

APPENDIX M8

CHARACTERISATION OF TAILINGS OF TSF SOIL – UPDATE 2005

ANGAS PROCESSING FACILITY

MISCELLANEOUS PURPOSES LICENSE APPLICATION

2019/0826



ABN | 67 062 576 238

Unit 7 / 202-208 Glen Osmond Road | Fullarton SA 5063



Job Reference No. 6411

TO: AUSTRALIAN TAILINGS CONSULTANTS PTY LTD
ATTENTION: Paul Williams
FROM: John Jeffery
DATE: 12 December 2005
SUBJECT: Angas Zinc Project - Characterisation of Tailings and TSF Soil - Update

This memorandum presents the results of the initial geochemical characterisation of soil and tailings samples from the Angas Zinc Project in South Australia. It updates a previous memorandum dated 8 November 2005 by the inclusion of multi-element data for the tailings solids and liquor, as well as initial leachate quality data from a column leach test being undertaken on the tailings solids.

1. Soils from Site of Proposed TSF

Sample Preparation and Testing

Five soil samples from the proposed site of the tailings storage facility (TSF) were provided for testing by EGi. Between 0.6 to 1.2 kg of each sample were provided in "as-sampled" condition. The samples were initially passed through a 10 mm screen to remove gravel sized material, then oven dried at 75 °C for 24 hours. The five samples were described as follows:

- Site TP2 2.0 m
- Site TP3 0.6 - 1.2 m
- Site TP4 2.5 m
- Site AH8 1.5 - 2.0 m
- Site AH8 2.5 - 3.0 m

The five soils were analysed for pH, acid neutralising capacity (ANC), electrical conductivity (EC), cation exchange capacity (CEC), and soluble and exchangeable cations. In addition, acid buffer characteristic curves were determined for three of the five soils. The main aim of these assays was to determine if the basement soils in the area of the proposed TSF have any capacity to neutralise any acidity that might be generated by tailings within the storage and/or have any capacity to retard the movement of any metals that might leach from tailings.

Soil Cation Exchange and Buffer Capacities

The soil assay results are given in Table 1. All five soils were alkaline and had some neutralisation capacity and cation exchange capacity, but the magnitude of these properties varied widely.

Table 1. Soils analysis

Parameter	Unit	Soil TP2 2.0m	Soil TP3 0.6-1.2m	Soil TP4 2.5m	Soil AH8 1.5-2.0m	Soil AH8 2.5-3.0m
<i>pH and acid neutralising capacity</i>						
pH		9.4	8.5	9.2	9.3	9.5
ANC	kg H ₂ SO ₄ /t	116	5	32	29	38
<i>Salinity and soluble salts</i>						
EC	µS/cm	416	211	109	176	206
Soluble Na	meq/100g	1.46	0.76	0.26	0.50	0.53
Soluble K	meq/100g	0.03	0.07	0.05	0.03	0.03
Soluble Ca	meq/100g	0.13	0.58	0.12	0.12	0.14
Soluble Mg	meq/100g	0.10	1.17	0.42	0.32	0.28
<i>Cation exchangeable capacity</i>						
CEC	meq/100g	20.7	11.9	12.6	10.5	9.1
Exch Na	meq/100g	3.3	2.1	0.3	0.4	0.3
Exch K	meq/100g	0.8	0.7	0.7	0.2	0.2
Exch Ca	meq/100g	7.2	6.3	8.0	7.3	7.2
Exch Mg	meq/100g	9.4	2.8	3.6	2.6	1.4

The soil sample from site TP2 at 2.0m depth had both the highest ANC and highest CEC. The ANC of this sample (116 kg H₂SO₄/t) was indicative of the presence of more than 10% carbonate mineralisation, and the CEC of 20.7 meq/100g suggests a significant clay content. It is expected that material as represented by this sample would have a high capacity to neutralise any acidic seepage and would also have the capacity to retard¹ the movement of metals through the basement of the TSF via adsorption processes.

Samples TP4 2.5m, AH8 1.5-2.0m, and AH8 2.5-3.0m were relatively similar in respect to their neutralisation and cation exchange capacities. The ANCs (29 to 38 kg H₂SO₄/t) were in the moderate range and such materials would be expected to provide reasonably good buffer potential in the event there was acidic seepage from tailings. These soils would also have some capacity to retard the movement of metals, although the CECs (9.1 to 12.6 meq/100g) were only about half the CEC of the sample from site TP2, and more typical of soils of medium to coarse texture (*i.e.* silt-sand soil types) rather than fine grained clay.

The soil sample from site TP3 0.6-1.2m had a CEC comparable to the three samples mentioned immediately above, but the ANC was markedly lower at only 5 kg H₂SO₄/t. This

¹ It should be noted that cation exchange / metal adsorption processes are pH dependent. Strong retardation would be expected at circum-neutral pH but would be less if acidification of the soils occurs.

value indicates little, if any, carbonate mineralisation occurs within the soil represented by this sample. This soil was from a shallower depth than the other samples, and hence the characteristics may reflect a different soil horizon.

Soil Acid Buffer Characteristic Curves

In addition to the assays described above, acid buffer characteristic curves were determined for samples TP2 2.0m, TP4 2.5m, and AH8 1.5-2.0m. The ABCC is determined by slowly acidifying a sample with dilute acid to around pH 3 over a 16 to 24-hour period. It represents a far less aggressive treatment of a sample than that applied in the ANC method, and provides an indication of the presence of more soluble carbonates within a sample such as calcite and dolomite.

The acid buffer characteristic curves for the three soil samples are illustrated in Figure 1. Reference curves for a range of mineral standards are also shown in Figure 1. With all three soils there was well defined plateau regions at the start of the buffer curve. These plateaus confirm readily available neutralisation capacity under circum-neutral pH conditions, which is essential for maintaining low metal solubilities.

2. Tailings Geochemistry

Sample Preparation

The tailings sample was prepared by Optimet as part of metallurgical testing for the project, and was provided as a slurry comprising approximately 6 kg of solids and 2.3 litres of liquor. The solids and liquor were separated by filtration then the solids were dried and sealed in an air-tight container. Sub-samples of the solids and liquor were then taken for initial geochemical characterisation. A 2 kg sub-sample of solids was also taken for column leach testing.

Acid Forming Characteristics

The results of assays carried out on the tailing sample are presented in Table 2. The tailings can generally be described as having a very high acid potential, with a total sulphur content of 20.8 %S. The ANC of the tailings was low (5 kg H₂SO₄/t), and the net acid producing potential of the tailings based on the sulphur and ANC results was equivalent to 631 kg H₂SO₄/t. When the tailings were reacted with hydrogen peroxide in the NAG test, a total of 462 kg H₂SO₄/t was produced. Although the NAG result was approximately 30% less than the NAPP, the results confirm the very high acid potential of the tailings and indicate that at least 70% of the sulphur was pyritic.

