GEOCHEMICAL ASSESSMENT OF THE POTENTIAL IMPACT OF DURBAN NAVIGATION COLLIERY DUMPS ON THE ENVIRONMENT, SOUTH AFRICA

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ABSTRACT

Durnacol colliery occurs in the Klip River coal field and started its operation in 1895, ceased production in 2000, and produced coking coal in its 105 years of operation. Dumps Nos.1 and 2 were used as disposal sites shortly after the mine started. Both dumps are small in size (<150 000m^2) and partially burnt or still burning. This study has assessed the potential environmental risk from the two dumps and its main objective was to conduct a comprehensive geochemical assessment of the potential environmental impact from the two dumps. The methodologies used included field observation, sampling, mineralogical (XRD), geochemical (XRF), water quality (AA and ICP-MS), field tests (Fizz, pH, EC), particle size distribution, Acid Base-Accounting (ABA) and kinetic geochemical modelling. The field investigation indicated no toe seepage around the two dumps.

Fizz rating of burnt material was higher than that of unburnt material on both dumps and paste pH proved to be neutral (pH 6-7). This study further indicated that the combustion/burning of coal discard slightly increase both pH and alkalinity, i.e., neutralisation potential. Burnt material therefore shows higher pH and alkalinity than unburnt material. The Acid Base-Accounting results indicated that both dumps have the potential to turn acidic as the majority of the samples taken had a sulphide sulphur content larger than 0.25%. The main acid generation and neutralising minerals are pyrite and calcite, respectively. Geochemical modelling based on a two-layer soil cover indicates no significant acid generation for Dump No.1 with a total dissolved solids concentration of 3 500 mg/ℓ and sulphate concentration of 2 100 mg/ℓ. Fair amounts of alkalinity was noted with low potential seepage volume. Geochemical modelling predicted that for Dump 2 significant acid will be produced in the first five years and continue in the same trend for about 20 years. TDS and SO_4 are high during the first five years and stabilise at much lower values thereafter. Alkalinity is generally low over the period, coupled with a low potential seepage volume.

The study concluded that one layer of soil cover should be placed on both dumps to inhibit further burning and also reduce acid mine drainage production. It was further recommended that there should be continuous monitoring of the boreholes in the vicinity of the dumps to establish the potential development and migration of a pollution plume around the dump in future. This comprehensive geochemical study may be used as a guide for similar mine waste dumps.

1. INTRODUCTION

Durnacol Colliery is located in the town, Durnacol, named after the mine, close to a number of small towns such as Dunhauser, Hattingspruit, Dundee, Glencoe and Wasbank. Whereas two major towns, Newcastle is located to the north and Ladysmith to the south. The coal field is Klip River in the central part of KwaZulu-Natal, South Africa (Figure 1). The mine started mining at the turn of the 20th century and ceased its production in 2000. The mine mainly produced coking coal for the shipping industries, and later for iron smelting. At the peak of mining operation, Durnacol employed about 5 000 workers. Durnacol is geologically located in the Klip River coal field, neighbouring with the coal fields of Ultrecht in the north-east and Vryheid in the east (Bell, et al., 2001) (Figure 1). All the coal fields in South Africa occur in the Karoo Supergroup of the Karoo basin. This study assesses the environmental impacts of coal dumps (1 and 2) at Durban Navigation Colliery (Durnacol), KwaZulu-Natal Province, South Africa. It then investigates restoration/remediation/rehabilitation measures based on the geochemical assessment including geochemical modelling for long-term water quality prediction.

2. METHODOLOGIES

The main research methodologies include field investigation, sampling, field tests, and laboratory analyses such as XRF, XRD, ABA, particle size analysis, and geochemical modelling. A total of 11 and 19 field samples were collected from Dumps No. 1 and 2, respectively. The sampling process considered the differences in material characteristics seen through visual observations. Samples were therefore taken of material that appeared different to obtain representative samples.

Field tests, performed on the above mentioned samples, included paste pH, fizz test and paste electrical conductivity (EC). The data were processed on site and on the basis of these results, 5 solid samples for Dump No. 1 and 8 solid samples for Dump No. 2 were collected, for additional field testing as well as detailed analyses.

Besides the on-site field tests, the samples were analysed for particle size, solid geochemistry by X-ray florescence (XRF) and Aqua Regia (strong acid dissolving the solid), mineralogy by X-ray Diffraction (XRD), and water extraction by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). All the analyses were carried out or organised by WaterLab in Pretoria, South Africa.

