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Yukon Conservation Society
Whitehorse, Yukon

Attention: Gerry Couture

Dear Gerry,

As per your request, I am providing my comments on the rinsing/neutralization plan for the Carmacks heap leach residues. I have reviewed the following documents from the YESAB online registry:

Alexco, January 2006. "Western Silver Corporation Carmacks Copper Project – Detoxification and Rinsing Testwork Report".
Alexco, June 2006. "Heap Rinsing Additional Information – Carmacks Copper Project".
Beattie Consulting Ltd., May 1998. "Carmacks Copper Project – Waste Neutralization Test Work".
Beattie Consulting Ltd., 2001. "Leaching and decommissioning of samples from Carmacks Copper Oxide Project".
Lawrence, May 1996. "Evaluation of the Mineralogy of a Sample of Carmacks Acid Leach Residue".
Lawrence, May 2006. "Review of Documents and Meeting Notes related to Mineralogy of Leach Residues – Carmacks Project".
Western Copper Corporation, February 2007. "Project Proposal – Revision No. 2, Carmacks Copper Project, Yukon Territory, Volume I, Main Report".
Western Copper Corporation, October 2006. "Conceptual Closure and Reclamation Plan Revision No.2".

To a large extent, my comments are based on my personal experience with rinsing and neutralization of acidic heap leach residues. Between 1996 and 1998, I was one of the two principal investigators involved in a study of copper heap-leach decommissioning at Noranda's Mines Gaspé site in Quebec. We tested sequential rinsing of the spent copper oxide ore with fresh water and alkaline solutions for accelerating the removal and the neutralization of contaminants. Due to the large cost ($2 million) of the pilot scale installations used in this study, similar investigations had not been carried out in the past and will probably remain rare in the future. Our results were published in a series of technical papers listed below, which in my opinion are highly relevant for the Carmacks copper project.

Catalan L.J.J. and M.G. Li, 2000. Decommissioning of Copper Heap-Leach Residues by Rinsing with Water and Alkaline Solutions – A Pilot Scale Study. *Environmental Engineering Science, 17(4):*191-202.

Catalan L.J.J., M.G. Li, and G. Comeau, 1998. Rinsing Copper Oxide Heaps Leached with Sulfuric Acid: A Pilot Study, *Proceedings of the Fifth International Conference on Tailings and Mine Waste '98*, Fort Collins, Colorado, 26-28 Jan., Balkema: Rotterdam, p881-893.

Li M.G., L.J.J. Catalan, S. Payant, and L. St-Arnaud, 1998. Characterization of Acid-Leach Residues for Decommissioning by Alkaline Rinsing, In *Waste Characterization and Treatment*; Petruk, W., Ed.; Society for Mining, Metallurgy, and Exploration, Inc: Littleton, Colorado, p91-108.

In the following, I will summarize the results of the rinsing/neutralization pilot tests carried out at Mines Gaspé and discuss their relevance to the Carmacks copper project. Next, I will provide specific comments on the test work that was done for the Carmacks copper project and the conceptual closure and reclamation plan proposed by Western Copper Corporation.

Pilot Scale Rinsing/Neutralization Tests at Mines Gaspé

At Mines Gaspé, the tests were carried out in vats measuring 23 m x 23 m in area and 4.6 m in height. Each vat was loaded with approximately 4000 tonnes of copper oxide ore using a crane equipped with a clamp bucket (Figure 1). The ore was then spread with a bulldozer. The loading procedures were designed to prevent segregation, so that the ore was homogeneous prior to leaching. A total of five vats were leached, and one was rinsed and neutralized (Vat #2) after leaching. Vats #3 and #4 were excavated after leaching, whereas Vat #2 was excavated after rinsing/neutralization.

