APPENDIX I Experimentation Documentary – Equipment and Procedure

A1.1 Sample Generation Documentary

A documentary of the sample generation operations that follows presents the sample PCBs used, a pictorial flow of the comminution stages, PCB fines health hazard and PPE, and a capture of PCB -75 µm fines sample (as generated).

I. Representative PCBs

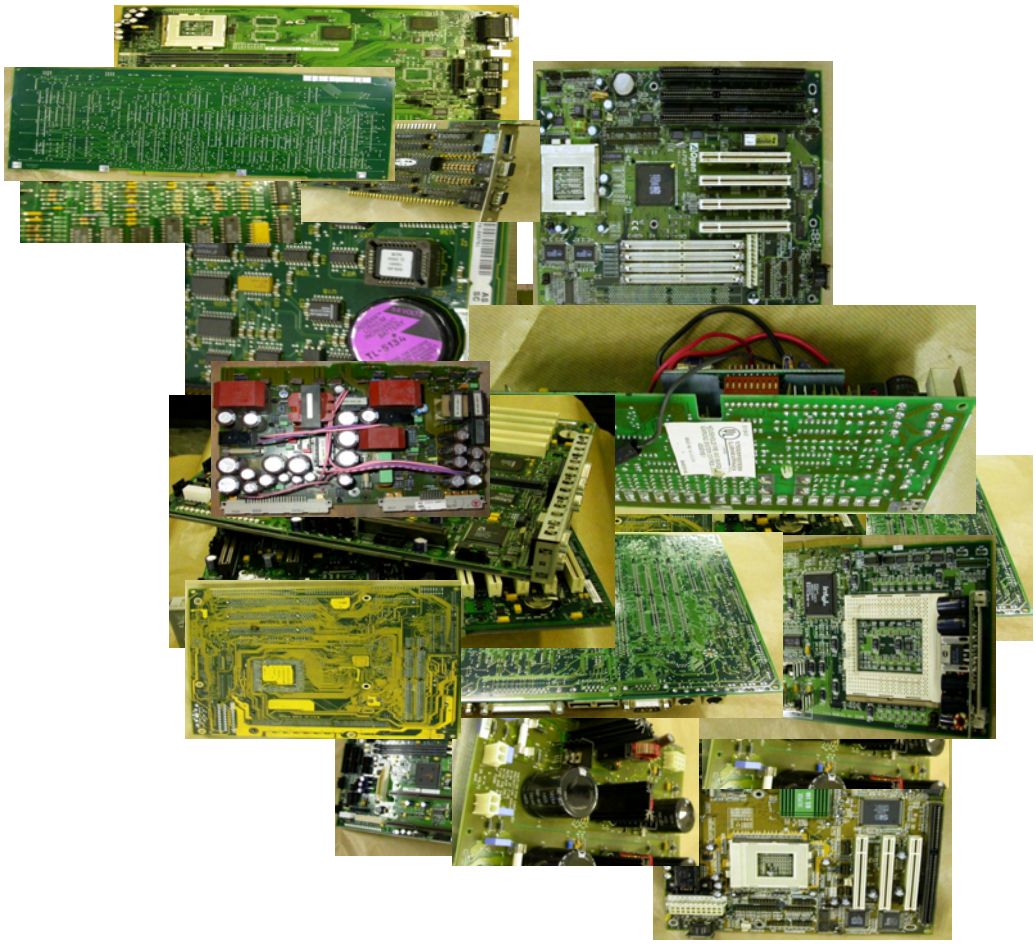


Figure A1.1: Representative PCB samples.

II. Comminution Stages

Pictorial summary of the comminution stages is shown in Figure A1.2

Figure A1.2: Pictorial flow of the comminution stages:

Hazardous components first removed from the boards; boards guillotined into fragments; closed hammer mill fine crushing; liberated metallic pieces separated from beaten bare boards; final closed hammer mill grinding of bare boards in stages and the final -75 µm fraction screened from the last −2 mm grinding.

III. PCB Fines Health Hazards and PPE

Health hazards associated with PCB comminution derive mostly from glass fiber particles. Inhaling or ingestion of various types of particles from PCB constituents is a general occupational hazard for comminution operation. Particles containing hazardous constituents and elements (such as mercury, polyvinyl chloride, cadmium, cobalt, lead, arsenic, selenium, brominated flame retardants, antimony trioxide flame retardant, etc.) can be air-borne and be ingested or inhaled. Possible effects of these constituents in the human biosystem include: severe skin irritation, respiratory problems, insomnia, memory loss, high blood pressure, cognitive functional loss, psychomotor skill and spatial skill loss, disruption of the endocrine system, increase risk of cancer in the digestive and the lymph system and neurological disorders. The recommended PPE for exposure to glass fiber fines (CSAO, 2005) which cover respiratory and skin protection, were used during the comminution work (as shown in Figure A1.3).

Figure A1.3: Picture showing full PPE gear employed during hammer mill comminution of PCB. The gear includes: N95 respirator, eye shield, laboratory coat and trousers, disposable hooded outer overall, safety shoe and ankle length PVC gloves with fabric inner lining.

A1.2 Equipment for Flotation Investigation

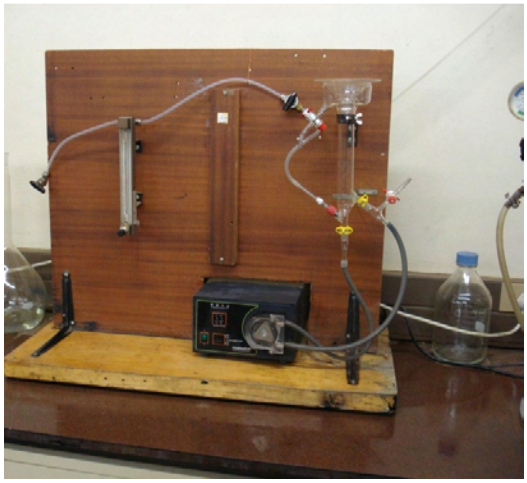


Figure A1.4: Cell used for the microflotation experiments

Figure A1.5: University of Cape Town Leeds flotation cell

Figure A1.6: Betachem Modified Bikerman froth stability test rig

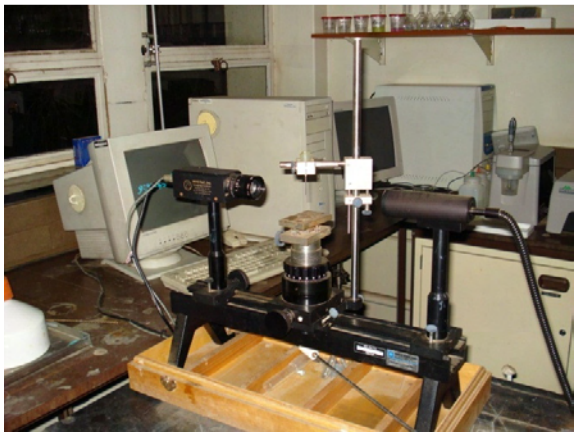


Figure A1.7: Goniometer stand

A1.3 Procedures

A1.3.1 Derivation of conversion factors for leach solution assay to actual sample assay

To ensure representative sampling, varying masses of sample were taken for digestion from different fractions; higher mass of sample from fractions with higher total mass. For every 50 g

mass of flotation fraction, a 2 g sample was taken for digestion. In small fractions, much lesser than 10 g, 1 g was taken.

Final leach solutions were always made up to 250 cm^3.

Given leach solution assay = y ppm = y mg/l:

→ y mg of the element is contained in one liter of such leach solution.

∴ 250 cm^3 contains y/4 mg, which is the total amount digested from the X g of sample.

∴ Actual assay, % = (y/4000x)*100

→ For x = 1 g, actual assay, % = y/40.

That is, y divided by a factor of 40 gives the assay in percentage.

For X =1, 2, 4, and 6, the factors follow as 40, 80, 160 and 240 respectively. For E12A, for instance, all the float fractions were between 10 – 50 g, hence 2 g samples were taken for digestion. The sink masses were between 100 and 150, and 6 g sample was taken. The conversion factor for the leach solutions for all the float fractions from E12A will therefore be 80, while for the sinks it will be 240, as in Table A3.2.

A1.3.2 Water Recovery Data and Collection Procedure

Water recovery in batch flotation can be determined as a fraction of the total water in the cell that is recovered into a float fraction (Zheng *et al.*, 2006). Data for this can be obtained by determining the amount water of added to the cell to replace the water recovered into the float fraction. A procedure considered more direct to determine water recovered into a fraction was used in the investigation by obtaining the mass difference between the wet float fraction and the sample recovered after drying. To do this, the following data were collected for each float fraction:

RW1 = Initial mass of bottle with rinse water

RW2 = Mass of bottle with rinse water after rinsing all the float fraction from the tip of the cell into the collection pan and from there into drying pan

RW = Mass of rinse water used = RW1 – RW2

A = Mass of all of wet float fraction, rinse water and drying pan

PS = Mass of pan and flotation fraction sample after drying

Hence:

Water Pull into a fraction (W_P, g) = A – PS – RW

With cell total water content regularly topped to approximately 3500 ml level for each fraction, then:

Water Recovery (W_{rec}, %) = W_P/35

This procedure is considered more accurate, as the actual amount of water recovered with the sample is used, compared to the assumption that the top-up water is the amount of water recovered into the sample. Topping-up exactly to a marked level under a heavily frothing pulp in a dynamic batch flotation may not be precisely done always. For example, it is easy to top-up to return the water level to 3490 ml total volume instead of 3500 ml, and the level will still be almost the same, given the relatively wide cross-sectional area of the cell. Assuming the actual drop was down to 3450 ml level, then recovered water will be determined as 40 ml instead of 50 ml, based on top-up water volume. Water recovery, in %, will then be computed as 40/35 instead of 50/35. Whereas, if the actual value of 50 ml is used, but the initial water volume is taken as 3500 ml instead of a possible 3490 ml (due to top-up error), the water recovery, in %, will be calculated as 50/35 instead of 50/34.9. The error in this latter approach is obviously quite minimal compared to the former.

APPENDIX 2: Results and Analysis – I

A2.1 Characterization

Table A2.1 Density values determination data

	Loose Bulk Density (g/cm^3)		Tapped Bulk Density (g/cm^3)		True Density (g/cm^3)	
	Constant Vol (ml).	Loose mass to fill (g)	Vol (cm^3) after tapping 200x	Tapped Density	Sample Mass (g)	Displaced Vol (cm^3)
Test I	100	53.33	57	0.94	20	7
Test II	100	54.88	58	0.95	20	7
Test III	100	53.98	57	0.95	30	10
Density	0.54 (δ_R = 1.4%)		0.94 (δ_R = 0.7%)		2.9 (δ_R = 2.3%)	

δ_R = relative standard deviation of the averaged data.

