Costelloe, Marina (2003) ***Environmental review of the Mary Kathleen uranium mine.*** **Masters (Research) thesis, James Cook University.**

Chapter 3 Waste rock piles

3.1 Introduction

Waste rock piles commonly contain large concentrations of sulphide minerals, which may undergo oxidation, producing a major source of metal and acid contamination. The complex microbiological, hydrological, mineralogical, and geochemical post-placement processes and their coupled interaction in mine waste environments are not completely understood (Nordstrom, 1977; Jambor and Blowes, 1994; Morin and Hutt, 1997; Jambor and Blowes, 1998; Nordstrom and Alpers, 1999).

At Mary Kathleen during the mining stage truck loads of ore and waste rock were directed to either high grade, low grade or waste piles. Rock from the high grade piles was then crushed. The beneficiation process then sorted crushed rock to 40mm and 150mm sized particles as well as ore grade and waste products. Crushed waste products were placed on waste piles. The presence of oxidising sulphides in waste rocks has the potential to cause acid mine drainage (AMD) (Alpers and Nordstrom, 2000). Oxidation of pyrite produces sulphuric acid that can release metals from other minerals (Nordstrom and Alpers, 1999). In addition, Harries (1996) states that the controlling mechanisms of oxidation in a waste rock dump are the supply of both oxygen and water. Water in the form of rain, serves as both a reactant and a medium for bacteria in the oxidation process, also the flow of water transports oxidation products. Metal leaching, even in the absence of acidic drainage, is also an important factor for assessing environmental contamination from waste rock piles at mine sites (Jambor and Blowes, 1998; Nordstrom and Alpers, 1999). The collection of representative waste rock samples and subsequent testing is complicated due to the composition, spatial distribution, and particle size heterogeneity of the waste material (Smith et al., 2000).

The main objectives of chapter 3 are to evaluate contamination of local soils, stream sediments and vegetation, to investigate the dispersal of contaminants into local drainage system, evaluate AMD processes, and measure the levels and causes of radiation in and around the waste rock piles. Six waste rock piles were surveyed at Mary Kathleen for geochemical and radiometric evaluation.

3.2 Location, rehabilitation and survey design

Waste rock piles at Mary Kathleen are defined as mounds of artificially placed rock dumps comprising from 2 m (boulders) to less than 63 μm sized particles of low grade ore and gangue materials. Waste rock piles selected for this research include the D Stockpile, Crusher, Goldings West, West Tip, South Tip and North Waste Tip pile (Figure 3.1). Figure 3.2 shows the locations of sample sites on and around waste rock piles.

Waste rock from open pit operations was placed into neighbouring valleys and on the slopes of adjacent hills close to the mine (Ward and Cox 1985). The dumps contain up to 24 million tonnes of waste rock. Waste rock piles are up to 30 m thick and appear physically stable (Figure 3.3). Waste rock dumps contain benign material (country rock) as well as mineralised material, which was mined but not milled. During the rehabilitation phase, piles were covered by a thin (<10 cm) veneer of benign waste, to promote plant growth and attenuate radiation levels. The tops of waste piles were ripped and seeded, using seeds from local grasses, trees and shrubs. Leaching of metals and salts from the dumps was not expected to be an environmental problem due to the large excess of acid neutralising potential in the waste rock (MINENCO, 1985).

Figure 3.1 Final waste rock positions (modified from MINENCO 1986)

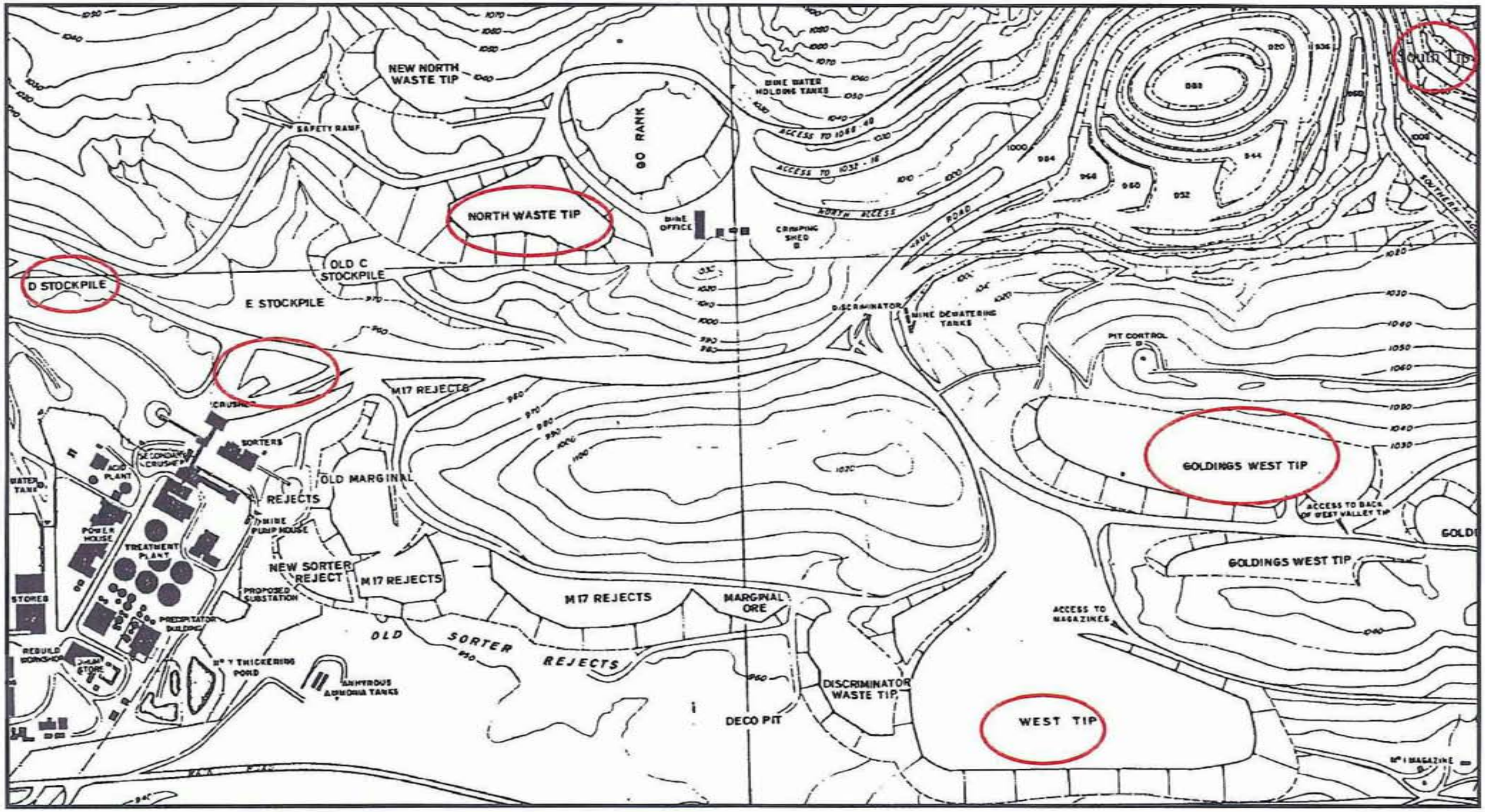


Figure 3.2 Waste rock locations with selected sample points and start points for radiometric traverses.

