Acid Base Accounting (ABA) of mine tailings for the Potential of Acid Mine Drainage in the Sabie-Pilgrim's Rest Goldfields, South Africa

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Abstract

The study noted that acid neutralising, calcite and dolomite bearing material was available at Glynn's mine tailings material that can be used to neutralise the acid generation capability of Nestor's mine tailings. The acid neutralising material would improve the acidic Nestor's mine tailings to an almost neutral pH, which is conducive for the growth of plants necessary for phytoremediation efforts.

The study however, noted that phytoremediation of Nestor mine tailings would not succeed because the plants could not grow in acidic soils. Nonetheless, the presence of acid neutralising material within Glynn's mine tailings can be used to neutralise the acid generation capability of Nestor mine tailings. Thus, the presence of acid neutralising material at a location less than a distance of 6 km would reduce transportation and material costs. This would ensure the success of phytoremediation efforts in saving the environment and the overall prevention of acid mine drainage.

Key words: Acid Base Accounting, Mine Tailings, Acid Mine Drainage, Net Acid Neutralizing Potential, Net Acid Potential

Introduction

Mining is one of the most important economic activities in South Africa. The country receives huge economic benefits from the mining industry. However, different kinds of mine residue deposits (herein referred to as mine tailings residue deposits) associated with the extraction and processing of metals stand out as sources of potential environmental pollution in specific mining areas and the country at large (McCarthy 2011). For coal and gold mining operations, these mine tailings are a continuous source of acid mine drainage (AMD) generation (Kleinman et al 1981; Oberholster et al 2013) and an environmental hazards (Rosner et al 1998; Nelushi et al 2013).

The Sabie-Pilgrim's Rest Goldfield, Mpumalanga, is one such area where gold mining activities occurred in the past. The area has numerous mine tailings of different ages and sizes. What is the key here is that a few or no environmental studies had been carried out on mine tailings; hence this study focused on the Nestor and Glynn's Lydenburg Gold mine tailings storage facilities. The main objective of this study was to determine the mineralogy and the geochemistry of mine tailings.

Location of the study area

The Nestor (NS) and Glynn's Lydenburg (GL) mine tailings, are located in the Sabie area of the Mpumalanga Province of South Africa (Fig. 1).

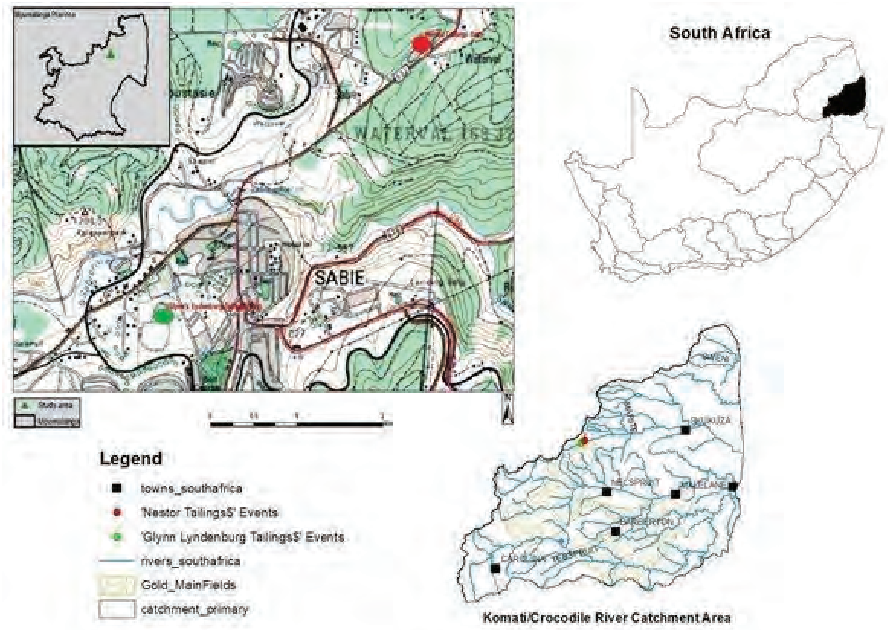

***Fig. 1** Location of the Study Area*

Methods

Sampling and Sample preparation

Thirty tailings profile samples and five grab samples were collected at mine tailings from 20 to 23 February 2015. A truck-mounted and a hand auger were used to collect samples up to the depth of 10 m at Glynn's Lydenburg tailings dam up to 3 m at the Nestor (drilling to 3 m) respectively. The samples were sent to the Council for Geoscience's laboratory in Pretoria, South Africa, for analysis.