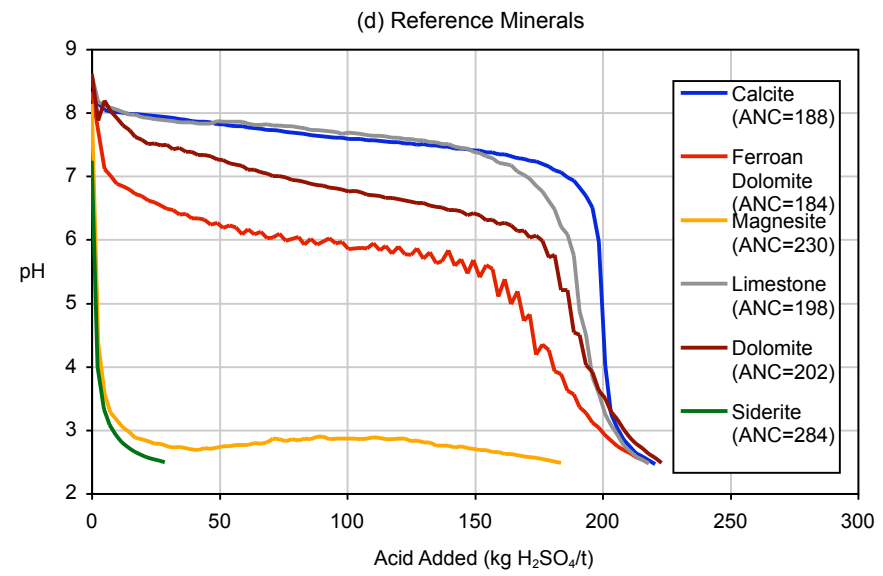
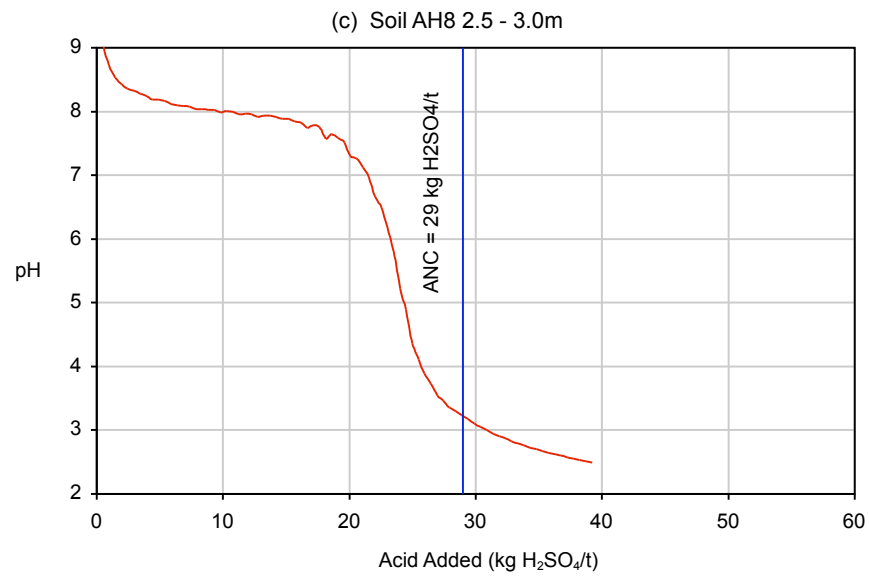
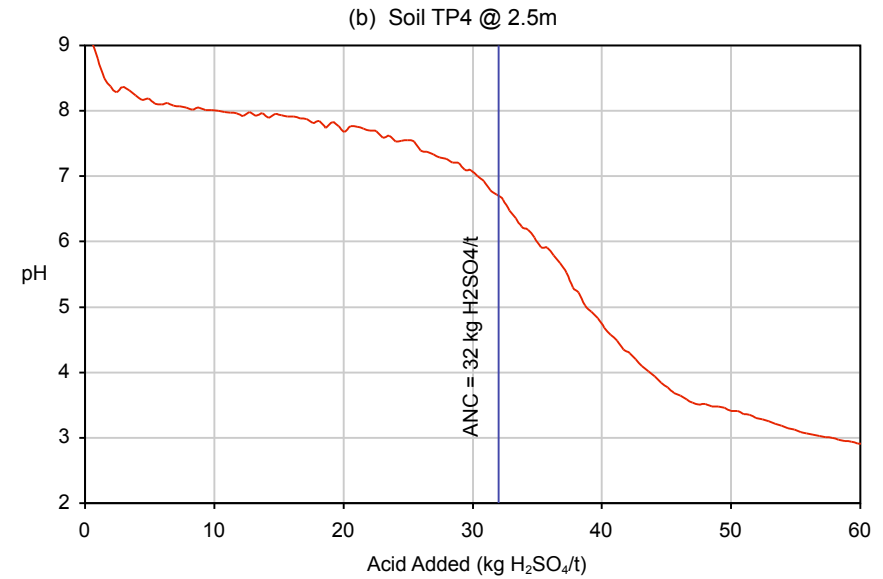
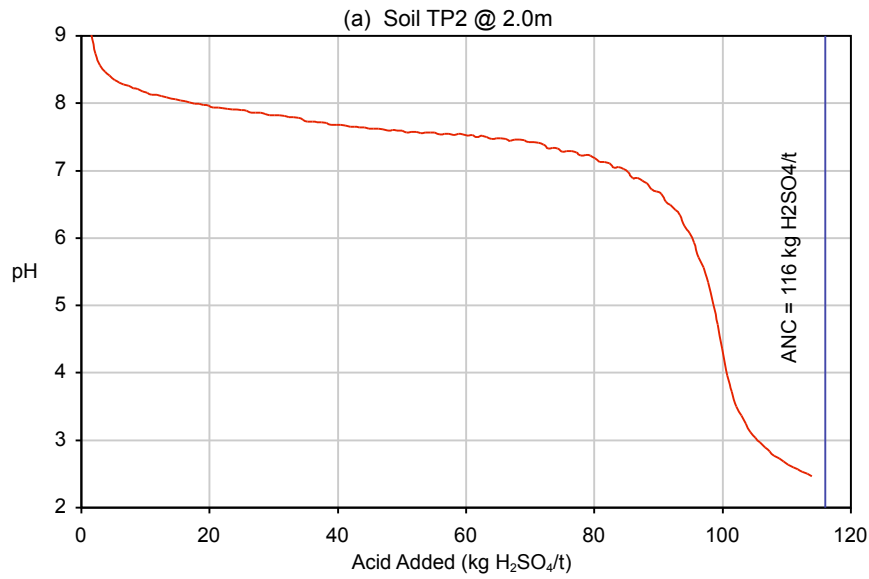


Figure 1. Acid buffer characteristic curves for TSF soil samples and reference minerals

Table 2. Acid forming characteristics of Angas tailings

Parameter	Unit	Result
Sulphur content	%S	20.8
Maximum Potential Acidity (MPA)	kg H ₂ SO ₄ /t	636
Acid Neutralising Capacity (ANC)	kg H ₂ SO ₄ /t	5
Net Acid Producing Potential (NAPP)	kg H ₂ SO ₄ /t	631
Net Acid Generation (NAG)	kg H ₂ SO ₄ /t	462
NAGpH		2.4
ARD Classification		PAF

Sequential NAG Test

The high sulphur content of the tailings necessitated multiple sequential reactions with hydrogen peroxide in the NAG test to fully oxidise all the sulphides present. Seven stages of reaction were required, as shown in Figure 2.

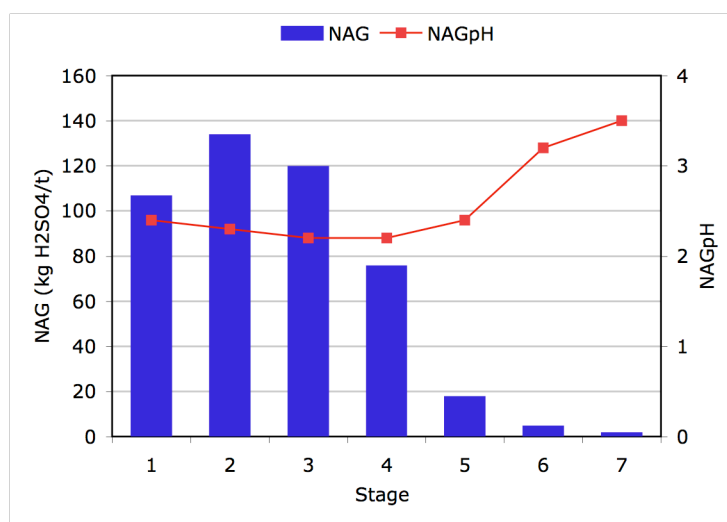


Figure 2. Acid generation in the sequential NAG test for Angas tailings

Acid Buffer Characteristic Curve

The limited availability of ANC within the tailings is confirmed by the acid buffer characteristic curve shown in Figure 3. Unlike soil, there was no initial plateau at the start of the curve which would indicate circum-neutral buffering by the tailings. Instead, there was an immediate decrease in tailings pH with acid addition, with the tailings acidifying to around pH 4 with the addition of only 5 kg H₂SO₄/t. These results suggest that the lag period for acid generation to occur in tailings exposed to atmospheric conditions will be short, probably in the order of weeks rather than years.

