Acid metalliferous leaching of a mineral sands deposit: From field to laboratory.

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Abstract

Several geochemical investigations were conducted as part of a pre-feasibility study (PFS) for a mineral sands deposit to determine whether mining activities will promote acid and metalliferous drainage (AMD), and the potential effects of AMD on process water quality and groundwater quality.

A combination of field techniques was used to 'screen' samples for more thorough static and kinetic investigations. The correlation of field and laboratory results have indicated the value of field testing in obtaining a rapid indication of potential contaminants of concern and in identifying lithological units to be targeted for further testing and mine waste management.

Keywords: AMD, metal leaching, mineral sands, static testing, kinetic testing, geochemical modelling

Introduction

Geochemical characterisation programs for investigating acid mine drainage (AMD) and metallifereous leaching (ML) is a technical process which involves the analysis of many samples via a range of different techniques. Accurate AMD and ML detection may save significant costs associated with remediation and lower the risks of environmental impacts. The use of appropriate infield observations and geochemical testing may significantly reduce the amount of samples needed for further laboratory testing by identifying units of greatest concern for AMD and ML and focussing the laboratory program on these units.

Methods

The geochemical characterisation program for this site is based on a combination of field investigations, static laboratory testing, kinetic humidity cell testing and geochemical modelling. The field program entailed geochemical logging of core and approximately 1000 *insitu* field investigations, including: pH measurements; hydrogen peroxide oxidised pH measurements (pH_{fox}); and, handheld X-ray fluorescence (XRF) testing (Niton XL3t GOLDD+ instrument). The results from the field program were used to 'screen' samples for more thorough static laboratory testing in order to sufficiently represent potentially acid forming (PAF) materials, non acid forming (NAF) materials and samples that were potentially metal leaching (ML). Samples with a $pH_{fox} < 4$ were considered to be PAF; samples with elevated metals were considered potentially ML; and, samples with a $pH_{fox} \geq 4$ and low metals were considered NAF.

The laboratory analysis was conducted on ~80 samples which were hand-picked based on the field investigations in order to adequately characterise the units associated with the mineral sands deposit. This analysis included, *inter alia*, a combination of acid base accounting (ABA), net acid generation (NAG) pH testing, total metal analysis, X-ray diffraction (XRD), shake flask extractions (SFE), humidity cell (kinetic) testing (not discussed) and geochemical modelling (not discussed) using PHREEQC (Parkhurst and Appelo, 1999) and Geochemist's Workbench (GWB) (Bethke and Yeakel, 2009).

Results and Discussion

Field results

Generally the field investigations indicated relatively neutral to slightly acidic pH values across the mineral sands deposit and at depth (Figure 1). Slightly alkaline pH values were observed in the top ~2 m of the soil profile reflecting calcite ($CaCO_3$) and /or gypsum ($CaSO_4$) in the subsurface. Below this horizon the field pH values dropped to around pH 6. This is probably not due to latent acidity produced by oxidation of Fe sulphides.

The pH_{fox} tests (Figure 2) identified two grey / black, fine to medium grained sand layers at a depth between ~40 to 50m that were potentially acid forming (PAF), due to the presence of reactive sulphide minerals (confirmed to be pyrite in subsequent meineralogical analysis) (Figure 3). The material oxidised by the hydrogen peroxide produced pH values below 2 (extremely acidic). The PAF material is associated with the mineral strand and an "organic" layer directly above the ore-body. According to handheld XRF results, the dark grey / black layers were also associated with elevated sulphide concentrations, supporting the pH_{fox} results. Similarly, the handheld XRF results indicated the mineral strand contained significantly elevated metals, including (amongst other metals), Th, U, Fe, As, Cu, Pb and Cr which may be of environmental significance. Based on the aforementioned results the samples could be classified as overburden (NAF), overburden organics (PAF) and ore-body materials (mostly PAF).

