"
362.8		End of Log Biwabik "C"

Collar elevation 1611.9

Note: *Descriptions below 188 feet from M. J. Severson, 1992.*

From	To	Lithology/Mineralogy/Comments
0	14	Glacial debris.
14	124	Duluth Complex rocks.
		Va hornfels @ 26.4-30.6, 31.6-34.5, 59.9-86.
124	133	Va hornfels, dark grey, locally bedded, locally graphitic, cordierite-quartz-biotite; granoblastic texture.
133	137.5	MG, grey-buff, very fine grained, massive, local bedding (inclusions?).
137.5	145.5	Va Sill, grey, fine grained, plagioclase-clinopyroxene-hornblende-biotite.
145.5	150.3	MG (fine grained sill?), orthopyroxene-quartz-biotite.
150.3	157.2	Va Sill, as above.
157.2	158	MG, w/inclusions(?).
158	165.7	Va Sill, clinopyroxene-rich near top; mineral amounts vary from mafic-rich (hornblende-clinopyroxene-plagioclase-olivine) to plagioclase-clinopyroxene-hornblende.
		@ 163-163.5 Chert.
		@ 165.2-165.7 Chert.
165.7	167.8	MG (Va inclusion?).
		@ 165.7- 166.2 Chert.
167.8	179	Va Sill.
		@ 174-175 Pegmatitic, graphic-textured granitic vein.
179	180	MG.
180	186	Transition rocks, "dirty" chert, partly bedded.

186	188	Biwabik "A", marble.
188	205	Biwabik "B".
		@ 202 coarse grained diopside.
205	216	Sill, Logan type.
216	242	Biwabik "C".

Description of Northshore Mining Co. DDH 61097 June, 2002 R. W. Ruhanen

Collar elevation 1611.3

Note: Descriptions from 190 – 244.5 adapted from M. J. Severson, 1992.

From	To	Lithology/Mineralogy/Comments
0	16.5	Glacial debris.
16.5	27	Va hornfels – Quartz, orthopyroxene, biotite.
27	65.8	Duluth Complex rocks. Olivine gabbro, norite.
		Va hornfels w/sulfides @ 40.4-50, 54-63.6.
65.8	69.8	Va hornfels.
		@ 66-66.3 Chert.
69.8	72.3	Chert.
72.3	85	Va Sill.
85	87	Massive Grey (MG) Massive greywacke/v fn gn sill?
87	91.8	Va hornfels, bedded, w/sulfides ½ - 1%.
		@91.2-91.5 Chert.
91.8	113	Recrystallized Va (Rxtl Va), quartz-cordierite(?)-biotite; local disrupted bedding.
		@ 112-113 Cordierite(?) biotite schist.
113	124	Va hornfels, bedded.

@ 120-122 Bedding disrupted.

124	124.5	Va Sill.
124.5	128	Rxtl Va, local disrupted bedding.
128	131.5	MG.
131.5	148.8	Rxtl Va, quartz, biotite, orthopyroxene, plagioclase.
148.8	151	Va Sill, Mafic-rich; plagioclase, orthopyroxene, hornblende, biotite.
151	157	Va hornfels, dark grey, black.
		@ 151.1-151.2 Chilled margin.
		@ 152.5-154 Core broken up, rubbly.
		@ 154.5-156 Grades into quartz-cordierite hnfls to 156.
		@ 157-160 Core broken up, rubbly.
157	165.5	Rxtl Va, local disrupted bedding.
		@ 159.5 Chert.
165.5	167.3	Calc-silicate, cherty, wollastonite.
167.3	179	Va Sill.
179	180	MG.
180	181	Va Sill.
181	182	Graphic granite, white.
182	183	MG.
183	183.2	Calc-silicate; wollastonite at top, bedded chert.
183.2	186.5	Va hornfels, bedded; could be transition to BIF.
186.5	190	Transitional to BIF? Interval missing.
190	197	Biwabik "A" Dirty chert, marble.
197	217	Biwabik "B"

217 228 Biwabik "C"
 228 244.5 Sill – Logan type?

