# PREDICTION OF WEATHERING OF MINE-MILL TAILINGS AND THE MIGRATION OF ACID CONTAMINANTS IN THE DESIGN OF TAILINGS IMPOUNDMENTS AND MANAGEMENT FOR OPERATION AND CLOSE-OUT

*Gordon M. Ritcey*

(G.M. Ritcey and Associates Inc., Nepean, Ontario, K2H 8A9, Canada ( gmritcey@attglobal.net)

## ABSTRACT

The type of design of a total tailings and waste management will be determined by many factors, including the type of solids and solutions deposited; the chemical and mineralogical aspects; the impoundment design; the disposal technique used; water management; and reclamation. To accomplish the optimum in design as regards minimizing the environmental impact at minimum cost, will initially require the assessment of waste materials when allowed to weather in the natural environment. The prediction of weathering and the subsequent migration and seepage from the impoundment is necessary in the optimal tailings management design.

The predictions of weathering and migration can be complex, in that many biogeochemical interactions take place in the microenvironment of the tailings impoundment. Typical reactions include dissolution; precipitation, re-dissolution, sorption, desorption, ion exchange reactions, oxidation-reduction, complex formation etc. These reactions are enhanced by biological processes.

Because of the complexity of the weathering processes, a prediction of weathering in the material that will be impounded, prior to the design of the tailing system would be useful in the optimization of the design criteria for minimizing environmental impact.

This paper describes a predictive methodology, developed by the author (1), that has been successfully applied to the assessment of rates of weathering in a tailings - waste rock impoundment, and the migration of contaminants. With the predictive techniques, performed as kinetic tests in various sized containers (lysimeters) containing the tailings /waste rock material, any adverse impacts can be determined. Effluent quality will be determined, disposal options can be examined and compared, and rehabilitation techniques subsequently designed to facilitate close-out when mining ceases,

## INTRODUCTION

Over time, as weathering of the tailings proceeds, seepage of contaminated solutions into the receiving environment results. The concern by the mine operators and the community may result in an attempt to treat the contaminated waters; to provide diversion ditching; consider recycle of water from the tailings pond; change the method of discharge; alter the height of the dykes, etc.

Often, the changes that are made appear to be based on the consideration of only the geo-technical aspects. Very little attention is being given to the many other complex systems within the total operation that can affect the waste management system.

The object of an integrated tailings research program is to develop a tailings management strategy based on obtaining an understanding of the biogeochemical reactions that occur during the weathering process. This will involve accelerated weathering tests under controlled conditions representing the geographical and meteorological conditions of a particular mining site. Such information will enable the prediction of mobility and migration of such contaminants as acid, alkalies, cyanides and metal contaminants within the tailings, and the migration to the environment. Based on the tests, various tailings management practices can be implemented, including the treatment of effluents during the operating phase, as well as producing design criteria for close-out.

The research into investigating tailings and waste materials for long-term leaching effects and migration to the environment started over 20 years ago. As a result of intensive investigations at CANMET, in Canada, a methodology was developed based on the research and on the data generated. Accurate predictions of acid generation, and rates of release resulted (Ritcey and Silver, 1982). Deposition methods were investigated (Silver, Ritcey and Cauley, 1985) and found to have significant effects on the water management and on contaminant mobility. The tests, performed in lysimeters, also indicated that stable "hardpans"(x) could be formed that would decrease the mobility of contaminants, and also that in addition to the oxidizing bacteria prevalent in the case of sulphides and oxidation, there were the reducing bacteria that could assist in the creation of anaerobic conditions for immobilizing sulphates (Ritcey, 1989).

This methodology (Ritcey and Chomyn, 1984; Ritcey, 1989) that was developed for research on tailings and wastes has been successfully applied to various mines in Australia, Africa, Brazil, Canada, France, and include acid producing as well as non-acid producing wastes. Mining operations include uranium, gold, cobalt, nickel, and copper. Some mines were new operations, some had been in production, while others had been abandoned for many years.

## METHODOLOGY

In an ideal situation, the design of a tailings and waste management scheme should be conducted concurrent with the metallurgy development. If the mine has already started operation, or has ceased operation, a program for close-out can still be developed by performing certain tests. These tests should be carried out in "lysimeters" under controlled, simulated accelerated weathering conditions in order to establish the impact of weathering on the long-term abandonment of waste rock and tailings.

Controlled tests to simulate weathering and to determine the effect of water transport on resulting migration are conducted in vessels known as lysimeters. The word Alysimeter@ has been described in the early agriculture literature, as well as the geological; reports. The following is a composite definition (Gary et al, 1972) of a lysimeter: Aa structure containing a mass of soil, . It consists of a basin, having closed sides and a bottom fitted with a drain. Quantities of material and/or artificial precipitation are measured, the seep percolate is measured and analysed, water of evaporation is measured, water taken up to plants is weighed, etc. Some typical lysimeter designs are given in the comprehensive text (Ritcey, 1989). The lysimeters should be constructed of a plexiglass-type material so that "weathering" can be observed. The size of the lysimeter should be such as to contain at least 50 kg of material so that sufficient depth and area are provided (the size may be considerably larger depending upon the test, the number of core samples to be taken, and the expected duration of the test). An outlet for the water discharge would be provided, with a "water table height control" which could be raised or lowered as required.