Table A2.2: PCB CF particle size distribution data

Sieve Aperture Diameter, µm	Cumulative Undersize, %	Rel. St. Dev., % (10 data)
75	98.6	0.4
53	85.1	0.9
38	66.7	1.6
0	0	0

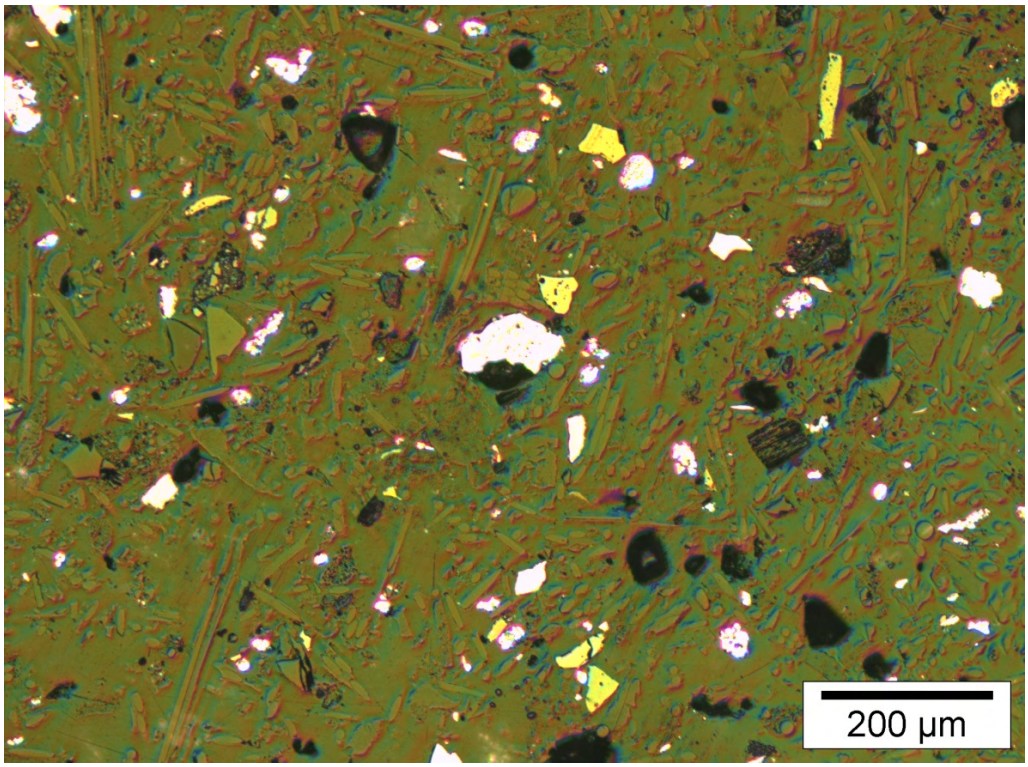


Figure A2.1: Optical micrograph of the binarised image of Figure 5.3 for circularity shape factor analysis of the metallic particles.

Table A2.3: ImageJ shape factor analysis data

#	Area	Circularity	Feret	%Area	FeretAngle	Solidity	#	Area	Circularity	Feret	%Area	FeretAngle	Solidity
1	18.18	0.87	6.64	100	149.04	0.89	59	851.62	0.52	56.55	100	77.78	0.88
2	181.49	0.86	17.55	100	144.25	0.93	60	225.65	0.37	27.62	100	21.8	0.65
3	376.3	0.7	29.73	100	167.83	0.87	61	48.05	0.71	10.1	100	16.39	0.84
4	23.7	0.66	7.94	100	21.04	0.8	62	687.66	0.5	45.52	100	124.29	0.84
5	79.87	0.69	15.34	100	164.93	0.9	63	104.87	0.44	21.66	100	153.43	0.8
6	1077.91	0.39	55.83	100	14.18	0.75	64	38.31	0.68	10.95	100	128.66	0.87
7	1380.18	0.24	99.56	100	84.75	0.79	65	28.25	0.58	11.06	100	11.89	0.89
8	84.74	0.5	15.04	100	155.38	0.79	66	21.75	0.5	10.27	100	33.69	0.75
9	86.69	0.59	15.4	100	51.01	0.82	67	31.82	0.7	9.28	100	100.62	0.87
10	569.8	0.51	37.47	100	61.88	0.76	68	53.9	0.89	9.95	100	156.37	0.91
11	371.75	0.47	35.54	100	131.1	0.79	69	121.43	0.73	14.81	100	112.62	0.89
12	124.67	0.44	17.99	100	169.05	0.73	70	36.04	0.84	8.7	100	148.39	0.9
13	28.57	0.6	8.68	100	23.2	0.76	71	110.71	0.54	21.45	100	106.99	0.86
14	1410.7	0.58	55.32	100	168.11	0.88	72	135.71	0.77	17.3	100	162.76	0.9
15	566.23	0.77	33.04	100	32.32	0.92	73	967.85	0.67	45.31	100	50.1	0.9
16	60.39	0.74	12.19	100	127.41	0.89	74	276.62	0.87	21.08	100	71.08	0.95
17	141.56	0.83	15.29	100	116.57	0.93	75	108.77	0.61	16.76	100	162.18	0.85
18	227.92	0.45	34.61	100	159.78	0.88	76	16.88	0.81	6.96	100	145.01	0.87
19	1257.13	0.79	45.54	100	58.3	0.95	77	80.19	0.65	13.01	100	28.81	0.82
20	173.05	0.74	18.86	100	25.02	0.9	78	614.61	0.25	64.16	100	19.72	0.69
21	75.32	0.69	15.04	100	142.7	0.9	79	60.39	0.7	11.75	100	22.83	0.83
22	119.48	0.6	18.66	100	77.66	0.84	80	18.18	0.59	7.92	100	59.74	0.77
23	212.34	0.61	20.65	100	65.56	0.85	81	102.92	0.48	18.86	100	154.98	0.81
24	110.06	0.91	13.54	100	157.75	0.95	82	168.51	0.74	18.39	100	73.81	0.89
25	46.43	0.61	12.8	100	147.72	0.81	83	173.7	0.81	18.24	100	14.47	0.93
26	390.58	0.3	54.78	100	18.81	0.76	84	938.63	0.66	52.53	100	49.4	0.92
27	251.95	0.66	25.95	100	70.77	0.9	85	45.45	0.82	10.75	100	122.01	0.92
28	295.45	0.34	32.39	100	39.29	0.72	86	113.64	0.75	16.84	100	23.96	0.89
29	167.53	0.87	16.94	100	109.65	0.94	87	24.03	0.84	7.43	100	147.53	0.89
30	36.36	0.67	9.74	100	20.56	0.82	88	157.47	0.78	18.87	100	118.89	0.92
31	896.75	0.6	50.97	100	174.23	0.83	89	272.73	0.7	23.05	100	81.47	0.86
32	237.66	0.68	21.08	100	108.92	0.88	90	78.25	0.72	14.29	100	23.5	0.88
33	281.17	0.73	26.35	100	21.57	0.92	91	312.98	0.57	29.3	100	13.5	0.86
34	20.45	0.61	9.01	100	108.43	0.85	92	190.58	0.52	23.42	100	18.43	0.84
35	289.93	0.83	24.47	100	12.09	0.94	93	827.59	0.35	43.93	100	9.71	0.78
36	33.12	0.73	9.97	100	30.96	0.86	94	299.35	0.61	28.03	100	153.43	0.85
37	20.13	0.43	9.7	100	49.76	0.6	95	90.26	0.78	13.7	100	135	0.87
38	31.17	0.46	11.75	100	104.04	0.76	96	84.41	0.82	12.09	100	171.87	0.91
39	56.49	0.74	13.01	100	151.19	0.88	97	992.52	0.68	42.98	100	96.09	0.89
40	1615.9	0.66	54.71	100	125.68	0.9	98	133.77	0.49	23.97	100	108	0.8
41	23.38	0.88	7.75	100	143.97	0.94	99	240.26	0.48	28.3	100	64.98	0.79
42	1233.43	0.48	55.73	100	127.1	0.83	100	250	0.7	24.51	100	162.41	0.89
43	256.17	0.44	35.99	100	156.68	0.82	101	653.89	0.55	43.62	100	23.89	0.82
44	544.8	0.49	38.7	100	76.37	0.84	102	38.64	0.78	9.97	100	30.96	0.87
45	600.64	0.45	35.57	100	58.09	0.8	103	48.38	0.63	12.5	100	24.23	0.85
46	101.3	0.63	14.7	100	125.54	0.83	104	112.99	0.6	19.9	100	113.63	0.83
47	40.58	0.79	9.69	100	151.93	0.89	105	175.32	0.77	17.67	100	159.23	0.89
48	770.12	0.25	61.75	100	48.37	0.69	106	1104.86	0.47	53.71	100	85.74	0.89
49	5467.49	0.46	125.01	100	3.4	0.82	107	168.51	0.83	19.15	100	120.38	0.94
50	375.65	0.33	33.79	100	174.19	0.67	108	55.19	0.69	12.99	100	15.26	0.92
51	28.57	0.8	8.06	100	8.13	0.88	109	14637.87	0.46	251.92	100	162.22	0.79
52	390.58	0.57	26.56	100	35.39	0.89	110	42.21	0.89	8.7	100	121.61	0.91
53	21.43	0.93	6.16	100	146.31	0.9	111	49.03	0.72	11.06	100	168.11	0.87
54	272.08	0.56	24.99	100	24.23	0.86	112	61.36	0.8	11.54	100	110.22	0.93
55	309.09	0.6	24.97	100	152.85	0.9	113	266.88	0.83	24.26	100	99.46	0.97
56	104.22	0.37	27.45	100	175.24	0.89	114	266.88	0.83	24.26	100	99.46	0.97
57	30.84	0.35	15.34	100	21.8	0.79	115	105.84	0.54	19.35	100	13.63	0.82
58	76.62	0.55	17.18	100	5.71	0.89	116	68.83	0.67	15.04	100	37.3	0.89

A2.2 NHR Froth and Mass Pull: Figures and Data

Figure A2.2: Natural hydrophobic froth build up under E21A condition in the first minute of aeration.

Figure A2.3: E21A at 30 minutes still showing froth loading

Figure A2.4: E21C at 28 min of flotation showing clean white unloaded froth
A 59 seconds movie clip showing this froth bursting readily as they are not longer loaded is here.

