Geochemical and Mineralogical Characterization of Precipitates from Sabie-Pilgrim's Rest Goldfields for the Potential of Acid Mine Drainage

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Abstract

The main aim was characterizing geochemistry and mineralogy of the efflorescent crusts that could further contribute to acid mine drainage of the two abandoned tailings storage facilities (TSFs): at Glynn's Lydenburg and Nestor mines for that. Soil samples in the mine surroundings were also analysed. The X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses were carried out on the efflorescent salts from both tailings storage facilities and surrounding soils. Secondary minerals such as gypsum and jarosite which have been reported to contribute to further acidification of water were found on the efflorescent salts. The obtained results indicated that quartz and mica are dominant primary minerals at both sites. Nevertheless, dolomite is the major primary mineral in the Glynn's Lydenberg tailings but is absent in the Nestor tailings storage facility. In the soils surrounding Nestor tailings storage facility, acid producing minerals such as ferricopiapite and fibroferriteand gibbsite were also detected. In addition, the mineralogy of the surrounding soils indicates the presence of smectite and kaolinite. The XRF results showed that in terms of major elements, the chemistry of both sites is dominated by SiO_2, Fe_2O_3, and Al_2O_3 followed by CaO, MgO. Also occurring in lesser concentrations were K_2O, TiO_2, Na_2O, MnO and Cr_2O_3. Trace elements such as As, Cu, Cr, Pb, V and Zn which can be hazardous to the environment were also found at both sites.

Keywords: Acid Mine Drainage, Efflorescent Crusts, Tailings Storage Facilities, X-Ray Diffraction, X-Ray Fluorescence

Introduction

Decades of mining in South Africa has resulted in acid mine drainage problem for certain regions. The Sabie-Pilgrim's Rest Goldfield had been producing gold since 18th century generating wastes in the form of tailings and waste rocks. This area has several mine tailings storage facilities of different ages and sizes.

The key here is that few environmental studies had been carried out on mine tailings; hence this study was focused on the two abandoned tailings storage facilities, Nestor and Glynn's Lydenburg. The main objective of this study was to determine the mineralogy and the geochemistry of efflorescent salts which can further contribute to acid mine drainage problem.

Location of the study area

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

Methods

Sampling and Sample Preparation

A total of eleven (11) samples were collected from Glynn's Lydenburg TSF and seven (7) samples were collected from Nestor TSF. Sampling was focussed on efflorescent salts (solid precipitates) from the TSFs sidewalls (Fig.2). Individual grab samples were taken, collected over regularised areas to a depth of about 5 cm, and as vertical profiles from the surface to the base of exposure (GL1-8 and NS1-3 and NS7). Additional sampling was done of the surrounding soils (GL9-11 and NS4-6), taken from small dug pits, to assess the contribution from the TSFs as well as for indications of secondary mineral products, or as background samples.

The collected tailings and soil samples were taken to the Council for Geoscience laboratory and submitted for trace element composition and mineralogy using XRD and XRF respectively.

The samples were analysed by X-ray florescence spectrometry (XRF) and X-ray diffraction spectrometry (XRD) according to procedures of USEPA (1986). The glass disks and wax pallets were analyzed using a PANalytical wavelength dispersive AXIOS X-ray fluorescence spectrometer that was equipped with a 4kW Rh tube. Both major and minor elements have been determined and reported as oxides and trace elements. Quality control/Quality assurance (QC/QA) was done using the in-house amphibolite reference material (sample 12/76). The X-ray diffraction (XRD) technique employed scanning from 2 to 70° 2θ CuKα radiation at a speed of 0.02° 2θ steps size/0.5 sec, with