Description of Northshore Mining Co. DDH 67037 June, 2002 R. W. Ruhanen

Collar elevation 1609.1

From	To	Lithology/Mineralogy/Comments
0	19	Glacial debris.
19	20	Biwabik I. F. boulder; quartz-diopside-magnetite.
20	26	Troctolite, anorthositic troctolite; heterogenous, inclusion-rich, patches of pyrrhotite, fine grained, grades coarser grained down hole. Plagioclase-olivine-biotite-pyrrhotite, trace chalcopyrite. Sulfides as patches, blebs, stringers, locally to 10 – 15% of rock, decreasing down hole. Plagioclase often twinned.
26	26.8	Norite; contacts sharp; fine grained plagioclase-orthopyroxene-biotite; non-magnetic; plag 60%, opx 30%, biotite 10%. Inclusion of Va?
26.8	33	Anorthositic troctolite, troctolite; coarse grained, heterogenous, similar to 20-26 exc. less sulfides. Oxides interstitial to plagioclase, becomes coarser grained down hole, more plag. rich. Plagioclase, olivine, biotite, pyrrhotite, oxide, chalcopyrite, milky quartz locally. @ 30-30.8 core broken up. @ 31.3-33 lighter colored, plag. 60% ol 35% ox 5% (graphite?). Trace pyrrhotite; sharp contacts.
33	35.4	Va hornfels inclusion; fine-medium grained, cordierite-rich; poikiloblastic-massive, sharp contacts. Cordierite 70%, quartz 20%, biotite 2-5%, pyrrhotite 5-8% as disseminated grains.
35.4	43.8	Anorthositic troctolite, troctolite; As 26.8-33 above; graphite?
43.8	45.2	Contact zone; fine grained cordierite-plagioclase-orthopyroxene-biotite in mixed proportions. Generally massive, sharp lower contact.

- 45.2 99 Cordierite hornfels; fine to medium grained, massive, cordierite-biotite-quartz; grades to recrystallized Va w/subhedral "decussate" biotite. Vaguely bedded, disrupted appearance 63.5-92.5.
- @ 50.2 vague bedding.
 @ 51 ¼ inch graphite "vein" @ 45 deg.to c.a.
 @ 63.5 1- ½ inch rounded inclusion/disrupted bedding.
 @ 67 1 – 2 inch fine grained "bed" assoc. w/fracture filled with orthoclase, quartz and biotite.
 @ 92.5-93.5 well bedded.
 @ 95 core broken up, rubbly; lighter colored, "spotted" section.
 @ 96-98.5 biotite-rich, massive, vague igneous texture? Chill zone?
 @ 97.5-99 core broken up, rubbly.
- 99 115 Massive Grey (MG); contact mixed texture, grain size; quartz and twinned plagioclase as coarser-grained, irregular patches (partial melt?). Fine grained generally, with plagioclase, orthopyroxene, biotite.
- @ 100 becomes grey, massive, fine grained "spotted".
 Irregular texture – Va inclusions?
- 115 120 Va Sill.
- 120 126.5 MG.
- @ 124.5 lamprophyric? partial melt? Pink, twinned feldspar, greenish mineral (cpx?) calcite, quartz, hornblende veinlet.
 @ 126 disrupted bedding.
- 126.5 132 Va Sill.
- 132 133 Chilled margin. Dark grey-black, sharp contact, becomes finer grained towards base; sharp contact w/lighter-colored, "spotted" section, core broken up (as 95-95.8 above). Serpentine-filled fractures.
- 133 137.5 "Spotted" rock – Va Sill? Core rubbly, broken, fractures, serpentine-filled fractures; Plagioclase, biotite, finer grained at contacts – probably sill.
- @ 134.8 pink feldspar-quartz veinlet.
 @ 137 broken core; bedding on one fragment.
 @ 137-137.4 rubble.

137.5 141 Chert; upper portion dark grey-black ("dirty"); becomes white-cream.