The simulated accelerated weathering will be based on the typical average rainfall per area of that site for the "wet" period, and determining the number of times acceleration of rain that can be applied to the lysimeter before the water "ponds" and does not surface dry prior to the next application of rain. The amount of acceleration will depend on the fineness of the tailings/waste rock, and the presence of clays. A ten-fold water application, for example, would equate to a simulation of 10 years, providing a wet-dry cycle occurs in the tests.

Initially, measurements of the effluent seepage may be taken weekly and analysed, for example: Cu Fe $SO_4$ Ca Mg Si Al Na Eh-pH, and oxidizing/reducing bacteria. After a few weeks, the frequency of sampling-analysis can be decreased to every 2nd week, and later monthly samples.

Solid samples will require less frequent sampling. If there is sufficient area on the surface of the lysimeter to permit a few core samples, then one after about 3 months, and of course one at the end of the tests. Examine the cores at depth (mineralogy) and perform the various chemical analyses, (as noted earlier), on the solids and the pore water. Compare the analyses of the solids with the material originally deposited in the lysimeter. Also, analyze for aerobic bacteria in the oxidizing zone, and anaerobic bacteria in the reducing zone, as well as Eh-pH of the zones if possible. Also compare the ore texture with the original, and assess if any particular degradation has occurred over time.

When a trend has been established, the test data should be examined, and a decision made whether to terminate some tests, or perhaps start new tests.

The above tests should be considered as preliminary tests to indicate whether a problem of AMD might be anticipated. The lysimeter(s) being tested for acid generation can be continued, and the biogeochemical reactions studied so as to make some predictions as to contaminant releases and mobility through the tailings. Subsequently, as the geochemistry is becoming evident, a close-out strategy may be developed by examining cover materials, and the development of a "hardpan" and an anaerobic zone. If water management is a problem, then there will be tests on examining various tailings deposition methods for best dewatering and compaction. The less water (and air, bacteria) entering the tailings will result in decreased rate of sulphide oxidation.

## CASE STUDIES

### Uranium Tailings

The initial tests using lysimeters were conducted in boxes, each containing about 1 tonne of tailings material.(Ritcey and Silver, 1982; Silver and Ritcey, 1982; Ritcey 1989) Although the main purpose was to determine the weathering and migration fate of radionuclides, the secondary was to determine the possible rate of release of acid during weathering. These tests were successful, for they predicted very accurately the rate of acid generation in those particular tailings as 3 years; the release of radio nuclides and downward migration and accumulation as fixed sulphate; in the presence of oxidizing bacteria (*Thiobacillus ferrooxidans)*, the rate of acid generation was enhanced; but that of radium solubility was depressed; when oxidizing bacteria was absent, the rate of acid generation was severely decreased while that of radium release was increased (Silver and Ritcey, 1985).

An oxidizing product of secondary iron minerals was generated in the upper weathering zone, and appeared to inhibit seepage over time. This was the first evidence of an oxidized zone of hardpan.

Subsequent tests on a Ni-As-S-U tailings (Ritcey, 1989) material indicated that although the sulphide content was about 0.5 % compared to the initial material examined (above) at 5%, there was some acid generation over time but which was neutralized by the contained alkalinity; retardation mechanisms were formed between As-Ra, thus stabilizing and impeding the migration of Ra.; salts generated by capillary action as drying of the tailings occurred were generated, which were identified to be characteristic of this type of uranium ore mineralogy; the deposit was subaeriel, and the weathering indicated run-off to exceed seepage, which indicated the migration problem would be minimal at close-out compared to the usual random spigot discharge; weathering showed the physical break-down of particles either by dessication or by freeze-thaw cycles, which would ultimately increase the rate of biogeochemical weathering.

Subsequent tests on a thickened discharge type of deposition (Silver, Ritcey, Cauley, 1985) showed that the amount of run-off vs. seepage was again higher as compared to that of subaeriel, and thus contaminant migration would also be decreased. Of course, the eventual rehabilitation and vegetation would be more easily facilitated.

When anaerobic conditions (low Eh) could be produced, such as disposal underwater (Ritcey. 1991) or when an organic cover could be used over sulphide tailings (Ritcey, 1989; Jongejan and Ritcey, 1982), the oxidation was inhibited and no acid was generated. The effluent pH was about pH 8. Reducing bacteria (*Desulphovibrio)* were found at the water table, along with the reduced metal sulphate as sulphide precipitates. This sulphide layer, which was becoming more impervious with time, was the first indication of a reducing hardpan formation. (This has been verified and identified in numerous base metal sulphide tailings impoundments).