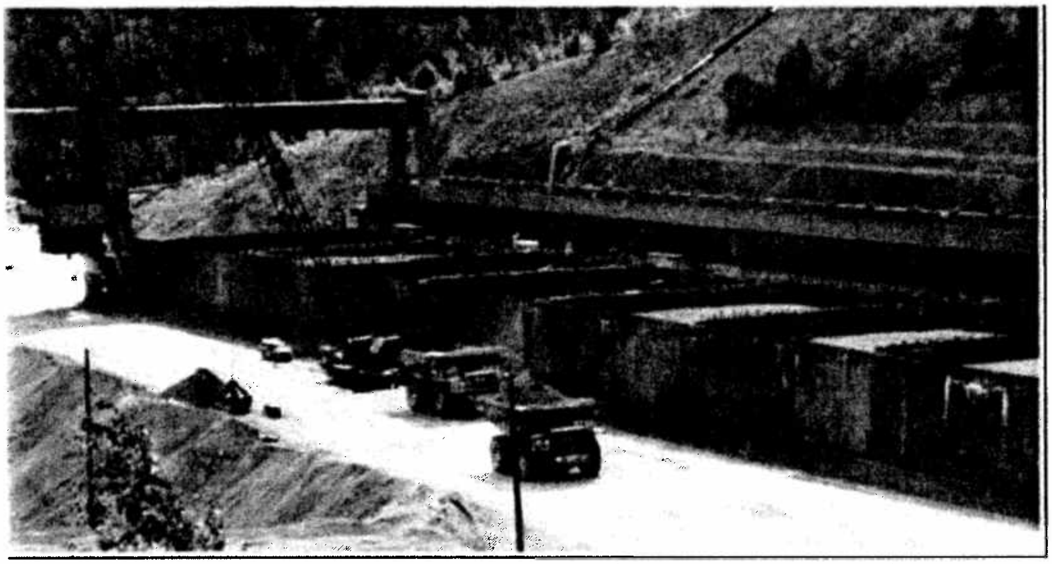

Figure 1: Vats used for leaching/rinsing/neutralization pilot tests at Mines Gaspé

The granulometry of the crushed Gaspé ore (Table 1) is similar to that of the Carmacks ore used in column tests (Alexco, January 2006). The mineralogy of the Gaspé ore prior to leaching (Table 2) is also somewhat comparable to that of the Carmacks ore, as described in Western Copper Corporation (February 2007, Section 3.1.3.3). Both ores contain malachite, significant quantities of iron hydroxides and oxy-hydroxides, and very little sulphide minerals.

Table 1. Mines Gaspé Ore Size Distribution

Mesh	Opening (µm)	Cumulative Passing (% mass)
5"		99.2
4"		97.3
3"		94.2
2"		81.7
1"	25400	50.2
3/4"	19050	42.8
1/2"	12700	33.5
3/8"	9525	27.3
4	4699	18.0
14	1168	9.6
28	589	8.0
48	295	6.9
100	147	5.8
200	74	4.4
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Table 2. Mineralogy of Gaspé ore prior to leaching

Mineral	Content (%)
Quartz	37.0
Augite	15.0
Feldspar	32.0
Sulphides	0.1
Malachite	1.0
Graphite	0.1
Hydroxides	14.0
Ilmenite	0.8

To simulate heap leaching, an acid leaching solution was percolated from rows of flexible plastic tubes installed on top of the ore and fitted with drip emitters (Figure 2). The distance between drip emitters was approximately 60 cm. Unsaturated conditions were kept over the entire height of the ore at all times.

Figure 2: Rows of flexible plastic tubes with drip emitters used to apply the leaching/rinsing/neutralizing solutions on top of the ore.