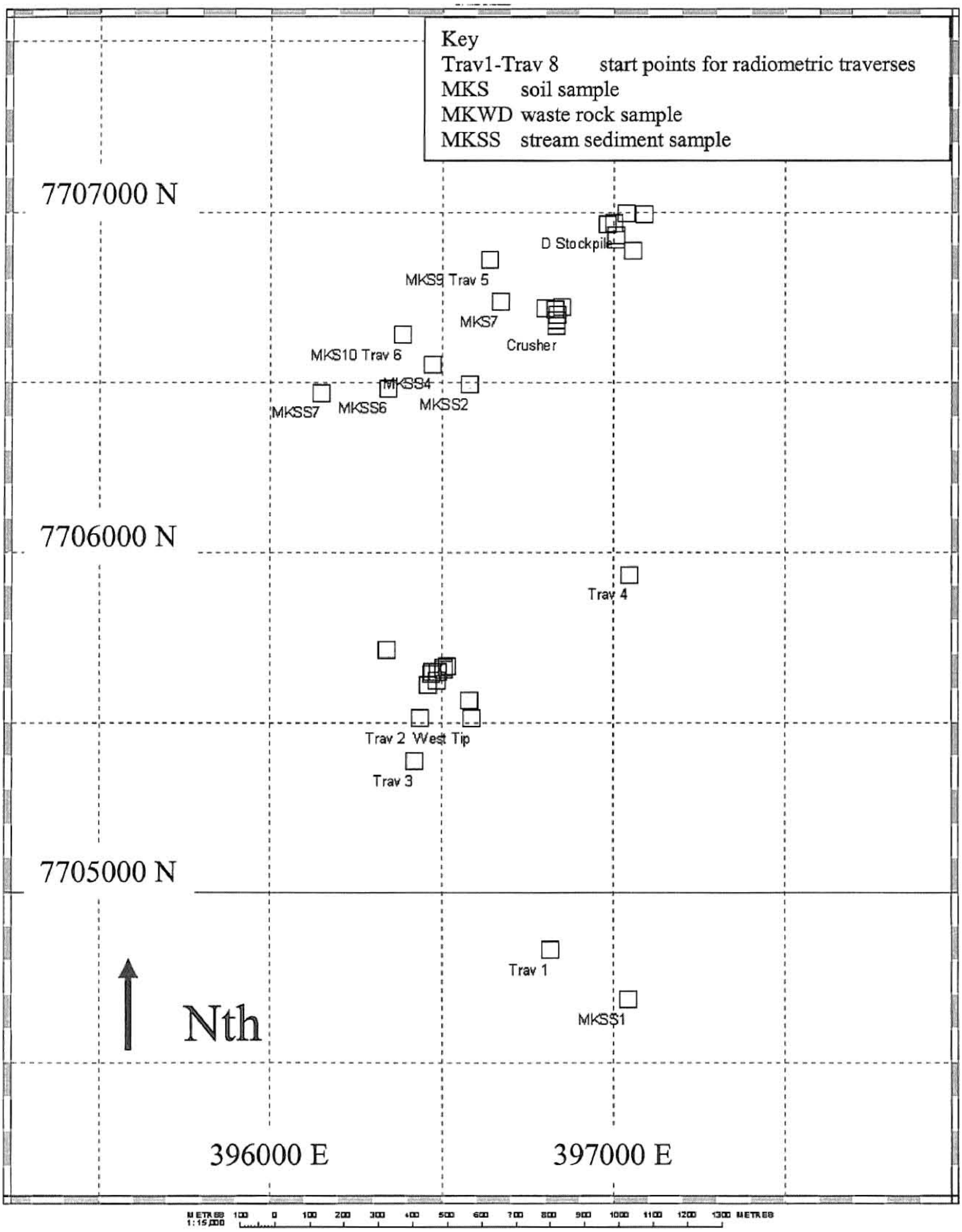
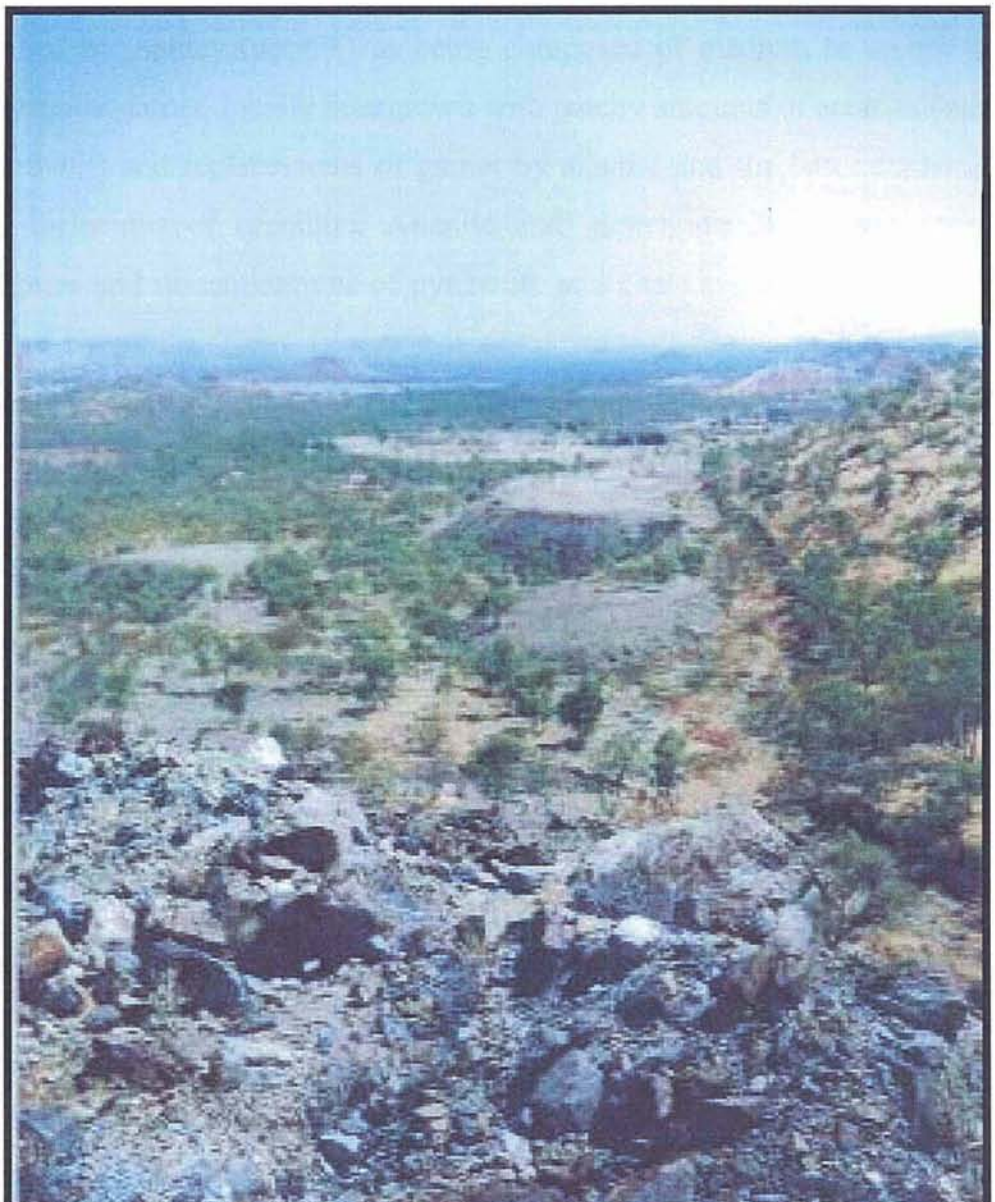


Figure 3.3 Photograph of waste rock piles from West Tip (Photographed 7-10-99).



3.3 Waste rock samples

3.3.1 Waste rocks

Waste rocks largely have the same mineralogy as pit wall samples (i.e. garnet, clinopyroxene, allanite, chlorite, calcite, pyrite, etc). MKWD3 sampled from the top of the West Waste Tip, can be considered representative of waste rock. MKWD3 is described by Ashley (unpub.) as being composed of medium to coarse grained in-equigranular garnet, locally intergrown with patchy amounts of apatite. There are also intergrowths and replacements of garnet by allanite and the latter contains scattered small inclusions of uraninite. Allanite and garnet are intergrown with scattered aggregates and disseminations of pyrrhotite and chalcopyrite, with pyrrhotite locally replaced by pyrite. There is also a trace of arsenopyrite. Uraninite has been partly replaced by metamict products, associated with a little late stage pyrite (Appendix 8).

Waste rock piles and sub-grade ore piles, are both characterised by wide variations in mineralogy and particle size. Generally, waste rocks contain high levels of Ce, Cu, La, Mn, S and U (Table 3.1). The rock geochemistry varies within each waste rock dump due to the variable abundance in individual minerals.

Table 3.1. Major (wt%) and trace element (ppm) geochemistry of West Tip, D Stockpile and Crusher waste rocks.

	Ca	Fe	K	Mg	Na
	%	%	%	%	%
West Tip					
MKWD1	18.5	11	0.34	0.6	0.6
MKWD2	19.3	11	0.10	0.9	0.5
MKWD3	19.1	10	0.17	0.8	0.4
MKWD4	17.0	12	0.16	0.7	0.4
MKWD5	20.2	11	0.41	0.6	0.4
MKWD8	5.5	5	2.37	1.6	0.9
MKWD9	3.3	6	2.30	1.7	0.5
MKWD10	16.5	9	0.49	0.7	0.5

MKWD11	14.6	9	0.37	0.6	0.5
MKWD12	7.8	6	1.69	1.8	0.8
MKWD15	16.5	9	0.36	0.8	0.4
	Ca	Fe	K	Mg	Na
	%	%	%	%	%
D Stockpile					
MKWD17	9.4	7	1.23	0.9	0.9
MKWD18	8.0	6	2.05	1.6	0.7
MKWD20	3.9	5	2.10	1.7	1.1
MKWD21	15.0	9	0.70	0.8	0.6
Crusher					
MKWD26	13.7	10	0.75	1.7	0.5
MKWD27	13.5	8	1.70	1.1	0.8
MKWD28	11.8	7	1.53	1.5	1.0
MKWD29	5.8	4	2.48	1.6	2.6
MKWD30	6.2	4	3.13	1.9	1.6

	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	Ppm	ppm	ppm	ppm	ppm	ppm	ppm
West Tip																
MKWD1	133	52	10400	3600	7310	2650	117	3820	291	11510	0	189	916	122	50	16
MKWD2	89	11	6810	562	4470	2940	55	3090	153	5110	0	145	439	109	57	12
MKWD3	95	15	7700	1520	5080	2620	75	2820	181	6640	0	224	565	115	58	15
MKWD4	120	21	8790	2850	5600	2450	177	5380	273	21210	16	319	927	98	59	15
MKWD5	90	135	6370	1240	4240	3320	28	3510	187	3150	0	221	658	117	71	26
MKWD8	21	429	954	441	585	1250	63	1270	36	2590	70	38	71	97	37	71
MKWD9	8	397	424	89	265	610	50	696	17	883	98	24	40	167	30	37
MKWD10	71	89	4530	756	2980	2190	77	2050	83	5420	32	101	253	88	47	25
MKWD11	159	58	11600	1920	7280	2040	58	3410	215	6700	43	290	710	92	50	20
MKWD12	107	300	7380	371	5160	973	112	1450	99	1970	90	191	374	91	35	46
MKWD15	103	54	7340	643	4770	2390	47	2390	112	3100	31	168	364	93	51	25
D Stockpile																
MKWD17	53	2960	2930	424	1900	13000	52	1430	49	2690	61	58	138	100	39	37
MKWD18	59	476	3310	715	2170	1610	42	1790	77	2710	90	86	265	96	35	63
MKWD20	26	588	879	297	584	2410	75	1130	31	758	52	34	76	101	36	74
MKWD21	124	157	7930	463	4950	2410	68	3620	231	3660	45	330	694	88	49	28
Crusher																
MKWD26	57	127	4090	3980	2400	2230	74	1800	82	17500	31	109	169	73	41	26
MKWD27	50	289	2810	620	1800	2050	45	2090	49	7870	37	89	129	75	41	37
MKWD28	69	194	4360	272	2790	2710	40	2070	115	2530	40	134	331	78	42	25
MKWD29	33	322	879	265	529	1460	36	1000	17	1340	33	27	36	73	29	53
MKWD30	25	510	660	121	405	1400	25	991	21	1490	39	22	29	63	28	61

The three waste pile samples contain similar average concentrations of Ca, Fe, K, Mg, Na, As, Ni, P, Pb, Th, V, Y and Zn to pit wall samples (Table 3.2). West Tip samples have two times the concentration of Ce, La and U compared to D Stockpile and Crusher pile samples, yet are comparable to pit wall samples. Crusher samples contain the lowest amounts of trace elements, except for S (6146 ppm) and Cu (1052 ppm). D Stockpile has elevated levels of Ba (1045 ppm) and Mn (4858 ppm) and low levels of S (2455 ppm) and Cu (475 ppm) compared to West Tip Crusher and open pit samples. D Stockpile samples were taken close to a small stockpile of manganese used in processing, which probably has influenced Mn values.

Table 3.2. Average major (wt%) and trace element (ppm) contents of pit walls and waste rocks from the West Tip, D Stockpile and Crusher.

	Ca	Fe	K	Mg	Na
	%				
West Tip	14.4	9	0.8	1	0.5
D Stockpile	9.1	7.0	1.5	1.2	0.8
Crusher	10.2	6.5	1.9	1.5	1
Open pit	17	11	0.4	1	0.6

	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	ppm															
West Tip	91	142	6573	1272	4340	2130	78	2717	150	6208	35	174	483	108	50	28
D Stockpile	66	1045	3762	475	2401	4858	59	1993	97	2455	62	127	293	96	39	51
Crusher	47	288	2560	1052	1585	1970	44	1590	57	6146	36	76	139	72	36	40
Open pit	104	61	6973	1973	4743	2544	123	3082	169	11309	9	175	544	109	58	15

White mineral efflorescences occur on waste rocks (Table 3.3), but are not as abundant as within the open pit. The geochemical data suggest that the phases represent a mixture of Ca sulphate (gypsum) + Fe sulphates (melaterite & copiapite).

Table 3.3. Geochemistry of MKE50 collected from the West Tip.

