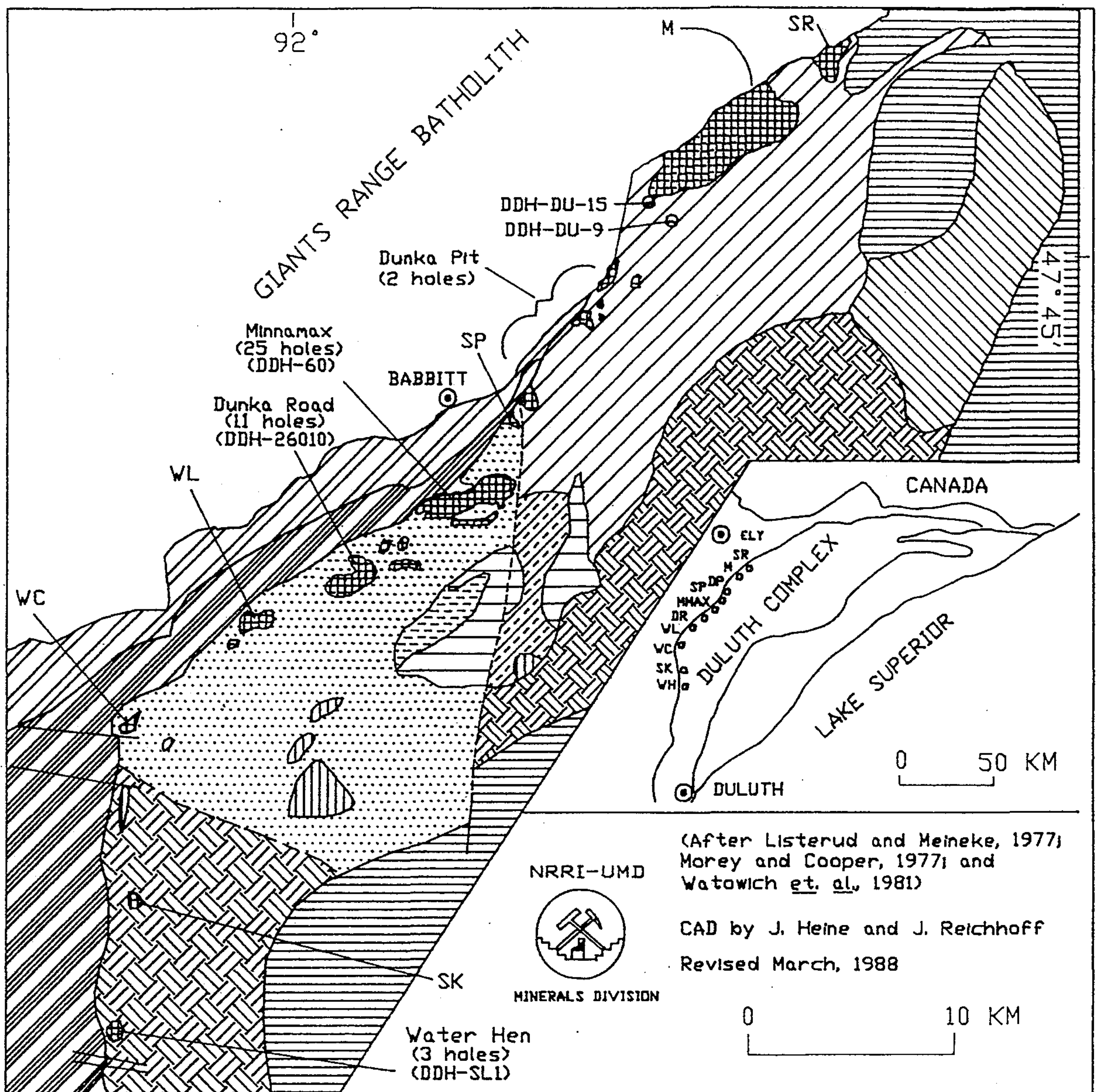
PLATINUM GROUP ELEMENT OCCURRENCES IN THE BASAL ZONE OF THE DULUTH COMPLEX



MAP LEGEND

- Cu-Ni DEPOSITS
- BALD EAGLE INTRUSION
- SOUTH KAWISHIWI INTRUSION
- POWERLINE GABBRO
- PARTRIDGE RIVER TROCTOLITE
- RAILROAD TROCTOLITE
- UNDIVIDED ROCK MOSTLY TROCTOLITE
- ANORTHOSITIC SERIES
- HORNFELS
- VIRGINIA FORMATION
- BIWABIK IRON FORMATION

Cu–Ni DEPOSITS

INSET LEGEND

DUNKA PIT AREA	- DP
DUNKA ROAD	- DR
MATURI	- M
MINNAMAX	- MMAX
SERPENTINE	- SP
SKIBO	- SK
SPRUCE ROAD	- SR
WATER HEN	- WH
WETLEGS	- WL
WYMAN CREEK	- WC

Figure 1. Location of drillholes with combined Pt + Pd contents greater than 500 ppb.

MINNESOTA MINERALS COORDINATING COMMITTEE

PLATINUM GROUP ELEMENT OCCURRENCES IN THE BASAL ZONE OF THE DULUTH COMPLEX

Introduction

The following represents a synthesis of work carried out by the Mineral Resources Research Center (MRRC), the Minerals Division of the Department of Natural Resources (DNR) and the Natural Resources Research Institute (NRRI). An initial evaluation of the metallurgical properties of chromitiferous drill core DU-15 from the Birch Lake region of NE Minnesota by MRRC (Sabelin, 1985, 1987; Sabelin et al., 1986) led to the discovery of platinum group elements (PGE) within the basal zone of the Duluth Gabbro. Because of this, the DNR decided to log and sample diamond drill core for both Cr and PGE contents. Analyses of 265 selected samples from 35 drill holes located within the base of the Duluth Gabbro and these data are presented by Dahlberg, 1987. A compilation of PGE contents of Cu-Ni sulfide deposits was made from private and public company records (Morton and Hauck, 1987). All these data combined constitute a very good data base for PGE potential in the basal zone of the Duluth Complex.