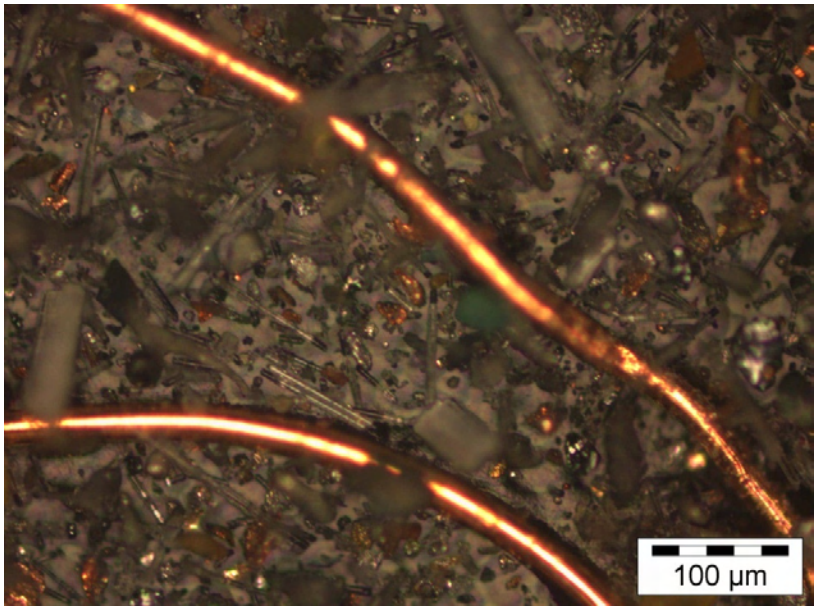


Figure A2.5: Optical micrograph of a PCB CF reverse flotation concentrate sample showing printed wiring board copper traces.

Table A2.4: Mass pull with time for flotation under the NHR scheme at varying kinetic conditions
(The experimental designations in Table 4.1 were given extra notations 1 and 2 representing duplicate investigations)

Experiment	Mass Pull (g)					CMP (g)	Sink (g)	CMP + Sink (g)
	1 min	4 min	10 min	18 min	30 min			
E11A	18.7	23.9	78.8	74.9	69.2	265.5	332.3	597.8
E21A1	11.7	24.9	47.1	43.7	35.6	163.0	135.4	298.4
E21A2	11.8	26.3	45.3	40.9	32.3	156.6	140.7	297.3
E21B1	24.1	67	90.3	35.2	6.8	223.4	76.4	299.8
E21B2	23.8	66.6	90.4	34.6	7.8	223.2	74.7	297.9
E21C1	32.2	105.3	90	14.6	1.6	243.7	55.7	299.4
E21C2	34.0	98.7	87.7	17.8	1.9	240.1	57.2	297.3
E22A1	18.9	36.3	56.9	42.8	27.5	182.4	116.9	299.3
E22A2	17.1	33.8	55.7	40.8	26.8	174.2	124.7	298.9
E22B1	44.4	115.3	72.9	5.7	0	238.3	60.4	298.7
E22B2	43.0	102.1	77.8	9.5	0	232.4	65.6	298.0
E22C1	79.3	145.5	34.1	0	0	258.9	40.7	299.6
E22C2	75.7	141.6	37.8	0	0	255.1	44.0	299.1

Table A2.5a: Cumulative Mass Pull data, % (from normalized mass pull, with CMP + Sink as 100%)

Experiment	1 min	4 mins	10 mins	18 mins	30 mins
E11A	3.13	7.13	20.31	32.84	44.41
E21A1	3.92	12.27	28.05	42.69	54.62
E21A2	3.97	12.82	28.05	41.81	52.67
E21B1	8.04	30.39	60.51	72.25	74.52
E21B2	7.99	30.35	60.69	72.31	74.92
E21C1	10.75	45.93	75.99	80.86	81.40
E21C2	11.44	44.64	74.13	80.12	80.76
E22A1	6.31	18.44	37.45	51.75	60.94
E22A2	5.72	17.03	35.66	49.31	58.28
E22B1	14.86	53.47	77.87	79.78	79.78
E22B2	14.43	48.69	74.80	77.99	77.99
E22C1	26.47	75.03	86.42	86.42	86.42
E22C2	25.31	72.65	85.29	85.29	85.29

Table A2.5b: Averaged cumulative Mass Pull data, % (as plotted in Figure 6.4)

- from normalized mass pull (CMP + Sink = 100%)

Experiment	0 min	1 min	4 min	10 min	18 min	30 min
E11A	0	3.13	7.13	20.31	32.84	44.41
E21A	0	3.95	12.54	28.05	42.25	53.65
E21B	0	8.01	30.36	60.59	72.28	74.72
E21C	0	11.09	45.28	75.06	80.49	81.08
E22A	0	6.02	17.74	36.56	50.53	59.61
E22B	0	14.65	51.08	76.34	78.88	78.88
E22C	0	25.89	73.85	85.86	85.86	85.86

Table A2.5c: Standard error of the means for each data point in Table A2.5a.

- Data used for error bars in Figure 6.4.

Experiment	0 min	1 min	4 min	10 min	18 min	30 min
E21A	0	0.024	0.275	0.001	0.442	0.975
E21B	0	0.025	0.021	0.092	0.029	0.204
E21C	0	0.341	0.645	0.926	0.370	0.318
E22A	0	0.297	0.707	0.895	1.220	1.331
E22B	0	0.217	2.387	1.536	0.896	0.896
E22C	0	0.580	1.191	0.563	0.563	0.563

- Standard error of mean, ε, related to standard deviation, δ, and sample size, n, as

$$\varepsilon = {}^{\delta}/_{\sqrt{n}} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{A2.1}$$

Table A2.6: First order fitting data of the cumulative mass pull for the plot in Figure 6.5 (ln Rm/(Rm-R) at each time, t)

Experiment	0 min	1 min	4 min	10 min	18 min
E11A	0	0.07	0.17	0.61	1.34
E21A	0	0.08	0.27	0.74	1.55
E21B	0	0.11	0.52	1.67	3.42
E21C	0	0.15	0.82	2.60	4.93
E22A	0	0.11	0.35	0.95	1.88
E22B	0	0.21	1.04	3.43	-
E22C	0	0.36	1.97	-	-

- For E22B, E22C regimes the responses are fully defined with fewer points. The first order expression becomes undefined before 30 minutes elapsed, as R continues to be equal to Rm after mass pull has stabilized.

A2.3. NHR Digestion Residue Analysis

F1, F2, F3, F4 and F5 pertain to float fractions collected at 1, 4, 10, 18 and 30 minutes respectively.

Table A2.7: Fraction of float fractions digested in hot aqua regia, % (indicative of metallic assay)

Experiment	F1	F2	F3	F4	F5	SINK
E11A	4.80	9.85	14.03	13.44	11.40	25.65
E21A	16.07	11.56	9.00	9.70	10.06	22.50
E21B	15.74	12.45	11.36	12.83	11.37	38.26
E21C	17.96	14.80	15.55	17.06	17.34	42.20
E22A	16.61	13.24	12.74	12.46	12.45	30.57
E22B	16.27	14.17	14.29	13.48	0.00	37.99
E22C	16.32	12.18	15.39	0.00	0.00	43.11

From fraction digested multiplied by mass of each flotation fraction, distribution of total metallic contents expressed as percentage was computed for each fraction. This is indicative of recoveries to each fraction.

Table A2.8: Distribution of total metallic content, %

Experiment	F1	F2	F3	F4	F5	SINK
E11A	0.77	2.00	9.41	8.57	6.71	72.54
E21A	3.95	6.22	8.74	8.62	7.19	65.28
E21B	6.73	13.69	18.36	8.02	1.49	51.73
E21C	9.62	24.46	22.38	4.47	0.49	38.58
E22A	4.96	7.69	11.89	8.64	5.60	61.22
E22B	12.21	26.44	18.49	1.75	0.00	41.11
E22C	23.46	32.42	10.26	0.00	0.00	33.86

Table A2.9: Digestion residue analysis data indicative of sink assay and recovery, with sink's mass percentage of feed, as plotted in Figure 6.6.

	Assay, %	Recovery,%	Conc Mass %
E11A	25.65	72.54	55.38
E21A	22.50	65.28	46.02
E21B	38.26	51.73	25.18
E21C	42.20	38.58	18.82
E22A	30.57	61.22	40.27
E22B	37.99	41.11	21.00
E22C	43.11	33.86	14.12

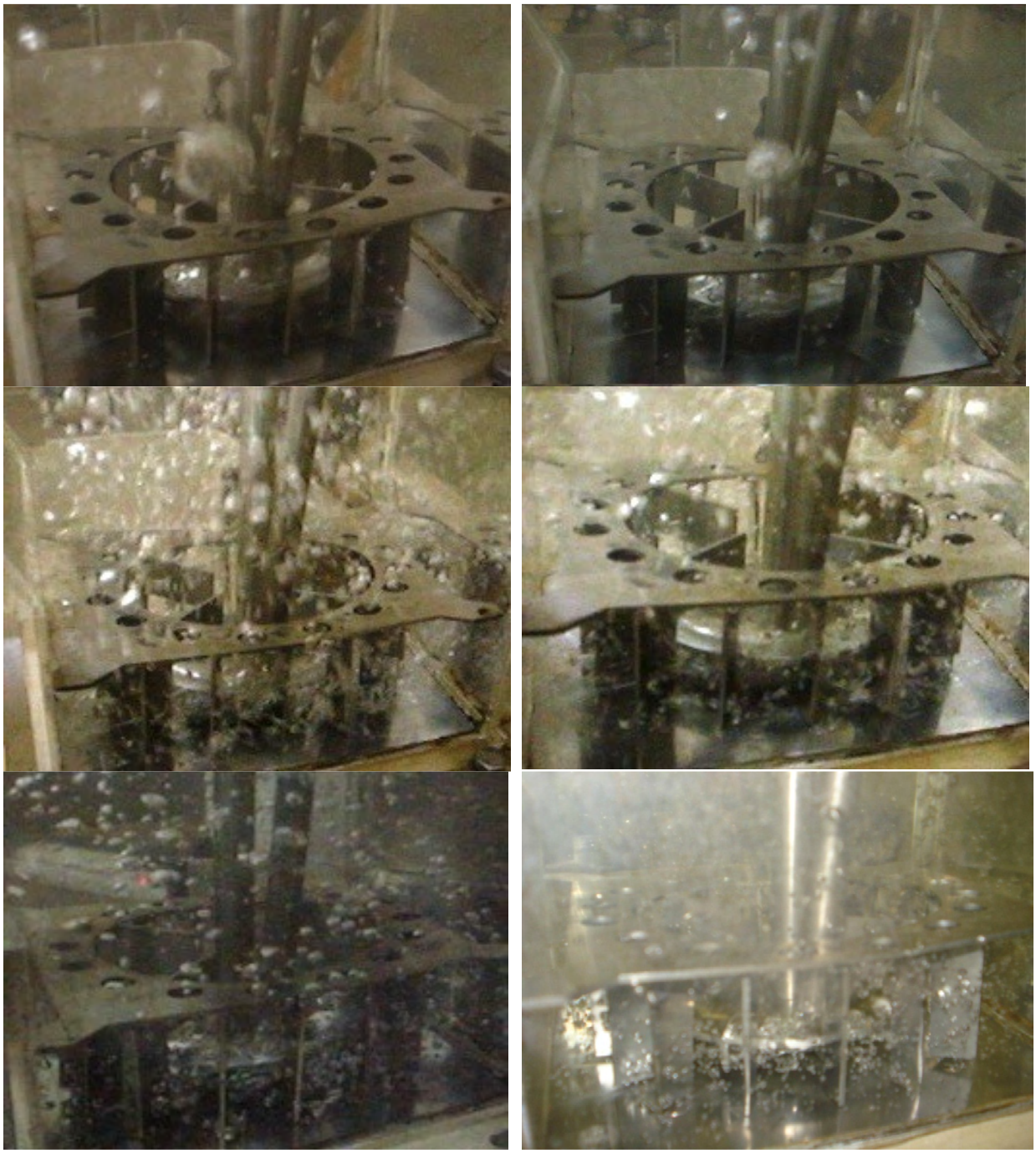
- Assay and Recovery extracted from Tables A2.7 and A2.8.
- Concentrate mass % is percentage of feed left in the final sink; percentage complement of cumulative mass pull after 30 mins in Table A2.5b.