Once the copper concentration in the leachate dropped below a value at which copper recovery was no longer economical, application of leaching solution stopped and the ore was allowed to drain for about 3 weeks. A summary of the operating conditions for the entire decommissioning test is given in Table 3. The spent ore was first rinsed with fresh water for 22 days at a rate of 16 $L.m^{-2}.h^{-1}$. Next, we rinsed at the same rate with lime solution containing 1 g/L to 0.06 g/L lime. Lime solution rinsing was aborted after 2 days, when we found that about 75% of the drip emitters were clogged by undissolved lime particles. The irrigation system was purged before resuming fresh water rinsing at a rate of 16 $L.m^{-2}.h^{-1}$ for another 75 days. Rinsing with a solution containing 3g/L sodium carbonate (Na_2CO_3) was then tested for 19 days at the same rate. Because its solubility in water is ~70 g/L (compared to ~1.5 g/L for lime), sodium carbonate caused less suspended solids problems than lime. During the 16 days of draindown that followed, we continued to collect and analyze the effluent. Next, we replaced the irrigation tubes with sprinklers to achieve a more uniform solution distribution over the ore surface. We then resumed sodium carbonate rinsing for 37 days at one quarter the previous rinsing rate (4 $L.m^{-2}.h^{-1}$). Sodium carbonate was added to the rinse solution at a concentration of 3 g/L only intermittently (i.e. generally 9 hours per day, 5 days a week). The rest of the time, the ore was rinsed with fresh water. Thirty minutes before turning off the rinse, a slug of 1 kg of Rhodamine B dye was injected in the rinse solution line to enable the visualization of flow routes during the subsequent excavation of the vat. The pilot test ended with a second draindown period of 18 days. A total of 6.35 m^3 of rinse solution per tonne of ore had been applied by the end of the pilot test. This is more than twice the amount of rinsing solution used in the column rinsing tests carried out with Carmacks spent ore (Alexco, January 2006; Alexco, June 2006).

Table 3. Operating Conditions Summary For Rinsing/Neutralization tests of Gaspé spent ore

Decommissioning Stages	Duration (Days)	Rinsing Flow Rate (L/m^2/hr)	Effluent Volume (NV$^{\&}$)	Cumulative Effluent Volume (NV)
Draindown after leaching	47	0	N/D$^+$	0*
Fresh water rinse (1)	22	16	1.00	1.00
Lime solution rinse	2	16	0.10	1.10
Fresh water rinse (2)	75	16	3.44	4.54
Soda Ash Solution rinse (1)	19	16	0.81	5.35
Draindown	16	0	0.06	5.41
Soda Ash Solution rinse (2)	37	4	0.90	6.31
Draindown	18	0	0.04	6.35

[&] 1 normalized volume (1 NV) = 1 m^3 of effluent per tonne of ore

[+] Not determined

[*] Cumulative effluent volume is calculated from the start of the first fresh water rinse

Figure 3 show the evolution of copper and pH in the effluent of Vat #2 versus normalized volumes (NV) of effluent during the decommissioning test. By definition, 1 NV corresponds to 1 m^3 of effluent per tonne of ore. Both the dissolved and the total concentrations of copper are depicted.