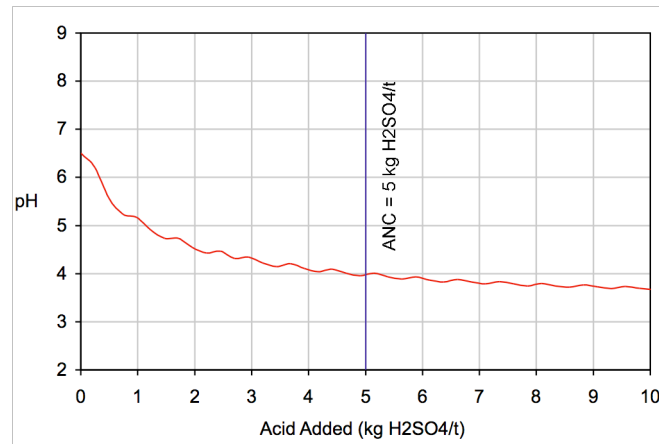


Figure 3. Acid buffer characteristic curve for Angas tailings

A kinetic NAG test was run on the tailings to provide additional information on the likely lag period. The pH and temperature profiles recorded during the kinetic NAG test are shown in Figure 4. The results indicate a rapid decrease in pH as the hydrogen peroxide started oxidising sulphides within the tailings. The pH of the NAG solution acidified to less than 4 within seven minutes of reaction, and reached a minimum of pH 1 at the height of the reaction when the solution reached boiling point after approximately 30 minutes. The pH then eventually equilibrated back to around pH 2.7 after cooling of the solution. This type of reaction profile typically indicates a very rapid response in acid generation under field conditions.

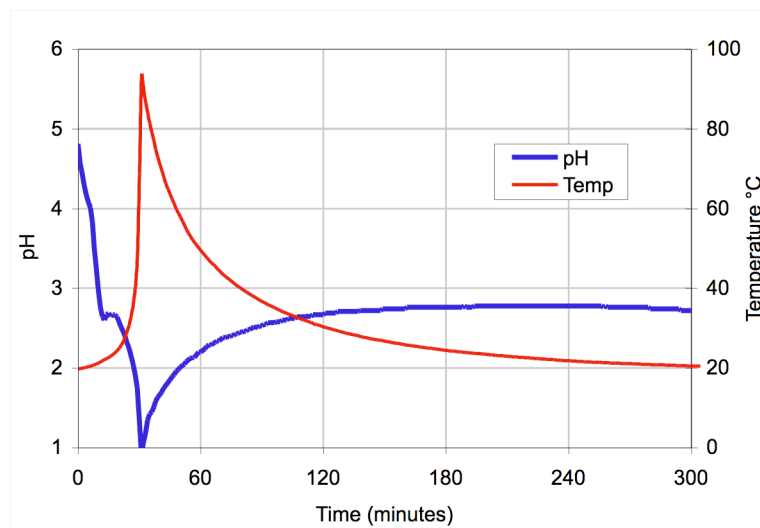


Figure 4. Kinetic NAG test reaction profiles for Angas tailings

Multi-Element Composition

The multi-element composition of the tailings solids is given in Table 3, together with the respective geochemical abundance indices (GAI). Multi-element analysis of the tailings solids was carried out by Genalysis Laboratory Services Pty Ltd using NATA registered procedures. Samples were digested by multi-acid addition and the digests were analysed for a suite of 29 elements.

Table 2. Multi-element composition of tailings

Element	Unit	Composition	Composition	GAI
		Angas Tailings	Median Soil	Angas Tailings
Al	%	1.89	7.1	0
Ca	%	0.11	1.5	0
Fe	%	30.1	4.0	2
K	%	0.56	1.4	0
Mg	%	0.47	0.5	0
Na	%	0.08	0.5	0
S	%	20.8	0.03	6
Si	%	18.2	33	0
Zn	%	1.2	0.009	6
As	ppm	328	6	5
Ba	ppm	99	500	0
Be	ppm	0.8	0.3	1
Cd	ppm	27	0.35	6
Co	ppm	57	8	2
Cr	ppm	365	70	2
Cu	ppm	1480	30	5
F	ppm	204	200	0
Hg	ppm	0.2	0.06	1
Mn	ppm	1641	1000	0
Mo	ppm	57	1.2	5
Ni	ppm	308	50	2
P	ppm	149	800	0
Pb	ppm	6915	35	6
Sb	ppm	17.6	1	4
Se	ppm	1.5	0.4	1
Sn	ppm	2.3	4	0
Sr	ppm	8.5	250	0
Th	ppm	6.9	9	0
U	ppm	6.8	2	1

Median soil abundance data were taken from Bowen, H.J.M. (1979). *Environmental Chemistry of the Elements*, Academic Press, New York, p36-37.

The GAI for a particular element provides an indication of the relative enrichment of that element within the tailings solids compared to the median soil abundance. The GAI is expressed on a log 2 scale which includes 7 integer increments (0 through to 6, respectively). A GAI of 0 indicates the element is present at a concentration similar to, or less than, median

soil abundance and a GAI of 6 indicates approximately a 100-fold, or greater, enrichment above median soil abundance. The main purpose of the GAI is to identify elements that occur at concentrations that may be environmentally significant. The multi-element data indicate significant enrichments (i.e. $GAI \geq 3$) relative to median soil in As, Cd, Cu, Mo, Pb, S, Sb and Zn.

Column Leach Test

A column leach test has been set-up to assess rates of sulphide oxidation, acid generation, and metals leaching from the tailings sample. The column test has been operating for four weeks and is scheduled to run over a period of 12 months. Since it is expected that the tailings will exhibit a high reactivity with respect to acid generation, the tailings were leached on a weekly basis for the first four weeks of the column test. The assay results for the first four weekly collections, as well as the composition of the initial tailings liquor, are given in Table 4. Leachate samples are analysed for pH, acidity, electrical conductivity, and a suite of 25 elements.

The initial leachate results confirm the rapid acidification of tailings, with leachate of pH 3.5 being produced within the first two weeks of column leaching. The concentrations of sulphate in leachate during the first four weeks averaged 1770 mg/L, and the sulphate release rate averaged 336 mg SO_4 /kg/week. This represents a relatively high rate of sulphate release, and indicates a high rate of sulphide oxidation taking place within the column of tailings.

The rate of leaching of zinc from the tailings is also increasing. The zinc concentration in the initial tailings liquor was 2 mg/L, but by week 3 it had increased to 138 mg/L, and in week 4 it was 199 mg/L. This indicates that sphalerite is readily oxidising when the tailings are exposed to atmospheric conditions.

In addition to zinc, there have been significant increases in the concentrations of cadmium (up to 447 μ g/L), cobalt (1530 μ g/L), nickel (up to 1490 μ g/L) and lead (up to 2455 μ g/L) in leachate from the tailings columns.

Leaching of the tailings column has now reverted to the standard four-week cycle that is normally used by EGi for column leach tests. This involves the addition of 250ml of deionised water each week for the first three weeks of each cycle (equivalent to 100 ml/kg/wk) to moisten the tailings, then flushing of the tailings on the fourth week by addition of 1000 mL of deionised water (equivalent to 400 ml/kg/wk).

Table 4. Preliminary results of column leachate test on Angas tailings

Parameter	Tailings Liquor	Column Leachate Week 1	Column Leachate Week 2	Column Leachate Week 3	Column Leachate Week 4
pH	7.3	5.8	3.5	3.5	3.6
Acidity (mg CaCO ₃ /L)	na	130	142	232	361
EC (µS/cm)	1210	1860	1380	1360	1430
Al (mg/L)	0.095	0.14	0.17	0.14	0.26
Ca (mg/L)	162	445	256	190	148
Cl (mg/L)	172	74	161	94	88
Fe (mg/L)	0.34	0.10	0.15	0.27	2.0
K (mg/L)	27	34	26	27	34
Mg (mg/L)	28	48	50	66	76
Mn (mg/L)	1.6	16.6	9.4	10.5	11.6
Na (mg/L)	109	69	35	37	45
Si (mg/L)	3.8	5.5	3.4	3.7	3.5
SO ₄ (mg/L)	486	1785	2080	1538	1671
Zn (mg/L)	2.0	82	75	138	199
Ag (µg/L)	0.03	0.11	0.05	0.03	0.04
As (µg/L)	6.8	4.5	32	13	39
Cd (µg/L)	6.8	202	196	308	447
Co (µg/L)	12.7	375	525	927	1530
Cr (µg/L)	<10	<10	<10	<10	<10
Cu (µg/L)	30	30	30	40	90
Hg (µg/L)	<0.1	<0.1	<0.1	<0.1	0.2
Mo (µg/L)	16.2	0.34	0.06	<0.05	<0.05
Ni (µg/L)	<10	620	580	980	1490
Pb (µg/L)	71	782	2071	3836	2455
Sb (µg/L)	12.5	1.6	0.98	0.71	0.61
Se (µg/L)	2.1	5.3	5.3	7.7	9.3
Sn (µg/L)	<0.1	<0.1	<0.1	<0.1	<0.1
Sr (µg/L)	414	985	616	57	25



Job Reference No. 6411

TO: AUSTRALIAN TAILINGS CONSULTANTS PTY LTD
ATTENTION: Paul Williams
FROM: John Jeffery
DATE: 1 September 2006
SUBJECT: Angas Zinc Project - Column Leach Testing of Tailings

Attached are the latest results from the column leach test being undertaken by EGi on a sample of tailings from the Angas Zinc Project. The tailings sample was prepared by Optimet as part of metallurgical testing for the project. Following initial geochemical characterisation of the tailings solids in October 2005, a column test was established which has now been operating for approximately 44 weeks.