A2.4 NHR ICPOES: Data and Analysis

See Appendix 3.

A2.5 Indication of bubble sizes at various kinetic regimes

a. d.



c. f.

Figure A2.6: Frozen frames showing variation of bubble sizes with impeller speed and aeration rate at: 1000 mlpm aeration and (a) 300 rpm (b) 400 rpm, (c) 500 rpm; and at 500 mlpm aeration and (d) 300 rpm, (e) 400 rpm, (f) 500 rpm.

A2.6 Estimation of Sb and Jg under E21C and E22B kinetic regimes

S_b bubble surface area flux is related to J_g, superficial surface area velocy and d_b, diameter of gas bubble in a flotation system as

$$S_b = 6J_g/d_b$$

while,

$$J_g = Q/A$$

where Q is the aeration rate, and A is the cell cross-section area.

By doubling Q (from 500 mlpm to 1000 mlpm) at constant A, Jg doubles in moving from E21C regime to E22B. That is,

$$J_{g\ E22B} / J_{g\ E21C} = (1000/A)/(500/A) = 2$$

An estimate of d_b follows from the operation of the impeller system. 8 stator bars breaks the air flow at the exist pipe per revolution to give the bubble sizes. Agitation speeds of 500 rpm and 400 rpm in E21C and E22B gives 4000 and 3200 stator breakages of air flow per minute in each regime respectively. All things beings equal, as a rough estimate, in E21C, 500 ml is broken into 4000 bubbles per minute. This gives 1/8 ml sized bubbles. Under E22B, 1000 ml air is broken into 3200 bubbles per minute, giving 5/16 ml sized bubbles. Estimate bubble size ratio under E22B to E21C therefore gives

$$d_{b\ E22B} / d_{b\ E21C} = (5/16) / (1/8) = 2.5$$

Estimating Sb with these parameter ratios

$$S_{b\ E21C} / S_{b\ E22B} = (6J_{g\ E21C} / d_{b\ E21C}) / (6J_{g\ E22B} / d_{b\ E22B})$$
$$= (J_{g\ E21C} / J_{g\ E22B}) * (d_{b\ E22B}/d_{b\ E21C})$$
$$= ½ * 2.5 = 1.25$$

A2.7 NHR Improvement

a. **b.**

Figure A2.7: Frozen frames showing bubble sizes at 300 rpm impeller speed and 500 aeration rate (a) before and (b) after modification of the Leeds cell impeller system.

Figure A2.8: NHR froth for the -75+38 µm size fraction. Low froth height is obvious compared to Figure A2.2

Table A2.10: Mass pull data after impeller modification – XNHR condition (Data for Table 6.4)

Mass Pull, g			
Experiment	18 min	30 min	48 min
XNHR1	62.3	15.8	8
XNHR2	58.7	18.4	8.8
XNHR3	63.9	16.3	6.5
Cumulative Mass Pull, %			
Experiment	18 min	30 min	48 min
XNHR1	41.6	52.1	57.5
XNHR2	39.3	51.6	57.5
XNHR3	42.9	53.8	58.1
Averaged Cumulative Mass Pull, % with standard errors of the mean			
XNHR	41.2	52.5	57.7
Standard Deviation	1.8	1.2	0.4
Standard Error of the means	1.1	0.7	0.2

Table A2.11: ICPOES scan assays of select elements in aqua regia leach solution of size classified PCB CF samples

Element	Assay, %	
	75-38 µm	-38 µm
Al	2.19	2.56
Ca	5.38	6.16
Cu	2.11	1.71
Fe	1.69	1.37
Mg	0.42	0.39
Mn	0.22	0.32
Ni	0.5	0.45
Zn	0.77	0.59

Table A2.12: Relative standard deviation (δ_R, %) of duplicate CMP data under varying reagent dosages for gamma depression.

Experiment	1 min	4min	10min	18min	30min
NHR	3.07	1.42	1.23	0.46	0.39
20 ppm	2.95	2.77	1.12	0.96	0.96
60 ppm	10.28	4.50	0.57	0.16	0.16
100 ppm	5.70	2.77	2.24	1.32	1.32
150 ppm	1.74	1.16	1.03	0.05	1.65

APPENDIX III Results and Analysis II – NHR ICPOES

Table A3.1: ICPOES raw assays (in ppm) of leach solution from flotation fractions of E21A1 and E21A2 (repeat) kinetic regimes

Fraction	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Pt	Si	Sn	Ti	V	Zn
E21A1 F1	5.4	283	0.8	614	179	243.0	16.7	9.3	124.0	0.55	<0.05	3.5	204.0	9.3	0.3	23.8
E21A1 F2	5.4	271	0.6	597	181	185.0	16.1	8.3	112.0	0.53	<0.05	2.9	182.0	7.7	0.2	24.0
E21A1 F3	5.1	274	0.6	596	179	154.0	16.2	7.8	101.0	0.51	<0.05	4.1	162.0	7.5	0.2	23.4
E21A1 F3	5.1	271	0.6	589	176	153.0	16.0	7.7	99.5	0.50	<0.05	4.0	162.0	7.4	0.2	23.1
E21A1 F4	5.1	278	0.6	608	180	135.0	16.2	7.6	94.8	0.49	<0.05	3.4	154.0	6.8	0.2	24.5
E21A1 F5	5.2	289	0.5	632	178	127.0	17.2	7.5	90.3	0.50	<0.05	3.3	145.0	7.0	0.2	24.7
E21A1 S	17.0	828	8.2	1570	1250	914.0	47.8	89.8	1010.0	6.93	0.1	9.1	1380.0	122.0	1.0	229.0
E21A2 F1	5.3	273	0.8	604	182	246.0	15.9	9.2	126.0	0.51	<0.05	3.5	207.0	8.8	0.3	23.8
E21A2 F2	5.5	275	0.7	603	187	203.0	16.3	8.7	117.0	0.50	<0.05	3.7	189.0	8.8	0.2	24.4
E21A2 F3	5.3	280	0.6	612	185	160.0	16.5	8.1	104.0	0.48	<0.05	2.5	169.0	8.1	0.2	24.0
E21A2 F4	5.0	296	0.6	642	180	137.0	17.6	7.6	94.9	0.45	<0.05	2.9	153.0	8.1	0.2	24.2
E21A2 F5	5.0	294	0.5	640	174	127.0	17.4	7.4	89.1	0.45	<0.05	3.9	143.0	7.6	0.2	24.0
E21A2 S	9.9	818	7.6	1560	1220	864.0	46.6	85.2	965.0	6.72	0.0	5.0	1330.0	111.0	0.9	220.0

A3.1 Sink Assay, Reconstituted Feed Assay and Enrichment Ratio

Table A3.2: Matrix of conversion factors for calculating actual assay for each flotation fraction in E21A1 and E21A2 (obtained as explained in Section A1.3.1).

Fraction	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Pt	Si	Sn	Ti	V	Zn
E21A1 F1	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 F2	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 F3	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 F3	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 F4	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 F5	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A1 S	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
E21A2 F1D	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A2 F2D	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A2 F3D	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A2 F4D	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A2 F5D	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
E21A2 SD	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240

Table A3.3: Calculated actual assay (%) for flotation fractions from E21A1 and E21A2 (Each factor in Table A3.1 divided by corresponding data in Table A3.2).

Fraction	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
E21A1 F1	0.0669	3.5375	0.0098	7.6750	2.2375	3.0375	0.2088	0.1163	1.5500	0.0068	0.0438	2.5500	0.1161	0.0033	0.2975
E21A1 F2	0.0680	3.3875	0.0080	7.4625	2.2625	2.3125	0.2013	0.1041	1.4000	0.0066	0.0356	2.2750	0.0959	0.0030	0.3000
E21A1 F3	0.0638	3.4063	0.0071	7.4063	2.2188	1.9188	0.2013	0.0963	1.2531	0.0063	0.0504	2.0250	0.0933	0.0028	0.2906
E21A1 F4	0.0641	3.4750	0.0069	7.6000	2.2500	1.6875	0.2025	0.0948	1.1850	0.0062	0.0428	1.9250	0.0851	0.0028	0.3063
E21A1 F5	0.0649	3.6125	0.0068	7.9000	2.2250	1.5875	0.2150	0.0935	1.1288	0.0062	0.0414	1.8125	0.0875	0.0029	0.3088
E21A1 S	0.0708	3.4500	0.0342	6.5417	5.2083	3.8083	0.1992	0.3742	4.2083	0.0289	0.0379	5.7500	0.5083	0.0041	0.9542
E21A2 F1	0.0661	3.4125	0.0094	7.5500	2.2750	3.0750	0.1988	0.1146	1.5750	0.0064	0.0431	2.5875	0.1095	0.0032	0.2975
E21A2 F2	0.0688	3.4375	0.0082	7.5375	2.3375	2.5375	0.2038	0.1084	1.4625	0.0062	0.0461	2.3625	0.1105	0.0031	0.3050
E21A2 F3	0.0668	3.5000	0.0078	7.6500	2.3125	2.0000	0.2063	0.1009	1.3000	0.0060	0.0313	2.1125	0.1016	0.0029	0.3000
E21A2 F4	0.0629	3.7000	0.0069	8.0250	2.2500	1.7125	0.2200	0.0954	1.1863	0.0056	0.0365	1.9125	0.1010	0.0029	0.3025
E21A2 F5	0.0619	3.6750	0.0068	8.0000	2.1750	1.5875	0.2175	0.0925	1.1138	0.0057	0.0489	1.7875	0.0951	0.0029	0.3000
E21A2 S	0.0411	3.4083	0.0316	6.5000	5.0833	3.6000	0.1942	0.3550	4.0208	0.0280	0.0208	5.5417	0.4625	0.0038	0.9167