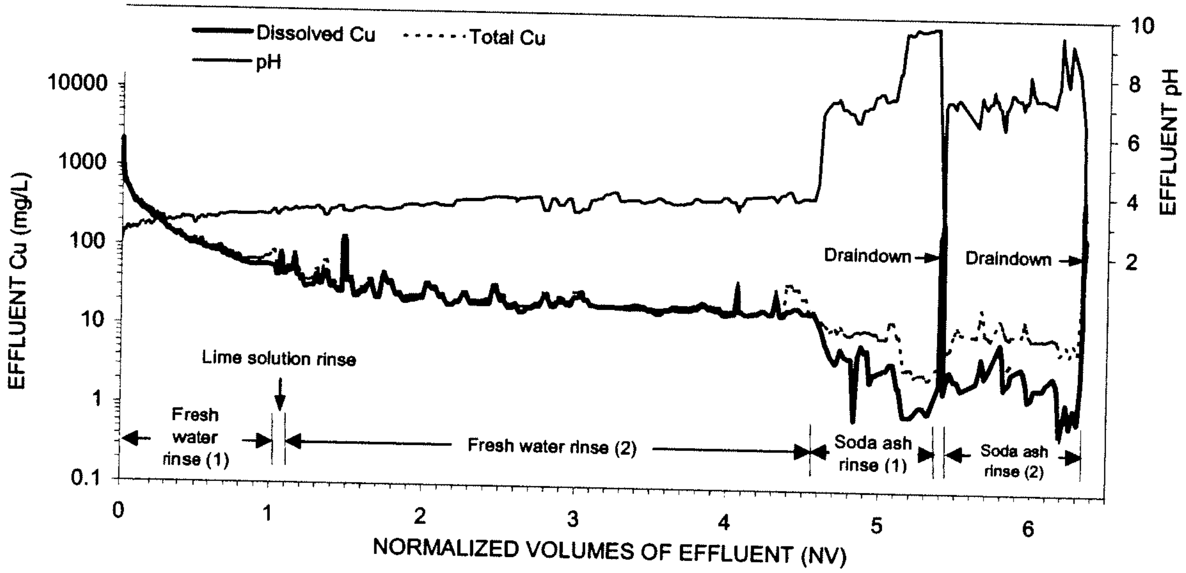

Figure 3: Evolution of pH and copper concentration in the effluent

The Cu concentration seemed to stabilize at ~20 mg/L by the end of the second fresh water rinse. Between the start of the first and the end of the second fresh water rinse, the effluent pH increased only from 2.2 to 4.0. The rate of pH increase also slowed down as fresh water rinsing progressed. These results are very similar to those reported for the spent Carmacks ore (Beattie Consulting Ltd., 2001; Alexco, 2006). Lime solution rinsing, did not have an appreciable effect on pH and the effluent concentration of copper.

When sodium carbonate was added to the rinse solution, the effluent pH quickly rose to ~ 7 and the dissolved Copper concentration dropped to between 0.8 and 7 mg/L. Total copper concentrations began to significantly exceed dissolved concentrations during sodium carbonate solution rinsing, possibly because of entrainment of precipitated malachite in the effluent. Geochemical modeling of the effluent chemistry suggests that copper precipitated as tenorite ($Cu(OH)_2.H_2O$) in the ore as the pH increased to pH~9.5.

When rinsing with sodium carbonate solution was stopped and the ore was allowed to drain down, the effluent pH dropped quickly to less than 3.0 and the copper concentrations rebounded to a very high value of 240 mg/L. Such behaviour was not reported for the Carmacks ore. A possible explanation for this difference is provided below. The change of solution distribution system at the end of the first draindown, from drip emitters to sprinklers, had little effect on the outcome of the second sodium carbonate rinse. The evolution of the effluent pH and metal concentrations that were observed during the first sodium carbonate rinse and draindown repeated themselves (Figure 3).

Upon completion of the decommissioning test, the Gaspé rinsed ore was excavated in five successive layers of similar thickness. Visual inspection of the ore during the excavation revealed no segregation of grain sizes. However, a pattern of brown and grey zones having vertical continuity and generally measuring less than 60 cm in width (similar to the distance between drip emitters) was visible everywhere in the ore (Figures 4a and 4b). Because the same pattern was observed during the excavation of Vats #3 and #4 that had been leached but not rinsed (Figure 5), it follows that the pattern was created during leaching. In the brown zones, the ore was consolidated by some cementing materials, which were identified to be natrojarosite and gypsum by x-ray diffraction analysis of the -200 mesh fraction. By contrast, grey zones remained loose. Because no rhodamine dye was detected in the grey zones, the permeability of grey zones must have been sufficient for the dye to be completely flushed out during the thirty minutes of rinsing after the injection. On the other hand, rhodamine was seen in the brown zones from the surface of the ore down to depths of about 12ft, thus indicating that brown zones were much less permeable than grey zones.