The samples were then ground using milling pots made of carbon steel to minimize the level of contamination on a single swing mill (TM-SPR003) method which involved air drying, crushing and milling of samples to a size reduction of <75 μm,. In between milling, the equipment was washed using distilled water and wiped with the disposable paper towels wetted with ethanol and then allowed to dry to avoid the contamination of samples.

Acid base accounting have been determined in terms of paste/initial pH, reactive S (%), AP (as kg/ton $CaCO_3$), and NP (as kg/ton $CaCO_3$). The calculated parameters, namely, net neutralizing potential (NNP as kg/ton $CaCO_3$) and net potential ratio (NPR) have been used as criteria the acid potential of samples. Graphically, these results clearly show the dominant trends in results as shown in figures. The criteria used to classify the acid-producing potential of the samples analysed are those used by Usher et al (2003), and these should not be used in isolation, but in combination to categorise material from non-acid generating to acid generating with a slight grey area in between. The following criteria have been used: Paste pH (measure of sample's immediate acidity or alkalinity); net neutralizing potential (NNP=NP-AP); neutralizing potential ratio (NPR=NP/AP) as per Price (1995); and percent sulphide-sulphur and NPR.

Samples were analysed by X-ray diffraction spectrometry (XRD) in accordance with procedures of USEPA (1986). The XRD technique employed Bruker D8 HRXRD spectrometer, scanning from 2 to 70 ^{o} 2θ Cukα radiation at a speed of 0.02 ^{o} 2θ steps size 0.5 sec with a LYNXEYE detector and generator settings of 40 kV and 40 mA. Semi-quantitative approximations of the minerals present were based on the relative peak heights area proportion according to Brime (1985).

Data Analysis

Microsoft Excel 2013 was used for calculating of average, standard deviation and plotting of graphs.

Results and discussion

Acid base Accounting (ABA)

Fig. 2 below shows subdivision based on acid potential (AP), neutralisation potential (NP) (i.e. Neutralising potential ration, NPR) and paste pH of the tailings collected at Nestor and Glynn's Lydenburg mine tailings storage facilities. Based on this subdivision, Nestor mine tailings samples are characterized by high AP than NP, and its net potential ratio is less than 1 (NPR<1). Their AP ranges from 1.56-140.31 kg $CaCO_3$/ton while NP ranges from -57.75 to -0.3 kg $CaCO_3$/ton. However, Glynn's Lydenburg Mine Tailings which is associated with dolomite mineralization show no potential to leach any acidic drainage. Based on ABA results, the tailings have more NP than AP, and plot at NPR>2. Their AP ranges from 7.5 $CaCO_3$/ton to 56.56 $CaCO_3$/ton while NP ranges from 7.5 to 207.88 $CaCO_3$/ton to 190 $CaCO_3$/ton. The results of AP/NP (NPR) are also confirmed by paste pH of the samples (Fig. 2). Nestor tailings samples are characterised by low paste pH (2.7 to 5), which is indicative of presence of sulphides or sulfates that have reacted to form acid. On the other hand, Glynn Lydenburg tailings samples are characterised by high paste pH (7 to 8.8), which could be indicative of high neutralising minerals.

Gold tailings of Nestor Mine are characterized of very low NRP of less than one (NPR<1) with considerable percentage of sulphur and are having greater potential of acid production (Fig. 3). Glynn's Lydenberg Mine tailings are having a higher than four NPR (NPR>4) and most of them fall on the zone wherein no further testing is necessary (Fig. 3).