Values of selected elements from all samples with combined Pt + Pd values in excess of 500 ppb are tabulated in Tables IA through ID. These represent 10% of the samples analyzed by DNR, 100% of those from DU-15 (MRRC), 14% for the Minnamax Property, approximately 60% of those from Dunka Road, and 7% for Waterhen (NRRI). Where there are missing values in the tables, the data do not exist, whereas a less than sign indicates the detection limit.

Discussion of Results

Birch Lake Area

The DU-15 drill hole is located just north of the Dunka Pit area (Figure 1, see front page) and lies to the south of the east-west trending Birch Lake break across the northeast trending basal contact of the Duluth Complex. It appears to lie within a five mile wide structural zone in the South Kawishiwi intrusion characterized by faults, diabase dikes (Morey and Cooper, 1977), and lineaments (Chandler, 1986). From the top to the bottom, the core consists of 2302 feet of sulfide-poor units composed of mixed amounts of olivine-bearing gabbroic, anorthositic and troctolitic rocks (Dahlberg, 1987), which are underlain by a 140.5 foot thick sulfide rich zone. Rock types in this zone include serpentinized ultramafic olivine-oxide cumulates which contain about 2-10% chalcopyrite, pyrrhotite, bornite and pyrite with traces of native Cu (Sabelin et al., 1986: Dahlberg, 1987). Within this sulfide zone is 30 feet of magnetite-ilmenite-Cr-spinel-olivine cumulate that averages greater than 2 ppm combined Pt + Pd (Table 1A). This oxide and PGE rich rock directly overlies the footwall rocks of the Giants Range Granite. According to Sabelin et al. (1986) :