As previously advised, the tailings solids have a high acid potential. The total sulphur content of the solids was very high (20.8 %S), the ANC was low (5 kg H₂SO₄/t), and the net acid producing potential (NAPP) based on the sulphur and ANC values was 631 kg H₂SO₄/t. Acidity equivalent to 462 kg H₂SO₄/t was produced when the tailings were reacted with hydrogen peroxide in the NAG test, which is approximately 30% less than the NAPP, but still indicative of a very high acid potential.

The column test is laboratory scale and comprises 2.5 kg of tailings solids within a plastic Buchner Funnel measuring 175 mm in diameter and 100 mm in height. The column is free draining and leachate is collected in a container positioned beneath the funnel spout. The leaching regime is designed so that the availability of water and atmospheric oxygen will not be limiting for sulfide oxidation processes.

In anticipation that the tailings would be highly reactive, they were subjected to a weekly leach for the first four weeks of the test. Thereafter, the standard four-week leach cycle was adopted. This involved moistening the tailings solids by addition of 250 mL of deionised water each week for the first 3 weeks of each cycle, followed by a flush stage on the fourth week involving addition of 1000 mL of deionised water. Leachate was collected in the 72-hour period following the flush, with approximately 400 mL of leachate typically collected.

Leachate assay results are provided in Table 1. Graphs showing changes in leachate composition through time are also provided for key parameters. At the time of preparing this memorandum, leachate assay data were available for the first 40 weeks of column operation. An additional leach cycle (week 44) has also been completed and the leachate is currently being analysed for multi-elements. The column test is scheduled to run for 52 weeks, which means there will be another two leach cycles.

The initial leachate results confirm the rapid acidification of tailings, with leachate of pH 3.5 being produced within the first two weeks of column leaching. Since then, the pH of leachate has fluctuated within a narrow range of 3.1 to 3.5, indicating some source of strong buffering at this pH.

The acidity of leachate increased in an exponential manner during the first 12 weeks before peaking at 6000 mg CaCO₃/L in Week 16. This represents an exceedingly high acidity leachate. Since then the acidity of leachate has steadily declined. Leachate collected after 44 weeks had an acidity of 2,405 mg CaCO₃/L which, although still relatively high, indicates a significant reduction in acid release (and hence sulphide oxidation) as sulphides are progressively oxidised and depleted. The high acidity values can be attributed primarily to dissolved iron and zinc within leachate.

The concentrations of sulphate in leachate during the first four weeks was relatively steady at between 1500 to 2000 mg/L. Sulphate concentration then increased markedly following a change to a four-week leach cycle, with a maximum concentration of 10,418 mg/L recorded at Week 12. This represents a very high rate of sulphate release, and indicates a high rate of sulphide oxidation taking place within the column of tailings. Since Week 12, sulphate concentration has followed a downward trend and by Week 40 had declined to 1,898 mg/L.

In contrast to sulphate, the leaching of zinc has involved two release stages, one peaking in Week 8 with a concentration of 386 mg/L, and a second larger release stage which peaked in Week 32 at a concentration of 577 mg/L. The double peak exhibited by zinc (as well as some other elements such as cadmium, cobalt and nickel) may reflect different mineralogical forms of zinc within the tailings solids with differing reactivity.

Overall, the results indicate that the tailings from the Angas Zinc Project are highly reactive and would be expected to generate highly acidic leachate if the solids are beached and exposed to atmospheric conditions. Prolonged exposure would not only lead to a low pH condition and mobilisation of sulphate iron and zinc, but also other elements such as aluminium, cadmium, cobalt, lead, manganese and nickel would be expected to occur at elevated concentrations in leachate.

A detailed report will be prepared on the column leach test following collection and analysis of column leachate on Week 52.

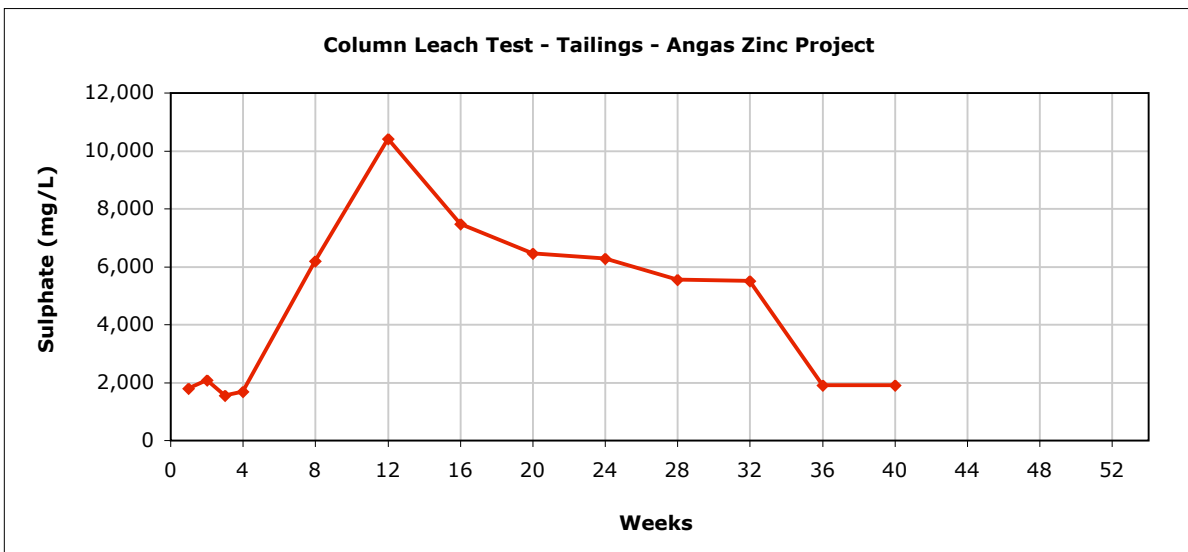
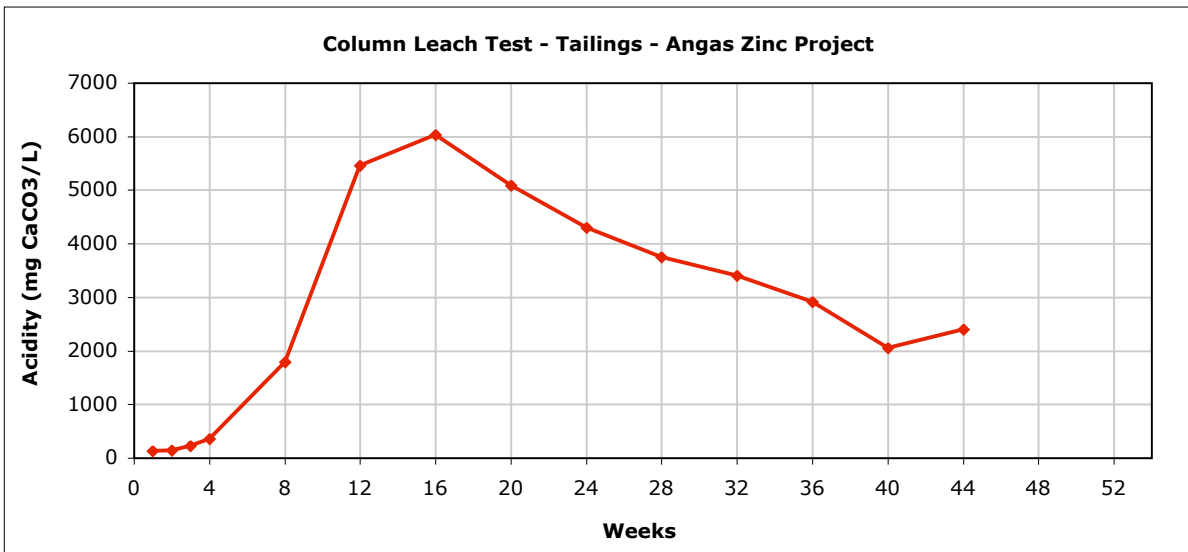
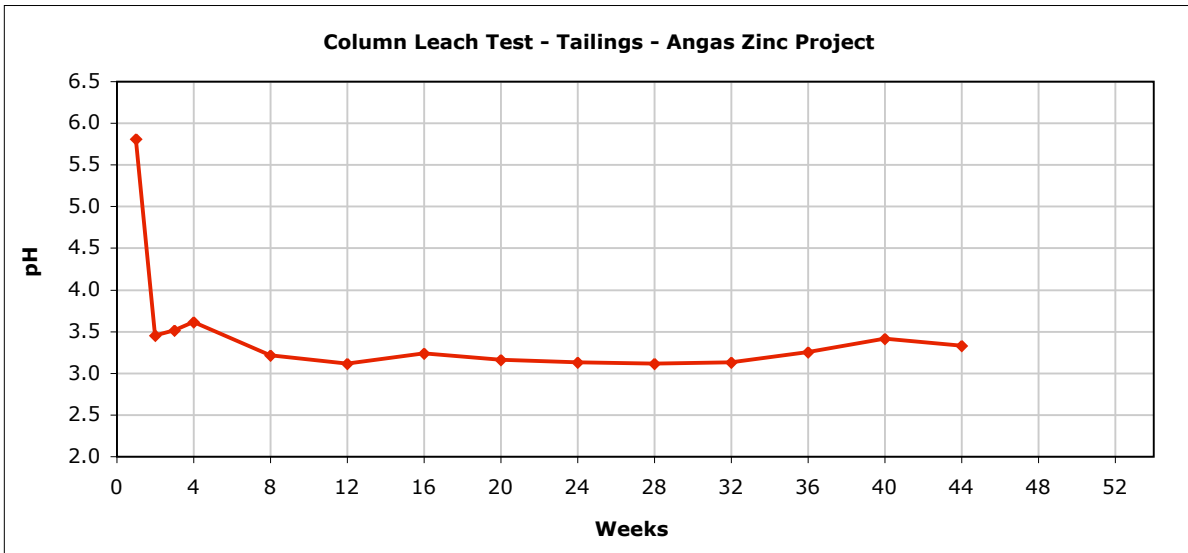
Table 1: Column leach test results for tailings from Angas Zinc Project.