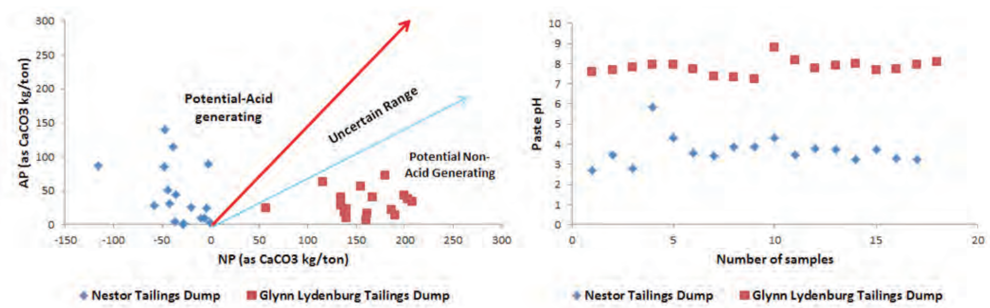

Fig. 2 *Classification based on acid potential (AP), neutralising potential (NP) and paste pH.*

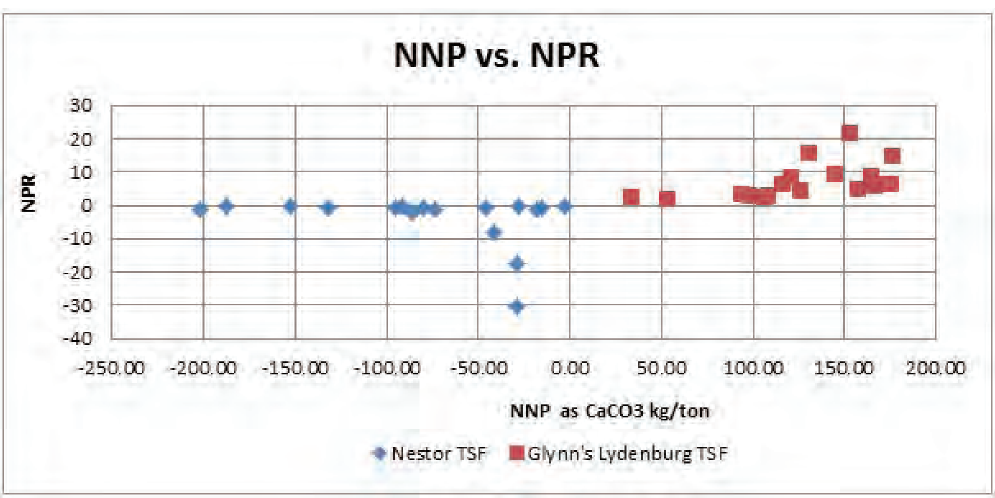

Fig. 3 *NPR vs NNP of Nestor TSF and Glynn's Lydenburg TSF*

Nestor Mine tailings have high sulphide concentration (in a range of 0.29 and 4.49 wt %) and negative NPR (ranging between -17.63 and 0), hence are potentially acid producing as their sulphur per cent exceeds 0.03 wt % described as acid producing (Fig. 4). On the other hand, Glynn's Lydenberg tailings have low sulphur concentration (ranging between 0.29 and 2.30 wt %) with high NRP values of up to 21.4, hence low AMD generating capacity. Sulphur percentage in Glynn's Lydenburg Mine tailings is less compared to Nestor Mine tailings (Fig. 4). Based on ABA results, NPR>2 in Glynn's Lydenburg Mine tailings, hence less likely to generate acid. This is confirmed by paste pH which ranges from 7.58 to 8.8 (Fig. 2).

Mineralogical Analysis of Mine Tailings

There is a wide range variation among the Nestor and Glynn's Lydenburg mine tailings' mineralogical composition based on X-ray diffraction (XRD) as expressed in weight percent (wt %) of bulk samples (Fig. 5). Both primary and secondary minerals were deduced from XRD mineralogical analysis.