"Chemical analyses show unusually high concentrations of Pt and Pd within this zone. Average values for Pt and Pd contents over the 9-ft. interval are 2516 ppb and 2583 ppb, respectively, or 5.099 g/t (0.15 oz/st) Pt plus Pd. Pt plus Pd contents from individual 1-ft. intervals are as high as 9123 ppb or 9.123 g/t (0.27 oz/st), and a 5-ft. interval in the richest part of the zone averages 7.443. g/t (0.22 oz/st) Pt plus Pd. The Pt to Pd ratio is near one over the entire zone, and the Pt and Pd correlate closely with Cr, which ranges from 1.9 to 5.3 % (Figure 2). Cu, Ni and S contents for the drill core interval are also given in Figure 2. Interestingly, the Pt-Pd high corresponds to a depletion in Cu, Ni and S.....The major oxide mineral is an Fe-rich or magnetite-rich spinel with high TiO_2 contents (6% to 12%) and variable MgO (1% to 3%), Al_2O_3 (2% to 6%) and Cr_2O_3 (trace to 10%) contents. It is associated with minor amounts of ilmenite and Al-rich or hercynite-rich spinel that appear to have exsolved from the magnetite-rich spinel.....Within the Pt-Pd zone the most common PGM found are Pt-Fe alloy and Pd alloys. Semiquantitative EDS analysis shows that Pt-Fe alloy grains have variable composition with Pt contents varying from 73% to 82% by weight and Fe from 14% to 20% by weight.....The data suggest that Pb, Cu and Ag occur with the Pd. A Ru-sulfide mineral was also observed in the Pt-Pd zone."

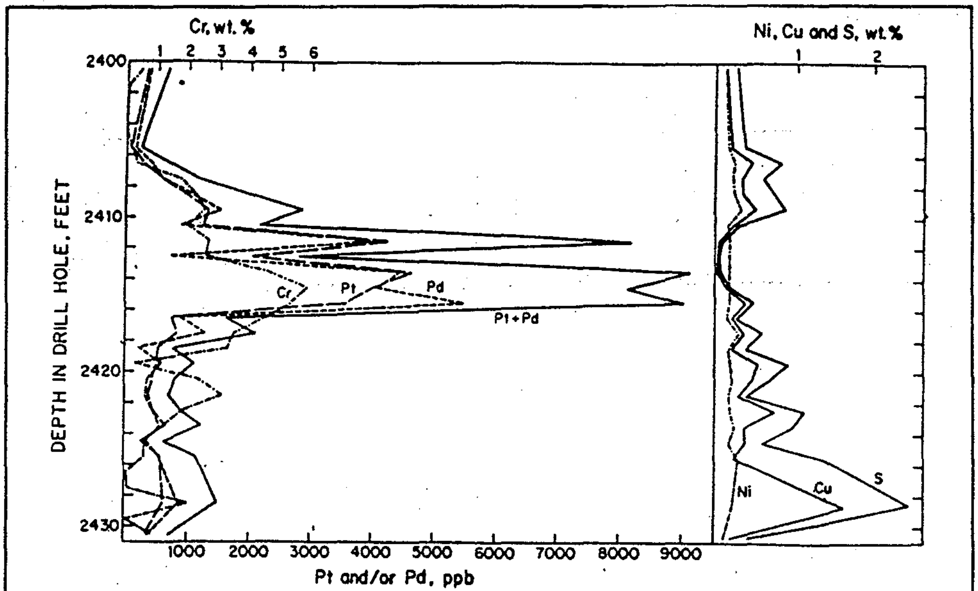


Figure 2. Elemental concentration profile for interval of drill core containing the Pt-Pd zone (after Sabelin 1986).