Geochemist's Workbench® 3.2 (Bethke 2001) was used to carry out the geochemical modelling tasks, which consisted of four major modelling programs: Rxn, Act2, Tact, and React (including Gtplot).

3. SITE CHARACTERISATION

Historical records are vague, but it would appear that Dump No. 1 was decommissioned no later than 1936, based on the sampling date. It is partially burnt (approximately 50%) and a portion is actively burning and has not been rehabilitated by the mine. A significant portion of the material on the dump has been reclaimed for making bricks. The mine intends to reshape the dump and to place a simple cover of compacted clay (400mm) and topsoil (150mm) over it. Material obtained from the immediate surroundings will be used for the cover. There is no visible seepage from this dump and vegetation on the dump composes mainly grass.

Dump No.1 is between 1 327 m and 1 351 m amsl, thus an elevation difference of 24m. It is characterised as small in size (65 m^2 footprint, 520 000 m^3 material) with approximately 50% of the material burnt. There is some topsoil but the thickness was not measured.

Dump No 2 is an old end-tipped discard dump and again it is presumed that the dump was also only utilised until 1936. It is also relatively small in size (114 000 m^2 footprint, 1 600 000 m^3 discard waste) with most of the material (70%) burnt. There was some slurry on the top of the dump as well as some building and road rubbles. 30 cm topsoil covers a third of the dump and no toe seepage was observed. The dump is still hot and one portion is actively burning. Approximately 70% of the dump consists of burnt material. Although the dump has not been rehabilitated, vegetation has established on the dump naturally over time. Building rubble was dumped on the eastern side and slurry was disposed of on the top of the dump. The current management strategy of the mine is to not reshape or cover the dump due to its small size, old age and mainly because most of the discard has been burnt. However, the final decision will be based on the outcome of this investigation. Vegetation on the dump was found to be mainly grasses and one indigenous tree, *Acacia karoo* (sweet thorn) and Eucalyptus trees. Dump No.2 is between 1 327m and 1 363m amsl thus an elevation difference of 33m.

4. SAMPLING, QUALITY ASSURANCE AND QUALITY CONTROL

The materials in Durnacol Dumps Nos. 1 & 2 can be distinguished from a geochemical perspective on the following basis: 1) "Old" unburned coal discard (exposed to heat from the burning outer layer – organic components probably largely volatilised); 2) Fine slurry with very low permeability (probably all unburned); 3) Burnt discard (ash) where some of the sulphides have been volatilised – also include dump components that are currently burning; 4) Contaminated soil underlying the dump; and 5) Groundwater.

Representative samples including burnt discard, unburned discard, slurry material and mixed material were taken from the dumps and subjected to various analyses, which include 1) Sieve and separate the < 2 mm and > 2mm fractions of the samples; 2) Modified Sobek ABA with ICP analyses and X-ray fluorescence (XRF) scans; 3) BCRI, ABA and ICP scan at each pH point; 4) 2:1 Extraction and then ICP scan; 5) X-ray Diffraction (XRD); and 6) Sulphur speciation. It should be noted that all the analyses were only performed on the < 2mm fraction. The amount of tests and analyses were performed as following: 1) 13 x sieve and separate; 2) 13 x Sobek, ICP, XRF; 3) 5 x BCIR, ICP at each pH; 4) 6 x Extraction and ICP; 5) 6 x XRD; and 6) 13 x Sulphur speciation.

Quality assurance and quality control are important components for this study. Field sampling and tests were properly based on the quality assurance and control programs to ensure that samples were collected, prepared and analysed according to scientifically acceptable and defendable methodologies including the documentation required to demonstrate that the correct procedures and methods were followed. These include field sampling and tests, laboratory sampling and analyses.

5. RESULTS

On Site Testing

For Dump No.1, from both the paste pH and fizz rating, it was concluded that both pyrite and calcite are depleted for the unburned discard samples, although it is more significant for calcite than pyrite. The on-site test results of paste pH, paste EC and fizz test on Dumps No. 1 and 2 showed that there is no clear correlation between the paste pH and fizz ratings but some unburned materials have higher fizz ratings than some of the burnt samples. The paste EC data were obtained and used to estimate TDS (mg/ℓ, EC multiplied by 7.5). The paste EC was averaged at 86 mS/m in a range of 0.226 to 191.9 mS/m, and TDS is averaged at 535 mg/ℓ in a range of 2 to 1 163 mg/ℓ for burnt and unburned materials. The low TDS value indicates a possible low risk for AMD and the fairly large range of TDS may indicate the variation of the materials in terms of effect of combustion process.