Deportment of each element to each float fraction obtained by multiplying assay (%) in each fraction with mass of the fraction (g). With a factor of 1000, this gives the deportment in mg. For E21A, E21A1 and E21A2 rows in Table A3.3 operated on respective parts of the column data in Table A2.4 to give Table A3.4:

Table A3.4: Deportment of selected elements to each flotation fraction, mg

Fraction	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
E21A1 F1	7.8	413.9	1.1	898.0	261.8	355.4	24.4	13.6	181.4	0.8	5.1	298.4	13.6	0.4	34.8
E21A1 F2	16.9	843.5	2.0	1858.2	563.4	575.8	50.1	25.9	348.6	1.6	8.9	566.5	23.9	0.7	74.7
E21A1 F3	30.1	1604.3	3.4	3488.3	1045.0	903.7	94.8	45.4	590.2	3.0	23.8	953.8	43.9	1.3	136.9
E21A1 F4	28.0	1518.6	3.0	3321.2	983.3	737.4	88.5	41.4	517.8	2.7	18.7	841.2	37.2	1.2	133.8
E21A1 F5	23.1	1286.1	2.4	2812.4	792.1	565.2	76.5	33.3	401.8	2.2	14.7	645.3	31.2	1.0	109.9
E21A1 S	95.9	4671.3	46.3	8857.4	7052.1	5156.5	269.7	506.6	5698.1	39.1	51.3	7785.5	688.3	5.5	1291.9
E21A2 F1	7.8	402.7	1.1	890.9	268.5	362.9	23.5	13.5	185.9	0.8	5.1	305.3	12.9	0.4	35.1
E21A2 F2	18.1	904.1	2.1	1982.4	614.8	667.4	53.6	28.5	384.6	1.6	12.1	621.3	29.1	0.8	80.2
E21A2 F3	30.2	1585.5	3.5	3465.5	1047.6	906.0	93.4	45.7	588.9	2.7	14.2	957.0	46.0	1.3	135.9
E21A2 F4	25.7	1513.3	2.8	3282.2	920.2	700.4	90.0	39.0	485.2	2.3	14.9	782.2	41.3	1.2	123.7
E21A2 F5	20.0	1187.0	2.2	2584.0	702.5	512.8	70.3	29.9	359.7	1.8	15.8	577.4	30.7	0.9	96.9
E21A2 S	57.8	4795.5	44.4	9145.5	7152.3	5065.2	273.2	499.5	5657.3	39.4	29.3	7797.1	650.7	5.3	1289.8

The elemental assay of each batch feed was reconstituted as deportment to all fractions divided by total mass of all the fractions, multiplied by 10^6, to give the assay in ppm. Sink elemental assays was computed as average of the two repeats as in Table A3.3, converted to ppm. Enrichment ratio calculated as sink assay divided by feed assay. This is gives the data in Table A3.5 for E21A, which contains enrichment ratio data for E21A in Table 6.3.

Table A3.5: Sink and reconstituted feed assays (ppm) and enrichment ratio (ER) under E21A kinetic regime

	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
Sink	559.6	34291.7	329.0	65208.3	51458.3	37041.7	1966.7	3645.8	41145.8	284.4	293.5	56458.3	4854.2	39.3	9354.2
Feed	602.4	34542.9	190.8	70976.6	35672.4	27514.3	2013.2	2203.8	25665.9	163.4	356.4	36884.8	2748.0	33.7	5906.1
ER	0.93	0.99	1.72	0.92	1.44	1.35	0.98	1.65	1.60	1.74	0.82	1.53	1.77	1.17	1.58

A3.2 Recovery of elements to sink over time

Recovery in percentage of elements to sink over time was computed as the quotient of (i) deportment to all fractions for the specific element less deportment to float fractions up to corresponding time and (ii) total deportment to all fractions for the specific element. The result was express in percentage as in Table A3.6. Data for each replicates were averaged for each regime as in Table A2.8 for E21A, where the recovery at 30 minutes equals final recovery for E21A shown in Table 6.3.

Table A3.6: Recovery (%) of elements to sink over time for E21A1

Time, min	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1	96.12	96.00	98.04	95.77	97.55	95.72	95.96	97.96	97.66	98.39	95.82	97.31	98.38	96.20	98.05
4	87.73	87.84	94.63	87.02	92.29	88.77	87.66	94.07	93.15	95.05	88.57	92.20	95.53	88.97	93.86
10	72.84	72.32	88.87	70.59	82.52	77.88	71.97	87.26	85.52	89.03	69.17	83.60	90.29	75.92	86.17
18	58.96	57.63	83.67	54.95	73.33	68.99	57.32	81.04	78.83	83.58	53.91	76.02	85.85	63.87	78.66
30	47.52	45.19	79.53	41.71	65.92	62.17	44.65	76.05	73.64	79.12	41.88	70.20	82.13	53.83	72.50

Table A3.7: Recovery (%) of elements to sink over time E21A2

Time, min	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1	95.11	96.12	98.03	95.83	97.49	95.58	96.12	97.94	97.57	98.45	94.43	97.23	98.41	96.23	98.01
4	83.78	87.42	94.21	86.54	91.75	87.46	87.24	93.59	92.55	95.09	81.16	91.61	94.82	88.08	93.45
10	64.84	72.16	87.95	70.31	81.97	76.43	71.77	86.63	84.87	89.52	65.67	82.94	89.14	74.85	85.74
18	48.73	57.59	82.93	54.94	73.37	67.90	56.87	80.68	78.54	84.80	49.34	75.85	84.05	62.85	78.72
30	36.21	46.16	79.05	42.84	66.81	61.66	45.24	76.13	73.84	81.04	32.07	70.62	80.26	53.41	73.22

Table A3.8: Recovery (%) of elements to sink over time E21A (Average for E21A1 and E21A2)

Time, min	**Ag**	**Al**	**Au**	**Ca**	**Cu**	**Fe**	**Mg**	**Ni**	**Pb**	**Pd**	**Si**	**Sn**	**Ti**	**V**	**Zn**
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	96	96	98	96	98	96	96	98	98	98	95	97	98	96	98
4	86	88	94	87	92	88	87	94	93	95	85	92	95	89	94
10	69	72	88	70	82	77	72	87	85	89	67	83	90	75	86
18	54	58	83	55	73	68	57	81	79	84	52	76	85	63	79
30	42	46	79	42	66	62	45	76	74	80	37	70	81	54	73

A3.3 Assay of elements in sink over time

Assay of element in sink over time was computed as 10^6 x quotient of (i) total deportment in all fractions less deportment in all mass pull up to corresponding times and (ii) total mass of all fractions less mass pull up to corresponding times.

Table A3.9: Assay (ppm) of elements in sink over time for E21A1

Time, min	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
0	672.8	34458.8	194.1	70785.0	35658.7	27646.7	2013.4	2220.7	25793.1	164.7	408.1	36968.6	2793.4	34.0	5940.3
1	676.7	34613.7	199.1	70936.6	36399.8	27689.6	2021.6	2276.3	26357.1	169.6	409.2	37642.9	2875.6	34.2	6094.4
4	676.4	34684.0	210.5	70585.8	37709.9	28123.8	2022.5	2393.7	27532.4	179.4	414.2	39059.4	3057.9	34.7	6388.7
10	684.8	34820.3	241.1	69823.1	41115.2	30084.2	2024.7	2707.6	30823.3	204.9	394.5	43185.7	3524.1	36.1	7152.7
18	695.9	34838.3	285.0	68244.5	45872.4	33459.8	2024.6	3157.4	35672.0	241.5	386.0	49302.6	4207.2	38.1	8198.0
30	708.3	34500.0	342.1	65416.7	52083.3	38083.3	1991.7	3741.7	42083.3	288.8	378.8	57500.0	5083.3	40.5	9541.7

Table A3.10: Assay (ppm) of elements in sink over time for E21A2

Time, min	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Si	Sn	Ti	V	Zn
0	532.1	34627.0	187.4	71168.1	35686.0	27382.0	2013.0	2187.0	25538.7	162.0	304.7	36801.1	2702.6	33.4	5872.0
1	531.8	34975.2	193.0	71662.1	36558.1	27501.7	2033.1	2250.7	26184.8	167.6	302.3	37600.7	2794.6	33.7	6047.2
4	516.0	35036.1	204.3	71285.4	37895.8	27717.5	2032.6	2369.1	27357.8	178.3	286.2	39018.8	2966.1	34.0	6351.4
10	483.9	35043.7	231.1	70181.0	41024.0	29351.9	2026.3	2657.2	30398.5	203.5	280.6	42808.3	3379.0	35.0	7061.1
18	449.7	34581.2	269.5	67800.6	45403.3	32242.6	1985.2	3059.9	34780.7	238.3	260.7	48407.4	3939.1	36.4	8015.3
30	410.8	34083.3	315.8	65000.0	50833.3	36000.0	1941.7	3550.0	40208.3	280.0	208.3	55416.7	4625.0	38.0	9166.7

Table A3.11: Assay (ppm) of elements in sink over time for E21A (Average for E21A2 and E21A2)

Time	Ag	Al	Au	Ca	Cu	Fe	Mg	Ni	Pb	Pd	Pt	Si	Sn	Ti	V	Zn
0	602.4	34542.9	190.8	70976.6	35672.4	27514.3	2013.2	2203.8	25665.9	163.4	1.1	356.4	36884.8	2748.0	33.7	5906.1
1	604.3	34794.5	196.1	71299.4	36479.0	27595.7	2027.4	2263.5	26271.0	168.6	1.2	355.8	37621.8	2835.1	34.0	6070.8
4	596.2	34860.0	207.4	70935.6	37802.9	27920.6	2027.6	2381.4	27445.1	178.9	1.3	350.2	39039.1	3012.0	34.3	6370.1
10	584.3	34932.0	236.1	70002.1	41069.6	29718.0	2025.5	2682.4	30610.9	204.2	1.6	337.6	42997.0	3451.6	35.5	7106.9
18	572.8	34709.8	277.2	68022.6	45637.9	32851.2	2004.9	3108.6	35226.3	239.9	1.9	323.4	48855.0	4073.2	37.2	8106.7
30	559.6	34291.7	329.0	65208.3	51458.3	37041.7	1966.7	3645.8	41145.8	284.4	2.4	293.5	56458.3	4854.2	39.3	9354.2

A3.4 Enrichment Ratio versus Recovery to sink for each element over time

Computations such as in A3.1 – A3.3 done for each kinetic regime gave data for recoveries versus assays over time for the elements for each regime as shown in Table A3.12 below for Au.

