

D-5

Post-Reflooded Mine Water Chemistry

TECHNICAL MEMORANDUM

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TO: Jon Cherry (KMC)

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SUBJECT: Eagle – Underground Water Quality at End of Mining with All Development Rock Backfill

BACKGROUND

The water-quality model for the underground mine in the Phase II Geochemistry Report is for an underground mine at full life-of-mine, without backfill. This is the hydraulic basis of the Golder Associates flow values (180 Usgpm total inflow) used in the model. In another Technical Memorandum [Geochimica, 2005a, “Water Quality in Underground Mine During Operational Conditions”, 07 November 2005], Geochimica evaluated water quality for a representative case during operation of the mine, when significant portions of the wall rock would be ore-grade, mineralized rock. In that evaluation, 50% of the wall rock was modeled as Massive Sulfide Ore, using the short-term (i.e., highest leaching rate) data for the ore.

At then end of mining, expected to be in Mine Year 8, essentially all ore-grade rock will have been mined out. KMC plans to backfill the Development Rock before the end of mining. Thus, there will be additional surface area beyond that calculated for the wall rocks alone. The Phase II report assumes that the Development Rock will be equally divided between Country Rock and Intrusives, but would contain no MSU or SMSU. Thus, all the additional surface area from backfilled Development Rock is non-ore grade rock.

TECHNICAL APPROACH

The model for water quality in the underground mine at the end of operations has been coordinated with the current hydrogeological investigations in order to develop a common basis for wall-rock surface area and total mine inflows. The crucial concern is what will be the impacts of final mine walls and backfilled development rock on water quality after mining ends. This problem is evaluated using data updated through laboratory reports in August 2005 (as were the operational case evaluations in Geochimica, 2005a).

The technical approach to the problem is identical to that used for the mine at end of operations and for the development rock at full pad volume, as documented in the Phase II Report (Geochimica, 2005b). The conceptual model for the physical system of the underground workings can be considered in terms of a unit portion of tunnel-like openings. The open workings have some geometric surface area that can be calculated simply from the

dimensions of the workings. For the purposes of illustration in the Phase II Report (Geochimica, 2005b), the tunnel is shown as circular in cross-section, but this is not essential. The geometric surface areas used in the model are derived from computations provided by the mining-engineering team that is planning the underground system. Because of natural fracturing and faulting and the effects of blasting, the total available surface area of the mine walls will be much greater than the apparent geometric surface area. Morin and Hutt (1997) have compiled data showing that available surface area on mine walls may vary from about 20 to about 125 times the apparent geometric surface area. At this time, there are no data on blasting effects, so we have made a reasonably conservative assumption that the actual surface area will be 100 times the apparent geometric surface area. The basic conceptual model is illustrated in Geochimica, 2005a and 2005b. The basic conceptual model for the development rock that will report as backfill is shown in Geochimica, 2005b and 2005 c.

The approach to developing a geochemical estimate is the same as that used in the Phase II Report for both the surface stockpile and the underground workings at the end of mining. The total surface area of mine walls is calculated as described in the paragraph above (i.e., adjusted to account for surface roughness and fracturing), and the inflow water volume is taken from the hydrogeologic model. Based on the 15-Feb 05 mine plan, Golder Associates Ltd. developed surface areas for the exposed walls and calculated mine-water inflow. Based on their results, the total geometric¹ surface area exposed in the underground will be 1.29 E+05 m². The long-term inflow for the entire open workings, based on Golder Associates hydrologic modeling, is assumed to be 981 m³/d (180 USgpm).

The volume, mass and leachability of the development rock that is to be developed is taken directly from the most current model of the Development Rock Pad, as documented in the Technical Memorandum, Geochimica, 2005c, ["Water Quality from the Development Rock Storage Pad During Operations, dated 07 November, 2005"].

The computational model begins with a mass-balance calculation that converts the observed leachate chemistry of test charges of representative rock samples (see below) to leach rates per unit surface area per unit time. The model then takes the total surface area of exposed rock (of each type) and computes an apparent mass leached. This mass is divided by the total inflow volume, producing an average concentration in the aqueous phase. Finally, in the other evaluations, this total mass-balance approach is provided as input to a numerical geochemical model [REACT (Bethke, 1996; 2005)] to compute possible solubility or other geochemical controls. For this evaluation, the average concentrations are sufficiently low that Geochimica judged that it was unlikely that there would be any attenuation by solubility controls for geochemically credible mineral phases. Therefore, the geochemical model was not applied and, the reported values can be considered conservative in the sense that possible controls have not been invoked at this stage.