Sample	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Th	U	V	Y	Zn
	%					ppm														
MKE50	11.16	17.94	0.25	0.39	0.16	63	49	2810	1090	2050	1400	206	3720	66	35700	80	67	74	36	13

3.3.2 Soils

Shallow skeletal soils on waste pile surfaces originate from soil placement during the rehabilitation phase. Soils topping waste rock piles were measured to depths between 0-10 cm. Samples of soils were obtained by sieving waste rock samples (< 2mm) collected from the top surface of the D Stockpile, West Tip, Crusher and the North Waste Tip (Figure 3.2). Soil mineralogies are dominated by quartz, albite, microcline and chlorite. The soils are acidic to neutral (Table 3.4), and soil conductivity is low, except for MKS47 which is very acidic and conductive. Sample MKS47 was located near a pile of sulphur used in processing.

Table 3.4. pH and conductivity of soils on and around waste rock piles.

Original sample	Sieved (2 mm)	pH	Conductivity (µS/cm)	Location
MKWD13	MKS40	5.8	027	West Tip top (subsurface sample)
MKWD14	MKS41	5.4	350	West Tip top (surface sample)
MKWD22	MKS42	6.3	081	D Stockpile top
MKWD23	MKS43	7	049	D Stockpile top
MKWD31	MKS44	7	028	Below Crusher pile (2m)
MKWD32	MKS45	6.3	099	Below Crusher pile (10m)
MKWD33	MKS46	7.2	131	Below Crusher pile (50m)
MKWD34	MKS47	3.8	1600+	Below Crusher pile (100m) near sulphur mound

Soils were also collected from the mill or old processing area (MKS7, MKS9, MKS10) and from the top of the North Waste Tip (MKS11, MKS12). Concentrations of more than 5 times the background levels occur for Ce, Cu, La, Pb, S and U in waste rock soils (Table 3.5). Elevated levels of As, Ba, Mn, Ni, P, Th and Zn compared to background soils also exist in waste rock soils (Table 3.5).

Table 3.5. Major (wt%) and trace element (ppm) content of soils from the waste rock piles and background areas.

Sample	Ca	Fe	K	Mg	Na
	%				
MKS7	1.9	5.1	3.2	0.5	0.9
MKS9	11.1	12.2	0.9	1.0	0.6
MKS10	4.9	6.3	2.6	1.0	1.1
MKS11	2.2	5.1	3.2	2.0	1.0
MKS12	4.1	5.8	2.1	1.5	1.4
Background (mean n=5)	2.1	5.0	2.4	1.3	1.7

	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	ppm															
MKS7	13	542	656	86	431	462	22	771	32	658	58	52	27	70	50	88
MKS9	76	1220	4060	968	2920	1950	85	3150	205	6630	50	210	59	100	43	38
MKS10	44	627	1970	353	1220	1550	51	1270	235	923	69	59	110	109	41	954
MKS11	18	717	421	232	284	2830	76	1080	27	1200	37	25	32	79	34	122
MKS12	33	595	899	334	598	2100	70	1020	25	627	53	38	63	109	37	62
Background (mean n=5)	<5	406	108	60	53	592	22	757	13	126	84	30	6	151	47	37

Soils in waste rock areas appear to be derived from sources with high Ce, Cu, La, Mn U and Zn trace element content. This indicates that soil of the processing area was not completely removed during the rehabilitation phase and that soil placed on waste rock piles during rehabilitation was originally not sourced from background areas. Some of the high levels of S and Mn can be attributed to dispersion of these elements from small piles of manganese and sulphur used in mineral processing.

3.3.3 Vegetation

Eight vegetation samples were taken from the West Tip and one from the Crusher site for identification (Appendix 6). Four samples were ashed and analysed for various elements (Table 3.6a). MKV26, MKV27 and MKV28 were sampled from the West Tip, MKV32 was sampled from the swamp area below the West Tip. MKV28 (Silky Oilgrass) contains the highest concentrations of Ce, Cu, La, Mn, Ni and U (Table 3.6a).

Table 3.6a. Major (%) and trace element (ppm) geochemistry of ashed plant samples from waste rock areas.

Sample.	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
	Aerva javanica (kapok bush)																				
MKV26	17.2	2.1	2.8	3.0	0.3	12	245	307	176	221	903	84	11800	13	9380	122	13	58	31	18	543
	Acacia chisholmii (Minerichie Wattle)																				
MKV27	22.0	0.5	3.6	3.4	0.5	11	70	71	146	58	311	42	9670	15	21300	339	9	2	14	4	415
	Cymbopogon bombycinus (Silky Oilgrass)																				
MKV28	6.6	3.4	2.9	1.0	0.2	24	62	1310	357	799	1040	143	3320	35	16500	37	32	226	41	15	253
	Melaleuca bracteata (Black Teatree, River Teatree)																				
MKV32	27.7	0.2	2.6	3.3	0.1	6	16	15	62	13	395	54	3530	0	11700	300	1	4	10	1	378

Table 3.6b. Major (wt%) and trace (ppm) element geochemistry of background (MKV13) sampled and West Tip (MKV26) sampled kapok bush

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Sr	Th	U	V	Y	Zn
	%					ppm															
	Background sample *Amaranthaceae Aerva javanica (kapok bush)*																				
MKV13	19.8	0.9	2.6	6.4	0.2	8	650	30	90	20	570	24	10400	5	9450	323	2	3	26	4	47
	West Tip sample *Amaranthaceae Aerva javanica (kapok bush)*																				
MKV26	17	2.1	2.8	3	0.3	12	245	307	176	221	903	84	11800	13	9380	122	13	58	31	18	543

The kapok bush (Table 3.6b) sample illustrates the accumulation of various heavy metals (Cu, Mn, Ni, Zn) and other elements (Ce, La, U) derived from the waste rock dump material.

Sporadic soil quantities and poor physical soil structure, poor water holding capacity and acidic soils (pH 5.4) are evident on the top of waste rocks. Non vegetated areas indicate one or more of the following occurs: that the colonising species are not sufficiently tolerant to the high levels of heavy metals on the bare waste rock sites; that soil acidity retards plant establishment; or additional environmental factors, such as low soil fertility and low water-holding capacity (Ernst et al., 1983) prevent vegetation growth on waste rock piles at Mary Kathleen.

3.3.4 Stream sediments below waste rock piles

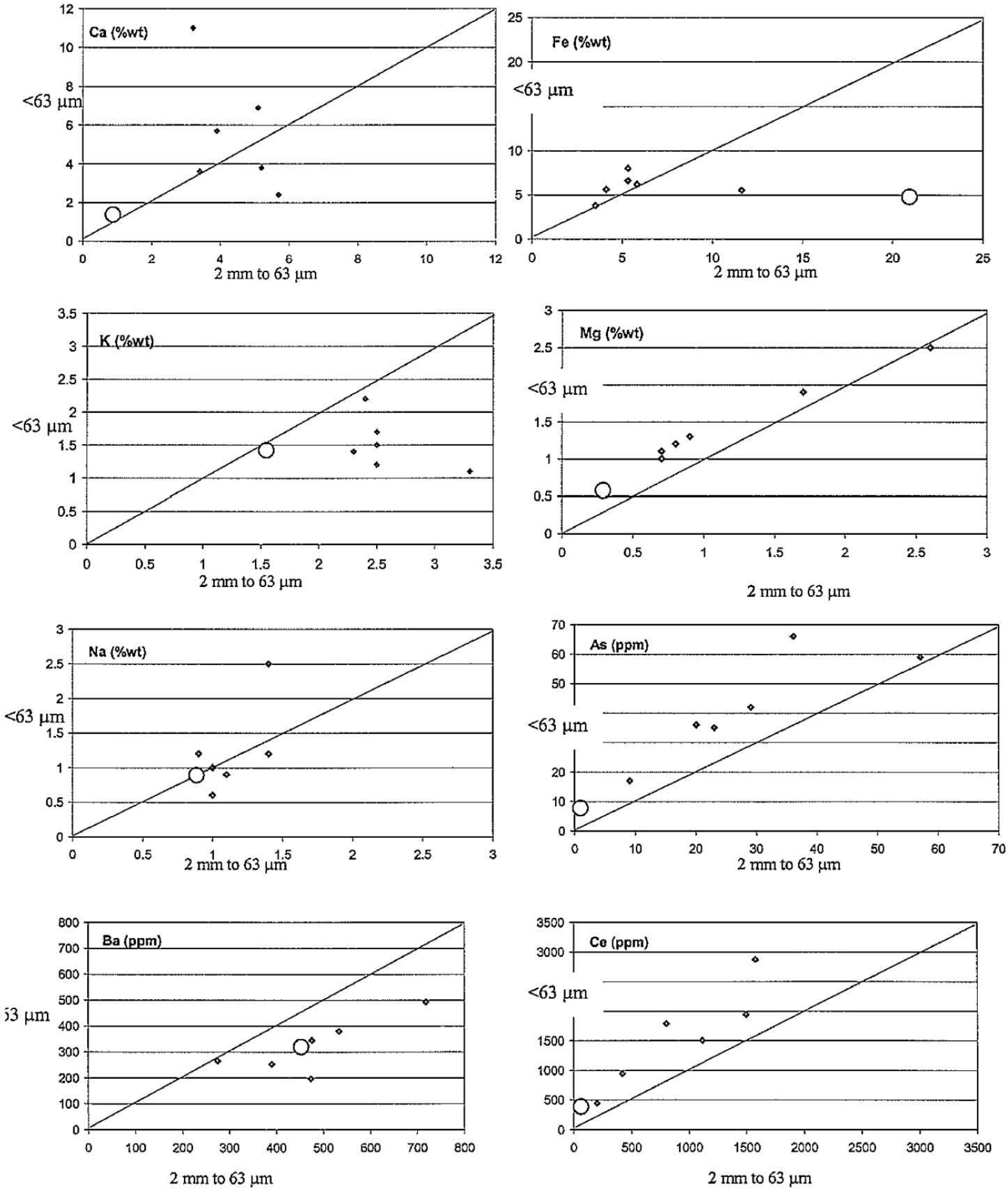
Stream sediment samples were collected from around the base of six rock piles (Figure 3.2). Samples were sieved to <2 mm to 63 μm (A) and <63 μm (B) fractions and analysed for major and trace elements (Table 3.7).

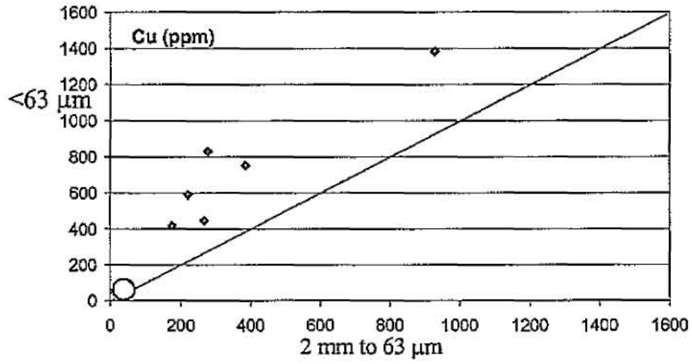
Table 3.7. Major (wt%) and trace element (ppm) geochemistry of stream sediments sampled from the base of rock piles (A samples sieved <2mm to 63μm and B samples <63 μm).