Table A3.12: Sink's Au recovery (%) versus assay (ppm) over time for the various kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Au-Rec	Au-Assay	Au-Rec	Au-Assay	Au-Rec	Au-Assay	Au-Rec	Au-Assay	Au-Rec	Au-Assay	Au-Rec	Au-Assay
100	190.8	100	203.4	100	203.5	100	201.1	100	221.5	100	209.4
98	196.1	95	211.7	92	211.1	97	207.5	91	236.4	79	224.9
94	207.4	86	251.3	70	276.5	92	225.3	76	345.3	59	471.4
88	236.1	74	381.5	61	499.6	85	269.9	66	618.4	51	763.1
83	277.2	69	507.3	61	611.1	80	325.2	64	676.6	51	763.1
79	329.0	68	547.8	58	626.6	77	382.7	64	676.6	51	763.1

For uniformity of effect assessment, the assay scale was converted to enrichment ratios taking the assay at time zero as the feed assay of the batch sample used for each regime. For Au, this gives Table A3.13, which is the data for Figure 6.7.

Table A3.13: Enrichment ratio (ER) versus recovery (Rec, %) for Au in sinks under varying kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Au-Rec	Au-ER	Au-Rec	Au-ER	Au-Rec	Au-ER	Au-Rec	Au-ER	Au-Rec	Au-ER	Au-Rec	Au-ER
100	1	100	1	100	1	100	1	100	1	100	1
98	1.03	95	1.04	92	1.04	97	1.03	91	1.07	79	1.07
94	1.09	86	1.24	70	1.36	92	1.12	76	1.56	59	2.25
88	1.24	74	1.88	60	2.45	85	1.34	66	2.79	51	3.65
83	1.45	69	2.49	60	3.00	80	1.62	64	3.05	51	3.65
79	1.72	68	2.69	57	3.08	77	1.90	64	3.05	51	3.65

Data for other elements for the plots in Figure 6.8 – 6.13 extracted from the analysis for all the regimes are presented in Tables following.

Table A3.14: Enrichment ratio (ER) versus recovery (Rec, %) for Pd in sinks under varying kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Pd-Rec	Pd ER	Pd-Rec	Pd ER	Pd-Rec	Pd ER	Pd-Rec	Pd ER	Pd-Rec	Pd ER	Pd-Rec	Pd ER
100	1	100	1	100	1	100	1	100	1	100	1
98	1.03	96	1.05	94	1.06	97	1.04	92	1.08	85	1.15
95	1.09	85	1.23	67	1.36	92	1.13	72	1.49	54	2.06
89	1.25	70	1.79	55	2.22	85	1.35	59	2.51	46	3.23
84	1.47	65	2.35	53	2.67	80	1.62	58	2.76	46	3.23
80	1.74	64	2.53	52	2.74	77	1.91	58	2.76	46	3.23

Table A3.15: Enrichment ratio (ER) versus recovery (Rec, %) for Ti in sinks under varying kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Ti-Rec	Ti-ER	Ti-Rec	Ti-ER	Ti-Rec	Ti-ER	Ti-Rec	Ti-ER	Ti-Rec	Ti-ER	Ti-Rec	Ti-ER
100	1	100	1	100	1	100	1	100	1	100	1
98	1.03	97	1.06	95	1.08	97	1.04	94	1.10	88	1.19
95	1.10	88	1.27	77	1.50	93	1.14	79	1.63	68	2.59
90	1.26	77	1.96	69	2.78	87	1.37	68	2.92	61	4.31
85	1.48	73	2.63	68	3.43	82	1.67	67	3.21		
81	1.77	72	2.85	66	3.52	79	1.96				

Table A3.16: Enrichment ratio (ER) versus recovery (Rec, %) for Pb in sinks under varying kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Pb-Rec	Pb ER	Pb-Rec	Pb ER	Pb-Rec	Pb ER	Pb-Rec	Pb ER	Pb-Rec	Pb ER	Pb-Rec	Pb ER
100	1	100	1	100	1	100	1	100	1	100	1
98	1.02	95	1.03	92	1.04	96	1.02	88	1.04	78	1.06
93	1.07	80	1.16	61	1.26	89	1.08	63	1.30	43	1.63
85	1.19	63	1.60	48	1.95	79	1.24	48	2.04	34	2.40
79	1.37	57	2.05	47	2.31	72	1.46	46	2.20		
74	1.60	55	2.20	45	2.37	67	1.68				

Table A3.17: Enrichment ratio (ER) versus recovery (Rec, %) for Cu in sinks under varying kinetic regimes.

E21A		E21B		E21C		E22A		E22B		E22C	
Cu-Rec	Cu-ER	Cu-Rec	Cu-ER	Cu-Rec	Cu-ER	Cu-Rec	Cu-ER	Cu-Rec	Cu-ER	Cu-Rec	Cu-ER
100	1	100	1	100	1	100	1	100	1	100	1
98	1.02	95	1.03	92	1.04	96	1.03	89	1.05	80	1.09
92	1.06	79	1.14	57	1.24	88	1.08	62	1.27	42	1.59
82	1.15	57	1.45	43	1.75	76	1.20	42	1.80	31	2.21
73	1.28	49	1.77	40	2.00	67	1.36	41	1.93		
66	1.44	47	1.88	38	2.04	61	1.53				

Table A3.18: Enrichment ratio (ER) versus recovery (Rec, %) for Fe in sinks under varying kinetic regimes

E21A		E21B		E21C		E22A		E22B		E22C	
Fe-Rec	Fe-ER	Fe-Rec	Fe-ER	Fe-Rec	Fe-ER	Fe-Rec	Fe-ER	Fe-Rec	Fe-ER	Fe-Rec	Fe-ER
100	1	100	1	100	1	100	1	100	1	100	1
96	1.00	90	0.98	86	0.97	93	0.99	80	0.95	70	0.94
88	1.01	70	1.01	50	1.04	83	1.01	52	1.08	37	1.40
77	1.08	51	1.30	37	1.51	70	1.11	37	1.56	27	1.93
68	1.19	44	1.59	36	1.73	61	1.24	35	1.65		
62	1.35	42	1.69	33	1.76	56	1.38				

Table A3.19: Enrichment ratio (ER) versus recovery (Rec, %) for Ca in sinks under varying kinetic regimes

E21A		E21B		E21C		E22A		E22B		E22C	
Ca-Rec	Ca-ER	Ca-Rec	Ca-ER	Ca-Rec	Ca-ER	Ca-Rec	Ca-ER	Ca-Rec	Ca-ER	Ca-Rec	Ca-ER
100	1	100	1	100	1	100	1	100	1	100	1
96	1.00	92	1.00	88	1.00	94	1.00	85	1.00	73	0.99
87	1.00	68	0.99	37	0.96	81	0.99	47	0.96	23	0.89
70	0.99	35	0.89	20	0.79	61	0.97	18	0.77	10	0.67
55	0.96	22	0.78	14	0.68	46	0.92	15	0.72		
42	0.92	19	0.74	12	0.66	35	0.87				

APPENDIX IV Process Water and Particle Surface Investigations

Table A4.1: Trace element levels in PCB CF flotation process water (ppm)

Element	Background	Lab Water	PCB CF	Element	Background	Lab Water	PCB CF
Ag	<0.01	<0.01	<0.01	**Na**	<0.01	3.24	14.04
Al	<0.01	<0.01	0.65	**Nb**	<0.01	<0.01	<0.01
As	<0.01	<0.01	<0.01	**Nd**	<0.01	<0.01	<0.01
Au	<0.01	<0.01	<0.01	**Ni**	<0.01	<0.01	0.07
B	<0.01	0.07	0.69	**Os**	<0.01	<0.01	<0.01
Ba	<0.01	0.08	0.56	**P**	<0.8	0.01	0.06
Be	<0.01	<0.01	<0.01	**Pb**	<0.01	<0.01	0.29
Bi	<0.01	<0.01	<0.01	**Pd**	<0.01	<0.01	<0.01
Ca	<0.01	1.47	7.07	**Pr**	<0.01	<0.01	<0.01
Cd	<0.01	<0.01	<0.01	**Pt**	<0.01	<0.01	<0.01
Ce	<0.01	<0.01	<0.01	**Rb**	<0.01	<0.01	0.01
Co	<0.01	<0.01	0.01	**Re**	<0.01	<0.01	<0.01
Cr	<0.01	<0.01	0.01	**Ru**	<0.01	<0.01	<0.01
Cs	<0.01	<0.01	<0.01	**Sb**	<0.01	0.00	0.08
Cu	<0.01	<0.01	0.25	**Sc**	<0.01	<0.01	<0.01
Dy	<0.01	<0.01	<0.01	**Se**	<0.01	<0.01	<0.01
Er	<0.01	<0.01	<0.01	**Si**	<0.01	0.39	2.76
Eu	<0.01	<0.01	<0.01	**Sm**	<0.01	<0.01	<0.01
Fe	<0.01	0.01	0.53	**Sn**	<0.01	<0.01	0.16
Ga	<0.01	<0.01	<0.01	**Sr**	<0.01	0.01	0.05
Gd	<0.01	<0.01	<0.01	**Ta**	<0.01	<0.01	<0.01
Ge	<0.01	<0.01	<0.01	**Tb**	<0.01	<0.01	<0.01
Hf	<0.01	<0.01	<0.01	**Te**	<0.01	<0.01	<0.01
Hg	<0.01	<0.01	<0.01	**Th**	<0.01	<0.01	<0.01
Ho	<0.01	<0.01	<0.01	**Ti**	<0.01	<0.01	0.05
In	<0.01	<0.01	<0.01	**Tl**	<0.01	<0.01	<0.01
Ir	<0.01	<0.01	<0.01	**Tm**	<0.01	<0.01	<0.01
K	<0.01	0.78	6.84	**U**	<0.01	<0.01	<0.01
La	<0.01	<0.01	<0.01	**V**	<0.01	<0.01	<0.01
Li	<0.01	<0.01	0.09	**W**	<0.01	<0.01	<0.01
Lu	<0.01	<0.01	<0.01	**Y**	<0.01	<0.01	<0.01
Mg	<0.01	0.38	3.09	**Yb**	<0.01	<0.01	<0.01
Mn	<0.01	<0.01	0.09	**Zn**	<0.01	0.01	1.28
Mo	<0.01	<0.01	<0.01	**Zr**	<0.01	<0.01	0.01

Particles – P1

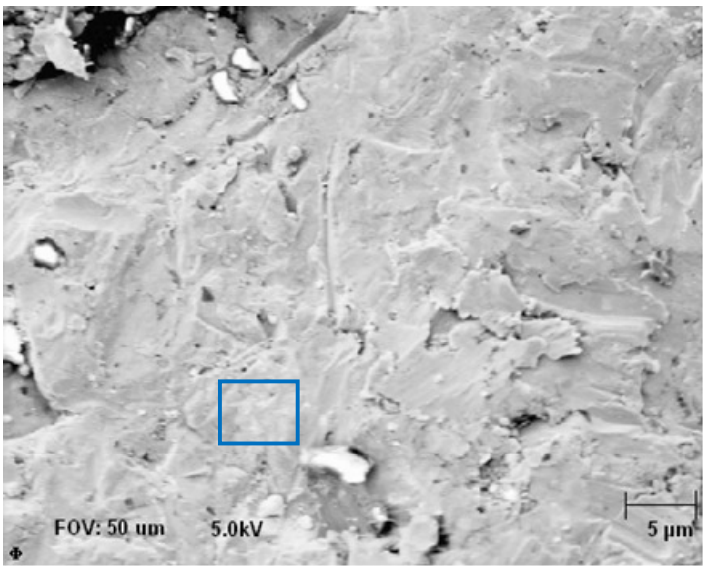


Figure A4.1: Secondary electron image on particle P1. Blue square indicates area of Auger electron spectroscopic analysis.