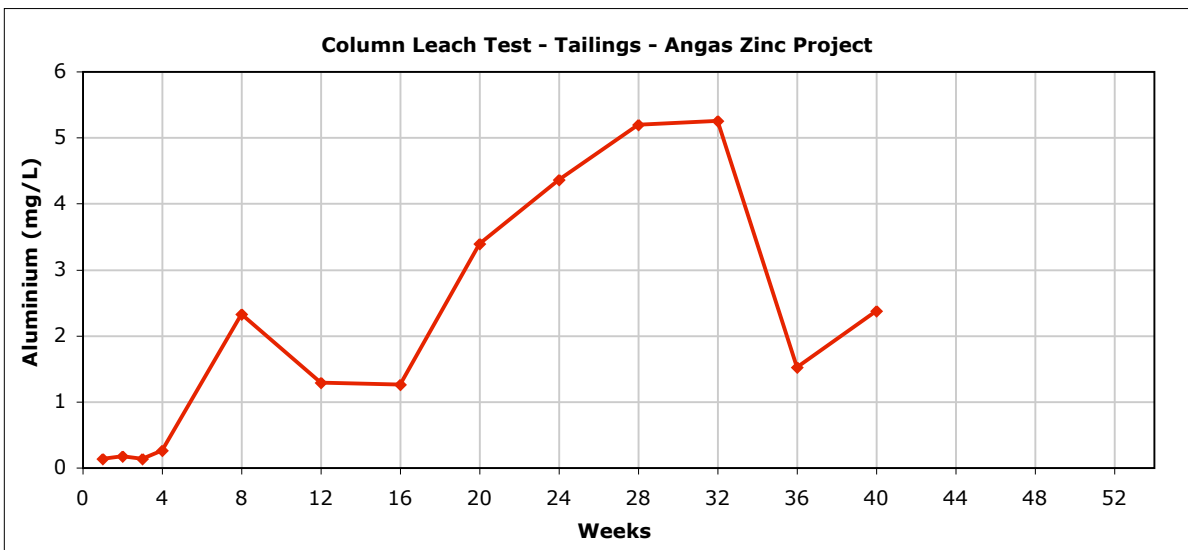
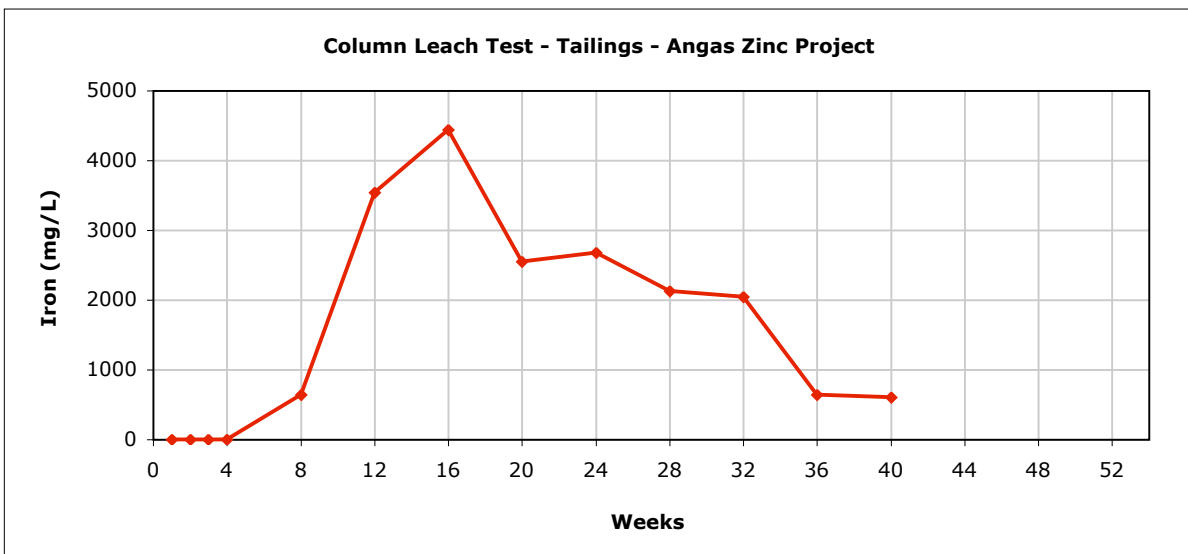
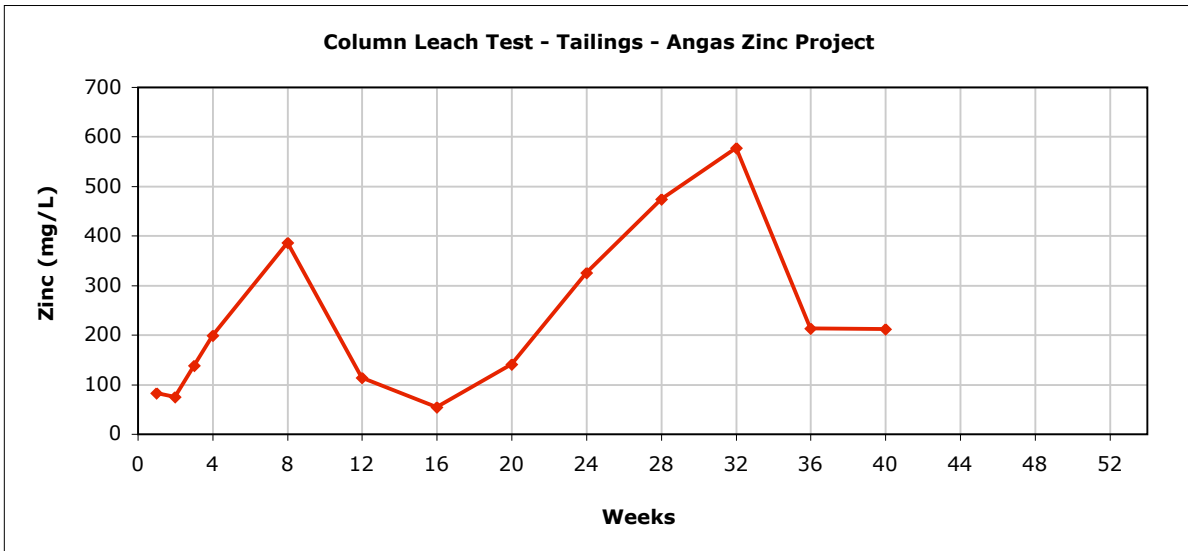
PROVISIONAL
RESULTS