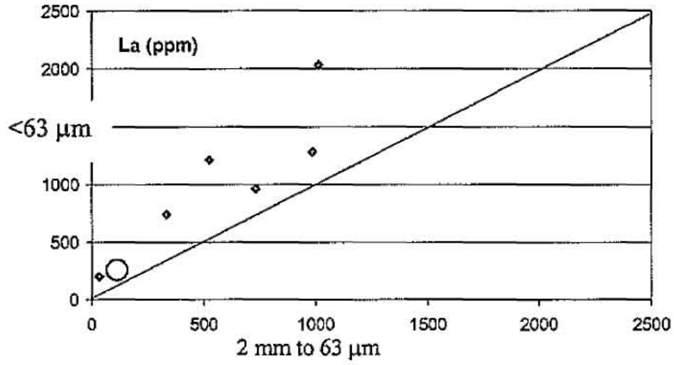
	Ca	K	Mg	Na	Fe	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Th	U	V	Y	Zn
	%					ppm														
	Creek draining South Tip																			
MKSS1A	5.7	2.4	0.7	0.9	11.6	57	718	199	220	114	1240	68	427	11	104	13	26	159	34	29
MKSS1B	2.4	2.2	1.0	1.2	5.5	59	492	444	588	270	673	131	676	15	2450	29	126	142	38	65
	Creek draining mill area, Crusher dump																			
MKSS2A	5.1	2.5	0.9	1.1	5.3	36	475	1570	384	1010	1400	57	1080	53	694	61	107	87	40	43
MKSS2B	6.9	1.7	1.3	0.9	8.0	66	344	2870	750	2030	2040	106	2330	93	1810	107	156	125	62	75
	Seepage area below West Tip dump																			
MKSS3A	5.2	1.5	2.6	1.4	5.8	29	275	1490	929	983	938	178	867	13	8070	19	100	148	46	202
MKSS3B	3.8	1.4	2.5	1.2	6.2	42	264	1940	1380	1280	871	273	1070	21	6790	31	129	133	54	309
	Creek on W side of mill area																			
MKSS4A	3.4	2.5	0.7	1.4	4.1	20	390	799	276	523	952	63	413	20	176	45	51	67	32	26
MKSS4B	3.6	1.2	1.1	2.5	5.6	36	252	1790	829	1210	1320	131	1180	33	662	66	128	109	47	43
	Wash below waste dump, E of mill																			
MKSS5A	3.9	2.3	1.7	1.0	5.3	23	533	1110	265	730	1110	130	976	23	1170	32	254	95	30	68
MKSS5B	5.7	1.4	1.9	1.0	6.6	35	380	1500	445	962	1300	173	1600	37	1960	49	437	117	43	92
	E Cameron Ck, down from mill																			
MKSS6A	3.2	3.3	0.8	1.0	3.5	9	473	418	174	331	774	122	534	18	434	23	34	82	30	78
MKSS6B	11.0	1.1	1.2	0.6	3.8	17	196	941	415	737	1540	239	1260	27	1220	42	86	90	42	157
	Background Ck, W of mill																			
MKSS7A	0.8	2.5	0.3	0.9	20.8	<5	463	61	13	31	205	12	258	15	40	25	5	45	25	18
MKSS7B	1.2	1.5	0.6	0.9	5.0	8	325	351	51	200	518	24	577	28	223	99	17	105	87	73

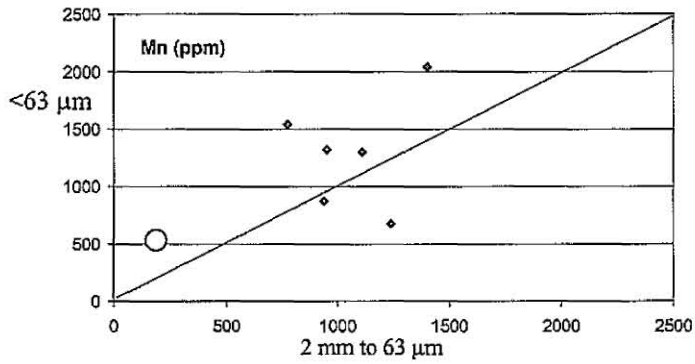
Concentrations of Ce, Cu, La, Mn, S, and U are at least 6 times higher than in the background (MKSS7) material (Figure 3.4). Fine (< 63 μm) fraction samples generally have higher concentrations of As, Ce, Cu, La, S, U and Zn and lower Ba and K than medium-grained fractions. Stream sediment sampled from seepage area below the West Tip has the highest Ce, Cu, La, Mn, Ni, S and Zn concentrations. The wash area below the Crusher pile contains elevated Ce, La, Mn, Ni values and the highest U (437 ppm) found in stream sediment samples for the minesite with the exception of the sediments collected from the tailings seepage point.

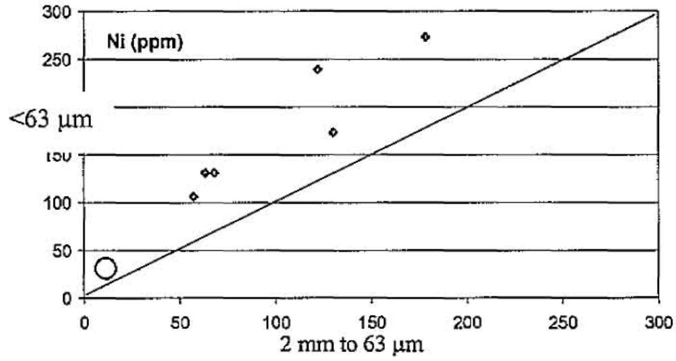
Figure 3.4. Scatter plots of medium grained (2 mm to 63 μm) vs fine grained (<63 μm) fractions for stream sediments sampled from the base of rock piles (MKSS1-MKSS6) and background (MKSS7). Key MKSS7 = O.

