Geochemical Characterization of Tailings, Kylylahti Cu-Co Project, Finland

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The proposed Kylylahti Cu-Co project, located in south-eastern Finland, is an 'Outokumpu style' deposit containing copper-cobalt-zinc-nickel-gold. As part of the feasibility study, the expected tailings material was geochemically characterized taking tailings samples from the flotation test circuits and the supernatant. The analytical testing program included ABA and NAG testing, chemical composition of tailings solids, semi-quantitative mineralogical identification by XRD, chemical analysis of tailings supernatant, and short-term leach testing. The tailings generated following modifications to the concentrator flowsheet were found to be non-acid generating; however, metal leaching was still considered an issue of potential concern. Long-term kinetic testing was suggested in order to reduce any uncertainty.

Key words: Geochemical characterization, tailings, supernatant, acid generation, PHREEQC, Finland.

Introduction

The proposed Kylylahti Cu-Co project, located in south-eastern Finland, is an 'Outokumpu style' deposit containing copper-cobalt-zinc-nickel-gold. The proposed mine will sell copper-gold concentrate and nickel-cobalt hydroxide. Ore will be processed via conventional crushing and ball mill grinding followed by 3-stage flotation of the bulk sulphide concentrate, with subsequent removal of 26-28% Cu and 12-15g/t Au concentrate. Tailings storage on surface will be minimized by returning most tailings underground in the form of paste fill and any potential acid forming waste rock will be crushed and used as fill. As part of the feasibility study, the expected tailings material was geochemically characterized by Golder Associates Ireland (2007a, 2007b) taking tailings samples from the flotation test circuits and the supernatant.

Analytical Methods

As no one analytical method or technique is capable of reliably predicting future drainage chemistry, a combination of analytical testing methods was performed on the samples. The analytical testing program included Acid Base Accounting (ABA) and Net Acid Generation (NAG) testing, chemical composition of tailings solids by XRF, semi-quantitative mineralogical identification by XRD, chemical analysis of tailings supernatant, and short-term leach testing as per EN-12457. The initial testwork was conducted in Canada by SGS Lakefield Research Limited and Maxxam Analytics Inc. from September 2006 through to February 2007. Modifications were then made to the concentrator flowsheet, and further testwork was performed in Australia by SGS Lakefield Research and Ammtec Ltd in April 2007. ABA results were interpreted using the guidelines presented in Price (1997).

Initial Testwork: Results and Discussion

A 20-litre sample of bulk rougher tailings was sent to Canada for the geochemical, geotechnical and rheological testwork, which is believed to have come from the same bench or pilot plant testwork as the tailings rougher sample. The tailings material would have come from a flotation test circuit, which is understood to have been buffered to pH 9 with lime. The processing would have involved taking core samples of ore, crushing, grinding and then floatation of sulphide minerals in one or more stages. Three separate aliquots were taken of this tailings material for the ABA and NAG testing, and these were analyzed separately. Similarly, short-term leach tests were conducted on three separate aliquots from the tailings materials sent to Canada.

ABA testing indicated that the tailings material was slightly alkaline (pH ~9), but contained significant concentrations of sulphide material (average 3.64%, with total sulphur content of 4.27%) (Table 1). Based on the evaluation of ABA results, the tailings were tentatively identified as having a potential for acid generation, although this was not corroborated by the results from the NAG testing.