DU-9, located 2400 feet south-east of DU-15 (Figure 1), intersects an oxide rich cumulate that is also high in PGE (Table 1A). Sample interval 2591'-2592' contains 2.8 ppm Pt and 0.55 ppm Pd whereas the sample interval from 2594'-2597' contains 0.35 ppm Pt and 1.3 ppm Pd. The former is associated with elevated Cr content (16000 ppm) and the latter with Cu sulfides (chalcopyrite and bornite). This may or may not be an extension of the intersection in DDH DU-15.

Minnamax Property

The Minnamax Cu-Ni deposit is located at the base of the Partridge River troctolite (Figure 1) close to the contact with the South Kawishiwi intrusion. Here the Duluth Complex consists of a highly heterogeneous mixture of anorthosite, olivine gabbro, troctolite, augite troctolite, picrite and norite with minor feldspathic dunite and pyroxenite. Inclusions of Virginia Formation, Biwabik Iron Formation and hornfels of basaltic composition are very common.

Of the 7 drillholes sampled by DNR in the area of the Minnamax property (Figure 1), 5 contained samples (24 total) that had elevated values of Pt and Pd (Table 1A); and 32 of 248 samples analyzed by Minnamax geologists had elevated values (Table 1B). Only 1 sample was highly anomalous (DDH 60, 1731'-1735') containing 14 ppm combined Pt plus Pd over 4 feet.

The elevated Pt + Pd values (Table 1A) associated with Minnamax drill core sampled by the DNR are found in locally pegmatitic areas of anorthositic gabbro. Pyroxene and plagioclase, both within these zones and above the enriched areas, are characteristically replaced by amphiboles, green biotite, chlorite and carbonate. The secondary amphiboles themselves are closely associated with copper sulfides. Throughout the drill holes, evidence of deuteric alteration is indicated by bleached plagioclase crystals and the presence of miarolitic cavities lined with thomsonite.

According to the NRRI, data collected from the Minnamax deposit indicate that the weighted mean value of Pt + Pd for the 248 samples analyzed is 378 ppb (median = 180) and, using a log-normal distribution, only those samples with combined Pt plus Pd contents in excess of 1253 ppb should be considered truly anomalous. All samples with Pt plus Pd greater than 500 ppb are listed in Table 1B and, of those, only 3 are greater than 1253 ppb. No follow-up work has been made on these samples to date.

Dunka Road

The Dunka Road Cu-Ni deposit lies within the Partridge River troctolite, just to the south-west of the Minnamax property (Figure 1). Rock types within the area vary from norite at the base to troctolite, anorthositic troctolite, gabbro, olivine gabbro and picrite. Overall, troctolite is most common with plagioclase and olivine occurring as cumulate grains. Interstitial minerals include ortho-and clinopyroxene, ilmenite, spinel, biotite and local sulfide. Biotite increases in abundance toward the base of the intrusion.

Within drill hole 26010 is a 3 foot intersection of 50% massive sulfides with approximately 9 ppm Pd and about 0.5 ppm Pt (Tables 1C and 1D, Morton and Hauck, 1987). The rock type is pegmatitic gabbro consisting of plagioclase, augite and ilmenite. The upper contact is gradational with white, highly altered, medium to coarse-grained gabbro. Alteration minerals include kaolinite and sericite after plagioclase, chlorite after pyroxene and numerous cross-cutting veinlets of natrolite and analcime. The lower contact is gradational with a medium-grained, pyroxene-bearing troctolite that is locally altered to chlorite.

The sulfides consist of chalcopyrite with minor pentlandite and pyrrhotite. There is approximately 10% secondary pyrite. Textures indicate that pentlandite, where present, is being replaced by chalcopyrite, magnetite, and violarite as well as secondary Pd-Ag-Sb bearing alloys, Pd tellurides, native Au and Pd bismuthenides. Analysis of trace elements indicates that this particular sample is also high in the following elements: As, Bi, Pb, Te, Se, Sb,and Sn. The textures and the chemical analysis seem to indicate that the high concentrations of Pd and Au may well be due to late-stage mineralizing fluids.