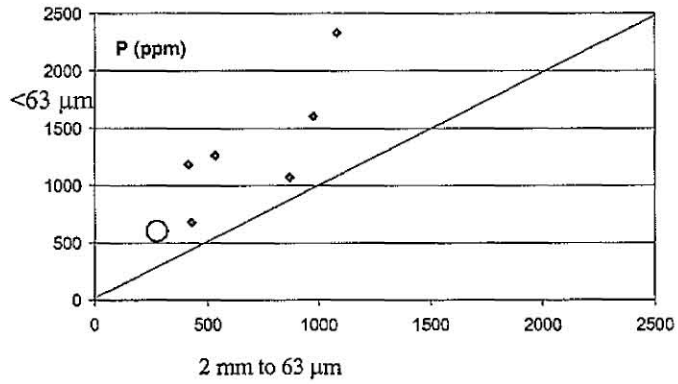


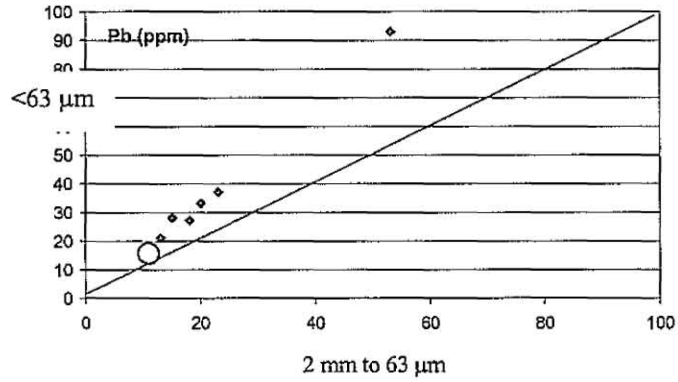

Cu (ppm)
<63 µm
2 mm to 63 µm
0 200 400 600 800 1000 1200 1400 1600

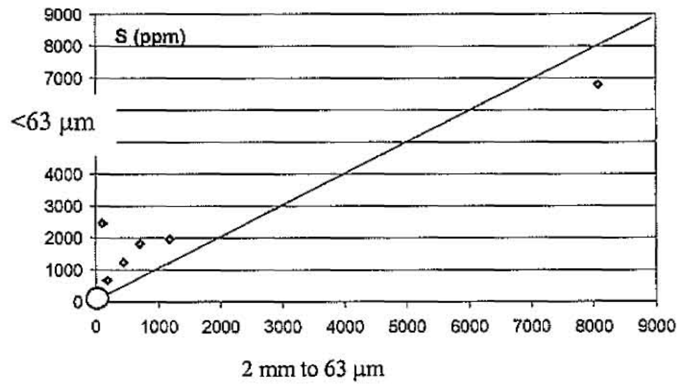

La (ppm)
<63 µm
2 mm to 63 µm
0 500 1000 1500 2000 2500

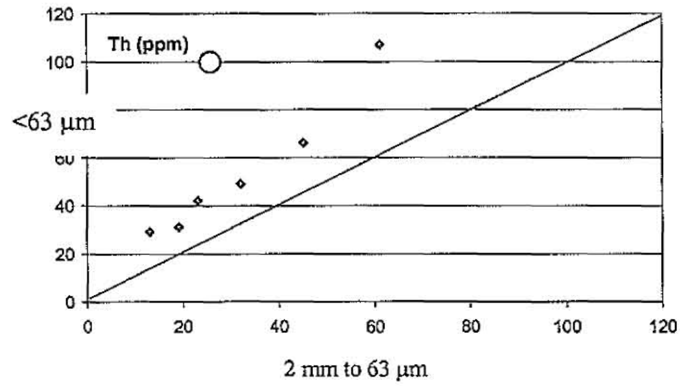

Mn (ppm)
<63 µm
2 mm to 63 µm
0 500 1000 1500 2000 2500

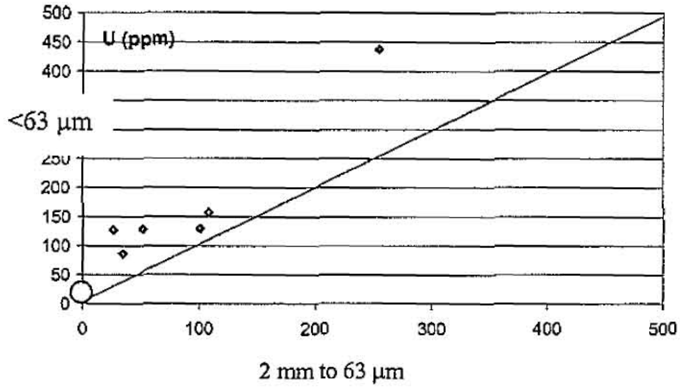

Ni (ppm)
<63 µm
2 mm to 63 µm
0 50 100 150 200 250 300

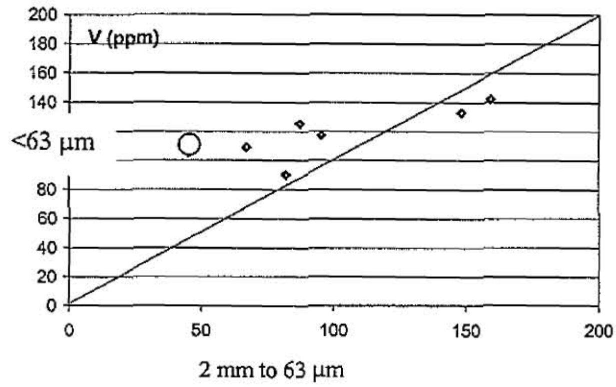

P (ppm)
<63 µm
2 mm to 63 µm
0 500 1000 1500 2000 2500

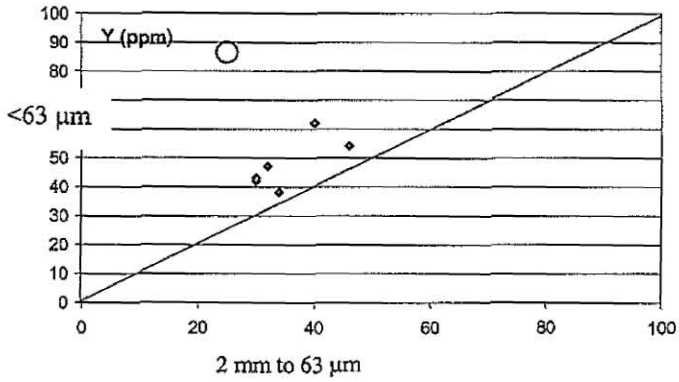

Pb (ppm)
<63 µm
2 mm to 63 µm
0 20 40 60 80 100

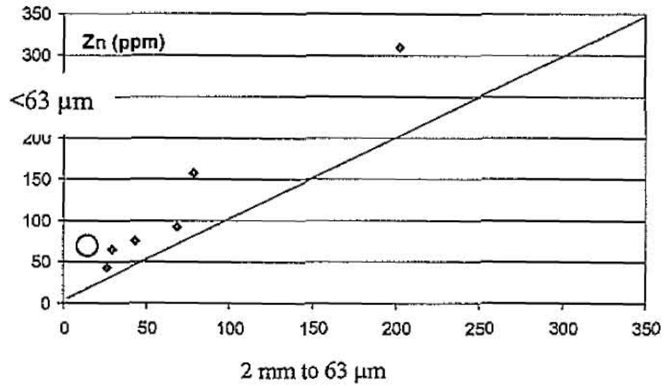

S (ppm)
<63 µm
2 mm to 63 µm
0 1000 2000 3000 4000 5000 6000 7000 8000 9000


Th (ppm)
<63 µm
2 mm to 63 µm
0 20 40 60 80 100 120


U (ppm)
<63 µm
2 mm to 63 µm


V (ppm)
<63 µm
2 mm to 63 µm


Y (ppm)
<63 µm
2 mm to 63 µm


Zn (ppm)
<63 µm
2 mm to 63 µm

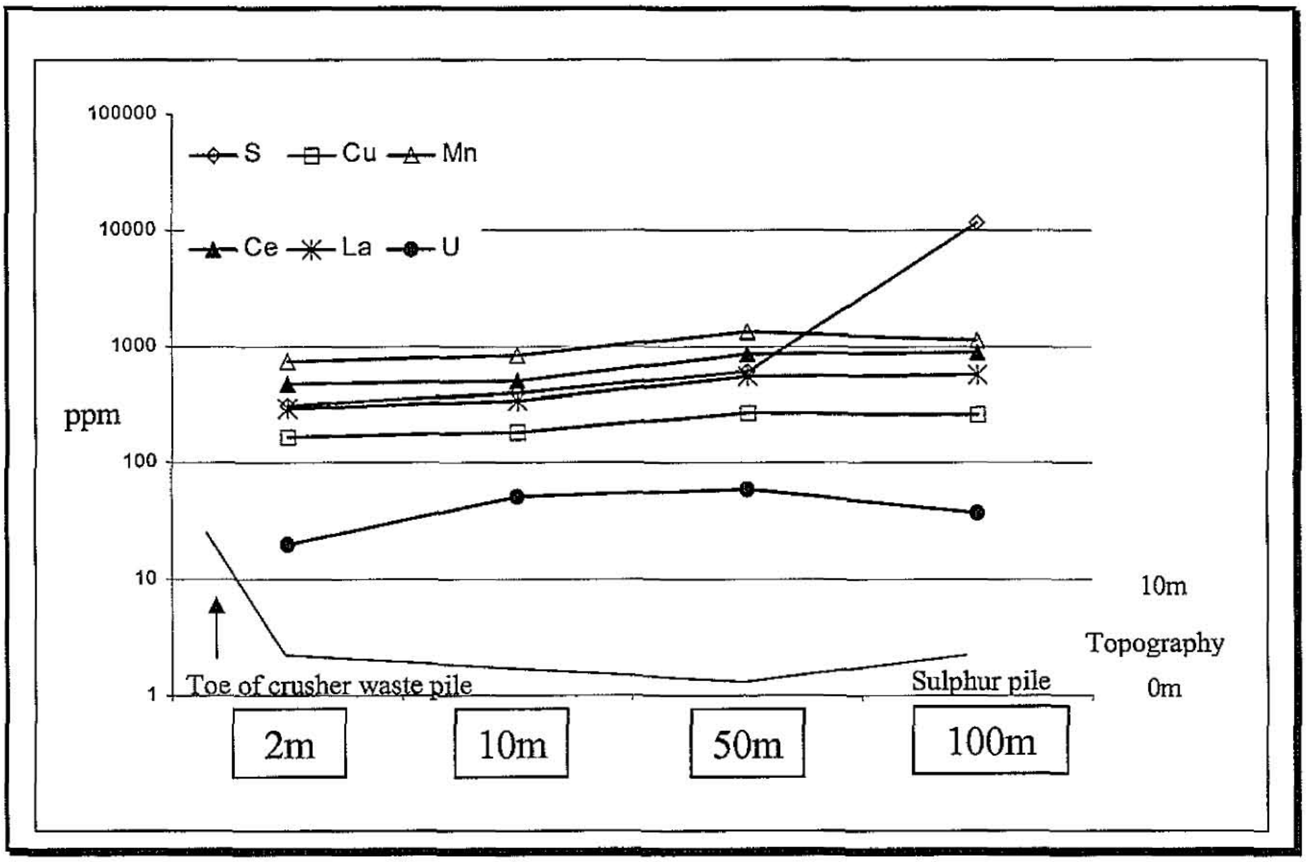
Stream sediments were sampled at 2 m, 10 m, 50 m and 100 m from the base of the Crusher pile and were submitted for geochemical analysis (Table 3.8). As previously mentioned, sample MKWD34 (MKSS73 < 2mm fraction) is located near a pile of sulphur used in mineral processing.

Table 3.8. Major (wt%) and trace element (ppm) geochemistry of stream sediments collected from below the Crusher waste rock pile (< 2mm fraction).

	Ca	Fe	K	Mg	Na	As	Ba	Ce	Cu	La	Mn	Ni	P	Pb	S	Th	U	V	Y	Zn
	%					ppm														
MKSS70 (2m)	3.8	4.5	2.8	1.6	1.0	10	544	467	168	294	739	33	874	10	314	25	20	97	29	25
MKSS71 (10m)	3.7	4.9	2.2	1.7	1.0	12	420	505	185	338	837	43	909	13	399	27	51	107	28	30
MKSS72 (50m)	4.5	5.7	2.3	1.4	1.0	19	450	853	266	551	1310	50	825	23	590	32	60	115	33	36
MKSS73 (100m)	4.4	5.0	2.3	1.3	1.2	17	458	875	262	565	1110	35	897	15	11500	23	37	115	31	36

Figure 3.5 clearly shows element concentrations are lowest in the sample collected 2 m from the base of the dump (MKSS70). Sediment collected in a topographic low, 50 m from the base of the dump (MKSS72), contains the highest Ce (853 ppm), Cu (266 ppm), La (551 ppm), Mn (1310 ppm), and U (60 ppm) values. Sulphur concentrations are highest 100m from the waste rock pile (MKSS73), due to the erosion of material from a remnant sulphur pile.

Figure 3.5. Trends of selected elements in stream sediments collected below the Crusher pile.



The stream sediment geochemistry clearly indicates metals are transported from the Crusher pile into local creek systems.

In chapters four and five further discussion on stream sediment analysis is undertaken. Element distribution from the tailings dam to Cameron Creek (chapter 4) and the mine site to Cameron Creek (chapter 5) will be compared and evaluated with the above waste rock sediment analysis to determine contaminant dispersal.

3.4 Radiometrics

3.4.1 Survey design

The geophysical survey traversed waste rock tops, slopes, bases and exposed and soil/vegetated areas. Exposure rates for environmental data (μR/hr, nSv/hr) and assays for geophysical data (concentrations of %K and ppm of U and Th) were recorded using a GR-320 Spectrometer. A Scintrex BGS-1SL scintillometer recorded Total Count in cps only. All radiometric data were tabulated and assessed for data quality. Exposure rates were converted from nSv/hr to mSv/year. Figure 3.6 is a photograph collage of surveys on West Tip and Crusher areas.

3.4.2 Geophysical analysis

Eleven waste rock areas were surveyed, eight traverses (traverses 1-8) were investigated with the scintillometer (Figure 3.7s to 3.10) and six (traverses 9-14) traverses were investigated using the gamma-ray spectrometer (Figures 3.11 to 3.13).

Figure 3.6

Photographs of waste rock pile geophysical surveys (Photographed 7-10-1999).

Figure 3.6a. West waste tip traverses 11 and 12.

Figure 3.6b. View of Crusher pile from concrete foundations (traverse 4).