Laboratory Results

Acid Base Accounting

The results confirmed that sulphur-bearing minerals are the primary source of acidity. The total oxidisable sulphur present in the samples indirectly represents the amount of material available to produce acidity; therefore, samples with a high oxidisable S % generally have a higher probability of producing acidity. The greatest total oxidisable sulphur is associated with the overburden organic layers and the ore-body with a median value of 0.66% S and 1.10% S, respectively. The overburden has very low oxidisable S content with a median value of 0.02% S. The maximum oxidisable sulphur measurements were approximately 4%, which is considered moderate. The sulphur present almost exists exclusively as sulphide (oxidisable), with a positive linear relationship between total oxidisable sulphur and total sulphur present.

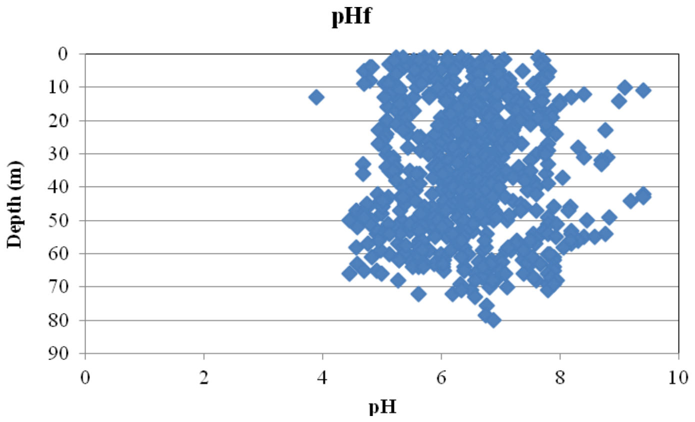

Figure 1 *Field pH values.*

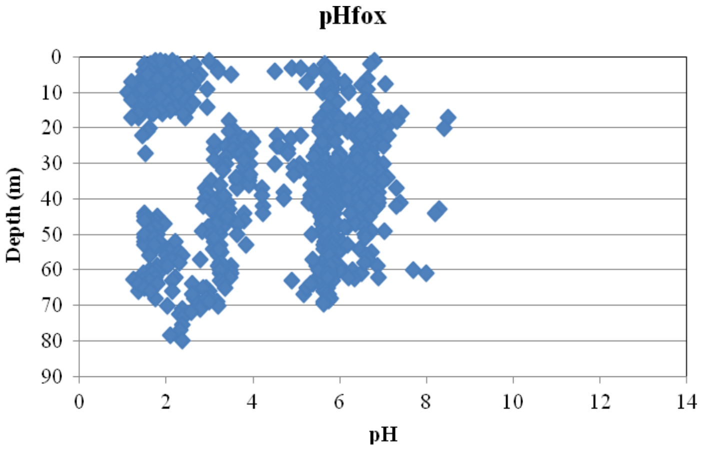

Figure 2 *Field* pH_{fox} *values.*

Directly related to the sulphide content, the MPA values for the overburden organics and ore-body is generally low to moderate with a medium value of 20kg H_2SO_4/ t and 33kg H_2SO_4/ t, respectively. The maximum MPA value recorded for the overburden organics (130kg H_2SO_4/ t) is considered moderate. The overburden MPA values are considerably lower than the overburden organics and ore-body.. Although the MPA values were generally low to moderate, the ANC values were extremely low, with the majority of samples indicating no acid buffering capacity within the limits of detection. The corresponding NAPP values for the overburden organics and ore-body are indicative of low to high acid generating material (PAF). The overburden NAPP values are generally indicative of non-acid forming materials (NAF).

The NPR (ANC/MPA) values indicate that the majority of samples, which mainly encompass the overburden organics and the ore-body, are likely to be acid generating, with an NPR < 1. These very low NPR values are due to the significantly low ANC values. The overburden generally has low MPA values and some ANC, corresponding to an overall NPR >1, which theoretically indicates the sample may maintain neutral pH. The samples which have NPR values < 1, also typically have higher total sulphur contents, illustrating the relationship between high sulphur concentrations and an increased potential to generate acidity (Figure 4). A large proportion of the overburden organics and ore-body falls in the domain of 'very high probability of acid generation' displayed in Figure 4.