LEACHATE CHEMISTRY IN MODEL INPUT

¹ As explained in Figure 1, the total surface area exposed to weathering is assumed at this stage to be 100 times the geometric area to account for roughness and fracturing (Morin and Hutt, 1994). Therefore, the surface area used for calculations of the Life-of-Mine model of water-quality impacts is 1.29 E+07 m².

In exactly the manner of the model in the Phase II report, we assume that a small portion of ore grade rock (2% Massive Sulfide Unit and 8% Semi-Massive Sulfide Unit) would be left in the walls of the underground mine at the end of mining. This accounts, conservatively, for ore grade rock left in pillars and other support pillars or at the physical limit of mining in the final outer walls. For both the development rock and the non-ore wall rock, we assume that there is 50% Country Rock and 50% Intrusive, with the intrusives split between Low- and High-S intrusives. The access development and the backfilled development rock will have been exposed to the underground air for a considerable period of time (several years). Note that is a different conceptualization than was used for active mining, for which we assumed that the ore would always be fresh rock. To represent the conceptualization appropriate for closure, we take long-term data [i.e., the maximum period available as of the August 2005 cutoff for this series of calculations] from the column-leach tests for the unmineralized intrusives and country rock. Input data, updated since Geochimica (2005b) to include the most recent results are summarized in Table 1. When input data are less than the limit of detection, they are entered in the model as $\frac{1}{2}$ the limit of detection.

OPERATIONAL MODEL RESULTS

The results of the equilibrated model are presented in Table 2 for the same parameters that are shown for input waters in Table 1. In cases where input data were less than detection, output data are modeled using a value of one half the largest detection-limit in the set. Readers are directed to the Phase II Report for further discussion about the modeling approach and assumptions.

Table 1 Input Leachate Chemistry for UG Mine at End of Mining² (mg/L except pH in su and Alkalinity in mg CaCO₃/L)

Parameter	Country Rock	Intrusive	SMSU	MSU
pH	6.1	7.1	4.76	4.15
Alkalinity	6.8	8.4	1	0
Total Dissolved Solids	145	164	772	391
Calcium	12	9	8.93	0.43
Magnesium	8	16	1.2	1.6
Sodium	2	3	3.3	1
Potassium	2	6	1	1
Bicarbonate	5.5	6.9	0.75	0
Sulfate	72	82	460	235
Chloride	0.5	0.6	1	2.5
Fluoride	0.07	0.09	0.02	0.02
Aluminum	0.32	0.62	0.019	0.005
Antimony	0.0004	0.0002	<0.0001	<0.0003
Arsenic	0.01	0.001	<0.0001	0.00013
Barium	0.007	0.015	0.03	0.002
Boron	0.03	0.13	0.66	0.012

² The reported values are observed concentrations from the Phase I and Phase II column tests. Background concentrations of groundwater infiltrating the workings are addressed by others.

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Table 1 (continued) Input Leachate Chemistry for UG Mine at End of Mining (mg/L except pH in su and Alkalinity in mg CaCO₃/L)

Parameter	Country Rock	Intrusive	SMSU	MSU
Cadmium	0.0020	0.0021	0.003	0.00085
Chromium, Total*	<0.0005	.0009	<0.0005	<0.0005
Cobalt	0.111	.053	0.721	0.363
Copper	0.40	1.13	0.017	0.015
Lithium*	0.007	.009	<0.005	<0.005
Lead*	0.007	.019	<0.0001	<0.0001
Iron	2.51	4.77	0.36	89.3
Manganese	0.48	0.17	0.0006	0.00055
Mercury *	<0.00005	<0.00008	0.006	<0.00001
Molybdenum*	<0.0004	<0.0001	<0.0004	<0.0004
Nickel	0.63	1.65	68.2	39.9
Selenium	0.0005	0.0032	0.016	0.0045
Silver*	<0.00002	<0.00001	0.0002	0.0002
Strontium	0.104	.09	0.06	0.0045
Thallium*	<0.0001	<0.0001	<0.0001	<0.0001
Vanadium*	<0.001	.0015	<0.001	<0.001
Zinc	0.32	0.18	0.06	0.0127

*: Values less than detection entered in model as ½ detection limit for calculational purposes

Table 2 Incremental Water Quality for UG Mine at End of Mining³ (mg/L except pH in su and Alkalinity in mg CaCO₃/L)