***Table 1** Acid Base Accounting and Net Acid Generation testing results*

		Initial Testwork		Testwork following flowsheet modification			
		Bulk Rougher Tests		Locked Cycle Tests		50kg Bulk Flotation Tests	
		Min	Max	Min	Max	Min	Max
Paste pH		8.85	9.17	-	-	-	-
S_{Total}	%	4.05	4.47	0.18	0.28	0.46	0.61
$S_{Sulphide}$	%	3.31	3.81	-	-	-	-
AP	kg $CaCO_3$/t	104	119	5.5	8.9	14.2	18.9
NP	kg $CaCO_3$/t	113	119	157	232	151	169
NNP	kg $CaCO_3$/t	-5.0	9.0	149	226	132	155
NP/AP	ratio	0.96	1.09	17.7	42.0	8.0	11.9
NAG pH		8.13	8.56	-	-	-	-
NAG	kg H_2SO_4/t	n.d.	n.d.	< 0	< 0	< 0	< 0

n.d.: not defined for NAG pH ≥ 4.5

The tailings solids were found to contain a number of metals in excess of residential and/or industrial SAMASE (Finnish) soils standards. These included: cobalt (754mg/kg), copper (432mg/kg), chromium (1241mg/kg), molybdenum (22mg/kg), nickel (666mg/kg), vanadium (189mg/kg) and zinc (298mg/kg).

In order to ascertain the mineralogy of the tailings material, both qualitative and semi-quantitative XRD analyses were performed. From Table 2, it can be seen that quartz (59.1%) and actinolite (15.4%) were, by far, the dominant minerals present in the tailings. Buffering capacity was available in the presence of calcite (4.1%) and dolomite (3.8%), to counter the effects of the sulphides present as pyrite (2.0%) and pyrrhotite (0.9%). Soluble salts included gypsum and jarosite.

***Table 2** Mineralogical composition of initial tailings*

Mineral	Composition	Tailings (wt%)
Quartz	SiO_2	59.1
Actinolite	$Ca_2(Mg,Fe)_5(Si)_8O_{22}(OH)_2$	15.4
Anorthite	$CaAl_2Si_2O_8$	6.8
Calcite	$CaCO_3$	4.1
Kornelite	$Fe_{2,3}(SO_4)_3 \bullet 7H_20$	3.9
Dolomite	$CaMg(CO_3)_2$	3.8
Mica (specifically Biotite)	$K_2(Mg,Fe)_3AlSi_3O_{10}(OH)2$	2.3
Pyrite	FeS_2	2.0
Pyrrhotite	$Fe_{1-x}S$	0.9
Chlorite	$(Mg,Fe,Al)_{12}[(Si,Al)_8O_{20}](OH)_{16}$	1.8
Gypsum	$CaSO_4.2H_2O$	Trace
Jarosite	$KFe_3(SO_4)_2(OH)_6$	Trace

Although the supernatant had relatively high conductivity (1550µS/cm), the pH was near-neutral (pH 8.0). The conductivity was attributed to elevated concentrations of sulphate (493mg/L), chloride (140mg/L), calcium (180mg/L) and sodium (120mg/L). Trace element concentrations were generally low; however, some were potentially of environmental concern. These included boron (89 µg /L), nickel (64µg/L), uranium (62µg/L), silicon (6.1mg/L), barium (59µg/L), cobalt (17µg/L) and aluminium (12µg/L).

Short-term leachability was determined through a two stage leach test (EN 12457-3) which was required by the EU Landfill Directive. Like many other static short-term tests, this test is not capable of simulating transient processes such as sulphide oxidation. The leachability tests indicated that the tailings material was well within the limits set up for waste to be disposed of in a non-hazardous waste-type facility.

Subsequent testwork: Results and Discussion

In order to increase the recovery of valuable metals, and produce a non-acid forming tailings stream, the Kylylahti concentrator flowsheet was then modified (Scriba, 2007). In the new process, pH was adjusted down to 6.5 (from 9.0), $CuSO_4$ was added during conditioning, and the sulphide flotation time was extended to increase the overall sulphide recovery thereby producing low sulphur tails. Consequently, the tailings and supernatant characteristics had to be partially re-evaluated. Samples for analysis were obtained from 50kg bulk flotation tailings, which were produced as a result of locked cycle tests.