In the Nestor TSF, predominant minerals include primary minerals: quartz (SiO_2) ranging from 64-87 wt%, followed by mica [$K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$], plagioclase ($NaAlSi_3O_8 – CaAl_2Si_2O_8$) and k-feldspar (Fig. 5A). Kaolinite is the secondary clay mineral which was found mostly on grab samples and on the depth of 2 m on one of handheld auger drilled holes, jarosite {$KFe_3(SO_4)_2(OH)_6$} and gypsum ($CaSO_4.2H_2O$) are secondary minerals which are dominant on top layers of the tailings of Nestor Mine. Goethite is a secondary oxide mineral absent in grab samples from Nestor tailings and is most concentrated in handheld auger samples. Gibbsite is not present in all Nestor TSF samples except for the one recorded at unoxidized 2 m depth in one of handheld auger samples. This indicates that the rate of sulphide oxidation is high in this saturated zone.

Quartz is the most dominant primary mineral and shows a constant trend from both grab samples and handheld auger samples with depth. This shows that it is less reactive in oxidizing conditions. Minerals such as quartz have no potential to neutralize acid, and this is mainly due to their physical property (hardness) and it has a relative reactivity of 0.004, which is twice slower than the relative reactivity of kaolinite (Sverdrup, 1990; Kwong, 1993). Pyrite (FeS_2) is the major acid producing mineral and hematite respectively. Mica is also common in high concentrations in both samples collected using handheld auger and grab samples. Calcite is absent in Nestor Mine tailings and dolomite was only found in two oxidized grab samples indicating that these tailings are acidic. The acidic nature of Nestor mine tailings would provide adverse conditions for growth of plants and grass that can be maybe used for revegetation of the tailings storage facility.