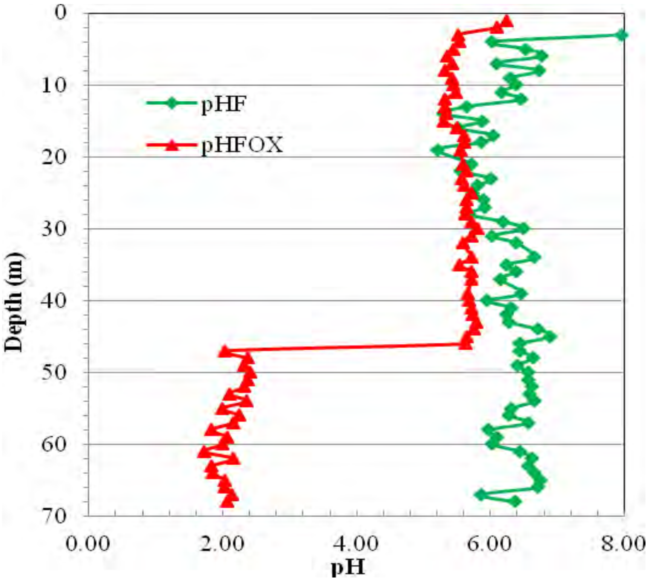

Figure 3 *Field pH and hydrogen peroxide oxidised pH versus indicating the presence of PAF ~45m down hole, due to reactive sulphide minerals.*

The NAG pH values indicate the overburden organics and the ore-body is likely to rapidly generate acidity upon oxidation, with median values of pH 2.55 (highly acidic) and pH 2.5 (highly acidic), respectively. The overburden is unlikely to rapidly generate acidity upon oxidation, with a median value of pH 6.20 (neutral). The distribution of the pH NAG values is displayed in Figure 4. The majority of these pH values are less than 4, which is conservatively considered PAF. The PAF samples were predominantly below 40 m (Figure 3), corresponding to the overburden organic layer and the ore-body. The organic overburden layer and the ore-body are collectively approximately 15m thick; therefore, making up about a 20% PAF layer in a 70m deep profile.

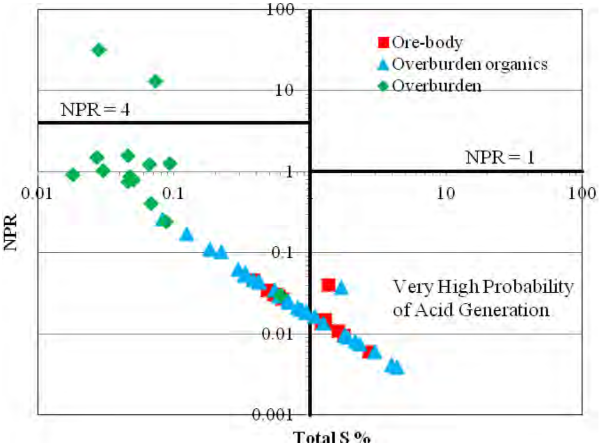

Figure 4. *Relationship between NPR and Total S%, with potential for acid generation.*

The final NAG pH values quite closely correspond to the field pH_{fox} measurements with a positive linear relationship. When the NAG pH values are compared to the NAPP values on an ARD classification plot (Figure 5), the overburden organics and the ore-body samples with a final acidic pH NAG value all fall within the PAF quadrant. All the overburden samples plot in the NAF quadrant or in the uncertain domains.