Water Hen Deposit

The Water Hen Cu-Ni sulfides differ from those deposits described above because they occur within a mafic to ultramafic body which has intruded troctolitic rocks at the base of the Duluth Complex (Figure 1). The intrusion itself consists of cyclical units of mineral-graded layers varying from dunite at their bases through troctolites to anorthosites at their tops (Mainwaring, 1975). Xenoliths of underlying Virginia Formation are found in the lower third of the intrusion. The sulfides occur either as massive or disseminated ores associated with dunites, both at the base of the intrusion and in zones forming the base of individual units, or as disseminations in peridotite containing graphite and recyrstallized xenoliths. Texturally the sulfides are interstitial between olivine and ilmenite.

Of 56 samples analyzed by American Shield (Morton and Hauck, 1987) only 1 had a concentration of combined Pt plus Pd of greater than 500 ppb and that was a sample SL-1, 680-683 feet (Table 1D). This proved to be from a cross-cutting orthopyroxenite dike that contained about 1 ppm each of Pt, Pd, and Au as well as 4.44 % Cu. In polished section, the sulfide and arsenide minerals in order of abundance are chalcopyrite (4%), bornite (2-3%), maucherite (0.5-1%), and pentlandite (0.5%). Minor minerals include sphalerite, native Ag, niccolite, parkerite (an anisotropic white mineral that contains Bi, Ni and S) and tetradymite (soft, anisotropic yellow mineral that contains Bi, Te and S) as an inclusion in parkerite. No Pt or Pd minerals have been identified.

Additional polished section analyses by the NRRI has revealed that there are two periods of sulfide mineralization at Water Hen: the first is composed of pyrrhotite, chalcopyrite, cubanite and some pentlandite which is the primary mineralization in the Water Hen deposit; the second consists of late stage chalcopyrite, bornite, maucherite, native bismuth, niccolite, parkerite, native Ag and tetradymite. This later stage is generally enriched in Cu, Ni, As, Bi, Ag, Pb, Se, Te and Sb contents (Table 1D).

Classification of the PGE Occurrences

The PGE occurrences of the basal zone of the Duluth Complex may be grouped in the orthomagmatic class with emphasis on contamination (MacDonald 1987). Textures and chemical analyses have indicated that the high concentrations of Pd and Au may well be due to late-stage mineralizing fluids.

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Table 1A: Data from Sabelin, 1985, and Dahlberg, 1987, Minnamax and *Dunka Pit Deposits*, DDH's DU-15 and DU-9. Samples with Total Pt+Pd >500 ppb.