Tailings from Glynn's Lydenburg are com-

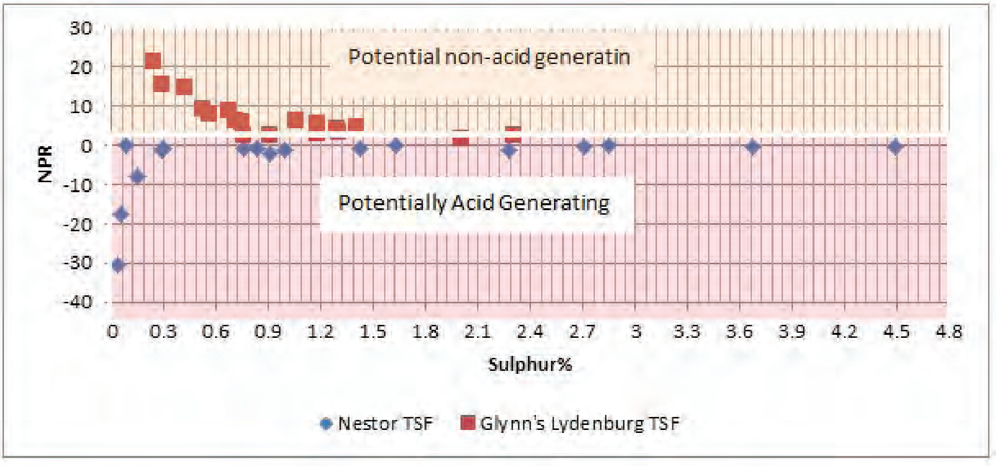

***Fig. 4** NRP vs Sulphur% in the Nestor TSF and Glynn's Lydenburg TSF*

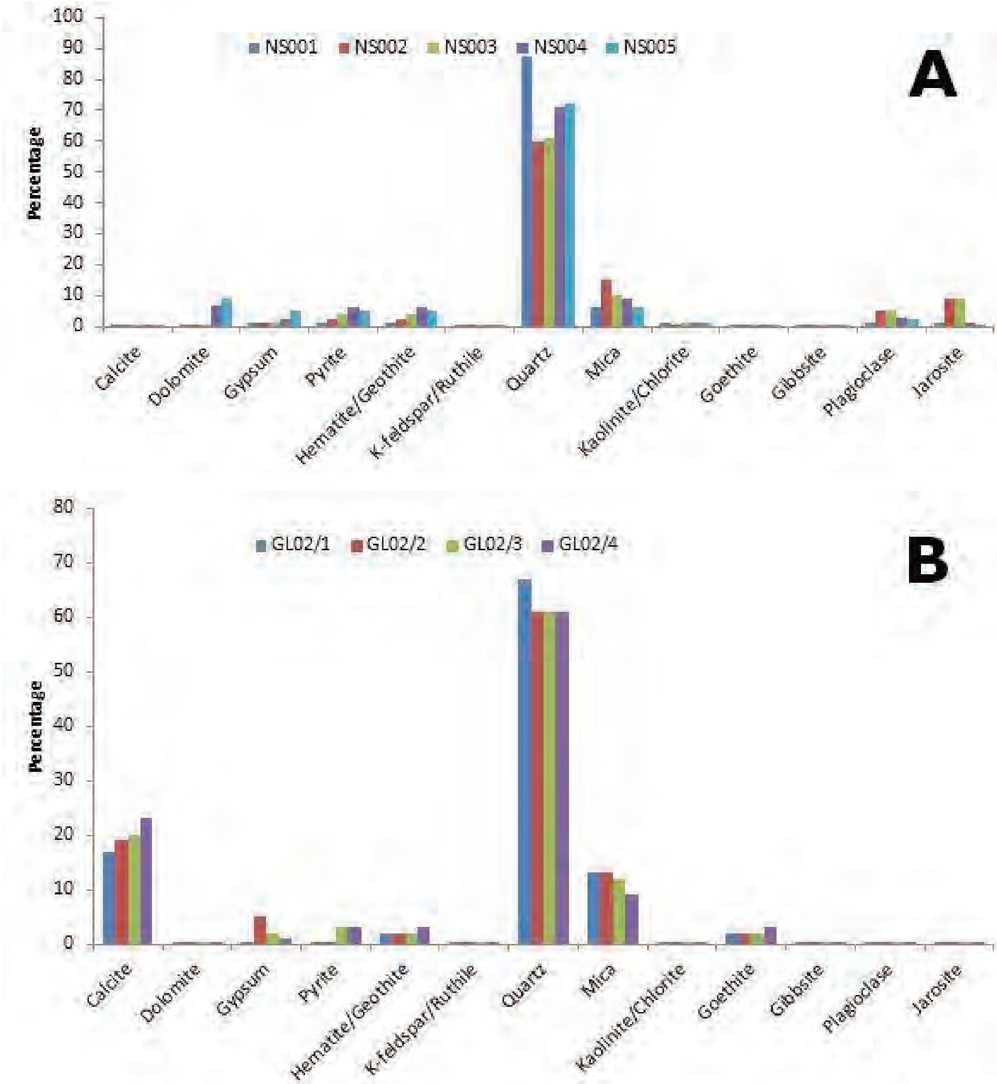

Fig. 5 *Mineralogical composition of (A) Nestor & Glynn's (B) Lydenburg TSFs samples as wt %*

prised of quartz and dolomite [CaMg (CO_3)] as major mineral assemblages (Fig. 5B). Quartz shows a constant trend with increasing depth (Fi. 5B). This shows that it is less reactive even under oxidizing conditions. Al_2O_3 and Fe_2O_3 show a slight constant trend with increasing depth and increases at depths. Cr_2O_3, K_2O, MnO and TiO_2 show a constant trend with depth.

Other primary minerals that are acid neutralizing include mica and plagioclase. Gypsum and goethite are also present as secondary minerals as neutralizing minerals, while the absence of jarosite in Glynn's Lydenburg Tailings dump could be attributed to less acidic conditions due to the presence of high concentrations of carbonates within the Malmani dolomite host rocks. Plagioclase was mainly found in truck-mounted auger samples and showed a constant trend of decreasing with depth. Mica being common in all three drilled holes including handheld auger samples also showed a decrease with depth trend. This can be attributed to low aid generation at unoxidized zones of the tailings dump (3-10 m) compared to semi-oxidized top part (0-2 m). Gypsum show a decreasing trend with depth in both handheld and truck-mounted augers drilled holes. The absence of dolomite in borehole GL 02/1-4 (Fig.