### Base Metal Tailings (Cu, Cu-Zn, Cu-Pb-Zn)

Tests on 75 different sample sources indicated that, when static acid-base accounting tests were performed and compared to the kinetic lysimeter tests, that there was only an agreement of perhaps 50% of the static tests (Ritcey, 1989; Lawrence, Ritcey et al., 1989; Lawrence, Poling et al., 1989). Further static tests were deemed as unreliable (this was subsequently verified in a nickel tailings evaluation). The tests were on samples containing as low as 0.25% S and ranging up to about 90% S. On the low sulphide material, if therẻ was sufficient calcareous minerals present, generally there was no acid migration problem and no release of metal sulphate. Providing an anaerobic cover over the tailings resulted in reducing bacteria at the water table and a high pH and low EhB even at the extremely high sulphide material. Similar results were also obtained when the sulphides were placed under water. The tests also indicated that only a small few cm. were required of either water or an organic soil (eg. compost) to achieve anaerobic conditions and therefore no production of acid, and the acid and metal sulphate that were produced were converted to metal sulphide precipitates in the anaerobic zone.

### (Ni)

This project was initiated while the total plant was in the design mode, and thus there could be an early influence on the ultimate design of the tailings management system. Although the plant is now well into the operational phase, the lysimeter tests are still progressing in order to provide data sufficient for the design for final close-out.

The mineralogy includes Mn in addition to Ni, together with lesser amounts of Co, Cu, Cr. Tests have indicated that unless there are anaerobic conditions, leaching of Mn and Ni can occur but acid is essentially neutralized by the calcareous material present; considerable sulphate is released, mostly present as Ca and Mg sulphate; water retention was improved with clay and soil; and an apparent suitable cover over the tailings could consist of crushed waste rock (to prevent salt migration upwards), soil, clay, followed by vegetation. Typical analyses of the exiting effluent are, in mg/L: Ni 0.01-0.07, Mn 0.04-0.13, pH 7.

### Gold Tailings

There have been about 80 lysimeter tests on this on-going investigation of long-time operating mine. The tests were designed to provide information and data that would be required for the eventual close-out. Because of the open pit operation, with increasing depth, the Au tenor decreased, while the sulphide content increased. Increased sulphides would mean more cyanide demand in leaching, and so flotation of the major sulphides would be considered if the lysimeter tests indicated that close-out of both low and high sulphide containing tailings would prove feasible.

The tests indicated that the low grade sulphides (0.1% S) resulted in no acid generation, an effluent pH 8.0, Eh of 250mV, but a solubility level of 0.3 mg/L As.

At the higher 0.3% S level, acid was generated; the effluent pH was about 2.5 and the Eh >500 mV, and salts were produced which travelled upwards; precipitation of As within the tailings was achieved if sufficient $Fe^{3+}$ was present in the oxidizing zone, and this precipitate appeared very insoluble within that particular microenvironment; Zn was precipitated or sorbed onto the Fe-As precipitate; the presence of excess carbonate (eg. limestone) results in the precipitation as Fe as a carbonate, resulting in solubilizing the As together with some Zn.

Organic and clay covers were successful in producing anaerobic conditions, such that sulphides were precipitated. With the Fe hardpan in the upper oxidizing layer, and the sulphide hardpan in the lower reducing zone, the effluent met environmental specifications as regards pH and metals content. (130 mg/L Sulphate, 0.03 mg/L As, and 0.02 mg/L Zn). Vegetation was easily sustained on the surface when the conditions were anaerobic. Samples of drill cores at 1% S were also successfully converted to anaerobic conditions; clay proved capable of sorbing the As; The clay could thus be considered for incorporation as a barrier for As. The $As^{2+}$ has a greater mobility compared to $As^{3+}$, providing there is sufficient $Fe^{3+}$ present to co-precipitate Fe-As.

Because of the success of the lysimeter tests and their analyses, prediction was possible in a number of areas throughout the operation. It was therefore possible to devise a scheme for the 3 phases - Operational, Transitional, and Close-out.

## CONCLUSIONS

In order to adequately model the mine-mill-tailings system and to make adequate predictions for long term safe containment of these wastes, the models need to be built upon a clear description of the chemical, geochemical, biological, and physical processes that occur in the tailings over time and therefore upon accurate data obtained from accurate analyses. Baseline data are therefore most important. From the time that the rock is mined and processed, and the wastes are discharged to the impoundment area, the solid and liquid effluents constantly undergo changes. Knowing and understanding these biogeochemical changes and determining the major factors will provide the understanding necessary for predictions to be made. The purpose is to ultimately describe the chemical and physical processes that control the migration of contaminants through and out of the tailings.

The examples to date have amply demonstrated the applicability of the methodology to the design of the tailings management system as regards weathering and prediction of contaminant release and migration.

## ACKNOWLEDGEMENTS

The author acknowledges Rio Tinto (Brazil ) in regard to the lysimeter investigations at the Rio Paracatu Mineracao gold operation and the Mineracao Serra da Fortaleza nickel mine. where the data on the gold and nickel case histories originated.

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