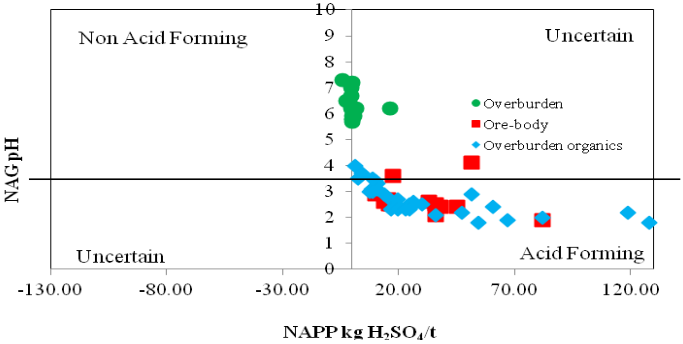

Figure 5. *NAG pH versus NAPP AMD geochemical classification chart.*

In order to better assess the potential for impact of metals, the assay results were compared with mean crustal abundance data to provide an indication of the extent of element enrichment. These comparisons are reported as geochemical abundance indices (GAI's). A GAI equal to, or above, 3 indicates a sample that is significantly enriched (Förstner et al., 1993). According to the geochemical abundance indices GAI's, there are a number of deleterious metals that are significantly enriched in the overburden, overburden organics and ore-body (Figure 6). Arsenic (As), is extremely enriched in the ore-body, and is significantly enriched in the overburden organics. Chromium (Cr), is significantly enriched in the overburden and overburden organics, and extremely enriched in the ore-body. Zirconium (Zr), as would be expected, is enriched in the ore-body. Uranium (U) and thorium (Th) are significantly enriched in the ore-body. The handheld XRF results obtained in the field quite closely match these results. The metals that are enriched within the overburden organic layers and the ore-body are associated with PAF materials. The oxidation of PAF materials to form acid may consequently liberate these deleterious metals that were once secured in minerals (via adsorption to the mineral surface, of via structural incorporation). The association of these metals with the minerals present in the materials requires further analysis.

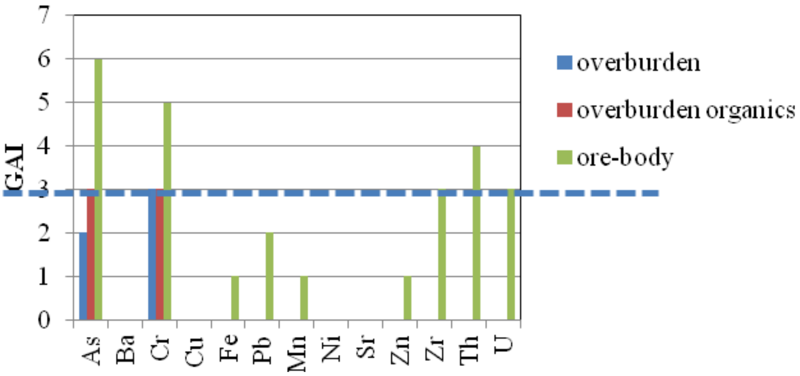

Figure6. *Geochemical Abundance index (GAI) for median values. Metals with a GAI > 3 are enriched relative to the crustal abundance of the particular metal.*

Conclusions

According to the field results there were three separate types of materials which behaved differently geochemically. These materials were categorised as overburden, overburden organics and ore-body. The ANC of all the materials was very low. The MPA values for the overburden were also very low and moderate for the overburden organics and ore-body. All of the ore-body and overburden samples showed pH NAG values < 4, while all the overburden samples showed pH NAG values >4. The detailed laboratory analysis supported the results obtained in the initial field investigations (pH_f, pH_{fox} and handheld XRF).

The total metal analysis conducted by the laboratory indicated significant enrichment of Cr in the overburden; As and Cr in the overburden organics; and, As, Cr, Zr, Th and U in the ore-body. These findings were also supported by the rapid infield testing by handheld XRF analysis. Ongoing SFE analysis and humidity cell testing will provide information on the leaching and mobility of these metals from the materials. The results indicate the overburden was shown to be NAF, with enrichment of Cr. The overburden organics were shown to be PAF with the enrichment of Cr and As. The ore-body was shown to be PAF with the enrichment of Cr, As, Zr, Th and U.

There is a positive correlation between the initial field results and the more detailed laboratory results, highlighting the value of field testing for obtaining a rapid indication of potential contaminants and in identifying lithological units to be targeted for further testing and mine waste management.

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