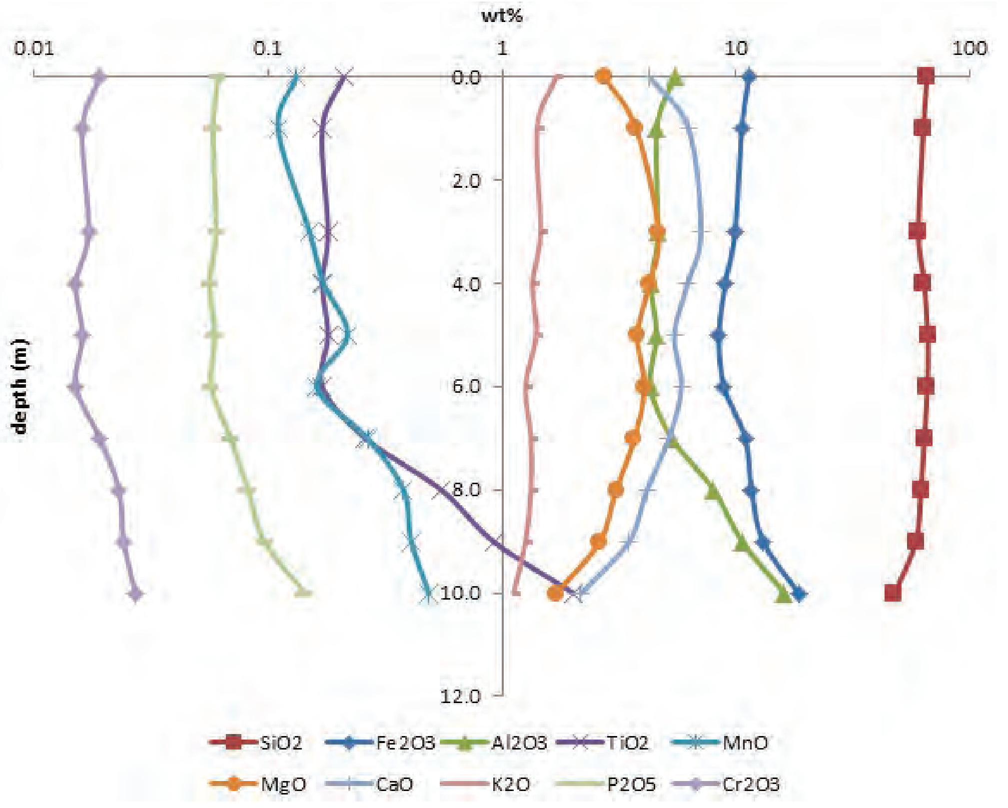

Fig. 6 Depth profile for major oxides in Glynn's Lydenburg tailings storage facility (Log 10 scale on x-axis)

5) can be attributed to oxidation that might be taking place within the top oxidized zone (0-2 m); however, the presence of calcite can add into neutralization potential to the acid that might be produced by primary mineral hematite. Gypsum is present in both truck-mounted auger samples and handheld auger samples showing a decrease with depth trend. Kaolinite was only found at unoxidized lower parts of the tailings dump between 8 and 10 m depth showing a rapid increase with depth (Fig. 5).

Conclusions

The study noted that acid neutralising, calcite and dolomite bearing material was available at Glynn's mine tailings material that was used to neutralise the acid generation capability of Nestor's mine tailings. The acid neutralising material would improve the acidic Nestor's mine tailings to an almost neutral pH, which is conducive for the growth of plants necessary for phytoremediation efforts. This interpretation of the geochemical and mineralogical data is also corroborated by the acid base accounting (ABA) which showed the relative acid and neutralization capacities and the resultant net acid generating capacity of the two tailings materials. The study further showed that the metal mobility was enhanced by the net acid generating capacity of the Nestor mine tailings. Whereas the alkaline conditions of the Glynn Lydenburg mine tailings lead to a non-acidic discharge. The presence of heavy metals, metal oxides, neutralizing oxides and acid-forming oxides in the mine tailings are likely to have negative impact on the environment.

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