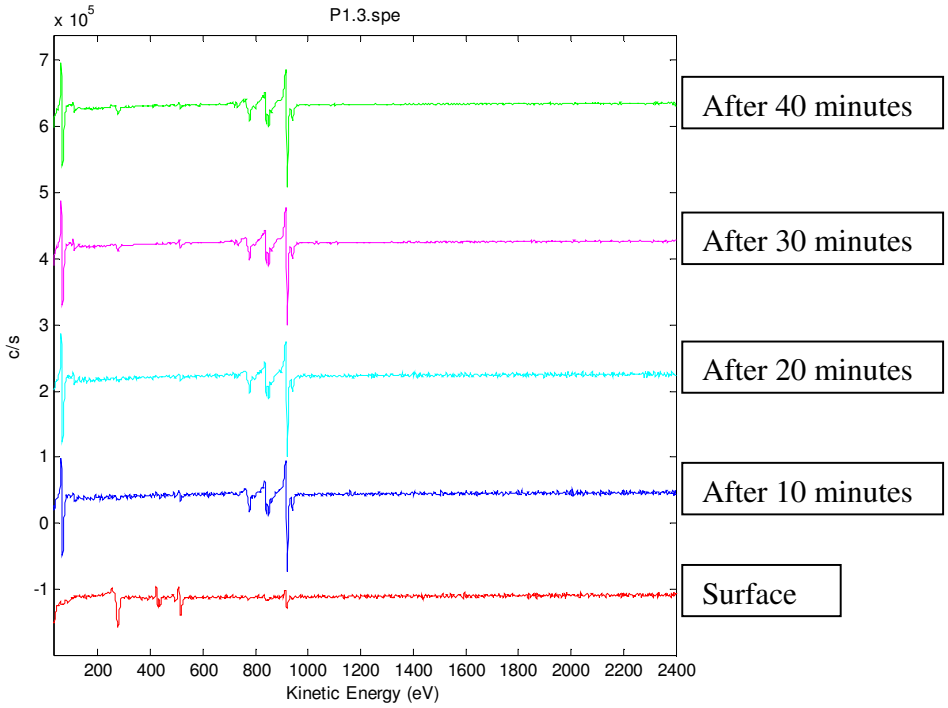


Figure A4.2: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of particle P1.

Particles – P2

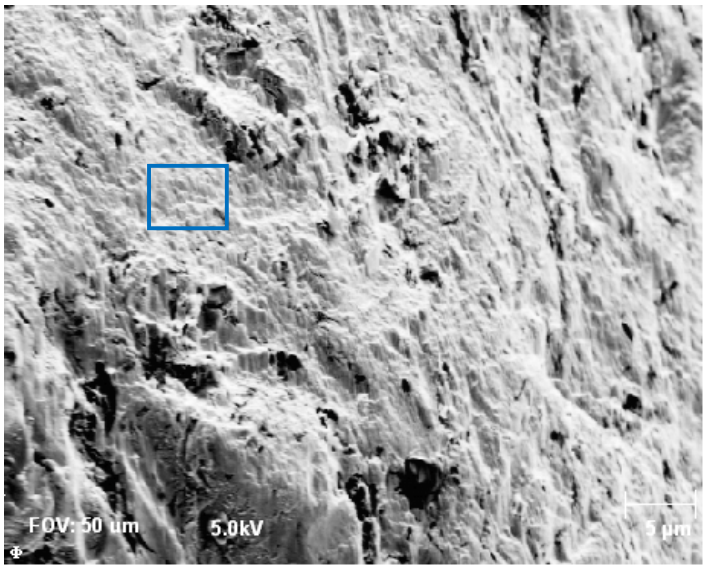


Figure A4.3: SEM secondary electron image on Particle P2 at 5 kV 10 nA primary beam current: Blue square indicates area of analysis.

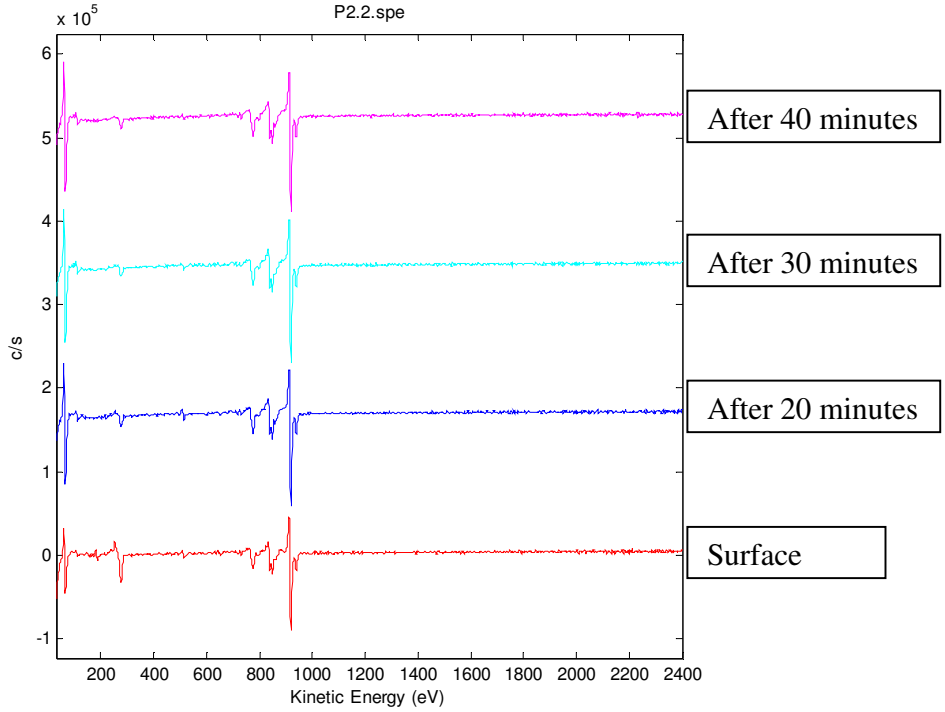


Figure A4.4: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of particle P2.

Fiber Particle – F2

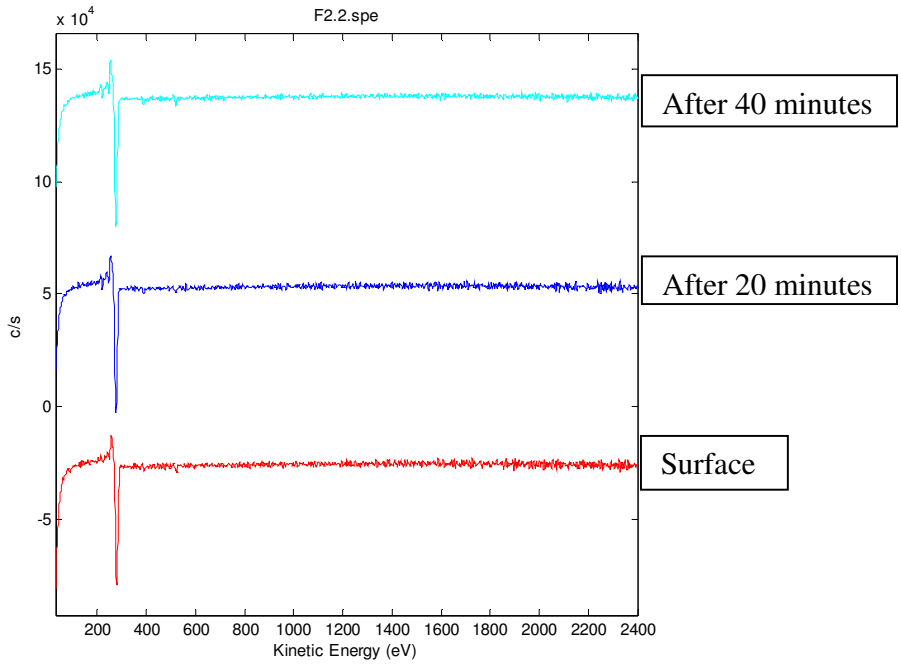


Figure A4.5: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of fiber particle F2.

Fibres Particle F3:

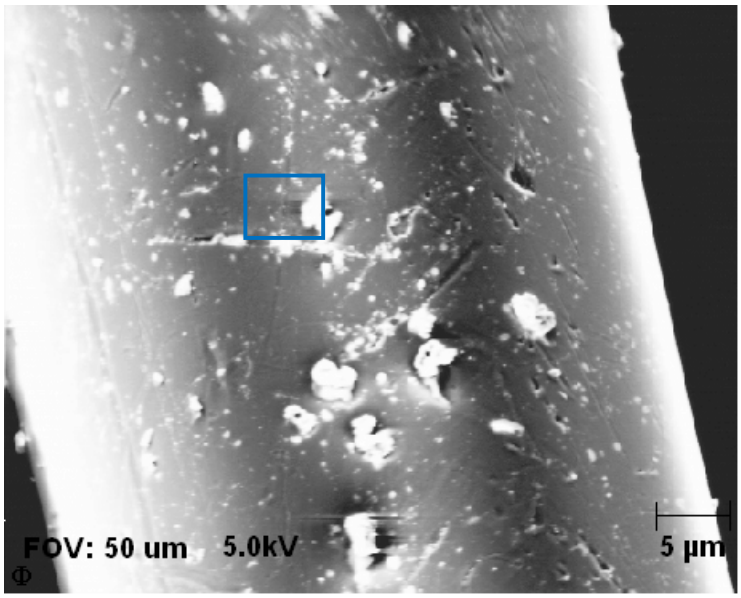


Figure A4.6: Secondary electron image on fiber particle F3 at 5 kV 10 nA primary beam current: Blue square indicates area of Auger electron spectroscopic analysis.