Parameter	Value	Parameter	Value
pH	6.8	Cadmium	0.00008
Alkalinity	9	Chromium, Total**	0.00013
Total Dissolved Solids	57	Cobalt	0.018
Calcium	5	Copper	0.0021
Magnesium	3	Lithium	0.0013
Sodium	1	Lead	0.00003
Potassium	2	Iron	0.78
Bicarbonate	11	Manganese	0.0016
Sulfate	28	Mercury **	0.00004
Cl	5	Molybdenum**	0.013
F	0.10	Nickel	1.77
Aluminum	0.004	Selenium	0.0006
Antimony	0.00003	Silver**	0.0045
Arsenic	0.00006	Strontium	0.04
Barium	0.008	Thallium**	0.008
Boron	0.07	Vanadium	0.0003
		Zinc	0.0019

** Input values for source rocks are less than detection, assumed to be ½ detection limit.

³ The reported values are incremental concentrations due to wall-rock leaching. Background concentrations of groundwater infiltrating the workings (evaluated by others) would be additive to these.

DISCUSSION

The only parameter that is noticeably different from common water-quality criteria in this evaluation is nickel. This is a high-grade nickel ore deposit, and nickel will be released during the incipient oxidation of pentlandite and pyrrhotite in the small amount of ore-grade rock that remains exposed in the mine walls or from the low-grade sulfides in the country rock and non-mineralized intrusives in wall rock and backfill. The small estimated values for cobalt, copper and zinc are likewise derived from oxidation of the small concentrations of sulfides in the wall rock and backfill. Unlike some other transition metals (e.g., Fe), there is no geochemically credible solubility control for Ni once it has been released, so its elevated concentration during operational conditions is expected. The pH estimate remains within water-quality criteria, and the model indicates the likelihood of residual carbonate alkalinity. Unlike the projected case for operational conditions (Geochimica, 2005 a), in which there is a very large reservoir of sulfide minerals from the exposed ore, in the post-mining case, the amount of acid generation from the small residual sulfide content does not overcome the available neutralization capacity.

As for the other Geochimica models for underground water quality (Geochimica, 2005a and 2005b), groundwater flowing into the workings will have reacted with surrounding bedrock over many of years and will already have a solute load that makes it different chemically from de-ionized water used in the column tests. Therefore, the outcomes from this modeling exercise need to be understood as incremental concentrations, the values of which need to be added to the likely groundwater chemistry in order to estimate the water that actually would report to sumps in the underground at the end of mining.

The results for the end of mining with all the Development Rock included is only slightly different from the values calculated in the Phase II Report (Geochimica, 2005b) without consideration of the Development Rock. In part, the differences result from use of updated kinetic test data, which generally show declining leach rates with time. Evaluation of the mass balance as applied to the conceptual model used for water-quality modeling explains why the impact of the Development Rock is small. Leach rates in this modeling approach are based on total surface area of exposed rock. The total increment of surface area (using the analysis for Development Rock from the Phase II report) amounts to about 22%. The total inflow value remains the same. Thus the expected water-quality is only slightly more concentrated than previously calculated. The effect is less than the full 22% surface area increase because there is no high-reactivity MSU or SMSU in the additional development rock, because no ore-grade rock will report there. The declining rate of leaching over time is characteristic of natural as well as laboratory weathering, provided there is not input of fresh acidity along the weathering path. As such we consider that the laboratory trends are good approximations of real-world weathering based on the test data that have been collected to date.

The calculations summarized here assume that the wall rock and backfilled development rock would weather as simulated by the column-test results available to date. These tests do not include the effects of any mitigation steps that might be considered, and therefore are conservative with respect to onset of acid generation. In Kennecott's planning, the long-term acidification potential would be controlled by the inundated condition. The solubility limit of dissolved oxygen in water is about 10 mg/L (ranging slightly, depending on

temperature and total dissolved solids). Because pyrite oxidation requires oxygen and the rate of oxidation is dependent on the amount of oxygen available, inundation is a demonstrated technology for limiting acid-rock drainage potential.

Re-saturation of the workings will require some time; estimation of the re-saturation rate is outside the scope of our terms of reference and is being addressed by others. The column tests conducted to date do not include the effects of any limestone or cement addition. Kennecott will add cement to structural backfill in the underground workings during mining, and this can be augmented with alkaline addition to other, non-structural backfill to provide additional available neutralization potential to the entire underground system. The use of limestone or other alkaline amendments would decrease the risk of acid generation until the system can be re-flooded, but would not significantly affect the water-quality outcomes of this evaluation in the short run. In particular, because the observed nickel concentration is controlled by release not by the pH condition, adding limestone would not decrease expected concentration of nickel. Quantitative evaluation of this potential mitigation step would require detailed engineering plans that would be formulated in subsequent, feasibility studies. However, it is clear that any such amendments provide additional water-quality protection against acid generation and elevated metals leaching

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