Figure 3.6c. Base of Crusher pile (traverse 9)

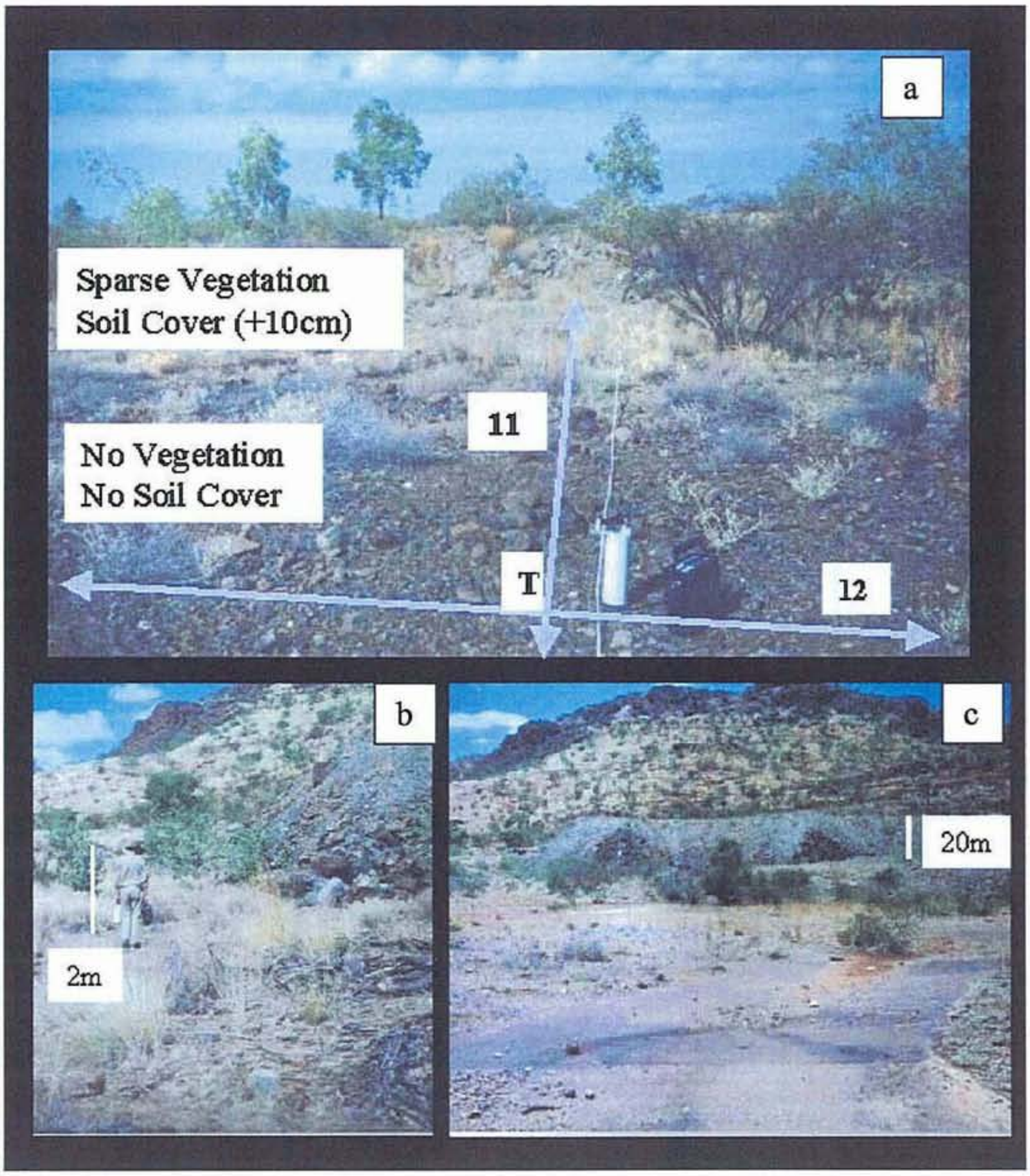
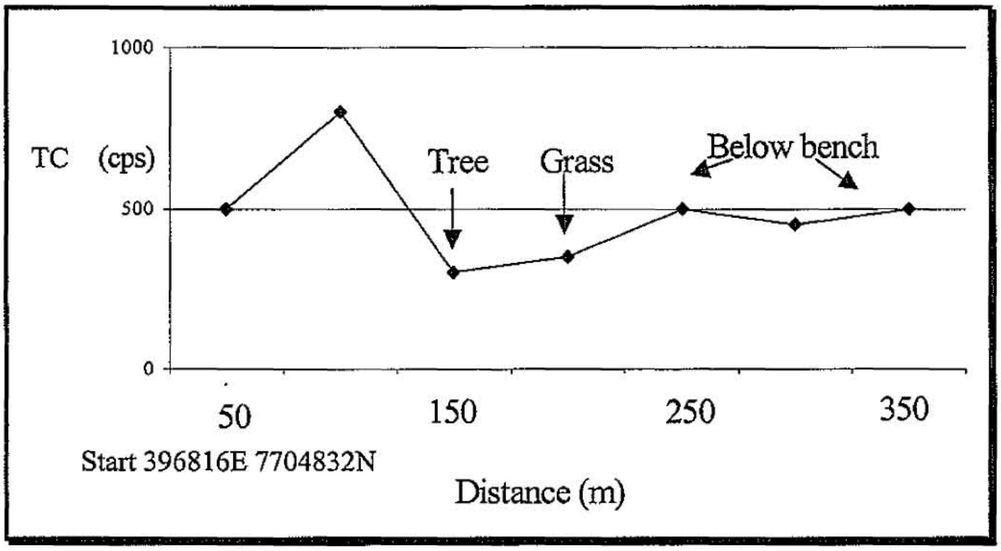
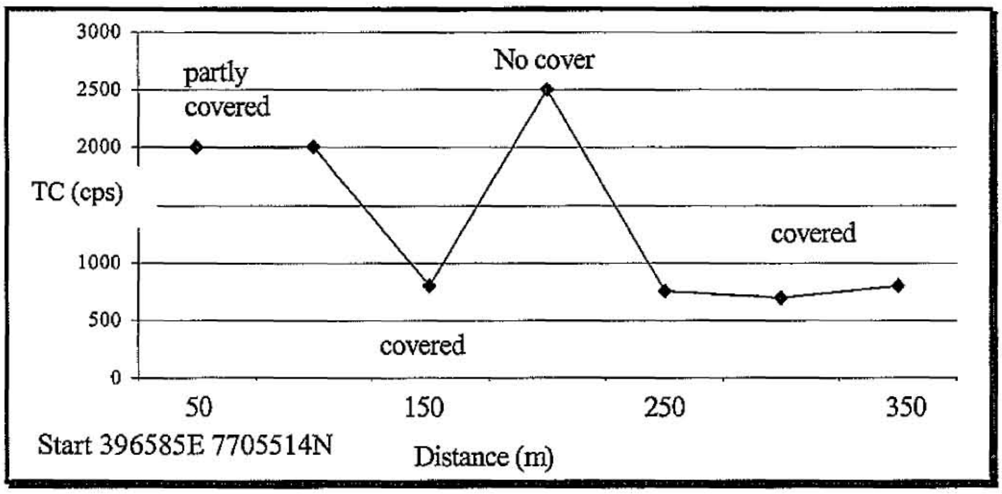


Figure 3.7. Radiometric data for the South Tip. *Traverse 1*



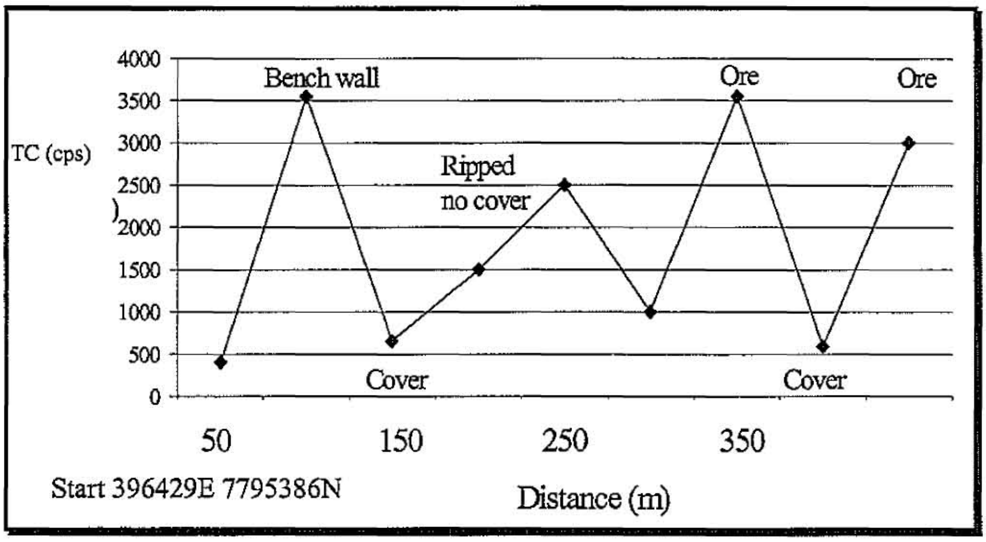
Traverse one across the South Waste Dump starts over exposed waste rock, continues to soil covered areas with established vegetation and ends on exposed waste rock. Maximum total count (800 cps) values were recorded on exposed waste rock and minimum (300 cps) values on vegetated surfaces.

Figure 3.8a. Radiometric data for the West Tip. *Traverse 2*



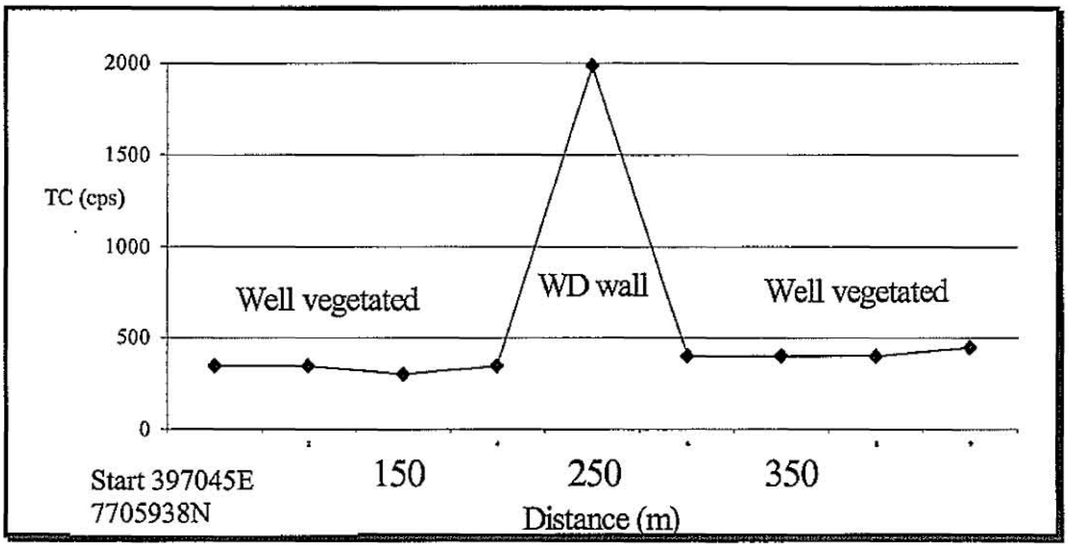
The survey of the West Tip top surface (bearing 250°) started on partially soil covered waste rock, continued across exposed and soil covered waste rock areas. Maximum total count (2500 cps) values were recorded on exposed waste rock and minimum (750 cps) values on soil topped surfaces.