DDH	Footage From	To	Au ppb	Pt ppb	Pd ppb	Ag ppm	Cu ppm	Ni ppm	Co ppm	S WT. %	Cr ppm	TiO2 WT. %	V ppm	As ppm	Bi ppm	Pb ppm	Se ppm	Te ppm	Sb ppm	Zn ppm	F ppm	Cl ppm
BA-1	2635	2643	76	130	640	<5	5600	700	100	0.76	120	0.91	93	1	<2	22	<10	<10	0.4	<200	260	900
BA-1	2643	2653	52	100	480	<5	4000	280	70	0.39	170	0.57	93	4	<2	26	<10	<10	0.2	<200	200	800
BA-1	2653	2663	52	90	430	<5	6300	430	90	0.67	140	1.11	140	3	<2	18	<10	<10	0.2	<200	170	800
BA-1	2663	2673	48	100	350	<5	4200	240	80	0.71	150	1.50	190	3	<2	17	<10	<10	<0.2	<200	150	600
BA-1	2673	2680	72	120	430	<5	5100	580	100	0.94	130	0.66	85	3	<2	13	<10	<10	<0.2	<200	120	550
BA-1	2690	2700	49	80	760	<5	4600	520	90	0.84	180	1.08	150	9	<2	11	<10	<10	<0.2	<200	160	<50
BA-1	2700	2710	83	170	750	<5	4700	900	100	1.04	220	0.85	130	2	<2	14	<10	<10	<0.2	<200	100	<50
BA-1	2718	2726	42	100	460	5	4600	860	140	1.41	190	0.95	200	9	<2	14	<10	<10	0.3	200	520	<50
BA-2	1866	1875	61	190	330	<5	3400	380	80	0.27	310	0.70	110	<1	<2	8	<10	<10	<0.2	<200	30	250
BA-2	1875	1884	71	230	380	<5	2700	240	60	0.19	350	0.67	93	<1	<2	7	<10	<10	<0.2	<200	<20	50
BA-2	1892	1897	75	170	440	<5	2800	360	60	0.23	220	0.90	95	<1	<2	7	<10	<10	<0.2	<200	<20	250
BA-2	2579	2582	110	40	540	<5	4100	340	70	0.83	80	1.06	130	1	2	16	<10	<10	<0.2	<200	70	350
BA-2	2781	2785	230	290	740	<5	6300	520	110	0.62	100	0.70	91	1	<2	10	<10	<10	<0.2	<200	120	500
BA-2	3253	3256	72	100	410	<5	4600	370	60	0.35	210	1.47	130	1	<2	33	<10	<10	<0.2	<200	350	300
BA-2	3474	3684	90	150	370	<5	9700	620	30	1.03	120	0.34	85	<1	3	39	<10	<10	<0.2	<200	210	<50
BI-134	1156	1166	53	100	360	<5	5759	1500	74	0.92	83	0.64	57	<2	<2	22	<10	<10	0.3	<200	140	110
BI-134	1216	1226	110	100	480	7	7782	2160	130	1.33	130	0.79	75	<3	<2	20	<10	13	<0.2	<200	150	220
BI-134	1706	1716	71	140	500	<5	6128	1500	87	0.82	120	1.62	123	7	21	16	<10	<10	0.3	<200	265	170
BI-144	665	675	67	100	360	<5	3580	1200	120	0.46	250	0.89	69	<1	<2	19	<10	17	<0.2	<200	165	150
BI-144	675	685	180	440	800	<5	9821	2490	130	1.28	100	0.73	52	<2	<2	14	<10	<10	0.2	<200	130	180
BI-144	685	695	150	130	740	<5	7943	1800	110	1.03	68	0.57	39	5	<2	17	<10	10	<0.2	<200	135	140
BI-147	1928	1940	100	150	440	<5	11170	2360	130	1.41	120	1.47	103	<3	<2	21	<10	<10	0.5	<200	240	250
DU-9	2591	2592	<5	2800	550	<5	130	430	50	nil	16000	5.57	1670	<1	<2	<5	<10	<10	<0.2	<200	110	<50
DU-9	2594	2597	230	350	1300	<5	1800	1600	90	0.23	420	0.58	73	<1	<2	<5	<10	<10	<0.2	<200	40	100
D-5	*1613*	*1614*	*160*	*470*	*410*	*<5*	*38000*	*75000*	*2100*	*36.70*	*50*		*45*	*2*	*5*	*<5*	*80*	*<10*	*<0.2*	*700*	*40*	*<50*
NM-5	*1859*	*1864*	*22*	*<10*	*460*	*<5*	*8500*	*3800*	*490*	*18.70*	*70*	*0.30*	*57*	*<1*	*2*	*8*	*10*	*<10*	*<0.2*	*200*	*nss*	*<50*
DUNKA PIT			*150*	*10*	*960*	*12*	*23000*	*4200*	*220*	*7.14*	*160*	*1.11*	*120*	*7*	*6*	*<5*	*21*	*<10*	*<.2*	*420*		*150*
DU-15	2400	2405	29	200	251	0.6	1650	1350	160	0.30	2750	6.39	550			1350	160		0.30	2750	6.39	550
DU-15	2405	2410	105	737	842	1.4	4025	2475	165	0.75	16220	6.70	525			2475	165		0.75	16220	6.70	525
DU-15	2410	2415	21	3239	2825	0.2	860	1740	172	0.09	36500	11.41	1480			1740	172		0.09	36500	11.41	1480
DU-15	2415	2420	155	1228	1682	1.1	3540	1900	162	0.51	33060	8.69	780			1900	162		0.51	33060	8.69	780
DU-15	2420	2425	149	433	410	1.6	4400	1920	146	0.73	18580	6.01	780			1920	146		0.73	18580	6.01	780
DU-15	2425	2430	113	516	596	2.4	6700	2033	130	1.38	11133	4.41	100			2033	130		1.38	11133	4.41	100
DU-15	2434	2438	86	760	890	<5	4300	1600	160	0.69	11000	5.29	610	<2	<2	7	<10	<10	<.2	360		50
average BA-1			59	111	538	0.6	4888	564	96	0.85	163	0.95	135	4	0	17	0	0	0	25	210	456
average BA-2			101	167	459	0.0	4800	404	67	0.50	199	0.83	105	0	1	17	0	0	0	0	111	243
average BI-134			78	113	447	2.3	6556	1720	97	1.02	111	1.02	85	2	7	19		4	0	0	185	167
average BI-144			132	223	633	0.0	7115	1830	120	0.92	139	0.73	53	2	0	17		9	0	0	143	157
average DU-15			94	1016	1071	1.0	3639	1860	156	0.64	18463	6.99	689			1860	156		0.64	18463	6.99	689