@ 139.5-140.5 rubble.

Note:Run blocks off.

141 154 Va Sill; sharp contacts.

154 155.5 Black, broken up, porous-rock; contacts sharp @ 45 deg. c.a.

155.5 166 MG; massive, fine grained, grey quartz-biotite-orthopyroxene rock; occasional 1/2" beds.

166 170 Va hornfels; gradational contact, grey, fine grained, quartz-biotite-cordierite(?); fractures subparallel to c.a. @ 170; occasional pyrite cubes on fracture faces.

End of core.

@ 167.5-168.2 Cherty.

@ 168 bedded, 1/2 " slightly magnetic.

Description of Northshore Mining Co. DDH 65223 June, 2002 R. W. Ruhanen

Collar elevation 1609.2

From	To	Lithology/Mineralogy/Comments
0	14.1	Glacial debris.
14.1	46	Olivine gabbro and norite. Fine grained, biotite-bearing. Grades into metabasalt below.
46	122.5	Metabasalt; dark grey-black, massive. @ 48.5 Quartz-plagioclase amygdules. @ 59.8, 78.5, 92.8 coarse biotite seams. @ 102-103 biotite-rich.
122.5	131	Bedded pyrrhotite (Po); Dark grey-black, carbonaceous, po as thin laminations, wisps to 1/16 inch in thickness.
131	132.8	Va hornfels; contact with bedded po gradational; po, graphite decrease, quartz and biotite increase. Fine grained.

@ 132 Graphic textured "granite" vein; orthoclase, quartz.

132.8 134 Recrystallized (Rxtl) Va; quartz-biotite; fine grained inclusions.

134 143 Cordierite hornfels; amounts of cordierite, biotite vary.

143 165 Massive Grey (MG); orthopyroxene-rich.

@ 165 Core broken, rubble.

165 191 Va Sill; plagioclase, hornblende, olivine, clinopyroxene;
below 182 becomes hornblende-rich; grades from fine grained
plagioclase-hornblende-biotite to hornblende-biotite.

@ 170.9 Core broken up.

@ 174.5 Core broken up; chert rubble.

@ 175.5-175 Chert; light colored, bedded in part.

191 194.9 Contact zone; fine grained, MG inclusions, fine grained sill,
hornblende to biotite rich.

194.9 200 End of Core Transition rocks; bedded chert, becomes
"dirty" below 195.1.

@ 200 Calc-silicate; bedded, wollastonite, calcite.

Description of Northshore Mining Co. DDH 67042 June, 2002 R. W. Ruhanen

Collar elevation 1602.0

From	To	Lithology/Mineralogy/Comments
0	12.6	Glacial debris.
12.6	64.2	Bedded Pyrrhotite (Po); Black, fine grained, cordierite-quartz-plagioclase-graphite-pyrrhotite. Cordierite porphyroblastic in part; Po as disseminated grains, blebs to ¼ inch, thin, wispy, laminations, discontinuous laminations. Over all texture varies between vaguely bedded, blotchy (chaotic) w/rounded & discontinuous laminations of cordierite-rich material w/wisps, patches of plagioclase-rich material; magnetic.
64.2	71	Va hornfels, grey, light grey, meta-greywacke-siltstone; massive to bedded; quartz-plag-biotite; pyrrhotite (Po) as stringers, disseminations to 1% locally; Po decreases down hole, biotite increases.

@ 64.2-64.9, top to bottom: ½ inch meta-sandstone? chert? w/ ½ - 1% fine disseminated Po; 1 inch band fine grained plagioclase-rich w/fine lamination of Po at top, subhedral plagioclase – volcanic? 1 – 1 ½ inch rock fragments; fractures w/orthoclase fillings; 1 to 2 inch, fine grained, grey quartz-plagioclase w/fine Po bands; 1 – 1 ½ inch graphite; ½ inch Po band.
 @ 65-66 Biotite schist; biotite decreases down hole.
 Graphite @ 69.8, 70.3.