Analysis of excavated ore samples showed that on average, grey zones had significantly lower copper and iron contents than brown zones. Since the ore was homogeneous in Cu content prior to leaching, and since rinsing with fresh water or alkaline solution did not significantly affect the Cu content of the leached ore, differences in copper contents between grey and brown zones must necessarily point to differences in degree of leaching. The grey colour of the well-leached ore likely resulted from contact with sufficient acid solution to dissolve the iron hydroxide coating.

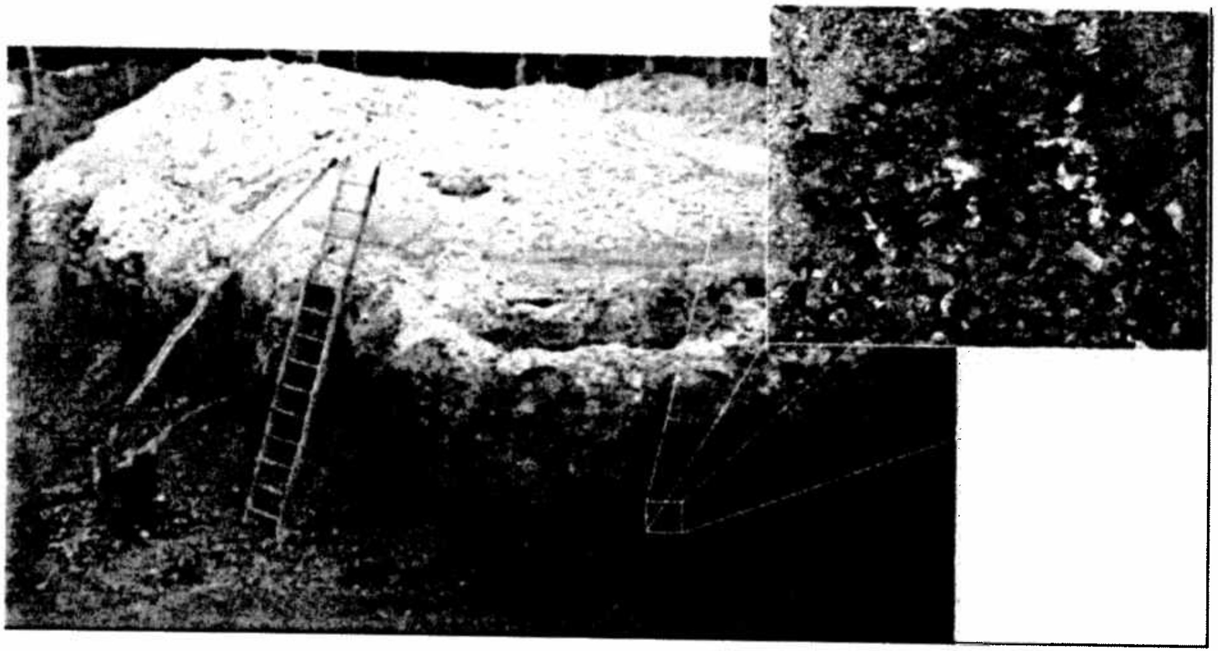

Figure 4a: Vertical section of rinsed ore during excavation of Vat #2 showing brown zones and grey zones. Snow appears white on top of the ore. Insert shows cemetation cause by precipitates in the brown zones.

Figure 4b: Vertical section of rinsed ore during excavation of Vat #2 showing brown zones and grey zones.