Table 1B: Data from Morton and Hauck, 1987, Minnamax Deposit
Samples with Total Pt + Pd >500 ppb

DDH	Footage From	To	Interv	Au ppb	Pt ppb	Pd ppb	Pt+Pd	Ag ppm	Cu	Ni	Co	%S	Cr ppm
BA-1	2590	2660	70	48			548	5.1	2300	870		0.376	
BA-1	2660	2720	60	55			993	5.1	4800	1450		0.56	
DRIFT A				120	250	520	770		14200	2400	160	2.58	
DRIFT B				62	360	290	650		10000	2100	180	2.13	
DRIFT D				1300	400	750	1150		43500	4600	250	10.02	
5	410	445	35	685			1164	12.7	22800	2050		2.79	
17	130	150	20	685			753	5.1	11400	2800	300	1.75	
33	490	505	15	171			1233	8.2	11900	1900	100	1.63	
40	690	710	20	171			548	5.5	7700	1860	100	1.06	
60	1731	1735	4	685			14041	23.3	60400	3400	400	6.49	
90	511	514	3		195	770	965	2.0	9800	1700		1.13	900
91	131	136	5		270	750	1020	2.6	6200	1300		0.68	3300
92	634	640	6		230	570	800	0.8	3000	700		0.43	900
96	139	145	6		155	725	880	2.0	6700	1600		0.83	700
103	115	119	4		175	400	575	0.7	3200	1200		0.39	
103	119	128	9		175	465	640	1.5	5300	1800		0.68	
105	1773	1793	20	342	137	514	651	14.7	51900	7000	300	9.94	
105	1842	1855	13	171	890	377	1267	25.3	48600	10400	600	15.25	
116	1660	1680	20	514			856	19.9	131900	6800	400	14.46	
116	1680	1698.	18.3	171			1164	30.1	135500	18300	800	22.85	
130	1703.	1710	6.5	171			514	11.0	57800	11300	500	16.07	
254	1793	1803	10		90	570	660	5.6	12400	2300		1.50	
254	1813	1823	10		170	370	540	4.6	16700	2800		2.19	
289	225	235	10		85	445	530	1.1	4600	1200		0.64	
295	1375	1435	60	100	140	620	760		7500	1800	110	1.1	
296	1307	1317	10		180	675	855	4.3	9200	2400		1.19	
296	1317	1327	10		170	610	780	4.0	10500	2500		1.12	
296	1337	1347	10		290	445	735	4.8	10300	2100		1.23	
296	1377	1387	10		80	520	600	6.0	13300	2700		1.56	
296	1397	1407	10		135	445	580	3.4	8200	1700		1.11	
296	1567	1577	10		705	185	890	3.2	6700	1400		0.92	
356	1400	1545	145	80	160	830	990		8900	2100	120	1.56	
364	1525	1606	81	110	1900	260	2160		14500	3200	180	3.44	
372	119	134	15		155	505	660	2.1	6700	1400		1.15	2100