For Dump No. 2, the averaged fizz rating is weak (1.4) for the unburned samples while the fizz rating is higher (2.1) for the burnt samples, which is the opposite trend when compared to Dump No 1. The depletion of pyrite is obvious from both the paste pH and the fizz ratings. More reactive calcite is available for chemical reaction in this case. There is a lack of clear correlation between the paste pH and fizz rating. The paste EC is averaged at 49.65 mS/m and TDS is averaged at 372 mg/ℓ in a range of 4 to 1 289 mg/ℓ, which is significantly lower than in Dump No 1. This indicates even less risk for the forming of acid mine drainage (AMD) in Dump No 2 than Dump No 1.

Analysis of Water from Pond Adjacent to Dump No. 1

It was requested to specifically consider the small pond adjacent to Dump No. 1 in terms of water quality. A grab sample was taken in bottles consisting of acidified (preserved) and unpreserved aliquots on 18 May 2001. The sample was refrigerated, and submitted for analysis on 20 May 2001. The preserved sample was analysed for metals, and the unpreserved sample was submitted for full chemical analysis.

In general, the water is well suited for domestic use, with the only problems being the high total iron concentrations (1.5mg/l) and the high total manganese concentrations (0.81mg/l). Iron concentrations in the range of 1 - 10 mg/l have pronounced effects on the taste of the water, which can also be associated with plumbing in terms of scaling and corrosion. Slight health effects may also be expected in young children and sensitive individuals. The concentration of dissolved iron in the water is dependent on the pH and the occurrence of manganese. The high occurrence of manganese could explain why the iron concentration is so high, although the water is rather alkaline with a pH of 7.9. Manganese concentrations in the range 0.15 to 1.0 mg/l affect the taste of the water and causes staining of plumbing fixtures and laundry, although no health effects occur.

According to the South African Water Quality Guidelines for Aquatic Ecosystems, the ammonia concentrations (0.3mg/l), dissolved manganese (0.25mg/l) and dissolved aluminium concentrations (<0.1 mg/l) are higher than the Target Water Quality Range. Ammonia affects the respiratory systems of many animals, but prior exposure or acclimation to ammonia increases the tolerance of fish and enables them to withstand concentrations that would otherwise be lethal. The use of explosives in the surrounding mine shafts could have contributed to the high levels of ammonia in the pond water. Toxic effects of aluminium are dependent on the species and life stage of the organism, calcium concentration and pH of the water. It must also be understood that guideline criteria for aluminium is tentative, because toxicity and bio-availability is governed by complex interactions with other water quality variables. Although the dissolved manganese concentration is higher than the Target Water Quality Range, it is still below the Chronic Effect Value and therefore protection of the aquatic ecosystems is ensured.

In the Durnacol Rehabilitation Plan, some water quality results dating back to 1936 were presented. These results were used to provide some context to the analysis of the seepage sample. Three sets of results did not contain magnesium analyses, and these were calculated based on the assumption that the analytical laboratory achieved a satisfactory ionic balance.

Analytical Results

Particle Size Distribution

The results of Particle Size Distribution (PSD) for the collected samples can be summarised as follows: 36% is larger than 4.75mm for unburned material, the smaller than 4.75mm fraction (4.75-2.8, 2.8-2.0, 2.0-1.7, 1.7-0.5, and <0.5mm) is at average of 0.91 mm in diameter. PSD results for all the samples collected at Durnacol Dump No 2 are summarised as follows: 23% is larger than 4.75 mm for unburned material. The smaller than 4.75 fractions are on average 0.96 mm in diameter.

Acid-Base-Accounting (Aba)

All samples were sieved and separated into two fractions: > 2 mm and < 2 mm. Only the smaller fraction was used for analyses, as the assumption was made that the reactivity of the larger particles are insignificant when compared with the fines. The chemical reactivity is dependent on the exposed surface area of the particles. Smaller particles are modelled as spheres that continually shrink as the pyrite reacts (shrinking core model), while the larger particles are modelled as having active areas where oxidation occurs.