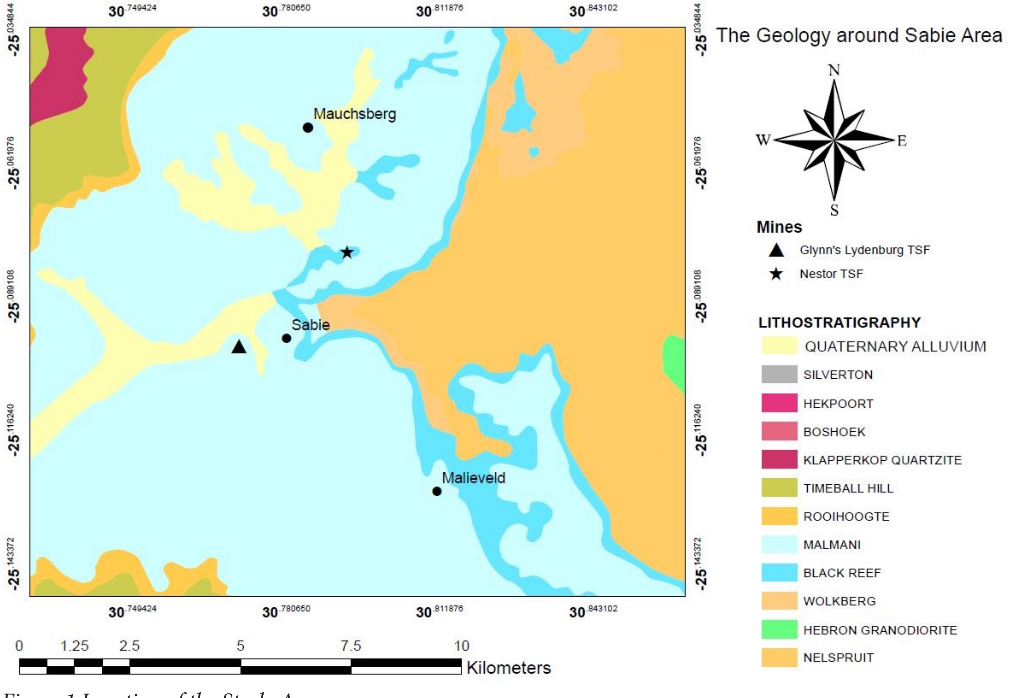

Figure 1 Location of the Study Area

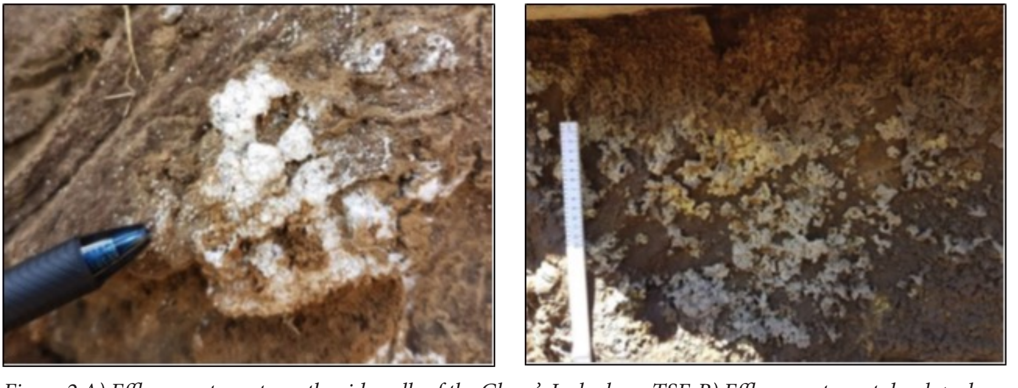

Figure 2 A) Efflorescent crusts on the sidewalls of the Glynn's Lydenburg TSF. B) Efflorescent crust developed on the slopes of the Nestor TSF

a LYNXEYE detector and generator settings of 40 kV and 40mA. Semi-quantitative approximations of the minerals present were based on the relative peak heights to area proportion according to Brime (1985).