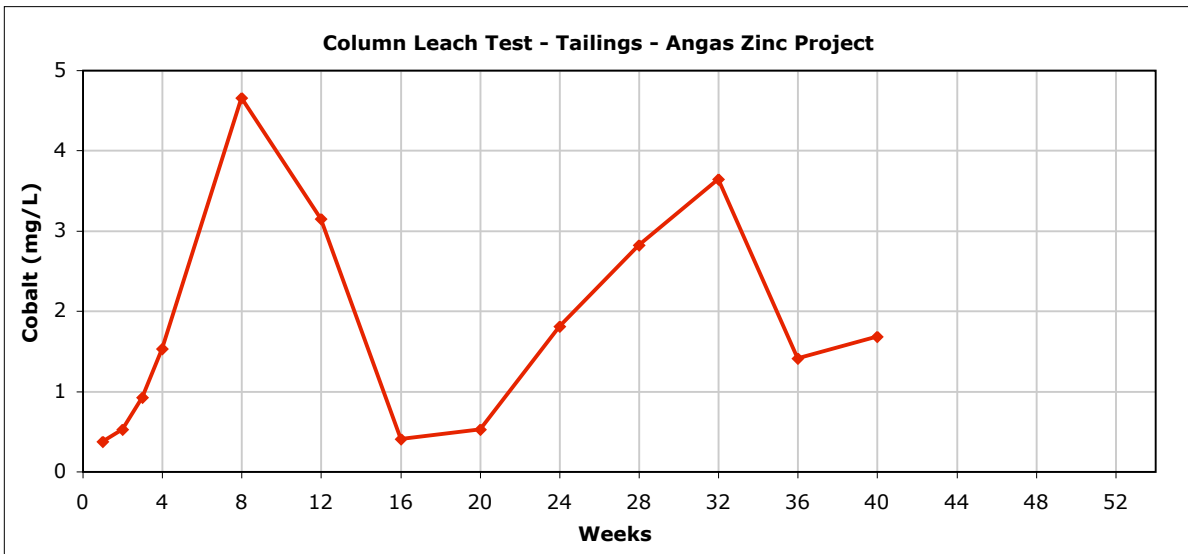
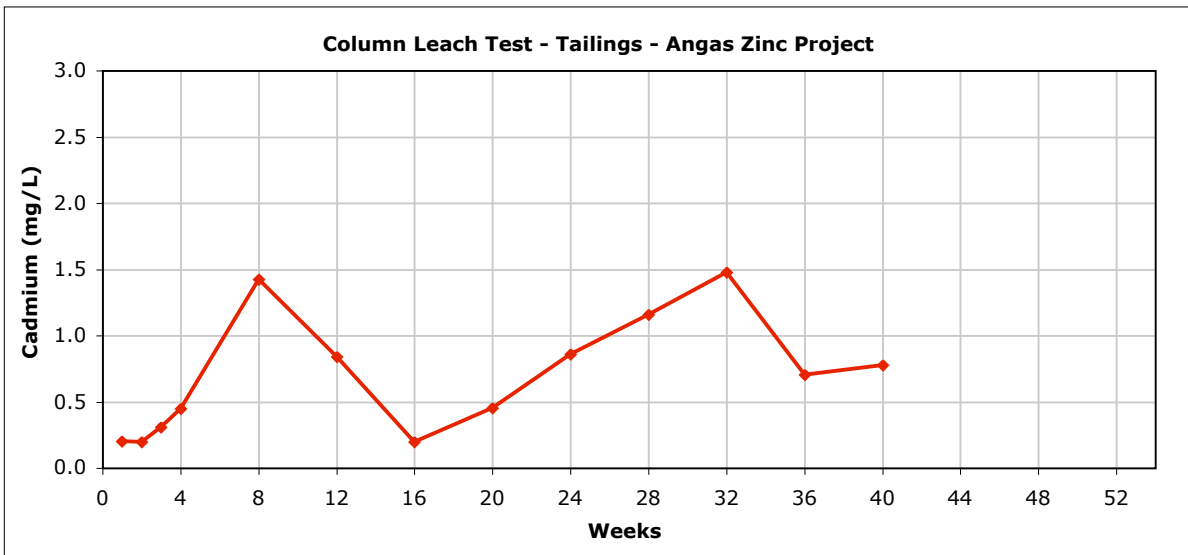
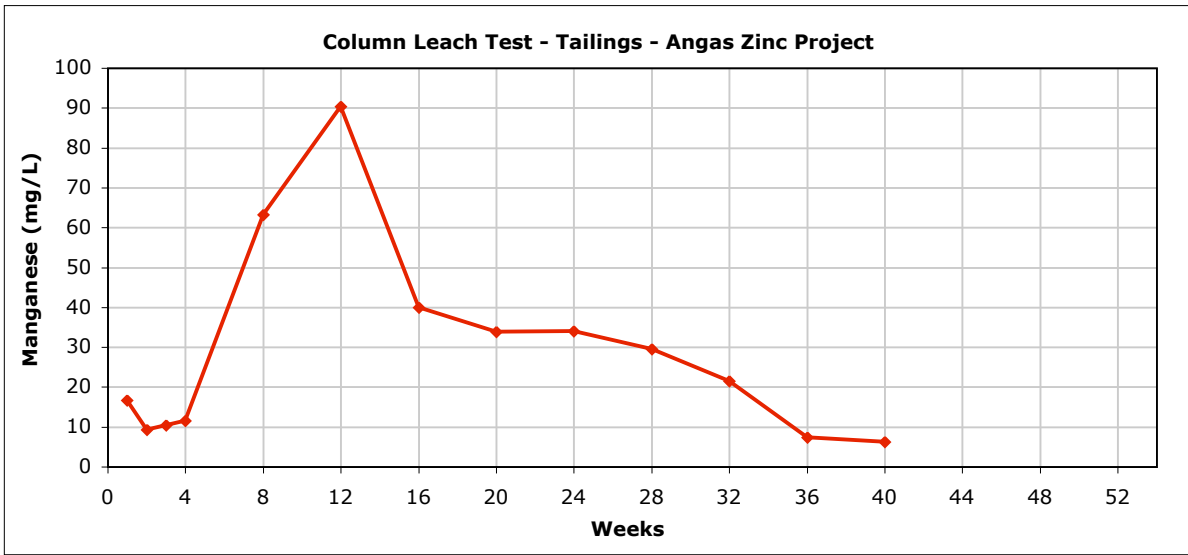
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Sulphur	ANC	NAPP	NAG	NAGpH	Weight	Start	Sample
%S	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t	kgH ₂ SO ₄ /t		g	Date	Code
20.8	5	631	107	2.4	2501	21-Oct-05	ANG/29114