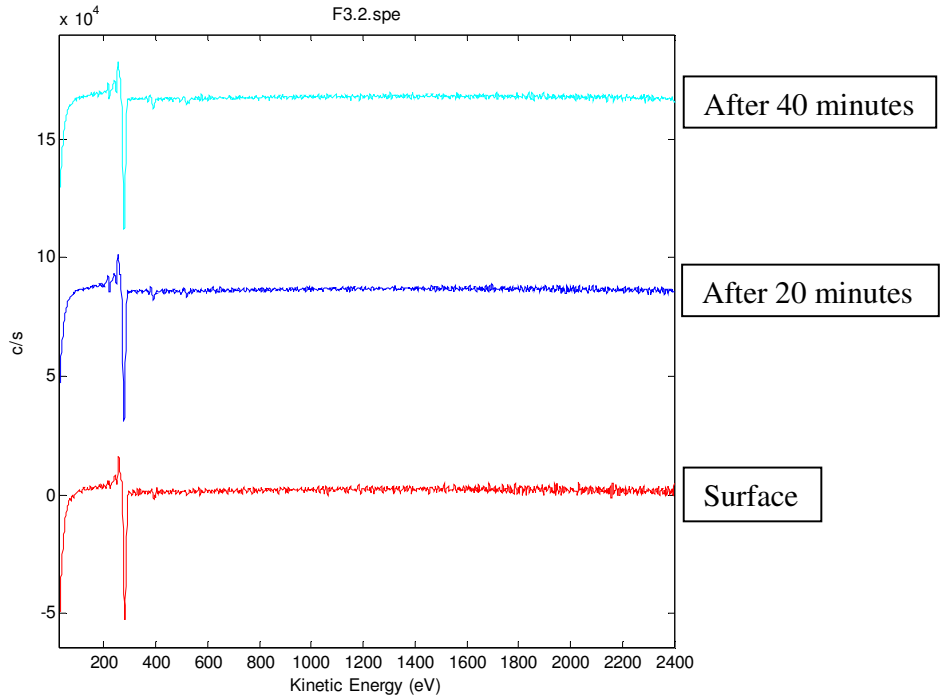


Figure A4. 7: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of fiber particle F3.

FIBER PARTICLE F4

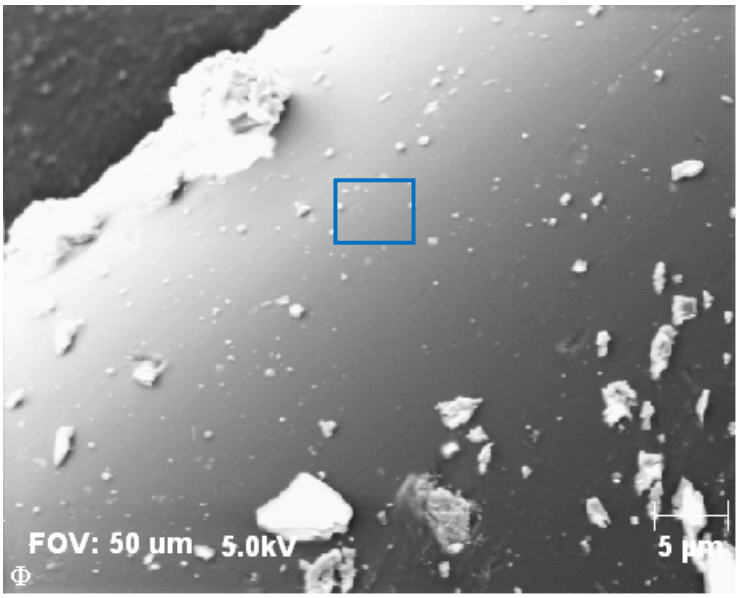


Figure A4.8: Secondary electron image on fiber particle F4. Blue square indicates area of Auger electron spectroscopic analysis.

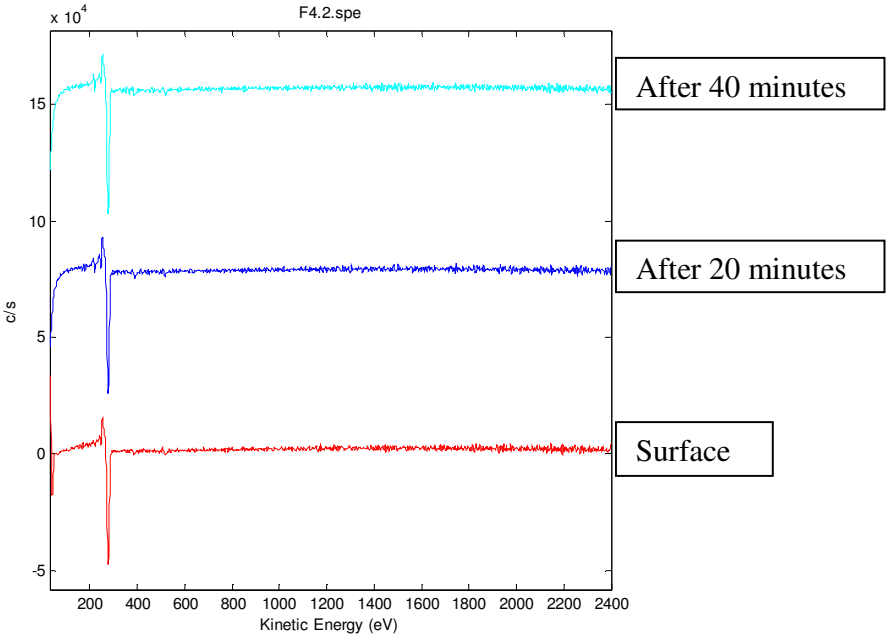


Figure A4.9: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of fiber particle F4.

Fiber Particle F5

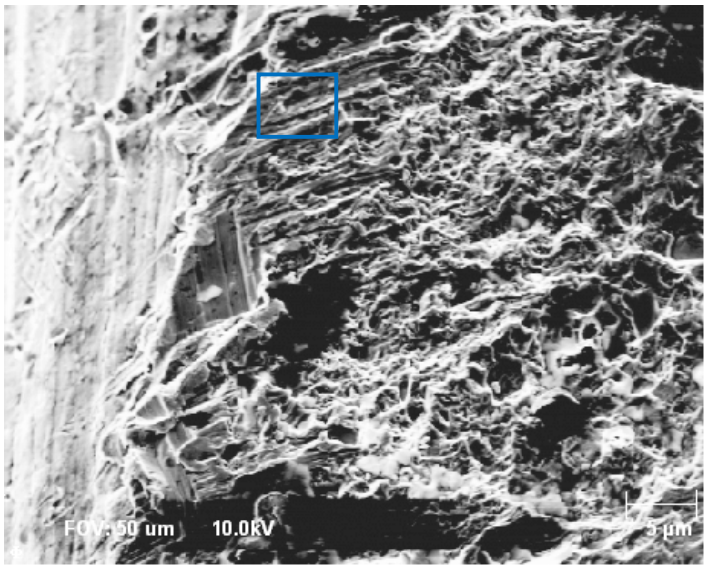


Figure A4.10: Secondary electron image on fiber particle F4. Blue square indicates area of Auger electron spectroscopic analysis.

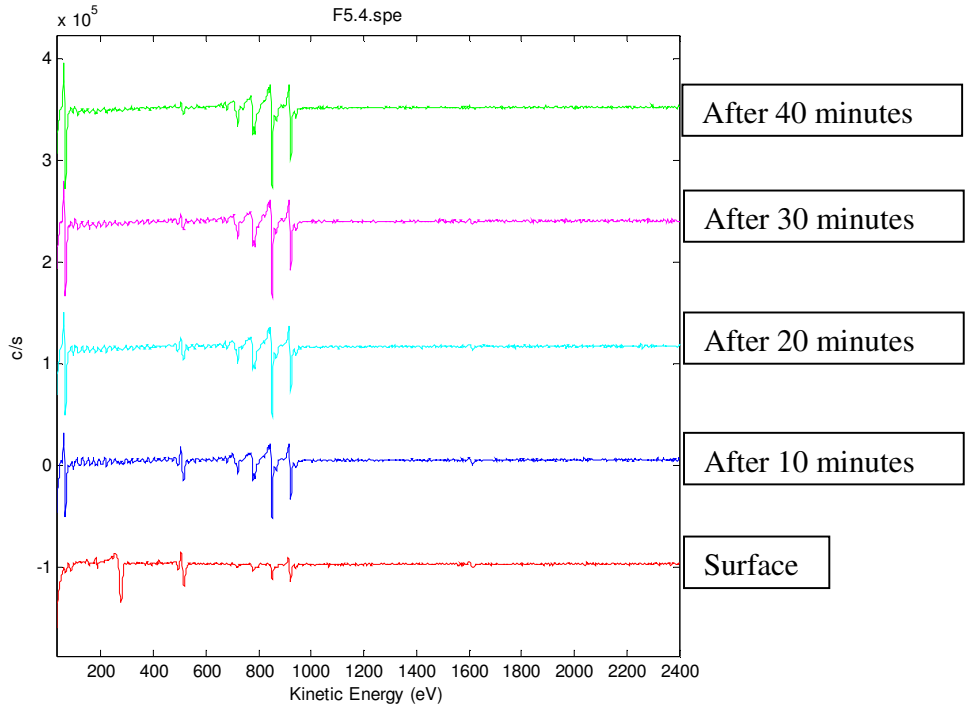


Figure A4.11: Comparison of AES survey spectra at various sputtering times on (indicative of depths from) the surface of fiber particle F5.

APPENDIX V PUBLICATIONS

1. Ogunniyi, I. O., Vermaak, M.K.G. and Groot, D. R., 2009. Chemical composition and liberation characterization of printed circuit board comminution fines for beneficiation investigations. *Waste Management,* Vol. 29, pp 2140 – 2146, 2009. http://dx.doi.org/10.1016/j.wasman.2009.03.004

2. Ogunniyi, I. O. and Vermaak, M.K.G., 2009. Froth flotation for beneficiation of printed circuit board comminution fines: an overview". *Minerals Processing and Extractive Metallurgy Review*, Vol. 30 (2), pp. 101 – 121. http://dx.doi.org/10.1080/08827500802333123

3. Ogunniyi, I. O. and Vermaak, M.K.G., 2009: "Application of froth flotation for beneficiation of printed circuit board comminution fines." *Mineral Engineering*, Vol. 22, pp. 378-385. http://dx.doi.org/10.1016/j.mineng.2008.10.007

4. Ogunniyi, I. O. & Vermaak, M. K. G., 2008: 'Froth flotation in e-waste processing'. *Mineral Processing 2008 (SAIMM), Aug. 7 & 8, Cape Town, South Africa, Book of Abstracts, pp OR 25.*

5. Ogunniyi, I. O. & Vermaak, M. K. G., 2007. 'Improving printed circuit board physical processing – An overview', *Proceedings of European Metallurgical Conference – EMC 2007, June 11 – 14, Dusseldorf, Germany, pp 1645 – 1656.*