Results and Discussion

Geochemistry of tailings precipitates

The XRF results showed that the chemistry of both sites in terms of major elements is dominated by major elements SiO_2, Fe_2O_3, and Al_2O_3 (Fig. 3). CaO was highly concentrated in Glynn's Lydenburg soils (up to 14.22 ppm at GL16) than Nestor (up to 12.68 ppm in efflorescent crusts at NS01) and MgO was only found in Glynn's Lydenburg (up to 5.09 in efflorescent crusts and 3.06 in soils). Also occurring in lesser concentrations were K_2O, TiO_2, MnO, Na_2O, MnO and Cr_2O_3. (Fig.3). Quartz is more dominant in major element in soils of Nestor Mine site (up to 88.48 wt. %) and enriched in efflorescent salts of Glynn's Lydenburg TSF (up to 60.35 wt. %) compared to soil samples of the respective site. Iron and aluminium oxides are also enriched in soil samples from both sites; Fe_2O_3 up to 12.84 wt. % in Nestor and 14.14 wt. % in Glynn's Lydenburg TSF salts with Al_2O_3 having higher concentrations in Glynn's Lydenburg TSF efflorescent salts (21.32 wt. %) compared to 20.37 wt. % in Nestor TSF precipitates (Fig. 3).

The sulphate minerals that contain Fe, Al and Mn generally accumulates in the form of efflorescent salts and essentially store acidity and will produce acid when dissolved in water during acid mine drainage formation (Naicker et al., 2003). Both sites are rich in Fe and Al hence likely to further generate acidity to the surrounding environment.

Metals and metalloids were also detected following the sequence As>Zn>Cr>Cu>V>Ni>Pb>Co (Fig.4). Soils from both sites are dominated by elements Cr, V, Ni, and Co compared to efflorescent salts; suggesting that mineralization might be of sync-Bushveld Igneous Complex age. The precipitates are dominated by As, Zn and Cu compared to soils samples with very high concentration of Pb reaching up to 400 ppm.

The fate of various metals such as Cr, Ni, Cu, Mn, Hg, Cd and Pb and metalloids such as As, Sb and Se is of great concern to the environment (Adriano, 1986; 1992). The USEPA listed metals of major interest in bioavailability study as Al, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Se and Sb (McKinney and Rodgers, 1992). Trace metals such as Cu, Cr, Pb, V and As occur within the efflorescent salts (Table 1) in excess of South African guidelines soil screening, National Norms and Standards

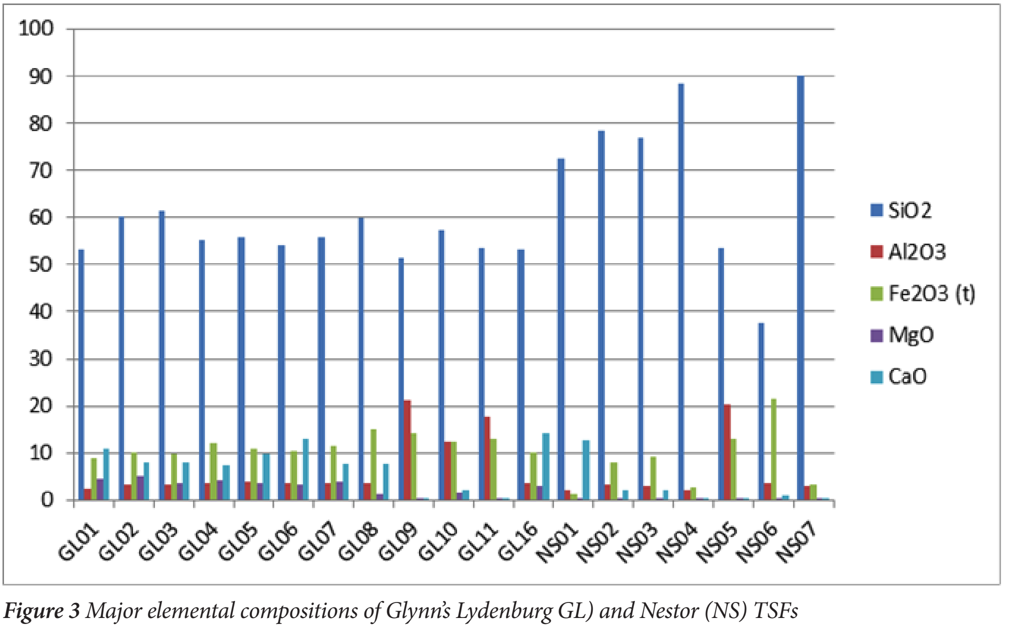

Figure 3 *Major elemental compositions of Glynn's Lydenburg GL) and Nestor (NS) TSFs*