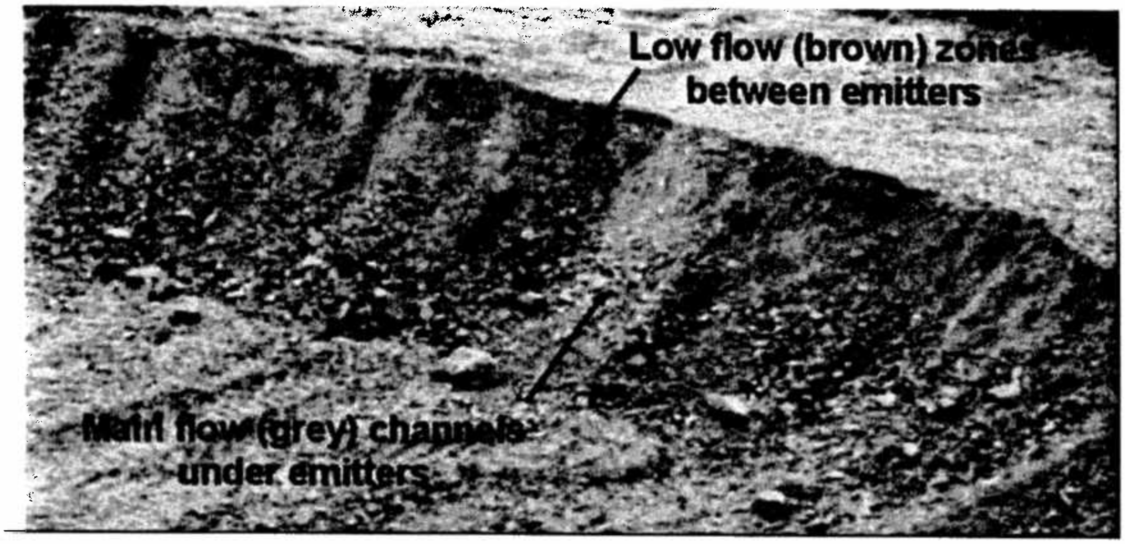

Figure 5: Vertical section of leached ore (not rinsed).

To compare the efficiency of rinsing in the two types of zones, we evaluated the ability of the grey and brown ore from Vat #2 to release acidity and metals to infiltrating water. This was done by mixing 1 kg of each material with 1.2 L of deionised water and bottle-rolling for 24 hours. The pH and concentrations of selected ions were then analyzed in the leachates. Because the pH was higher and copper concentrations were lower by two orders of magnitude in the leachate of grey samples, we concluded that rinsing was much more efficient in grey zones than in brown zones, which is consistent with the fact that grey zones were more permeable and located directly below drip emitters.

In the Mines Gaspé plot tests, preferential flow of the leaching solution took place in routes directly beneath the drip emitters. Between these routes, higher-pH gaps may have favoured the precipitation of natrojarosite and other secondary minerals. These minerals then plugged the pores in the ore, caused cementation, and reduced the permeability. Mineral precipitation was probably a self-reinforcing process in brown zones because the loss of permeability led to a further reduction in the flow rate of acid solution through these zones, and therefore to a higher pH and to more precipitation. After leaching, residual concentrations of mobile metals in the spent ore were divided between main flow routes (interconnected pores in the grey zones under drip emitters), low-flow routes (interconnected pores in the brown zones between drip emitters), intraparticulate pores, and possibly sorption sites on the ore grains. Intraparticulate pores include dead end pores and fractures. Because intraparticulate pores mostly contain stagnant solution, molecular diffusion is the main process by which they can release acidity and metals.

The fast decrease of metal concentrations in the effluent at the beginning of the first fresh water rinse (Figure 3) coincided with the displacement of these metals from the main flow routes. During the slow phase of water rinsing, effluent concentrations of copper were controlled by the slow release of metals from low flow routes and intraparticulate voids. During soda ash solution rinsing, precipitation of Cu in the main flow routes significantly lowered their concentration in the effluent. However, low flow routes may have retained elevated concentrations of dissolved metals even throughout sodium carbonate rinsing, because the residual acidity diffusing from adjacent intraparticulate pores sites may have been sufficient to neutralize the small amount of incoming alkalinity. As long as rinsing continued, whatever acidity was released from low flow routes was neutralized by the excess alkalinity present in main flow routes and, therefore, did not impact on effluent quality. Nevertheless, this pattern changed when rinsing stopped and the ore was allowed to drain. Main flow routes emptied quickly, whereas solution contained in low flow routes drained more slowly and for a longer time. As a result, the fraction of draindown solution contributed by low flow routes increased with time, the effluent pH dropped, and the concentration of copper in the effluent bounced.