Figure 3.8b. Radiometric data for the West Tip. *Traverse 3*



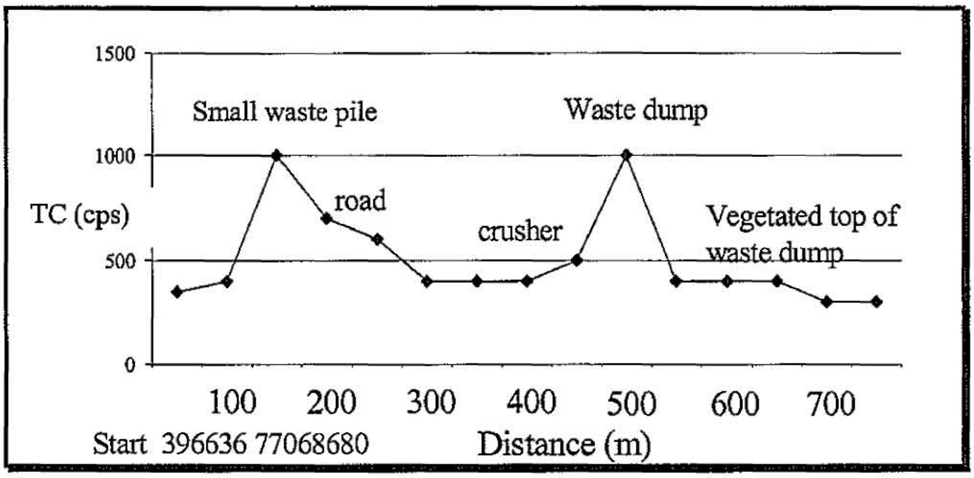
Traverse 3 is also across the West Tip (bearing 35°). It started on soil covered waste rock, continued to the bench wall (made of waste rock) and traversed across exposed and non exposed waste rock areas. Maximum total count (3550 cps) readings were recorded on exposed rock boulders, these high readings indicate that these rocks contain uranium ore. Minimum readings (400 cps) were measured on soil topped surfaces.

Figure 3.9a. Radiometric data for the Crusher pile. *Traverse 4*



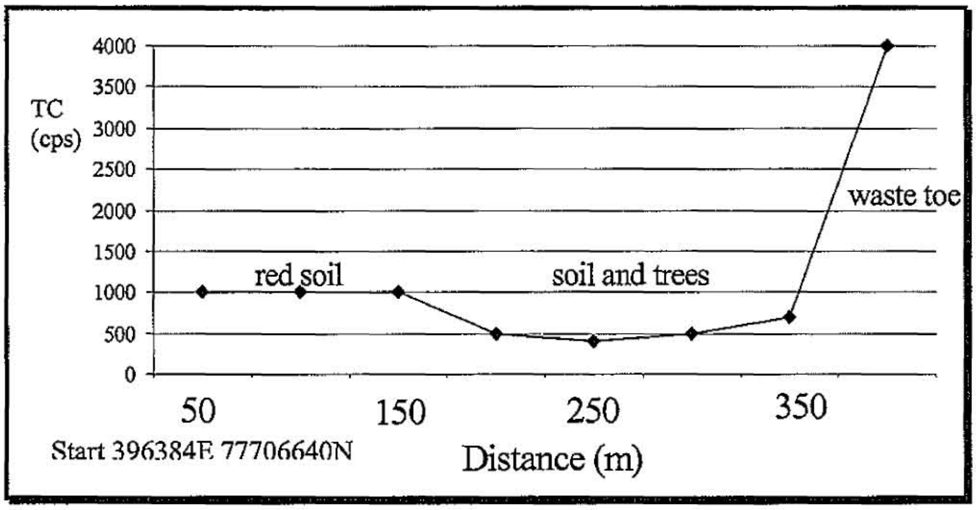
Starting on the concrete foundation (Bearing 0°) near the base of the Crusher pile, the survey traversed the waste rock wall and continued to another well vegetated area. A maximum total count (2000 cps) reading was recorded on the bench wall, and minimum readings (300 cps) were measured on areas away from waste rock piles.

Figure 3.9b. Radiometric data for the base of the Crusher pile. *Traverse 5*



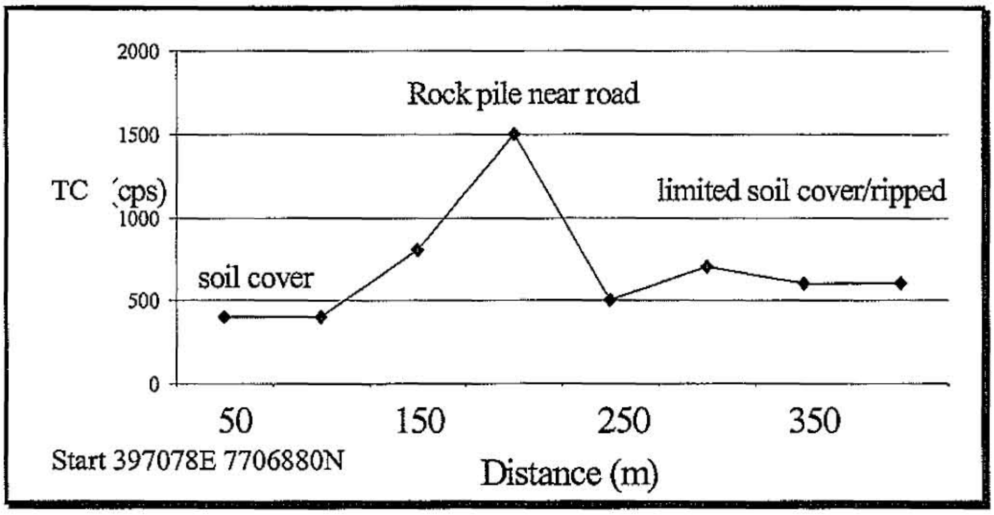
Traverse five started in the old processing area (bearing 180°), continued over the concrete foundation up the Crusher pile slope to the top of the dump. The maximum total count (1000 cps) reading was recorded on the waste rock pile slope, and minimum readings (300 cps) were measured on areas away from the waste rock pile and on the well vegetated top of the Crusher pile.

Figure 3.9c. Radiometric data for the processing area to the base of the Crusher pile. *Traverse 6*



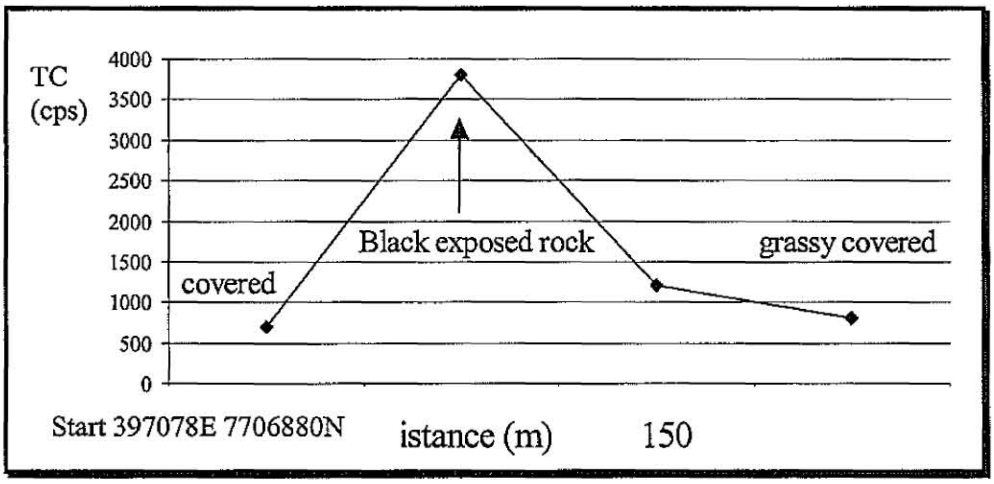
Starting below the Crusher pile around mill site (Bearing 80°) the survey headed toward the waste pile toe. Maximum total count (1000 cps) readings were recorded on the waste rock pile toe, and minimum readings (400 cps) were measured on areas away from the waste rock pile. The area noted as red soil (poorly vegetated) within the old mill/processing site had elevated readings (1000 cps) and corresponds to MKS10.

Figure 3.10a. Radiometric data for the North Waste Tip. *Traverse 7*



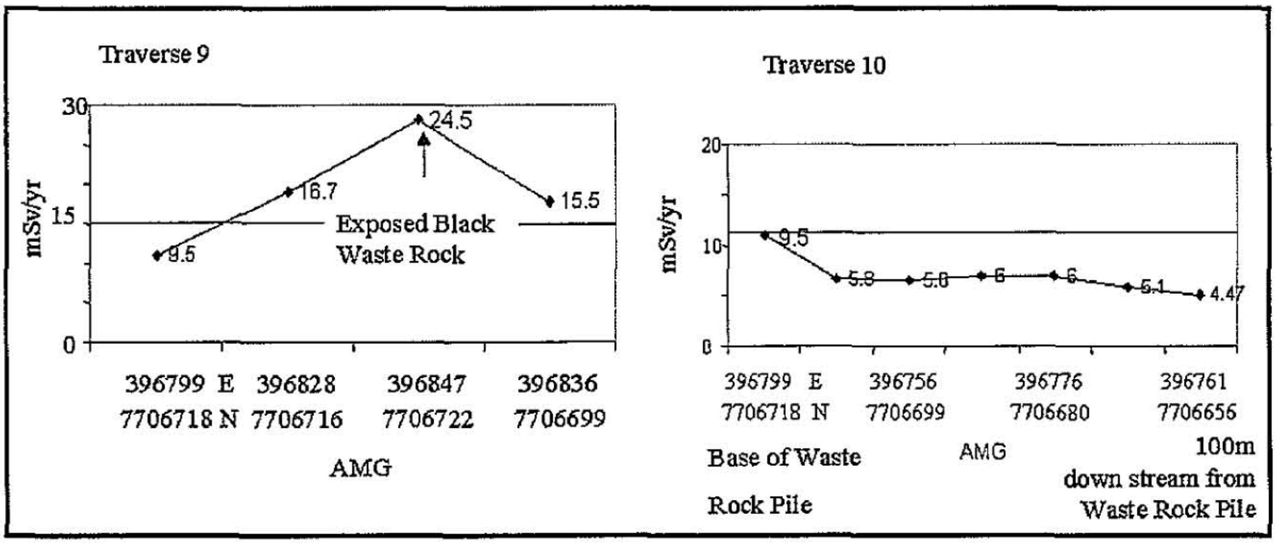
Traverse seven surveyed across the top of the North Waste Tip (bearing 10°). The maximum total count (1500 cps) reading was recorded on the waste rock pile toe, and minimum readings (400 cps) were measured on areas where waste rock is covered with soil. Soil cover that is ripped, provided less radiation dampening than full soil cover (total count 500 cps - 700 cps).

Figure 3.10b. Radiometric data for the North Waste Tip. *Traverse 8*



Traverse eight is also across the top of the North Waste Tip (bearing 100°). The maximum TC (3800 cps) reading was recorded on exposed ore and minimum readings (700 cps) were measured on areas where waste rock is thinly covered with ripped soil and sporadically grassed areas.