for Remediation of Contaminated Land and Soil Quality in the Republic of South Africa (DEA, 2013).

DWAF (1996) showed that concentration of Cu in water over 30 mg/L results in liver, kidney and blood cells damage. Alloway and Ayres (1997) Cr VI is more toxic than Cr III wherein Cr VI concentration of 0.5 g/ml is considered to have negative effect.

The concentrations of As in both tailings storage facilities and surrounding soils are high and likely to cause As poisoning. A concentration of 100 mg/L As in soil can reduce crop yield by 90% and can lead to As poisoning which can result in diseases such as lung and skin cancer (Harada, 1996). Physically, the crusts showed different colourations with Glynn's Lydenburg having whitish colour and Nestor had brownish to yellowish colour. This could be attributed to the elevated concentrations of Fe in Nestor compared to Glynn's Lydenburg.

***Table 1** The distribution of metals and As (range, ppm) average values are given in brackets*

Metal	Nestor TSF	Glynn's Lydenburg TSF	All land uses, protective of water resources	Informal residential	Standard residential
As	4.6-1904 (814)	4.6-4362 (2136)	5.8	23	48
Co	1.5-109 (24)	1.5-109 (26)	16	1100	2300
Cr	43-114 (109)	43-301 (150)	6.5	6.5	13
Cu	15-264 (89)	15-264 (83)	20	110	230
Ni	7.7-162 (47)	7.7-162 (78)	150	150	320
Pb	9.9-400 (133)	9.9-400 (22)	240	920	1900
V	9.7-237 (60)	9.7-282 (115)	150	150	320
Zn	1.5-166 (89)	1.5-215 (83)	240	920	1900

Mineralogy of tailings precipitates

The mineralogical composition of efflorescent salts was determined using XRD analysis. The dominant primary minerals in both precipitates materials are quartz and mica. In Glynn's Lydenburg dolomite is the major primary mineral found within the salts and is absent in Nestor tailings salts (Fig.5).

Soluble secondary salts store acid and metal in their solid phase, hence they are of environmental concern. Their dissolution can result in potentially detrimental flushes of acid and metals into ground and surface water during periods of rainfall or snowmelt (Nordstrom and Alpers, 1999). Plumlee et al. (1995a and b) showed that jarosite is a common salt in many mine waste materials that readily release acid and metals during rain storms or laboratory leach tests. In terms of secondary acid-producing minerals gypsum dominates both sites. Another acid producing mineral jarosite was only found at one Nestor TSF salts sample while