Although the utilization of sprinklers during the second sodium carbonate solution rinse improved the uniformity of solution distribution on the ore surface, it did not reverse the mineral precipitation that had previously occurred between drip emitters during leaching because the flow in the cemented regions was too small to allow appreciable mineral dissolution. As a result, the rinsing of contaminants from brown zones was not significantly improved, and metal concentrations rose again during the following draindown.

The above results are very relevant to the Carmacks heap leach project because they clearly show that the design of the solution application system (drip emitters) strongly affects the efficiency of both leaching and rinsing. Column tests carried out with the Carmacks ore samples were not able to simulate the flow heterogeneities that result from the use of drip emitters, which are the mode of solution application proposed for the full scale heap (Western Copper Corporation, February 2007). The lack of rebound for pH and copper concentrations in the column tests suggests that the ore was uniformly leached and rinsed in the columns, probably because the solutions were uniformly distributed on the top of the columns and solution channeling was minimal in the columns. However, the use of drip emitters on the full scale heap will likely result in flow heterogeneities similar to those evidenced in the Mines Gaspé pilot trials. This, in turn, will lower the rinsing efficiency and could very significantly increase the length of time required to achieve an effluent that meets regulatory limits. It is uncertain whether reducing the spacing between drip emitters could completely resolve this problem. It also remains uncertain whether improvements to the homogeneity of solution distribution would suffice in practice to prevent low flow zones, since other factors can also contribute to flow heterogeneities. For example, low permeability zones can arise during heap construction from compaction by heavy equipment, size segregation by stacking fines on top, compaction of lower lifts by upper lifts, and migration of fines.

Specific Comments on the Conceptual Closure and Reclamation Plan for the Carmacks Copper Project

The closure plan aims to achieve a “walk away” scenario that will require no further monitoring and maintenance. The proponent claims that the long-term objective of a “walk-away” closure condition has been shown to be technically feasible (Western Copper Corporation, October 2006). When considering the technical information provided to sustain this claim, my opinion is that this claim is premature. I think that further testing is necessary, especially at a larger scale, to assess the effect of the solution distribution system on the rinsing efficiency. During these tests, the solution application system should be optimized to minimize channeling and the formation of low permeability zones. Also, the composition of the draindown solutions should be analyzed to check for the possibility of rebound in copper concentrations once the flow of rinsing and neutralization solutions is shut-off.

There are reasons to suspect that precipitation of secondary minerals during leaching and/or rinsing will affect the permeability of the Carmacks ore in some places and thus affect the rinsing efficiency. For example, Beattie Consulting Ltd. observed that 1) the leach solids became less permeable due to precipitation and deprecipitation of secondary minerals (p.2 of their report); 2) acid leaching of the Carmacks material results in an alteration process, likely to a clay-like mineral phase; 3) the bottom section of one of the test columns (column AB) had become cemented by iron precipitates after rinsing (p. 44 of their report). Western Copper Corporation (October 2006) reports that physical degradation and precipitates in the columns were formed both during acid leaching and during neutralization. These contributed to lower the permeability in local areas, thus limiting local rinsing and neutralization efficiency. In page 3-5 of their report, they admit that some weathering and precipitation are inevitable and can result in lower permeability zones in the heap.

The effect of sodium carbonate rinsing on the mineralogy of the spent ore is not sufficiently well understood. Therefore, it is difficult to predict with confidence whether the effluent will remain neutral/alkaline in the long-term after decommissioning. Beattie Consulting Ltd. (2001) claims that the effect of neutralizing with sodium carbonate solution is "to convert the surface of the alteration products formed during leaching so that they become stable and cease releasing their constituents such as aluminum in solution." However, no reference or data are provided to support this statement. Further work is required to characterize the spent ore after neutralization with sodium carbonate to assess possible mineralogical changes as a result of rinsing/neutralization. One should also investigate whether copper and other regulated metals remain as precipitates in the heap after neutralization, since a change in pH at a later date could re-dissolve these precipitates and release the metals in the effluent.