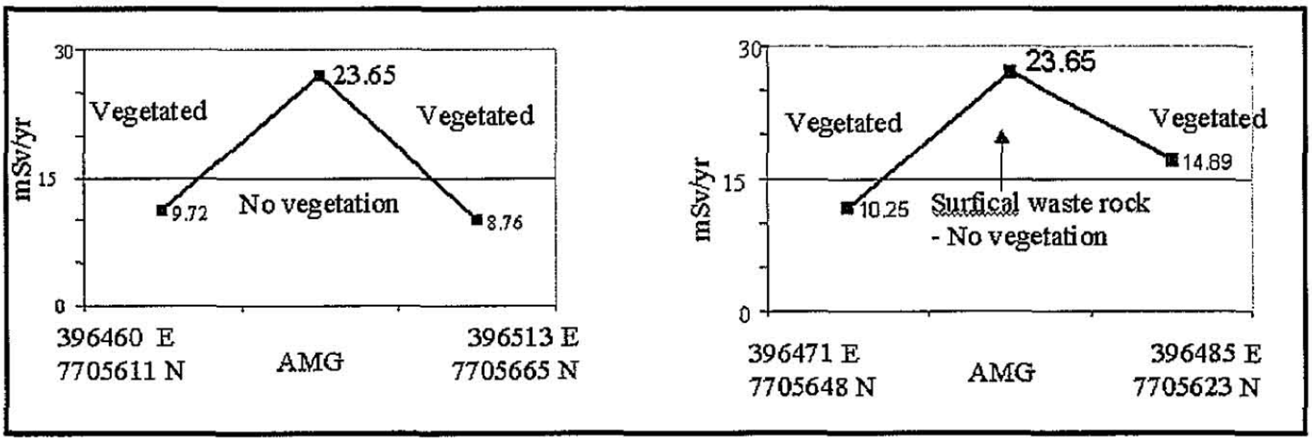
Figure 3.11. Crusher pile exposure rate data (mSv/yr).



Traverse 9 measured around the base of the Crusher pile with maximum radiation at (24.5 mSv/yr) where ore was exposed. Traverse 10 started at the base of the Crusher pile and followed the drainage channel away from the waste rock pile. Maximum radiation at (9.54 mSv/yr) was at the toe of the waste rock pile and decreased significantly away from the pile (to 4.47 mSv/yr).

Figure 3.12. West Tip exposure rate data (mSv/yr).

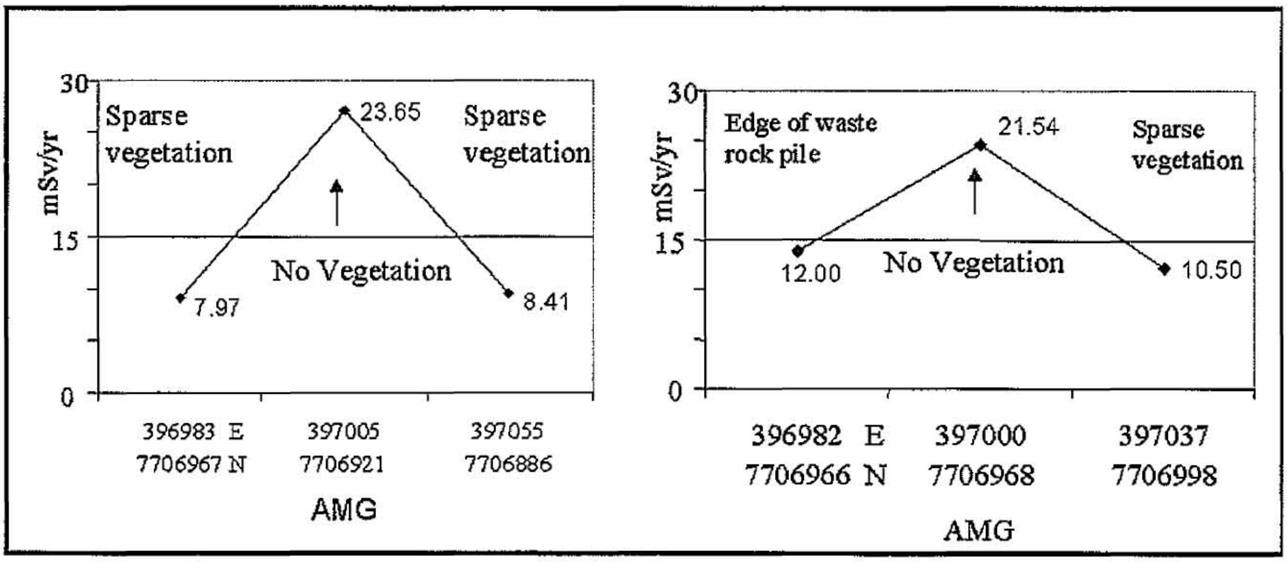
Traverse 11 and Traverse 12



Traverse eleven and twelve intersect on the West Tip at the maximum reading of 23.65 mSv/yr, which also corresponds to the area with no soil or vegetation cover.

Figure 3.13. D Stockpile exposure rate data (mSv/yr).

Traverse 13 and Traverse 14



Traverse thirteen and fourteen surveyed the top of the D Stockpile. Radiation maxima occur on exposed waste rock (23.65 mSv/yr and 21.54 mSv/yr) and minima where waste rock is covered by soil and sparsely vegetated areas.

Total Count (cps) readings were highest along traverse 3 on the West Waste Tip where readings reached 3500 cps on bare waste/ore rock. Exposure rates reached 25 mSv/yr on bare waste rock on the Crusher pile. Maximum exposure rate values (Table 3.9) on waste rock piles are similar to the maximum exposure rates surveyed in the open pit over known ore lenses. Clearly waste piles contain rocks with significant amounts of uranium ore.

Table 3.9. Maximum and minimum exposure rates (mSv/yr) on West Tip, Crusher, D Stockpile and open pit compared to background values.

Area	Maximum	Minimum
West Tip	23	8.76
Crusher	25	9.55
D Stockpile	23	7.97
Open Pit	25.4	8.41
Waste rock background*		4.5
Background (UNSCEAR 2000)		2.4

** recorded 100m from Crusher pile.*

3.5 Discussion

3.5.1 Surface processes

As discussed in Chapter two, the oxidation of pyrite and other sulphides and the dissolution of soluble iron sulphate minerals occurs within the open pit, due to the minerals present in the ore, and hence the same processes occur in the waste rock areas. Metals may also be leached from waste rocks when minerals dissolve as water moves though the waste rock pile.

Active weathering and erosion of waste material into the local drainage system is indicated by a five fold enrichment of Cu, Mn, S, Ce, La and U in stream sediments accumulating in topographic lows, below waste rock piles, compared to a background sample (MKSS7). Fine fraction (< 63 μm) stream sediment samples have the highest metal concentrations, either a) due to the large specific surface areas and the presence of metal-oxide coatings on mineral surfaces that tend to adsorb metals (Plumlee, 1999) and or b) erosion of metal rich fines from the waste dumps into the local drainage system.

At the former crusher site, contaminants (Cu, Mn, S, Ce, La, U) in stream sediments of waste rocks can also be attributed to inadequate removal of contaminated material during the rehabilitation phase and active erosion of stockpiles process chemicals (Mn, S).

It appears that the main reason for the lack of vegetation on waste rock pile areas is the lack of soil. Also, the release of acid due to the oxidation of sulphides may retard plant growth (Pulford et al., 1983; Dave et al., 1985). The biogeochemistry of *Cymbopogon bombycinus* (Silky oilgrass) (MKV28; Ce 1310 ppm, Cu 357 ppm, La 799 ppm, Mn 1040 ppm, U 226 ppm) implies that these elements are bioavailable in and around waste rock areas.

3.5.2 Soil and Stream sediment contamination assessment

Ecological investigation levels have been exceeded for As (>20 ppm), Cu (> 100 ppm), Mn (>500 ppm) and S (> 600 ppm) for soils collected within the waste rock area. Health investigation levels for 'standard residential' have been exceeded for Mn (>1500 ppm) in soil samples MKS9, MKS10, MKS11 and MKS12.

The interim sediment quality guidelines (ISQG) high trigger values have been exceeded for stream sediment samples MKSS1, MKSS2, MKSS3, MKSS4 and MKSS5 for Cu (>270 ppm) and Ni (>52 ppm). Low ISQG trigger values for the above mentioned elements and As (>20 ppm) and Zn (>200 ppm) have been exceeded.

3.5.3 Radioactivity and exposure assessment

Exposure rates and total count readings are highest on areas of exposed rock. High radiation levels (> 2500 cps) at numerous sites indicate that the rubble consists of a significant portion of uranium mineralised material. Gamma-radiation is consistently reduced to background levels (approx TC 400 cps or 2.4 mSv/yr) on waste rock piles with soil and vegetation cover. Stream sediment at the base of the Crusher pile emitted the highest TC (1500 cps) for stream sediment samples at the mine site. A thick cover of benign waste does reduce gamma-radiation emissions to background levels by attenuating radiation emissions and encouraging vegetation which further reduces radiation levels.

3.6 Suggested rehabilitation of waste rock piles

Practices to reduce physical and chemical mobilisation of contaminants from waste rock dumps include covering the surface with a low permeability benign soil layer to reduce oxygen circulation and water infiltration. Such a cover prevents the infiltration of water making contact with waste material. It also promotes vegetation growth on piles and enhances evaporation therefore reducing the amount of infiltrating water (Fernandes et al., 1998).

Rock from Mary Kathleen waste piles should not be used for road base or land-fill construction due to radiation levels and high levels of Ce, La, Mn, and U. Waste rock should remain in current heaps until such time reprocessing of uranium or extraction of REEs or other elements become economic options. Signs warning people not to climb on piles could be erected, preventing injury due to falls.

3.7 Summary

Waste rocks have the same mineralogy as pit wall samples (i.e. garnet, clinopyroxene, allanite, chlorite, calcite, pyrite, etc). The waste rock pile geochemistry is similar to pit wall geochemistry with high levels of Ce, Cu, La, Mn and locally ore grade levels of U (up to 927 ppm). Sulphide oxidation and acid mine drainage has minimal impact in and around waste rock areas at this point in time.

Elevated levels of uranium in stream sediments and soils indicate uranium and other trace elements (e.g. Ce, La, Mn, S, Zn) are being transported from waste rock piles into the local drainage system. Soil and stream sediments within the waste rock areas at Mary Kathleen contain high levels of Ce, Cu, La, Mn, S and U. The bioavailability of Ce, La, Mn, S, U and Zn is recognised within the waste rock area, as elevated levels exist in ashed plant samples.

Radiation levels on exposed waste rock pile surfaces are at the same level as ore in the open pit (24 mSv/yr) and are reduced significantly by a thin cover of soil to background levels (2.4 mSv/yr or 400 cps).