71	73	Massive Grey (MG).
73	74	Va hornfels, bedded, graphitic.
74	76	Va Sill.
76	84.9	Recrystallized (Rxtl) Va, pyrrhotite trace to ½ %.
84.9	112	Va Sill, clinopyroxene-rich.
112	115	MG.
115	120	Va Sill.
		@ 110-120 Broken core, rubbly in places; vertical quartz-filled fractures 110-112.
120	128	MG.
128	131	Va Sill.
131	135	MG.
		@ 132-133.2 Dark grey-black, porphyroblastic, biotite-rich, blasts of carbonate? Vague bedding locally; volcanic component? Basal 2 inches bedded.
135	138	Va Sill.
138	139.5	Calc-silicate; chert, wollastonite.
139.5	148.8	Va Sill.
		@ 141.1: 2 inch pegmatitic, graphic-textured, orthoclase-quartz-hornblende "granite".

148.8	155.2	MG, bedded inclusion(?) @ 149.
155.2	160.5	Va Sill.
160	167	Transitional rocks; "dirty" cherts. @ 162.3-162.4 Calc-silicate; garnets. @ 162.5 White, graphic-textured, orthoclase-quartz "granite".
167	173	Biwabik "A"; cherty at top, marble.
173	179.9	Biwabik "B". @ 171-172 Magnetite, carbonate vein, massive.

Description of Northshore Mining Co. DDH 70162 June, 2002 R. W. Ruhanen

Collar elevation 1580.9

From	To	Lithology/Mineralogy/Comments
0	21.8	Glacial debris.
21.8	29.2	Massive Grey (MG) Grey, massive, fine grained, quartz-orthopyroxene-biotite; biotite increases downhole; local spotted appearance.
29.2	31	Va Sill, associated with graphic-textured quartz-feldspar veining.
31	32.4	MG, Very fine grained, w/rounded and bedded inclusions.
32.4	42.5	Recrystallized (Rxtl) Va, granoblastic quartz-orthopyroxene-biotite hornfels w/rounded inclusions, disrupted bedding. @ 40-42 biotite increasing.
42.5	43.8	Va Sill, fine grained plagioclase-orthopyroxene-clinopyroxene biotite.
43.8	47	Va hornfels, bedded, bedding ~ 45 deg to core axis.
47	56.8	MG, grey, fine grained, massive.

56.8	58.8	Va Sill.
58.8	60.5	MG, locally bedded (inclusions?) .
60.5	62.5	Rxtl Va.
62.5	68	Va Sill, hornblende-rich.
68	73.8	MG, disrupted bedding @ 68-70. @ 68-70 Rxtl Va.
73.8	89.8	Va Sill. @ 77-79 Calc-silicate (Va hornfels? BIF "A"?). @ 78 2 inch vein, biotite books, green mineral; quartz w/magnetite at lower ½ inch, subangular clasts Va.
89.8	91	Graphic textured "granite"; Quartz-feldspar w/alt. rock frags.
91	99.5	Transition rocks, lighter colored, bedded chert, calc-silicate in part; fine laminated quartzite/mudstone.
99.5	103.2	Biwabik "A", chert, marble.
103.2	110	Biwabik "B", chert, diopside.

Description of Northshore Mining Co. DDH 67050 June, 2002 R. W. Ruhanen

Collar elevation 1557.6

From	To	Lithology/Mineralogy/Comments
0	34.3	Glacial debris.
34.3	42.3	Va hornfels; biotite-quartz schist 34.3-34.9. @ 36.8 3 inch "dirty" chert.
42.3	42.9	Chert; bedded at top, contacts sharp.
42.9	43.5	Va hornfels; biotite-rich; graphite?. @ 43 Biotite decreasing; grades to massive grey below.