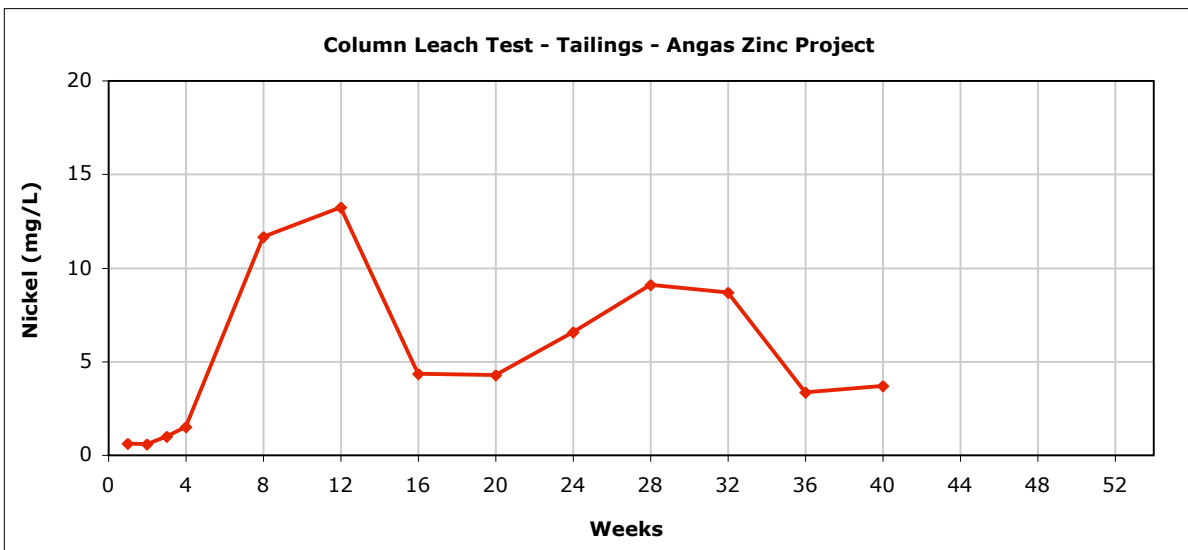
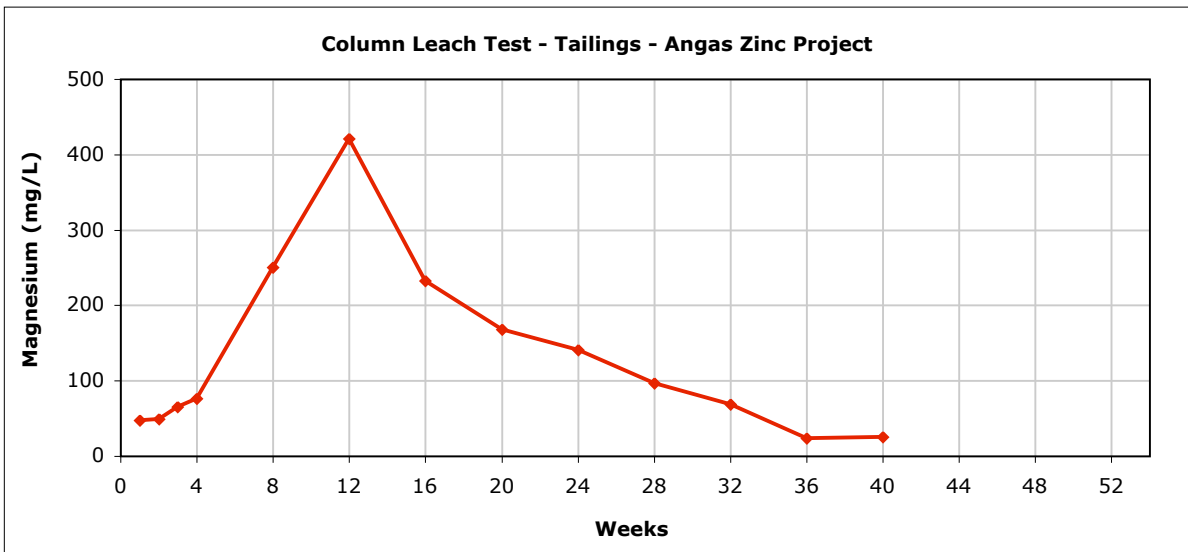
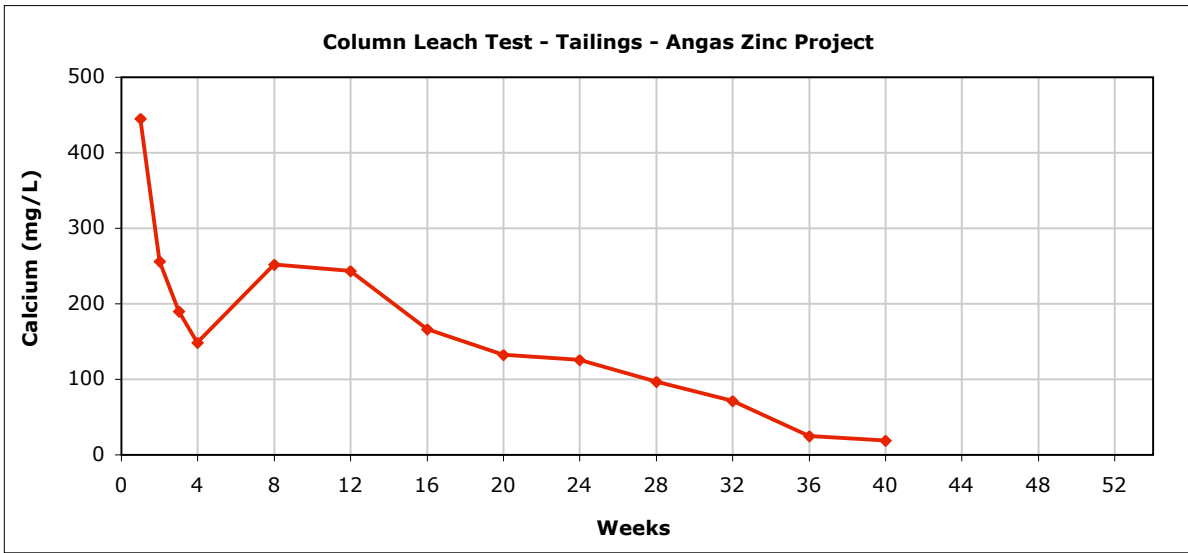
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		24-Oct-05	31-Oct-05	7-Nov-05	14-Nov-05	12-Dec-05	9-Jan-06	6-Feb-06	6-Mar-06	3-Apr-06	1-May-06	29-May-06	26-Jun-06	24-Jul-06	21-Aug-06	18-Sep-06	16-Oct-06
		29114-1	29114-2	29114-3	29114-4	29114-5	29114-6	29114-7	29114-8	29114-9	29114-10	29114-11	29114-12	29114-13	29114-14	29114-15	29114-16
Volume	ml	476	516	486	411	386	388	386	384	386	381	389	383	386	381		
pH	-	5.8	3.5	3.5	3.6	3.2	3.1	3.2	3.2	3.1	3.1	3.1	3.3	3.4	3.3		
EC	dS/m	1.86	1.38	1.36	1.43	2.87	4.25	5.21	5.29	4.66	3.81	3.67	2.24	2.16	1.67		
Alkalinity	mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Acidity	mg/l	130	142	232	361	1,789	5,465	6,032	5,089	4,305	3,746	3,403	2,918	2,053	2,405		
Ag	mg/l	0.00011	0.00005	0.00003	0.00004	0.00003	0.00136	0.00022	0.0001	0.00008	<0.0001	0.00016	<0.0001	<0.00001			
Al	mg/l	0.14	0.17	0.14	0.26	2.3	1.3	1.3	3.4	4.4	5.2	5.3	1.5	2.4			
As	mg/l	0.005	0.032	0.013	0.039	0.020	0.021	0.016	0.02	0.016	0.013	0.023	0.009	0.014			
Ca	mg/l	445	256	190	148	252	243	166	133	125	97	71	25	19			
Cd	mg/l	0.20	0.20	0.31	0.45	1.43	0.84	0.20	0.45	0.86	1.16	1.48	0.71	0.78			
Cl	mg/l	74	161	94	88	50	75	70	55	28	37	27	23	35			
Co	mg/l	0.38	0.53	0.93	1.53	4.66	3.15	0.41	0.53	1.8	2.8	3.6	1.41	1.68			
Cr	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.04	<0.1	<0.01	<0.01	0.03			
Cu	mg/l	0.03	0.03	0.04	0.09	0.13	<0.01	0.03	0.10	0.10	<0.1	<0.01	0.06	0.04			
Fe	mg/l	0.10	0.15	0.27	2.04	644	3,538	4,436	2,548	2,680	2,130	2043	641.86	605.57			
Hg	mg/l	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0003	<0.0001	<0.001	<0.0001	<0.001	<0.0001	<0.001	<0.0001			
K	mg/l	34	26	27	34	27	40	33	21	20	19	15	12	9			
Mg	mg/l	48	50	66	76	251	421	233	168	141	97	68	24	25			
Mn	mg/l	17	9	10	12	63	90	40	34	34	30	21	7	6			
Mo	mg/l	0.00034	0.00006	<0.00005	<0.00005	<0.00005	0.00131	0.00029	0.0010	0.0018	0.0053	0.0008	<0.0005	0.0003			
Na	mg/l	69	35	37	45	67	44	27	21	9.1	3.0	4.8	16.6	38.9			
Ni	mg/l	0.62	0.58	0.98	1.5	12	13	4.4	4.3	6.6	9.1	8.7	3.4	3.7			
Pb	mg/l	0.78	2.1	3.8	2.5	3.4	2.8	2.7	2.6	2.3	1.8	1.9	2.2	2.5			
SO4	mg/l	1,785	2,080	1,538	1,671	6,190	10,418	7,464	6,449	6,269	5,547	5507	1892	1898			
Sb	mg/l	0.0016	0.0010	0.0007	0.0006	0.0011	0.0042	0.0064	0.0105	0.00011	0.00010	0.0033	0.00080	0.00392			
Se	mg/l	0.005	0.005	0.008	0.009	0.021	0.029	0.017	0.016	0.036	0.031	0.045	0.014	0.020			
Si	mg/l	5.5	3.4	3.7	3.5	7.7	20	7.9	11	14	15	11	12	10			
Sn	mg/l	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.001	<0.0001	<0.001	<0.0001	<0.001	<0.0001			
Sr	mg/l	0.99	0.62	0.06	0.03	0.02	0.05	0.067	0.027	0.022	0.017	0.020	0.012	0.016			
Zn	mg/l	82	75	138	199	386	114	54	141	325	474	577	213	212			