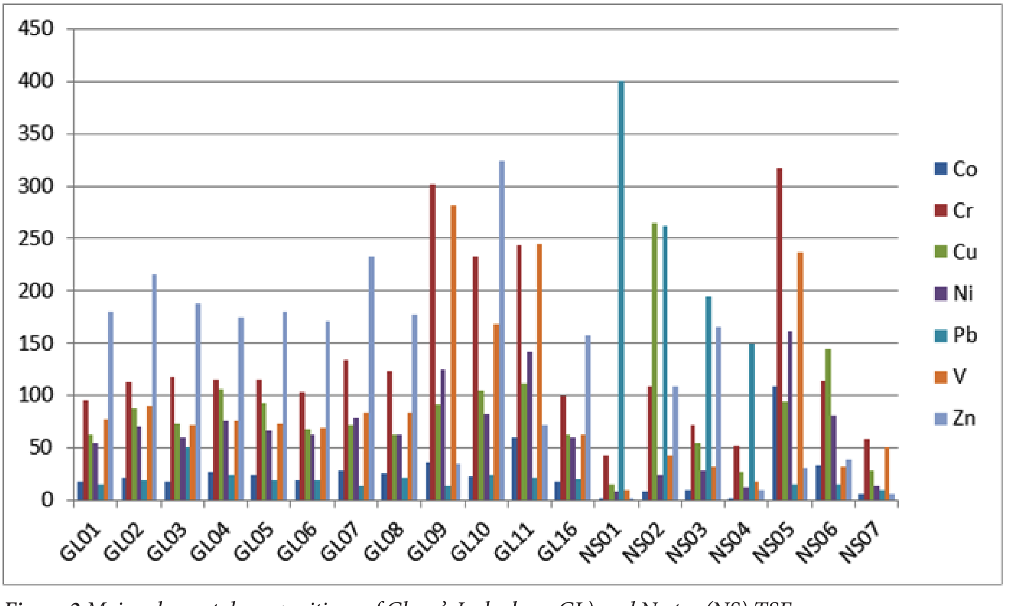

***Figure 3** Major elemental compositions of Glynn's Lydenburg GL) and Nestor (NS) TSFs*

gibbsite was only found on the surrounding soils at both sites. According to Blair et al. (1990); Jambor et al. (2003); Lottermoser (2007); Thornton (1996); Williams (1975) acid mine drainage (AMD) can also acidify and contaminate soils located near mining areas and in floodplains downstream of them. In the soils surrounding Nestor TSF, acid producing minerals ferricopiapite, fibroferrite, jarosite and gibbsite are present (Fig. 5) and the Klein-Sabie river is located just 300m south of the tailings storage facility. The mineralogy of the surrounding soils in both sites indicates the presence of smectite and kaolinite (Fig. 5).

Conclusions

The obtained results indicated that quartz and mica are dominant primary minerals at both sites. Nevertheless, dolomite is the major primary acid-neutralizing mineral in the Glynn's Lydenberg tailings but is absent in the Nestor tailings storage facility. In terms of secondary minerals, gypsum dominates both sites. In the Nestor tailings, acid producing minerals such as ferricopiapite, fibroferrite, jarosite, and gibbsite were also detected. In addition, the mineralogy of the surrounding soils indicates the presence of smectite and kaolinite. Acid-producing sulphite gibbsite was also found in the surrounding soils at both sites. The XRF results showed that in terms of major elements, the chemistry of both sites is dominated by SiO_2, Fe_2O_3, and Al_2O_3. Also, trace elements such as As, Cu, Cr, Pb, V, and Zn, were also found in elevated concentrations. These elements can be hazardous to the environment in higher quantities. The results principally point to the capacity of crusts to store contaminants.

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References

Blair RD, Cherry JA, Lim TP, Vivyurka AJ (1980) Groundwater monitoring and contaminant occurrence at an abandoned tailings area, Eliot Lake, Ontario. In: Proceedings of 1st international conference on uranium mine waste disposal, pp 911–944.

Brime C (1985) The accuracy of X-ray diffraction methods for determining mineral mixtures. Mineralogical Magazine, 49(353), p 531-538.

Department of Environmental Affairs (DEA) (2013) National Norms and Standards for Remediation of Contaminated Land and Soil Quality in the Republic of South Africa.

Harada M (1996) Characteristics of industrial poisoning and environmental contamination in