Further ABA, NAG testing and chemical analyses of the supernatant from the low-sulphur tails were performed. As can be seen in Table 1, total sulphur content varied from 0.18-0.61%, which is significantly lower than reported initially. The Acid Potential (AP) was also significantly reduced to 6-19kg $CaCO_3$/t; whilst neutralization potential (NP) increased to 151-232kg $CaCO_3$/t. The NNP and NP/AP values increased substantially and the tailings are now non-acid generating.

Whilst the pH of the supernatant remained near-neutral (pH ~7.7), the conductivity was significantly higher in the subsequent (2700-3000µS/cm). The supernatant also has a higher sulphate concentration and consequently higher conductivity than observed previously; but the overall geochemistry remains similar. Trace metals identified in the earlier testing as being of potential concern, are still present in the supernatant and occur in higher concentrations than previously identified. These include antimony, manganese and nickel. In light of this, metal leaching is still considered an issue of potential concern.

Geochemical modelling

Screening level geochemical modelling using the equilibrium speciation and mass-transfer code PHREEQC Version 2.12 (Parkhurst and Appelo, 1999) was conducted to determine the saturation indices of geochemically credible mineral phases that might control supernatant composition. The MINTEQv4 database was used, and concentrations of constituents that were below detection limits were entered into the model at half the detection limit. The results are presented in Table 3.

Table 3 *Saturation indices of selected geochemically credible phases in the supernatant*

Phase	Composition	Initial testwork	Testwork following flowsheet modification	
		Rougher tailings	Semi-massive ore	Disseminated ore
Barite	$BaSO_4$	0.77	1.35	1.41
Calcite	$CaCO_3$	0.50	0.47	0.13
$Cr(OH)_3$ *(am)*	$Cr(OH)_3$	1.22	1.02	0.84
Diaspore	AlOOH	1.60	1.99	2.36
Dolomite	$CaMg(CO_3)_2$	0.57	0.18	-0.29
Ferrihydrite	$Fe(OH)_3$	2.57	2.00	1.79
Gibbsite	$AlOH_3$	0.21	0.60	0.97
Goethite	FeOOH	5.31	4.73	4.53
Gypsum	$CaSO_4.2H_2O$	-0.76	-0.04	-0.22
Jarosite-K	$KFe_3(SO_4)_2(OH)_6$	-0.45	-0.09	-0.51
Magnesite	$MnCO_3$	-0.92	-1.28	-1.42
SiO_2 *(am)*	SiO_2	-1.21	-1.18	-1.08

Note: Samples used in the testwork following flowsheet modifications comprised composites of semi-massive ore (representative of the early years of production) and disseminated ore (to be predominantly mined in the later years of the project).

Carbonate phases, such as calcite and dolomite, are in equilibrium with the supernatant and will provide pH buffer capacity. Note that both calcite and dolomite were detected by XRD in the tailings themselves. Gypsum also was tentatively identified by XRD and found to be in equilibrium with the supernatant. Ferrihydrite and goethite were oversaturated in the supernatant, as was $Cr(OH)_3(am)$. Two secondary minerals of potential environmental significance (as they may dissolve and serve as a source of trace metals, sulphate and/or acidity) were identified as being in equilibrium with the supernatant: gypsum and jarosite. Although the tailings contained significant primary silicate minerals, the supernatant was found to be undersaturated with respect to any of these.

Conclusions

Due to their significantly lower sulphur content, the tailings produced following modifications to the flowsheet are non-acid generating. The supernatant is characterized by high conductivity and some parameters are of environmental concern, including SO_4, Sb, Mn and Ni. In light of this, metal leaching is still an issue of potential concern. The geochemical program conducted on the tailings in this study only included static tests that are not capable of simulating long-term conditions, in particular when transient processes (e.g. sulphide oxidation) are expected to occur. In light of the lack of acid generation potential, long-term testing is not thought to be an essential requirement, but has been suggested to reduce any uncertainty regarding long-term sulphate and metal leaching behaviour.

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