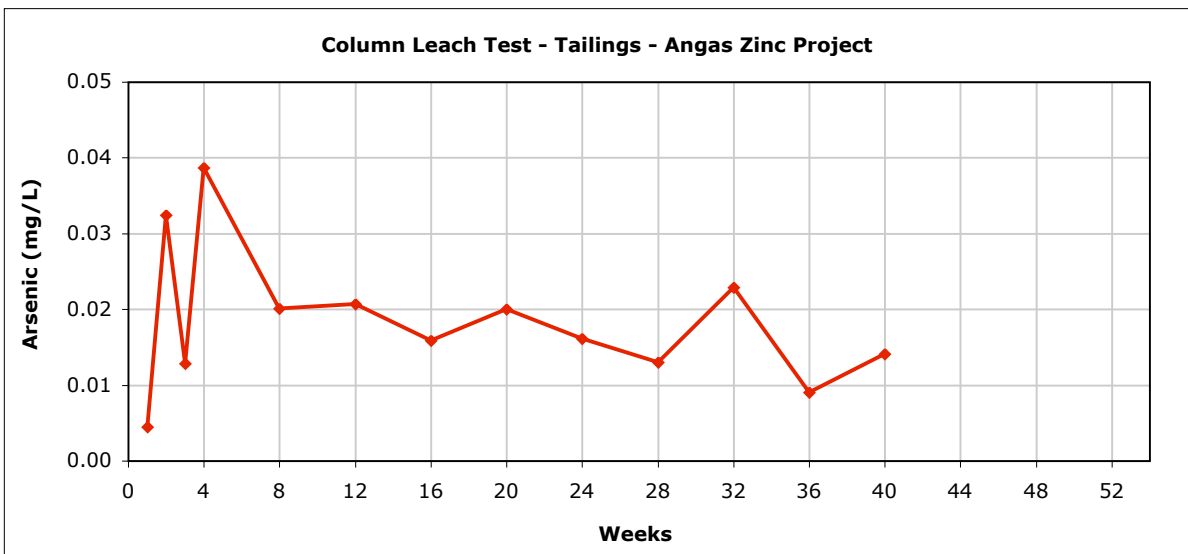
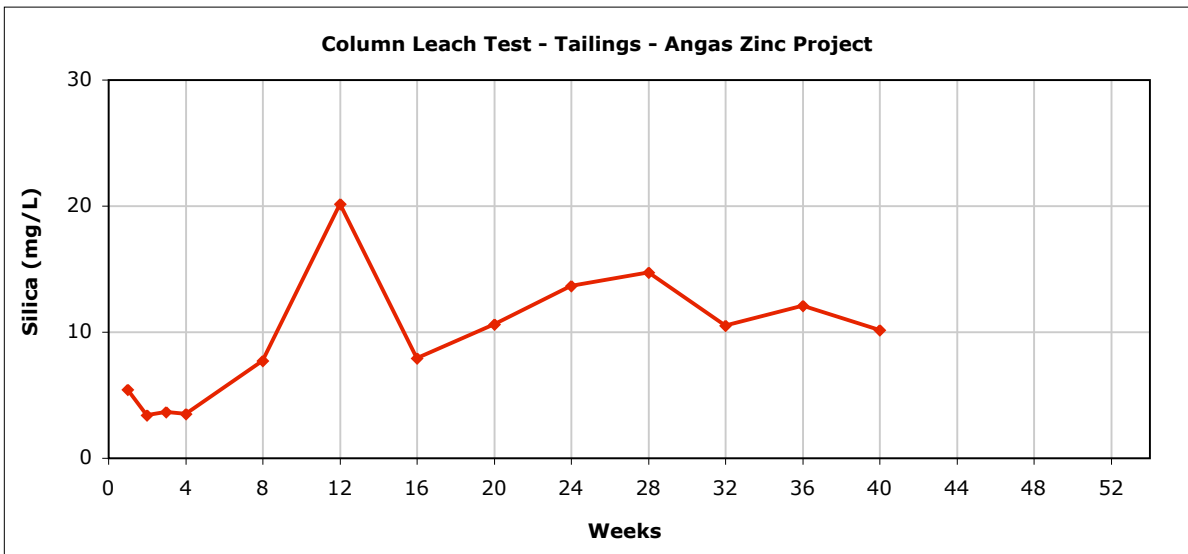
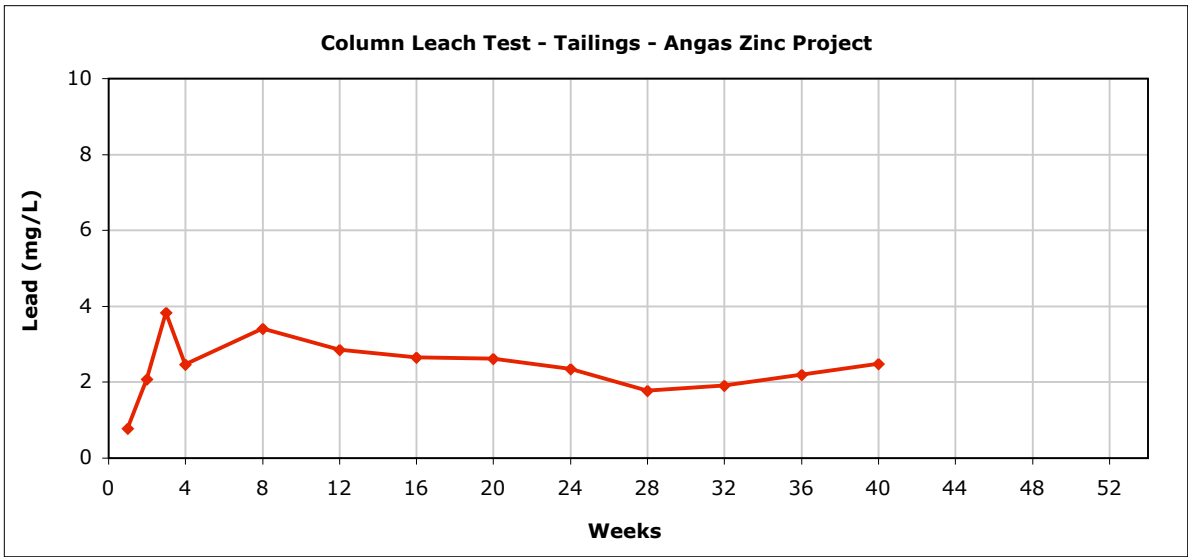
Awaiting assay Results











APPENDIX F