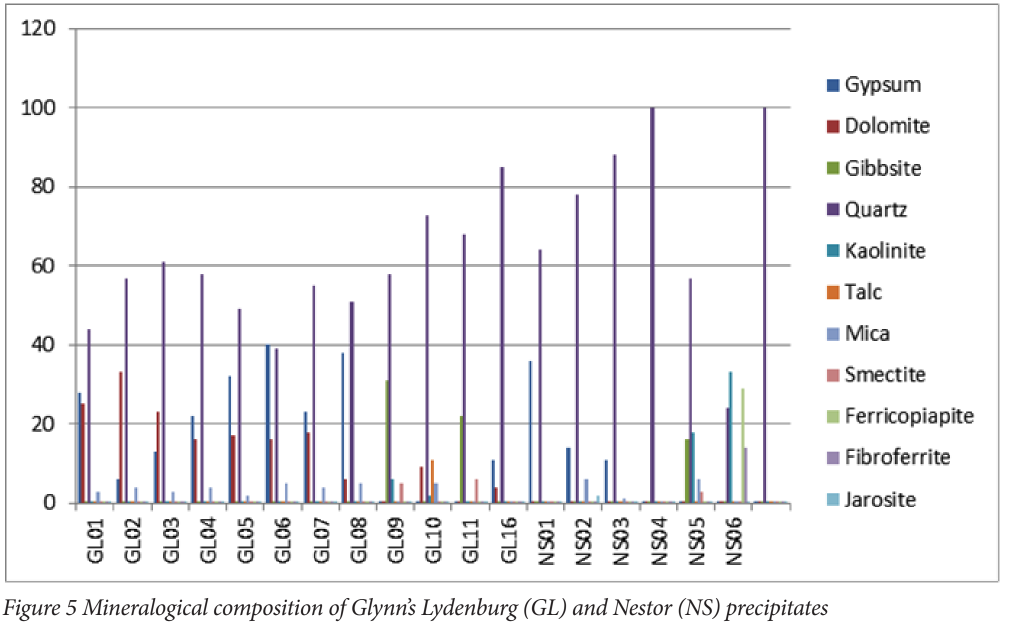

Figure 5 Mineralogical composition of Glynn's Lydenburg (GL) and Nestor (NS) precipitates

developing countries. Environmental Sciences, 4(Suppl), p 157-169.

Jambor JL, Blowes DW, Ritchie AIM (eds) (2003) Environmental aspects of mine wastes. Mineral Associationof Canada Short Course Series 31, Quebec.

Lottermoser BG (2007) Mine Wastes: Characterization, Treatment and Environmental Impacts. 2nd edit., Springer, Berlin.

Naicker K, Cukrowska E, McCarth, TS, (2003) Acid mine drainage arising from gold mining activity in Johannesburg, South Africa and environs. Environ. Pollut. 122, p 29-40.

Nordstrom DK and Alpers CN (1999) Geochemistry of acid mine waters; in Plumlee, G.S., and Logsdon, M.J. (eds.), The Environmental Geochemistry of Mineral Deposits, Part A. Processes, Techniques, and Health Issues: Society of Economic Geologists, Reviews in Economic Geology, v. 6A, pp. 133–160.

Plumlee GS, Gray JE, Roeber MM, Jr, Coolbaugh M, Flohr M, and Whitney G (1995a) The importance of geology in understanding and remediating environmental problems at Summitville; in Posey, H.H., Pendleton, J.A., and Van Zyl, D. (eds.), Summitville Forum Proceedings: Colorado Geological Survey Spec. Pub. No. 38, pp. 13–22.

Plumlee GS, Smith KS, Mosier EL, Ficklin WH, Montour M, Briggs, PH, and Meier AL (1995b) Geochemical processes controlling acid-drainage generation and cyanide degradation at Summitville; in Posey, H.H., Pendleton, J.A., and Van Zyl, D. (eds.), Summitville Forum Proceedings: Colorado Geological Survey Spec. Pub. No. 38, pp. 23–34.

Thornton, I (1996) Impacts of mining on the environment: some local, regional and global issues. Applied Geochemistry 11:355–361.

United States Environmental Protection Agency (USEPA) (1986) Test Methods for Evaluating Solid waste, 3rdedition, Office of Solid Waste and Emergency Response, Report SW-846, volume 1, November 1986 with revisions to January 1995.

Williams RE (1975) Waste production and disposal in mining, milling and metallurgical industries. Miller Freeman Publications, San Francisco.