43.5	73.6	Massive Grey (MG); light grey, fine grained, massive, vague bedding locally. @ 61.5-62.8 Biotite schist, foliation = bedding. @ 64.8-67 Bedded; biotite increasing. @ 70-70.2 Graphic-textured "granite". @ 73-73.6 Va hornfels; bedded, biotite-rich; core broken up. @ 73.5 1 inch graphic textured "granite".
73.6	76	Va Sill; Contact sharp; light grey, plagioclase-quartz-biotite; inclusions of Va hornfels.
76	79.5	MG; very fine grained, sharp contact with sill.
79.5	82.5	Va Sill.
82.5	89.5	MG; grades into hornfels below. @ 86-86.3 Graphic textured "granite".
89.5	89.8	Va hornfels; very fine grained, dark grey to black, bedded, slightly magnetic, biotite-quartz-magnetite; grades into Va hornfels below.
89.8	93	Va hornfels; black, bedded, rounded to tabular fragments, spotted appearance, biotite-rich, trace pyrite.
93	94	Chert; well bedded at top, vague bedding throughout. @ 94 core broken up; fractures filled with feldspar (orthoclase?), quartz, epidote(?), biotite, (hornblende?). Lamprophyre?
94	98	Sill – Logan type? Chilled contacts.
98	99.8	Chert; massive.
99.8	105	Sill – Logan type? @ 99.8-100.5 Core broken up; rubble.
105	107	Va hornfels (MG?); grades into "dirty" chert.
107	108.9	Chert; bedded, becoming massive at base; sharp lower contact, soft sediment deformation. @ 107.8-108.3 Calc-silicate.

108.9	111.9	Va hornfels (MG?); very fine grained, quartz-orthopyroxene-biotite. @111.7-111.9 bedded.
111.9	112.4	Calc-silicate-marble, coarse crystalline, bedded. @ 112.4 garnets to ½ “.
112.4	119.5	Chert; bedded, becomes “dirty” at base; Biwabik “A”? Transition?
119.5	124	Biwabik “A”; marble, magnetite bands at base.
124	125.5	Biwabik “B”; chert-diopside. End of Core.

Description of Northshore Mining Co. DDH 65249 June, 2002 R. W. Ruhanen

Collar elevation 1546.4

From	To	Lithology/Mineralogy/Comments
0	25	Glacial debris.
25	32.2	Va Sill; plagioclase, hornblende, clinopyroxene, olivine, biotite. Variable grain size; fine, medium.
32.2	35	Massive Grey (MG) Grey, fine grained, vague bedding. @ 33-34 Va hornfels; bedded.
35	38.5	Va Sill; Plagioclase, clinopyroxene, olivine; hornblende(?) -rich 37-38.5.
38.5	39	Vein; Amorphous, light green mineral rimmed by pink feldspar; w/quartz, biotite “books”.
39	40	Va hornfels, fine grained, grey, bedded; @ 39.5 biotite-rich. @ 39.7 dark grey-black biotite (quartz?), vague “felty” texture w/vague glomeroporphyroblasts(?); felty “spots”; sharp contact with chert beneath; Volcanic?
40	41	Calc-silicate; chert, calcite, idocrase, trace pyrrhotite; grades to light grey, granular cherty rock to 41.

41	60.5	MG; fine grained, grey, massive quartz-orthopyroxene-biotite. @ 45.5 Disrupted bedding – inclusion? @ 46-46.5 Core broken up; rubbly to 50.
60.5	64.5	Recrystallized (Rxtl) Va; fine grained; quartz, subhedral biotite.
64.5	68.5	Va Sill; Upper contact broken up; grey, plagioclase, clinopyroxene, biotite. Calcite veins at top. Lower contact sharp.
68.5	74.5	Rxtl Va. @ 77-79 core broken up.
74.5	88	Va hornfels; becomes siliceous, dark grey-black, granular, bedded. @ 85-88 Mud fragments; poor recovery.
88	89.5	Core broken up; rubble, clay.
89.5	90	Va hornfels, fine grained, bedded.
90	95	Core broken up; bedded locally, granular to fine grained; transition to Biwabik "A".
95	98	Biwabik "A"
98		End of Core Biwabik "B"

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