Although it seems well established that the spent ore has no net acid generation potential (Lawrence, May 2006), it is important to realize that the spent ore will continue to release soluble metals and acidity gathered from leaching if it is not properly neutralized during decommissioning.

If the efficiency of rinsing is significantly hindered by the presence of low permeability zones in the spent ore, similar to what happened in the Mines Gaspé pilot tests, then the planned 4.5 years of rinsing/neutralization will likely be insufficient to meet the MMER standards in the heap effluent. In such case, the available information does not allow to predict by how long the rinsing/neutralization would have to be extended to meet the MMER standards.

More specific information is necessary on how the heap effluent from rinsing and neutralization operations will be treated. The water treatment plant is said to be designed with "a treatment capacity sufficient to handle seepage and any contaminated run-off from the area of the closed leach pad" (Western Copper Corporation, October 2006). However, the effluent flow rates during rinsing and neutralization are expected to be much higher than seepage and runoff from atmospheric precipitation. I couldn't find specific information on the flow rate at which heap rinsing and neutralization will be implemented during heap decommissioning in the Conceptual Closure and Reclamation Plan. The time required to achieve MMER limits will be dependent on the flow rate. The column rinsing and neutralization tests were carried out at a solution application rate of 10 L/h/m^2 (Alexco, January 2006), and the 4.5 years allocated for heap rinsing and neutralization are based on scale up from the results of the column tests (Alexco, June 2006) assuming a solution application rate of 400 m^3/h for the full scale heap. At this rate, only an estimated 1/8th of the heap area will be rinsed at any given time. However, there is no indication in the conceptual closure and reclamation plan submitted by the proponent that the full-scale heap will be rinsed and neutralized at this application rate (400 m^3/h) throughout the entire year, or that the water treatment plant will have sufficient capacity to treat the resulting effluent flow rates. This needs to be clarified.

In the eventuality that the heap effluent does not meet MMER standards after 4.5 years of rinsing and neutralization, the reclamation plan indicates that a contingency water treatment plant would be running for some time, although the closure date for this treatment plant is unclear. According to the closure and reclamation schedule Gantt chart (Table 7.1 in Western Copper Corporation, October 2006), the contingency treatment would end after 16 years, but Drawing ACG-S-01.001 in Western Copper Corporation (October 2006) shows that the contingency water treatment plant would close after 10 years. In any case, it is questionable whether the effluent will meet MMER standards at that time.

Once the water treatment plant is closed, "passive measures" such as a limestone trench, biological treatment cells, and an infiltration gallery will be used for long term release of the heap effluent to the environment. This will last for another 10 years according to Drawing ACG-WS-01.001, although I couldn't find this step in the Closure and Reclamation Schedule Gantt chart (Table 7.1 in Western Copper Corporation, October 2006). However, a limestone trench will not increase the pH at sufficiently high values to reduce the solubility of copper below the MMER standards. Moreover, the efficiency of biological treatment cells will be limited since bacteria may die off during the harsh winters. The reclamation plan provides no data to demonstrate that these "passive measures" would be successful at treating the effluent to MMER standards. On the other hand, the heap effluent volume, even if a cover is put in place, would be significant (20,000 m^3) and would be concentrated in the period of April to August. Therefore, the possibility of significant adverse environmental impacts exists if the water treatment plant is discontinued before the heap effluent meets MMER standards.

I am concerned that the proponent is considering disposing the sludge from water treatment in the leach pad (Western Copper Corporation, October 2006, p. 3-6). If non-neutralized zones remain in the heap, they could cause metal hydroxides in the sludge to dissolve, thus releasing soluble metals. Solidification of the sludge with cement prior to final disposal would be a safer alternative, as the alkalinity and sorption capacity of hydrated cement will offer protection against metal releases from the sludge.

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