Table 1C: Data from Morton and Hauck, 1987, Dunka Road Deposit
Samples with Total Pt+Pd >500 ppb

DDH	From	To	Feet	Au ppb	Pt ppb	Pd ppb	Pt+Pd ppb	Ag ppm	Cu ppm	Ni ppm	Co ppm	%S
26030	686	726	40	68	205	719	925		6400	1900	170	1.47
26033	960	980	20	68	274	1404	1678		8300	2300	120	1.11
26044	67	122	55	68	171	1027	1199		4700	1700	100	0.90
26044	67	122	55	68	171	1027	1199		4700	1700	90	0.90
26044	107	117	10	68	205	959	1164		6400	2000	90	1.00
26045	7	24.5	17.5	68	411	1062	1473		4900	1500	90	0.57
26047	518	558	40	103	342	1507	1849		5500	3500	170	0.77
26010	**115.5**	**118.5**	**3**	**1712**	**514**	**8904**	**9418**	**25.00**	**56400**	**6400**		**11.99**
26010	280	282	2	3	171	342	514	0.03	10000	6500		14.44
26015	351	361	10	342	342	1027	1370	4.11	8000	1900		0.90
26015	361	371	10	171	171	514	685	0.34	8700	2500		0.96
26017	715	725	10	3	342	856	1199	0.03	11000	3400		1.34
26017	725	735	10	342	342	685	1027	0.03	10400	2800		1.43
26021	384	394	10	342	342	685	1027	0.03	9000	2700		1.27
26021	394	404	10	3	342	856	1199	0.03	9700	2800		1.56
26026	315	325	10	171	514	856	1370	0.03	10200	2100		1.20
26026	325	335	10	171	342	856	1199	0.03	9800	3300		1.46
26026	495	505	10	171	171	514	685	4.11	9500	2400		1.55
26030	686	696	10	342	342	685	1027	0.03	8700	2400		1.16
26031	826	829	3	3	171	342	514	0.03	12500	6900		7.29
26033	960	970	10	3	342	1199	1541	0.03	10000	2700		1.09
26033	970	980	10	342	342	685	1027	0.03	7300	2200		0.92

Table 1D: Re-assay NRRI, Morton and Hauck, 1987, Water Hen and Dunka Road Deposits
Samples with Pt+Pd >500 ppb

DDH	Footage From	To	Au ppb	Pd ppb	Pt ppb	Ag ppm	Cu ppm	Ni ppm	Co ppm	%S	Cr ppm	V ppm	As ppm	Bi ppm	Pb ppm	Se ppm	Te ppm	Sb ppm	Zn ppm	Cl ppm
Water Hen																				
SL-11	729	737	100	360	160	2.8	6800	2600	157	2.83			700	4.2	13		0.13	28		<80
SL-13	1101	1102	240	300	240	12.1	>20000	2400	156	4.55	15		27	16	57	14	2.2	6		426
SL-1	680	683	1027	1370	1027	44.2	44400	6900	800											
Dunka Road																				
26010	115.5	118.5	1350	150	8800	15.0	>20000	5036	336	12.2	31	9	250	12	247	25	170	22	285	<200