The results of Sobek ABA, BCRI and ICP-MS scans indicate that leachability of the major and some of the trace metals are positively correlated with a decrease in pH. The most leachable components were Ca, Mg, Sr, Na, and the trace metals Mn, Al, Zn, Co and Ni.

Sulphur Analyses on Samples from Durnacol Dumps

The sulphur concentrations were plotted in a stock diagram showing the values of maximum, average and minimum of total sulphur (S_{total}), sulphate-sulphur and sulphide-sulphur. Sulphur comprises sulphate-sulphur and sulphide-sulphur in both cases, and the results indicate that the sulphur contents were changed in the burnt samples while these do not have similar trends for the burnt and unburned materials in Dump Nos. 1 and 2. Total sulphur and sulphate-sulphur have a similar trend to sulphide-sulphur.

In Dump No. 1, sulphur concentrations in the unburned samples are much lower than in the burnt samples, but there is an opposite trend for Dump No. 2. The reason is not clear. It might be due to a small sample number. Therefore, laboratory test may be conducted for further study in future.

Sulphide-sulphur in both Dumps Nos. 1 and 2 is larger than 0.25%, which indicates that the material is potentially acid-generating. There is a similar sulphur concentration in the unburned samples in both Dumps Nos. 1 and 2. However, the sulphur concentration is much higher for burnt samples in Dump No. 1 than in Dump No. 2. Therefore Dump No 1 has a higher potential acid generation risk than Dump No 2 since it has a higher percentage reactive material (only 50% burnt material in Dump No. 1) than Dump No. 2 (70% of burnt material).

According to Sobek, *et al.* (1978), samples can be classified based on sulphide-sulphur content and the ratio of NP:AP. From Figure 2, it is evident that all the samples from Dump No 1 and most of the samples from Dump No 2 belong to Type I, *i.e.* potentially acid generating. It is worthwhile to notice that two burnt samples from Dump No 2 fall in Type III, *i.e.* no acid generation. It indicates that the combustion process did reduce sulphide-sulphur (pyrite) concentration more than it did calcite concentration.

Geochemistry and Mineralogy

Solid samples collected at Durnacol Dumps have been analysed for major chemical element compositions by XRF which actually shows the geochemical composition of the ash of the discard while the Loss of Ignition (L.O.I.) actually indicates chiefly carbon with a little bit of burnable components such as sulphides and calcite. The geochemical compositions are characterised by the follows: 1) High concentrations of SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O (>1%) with minor amounts (<1.0%) of TiO_2, MgO, Na_2O, P_2O_5 and trace amount of MnO (0.01%) and Cr_2O_3 (<0.02%); and 2) Some samples have as high as >68% of L.O.I., i.e., carbon.

The results of ICP MS scan analysis are characterised by the following: 1) The highest concentration is Fe, and then Mg, Ca, Na, K, Ti, Si, Al; and 2) some heavy metals can be leachable such as Cr, Ni, Zn, V, and Cu.

Mineralogical concentrations were determined by XRD. The major minerals include primary minerals of quartz, plagioclase, microcline, calcite and secondary minerals of anatase, gypsum, mullite, jarosite, hematite and clay minerals of kaolinite, and smectite. Sulphide minerals were not detected by XRD. Only some minerals were considered as being present for purposes of kinetic modelling, which included plagioclase, calcite and pyrite (detected by analysing of sulphide sulphur).

6. GEOCHEMICAL MODELLING

Inflow into both dumps is from rain, determined from rainfall records. Outflows are: evapo-transpiration - determined from evapo-transpiration data and taking account of absorbance of hot discard and the absence of a soil cover in Dump No 2; runoff - calculated from infiltration modelling; and seepage that reports to the underlying groundwater via the node. Seepage was calculated as the difference between rain and the sum of evapo-transpiration and runoff based on the assumption that the water storages in the dumps were kept unchanged.

The mineral reactivity is divided into reactive and non-reactive types. The reactive minerals include primary minerals, *e.g.* pyrite, calcite, plagioclase, and secondary minerals, *e.g.* gypsum and alunite. The non-reactive minerals include primary minerals, *e.g.* quartz, kaolinite, mica and secondary minerals, *e.g.* jarosite-K, jarosite-Na and hemate. The reactive minerals were included in the model, while the non-reactive minerals were not considered in the model due to their slow reaction rates in general.

It is intended to cover Dump No. 1 and therefore the dump was modelled as having a cover. This node consists of old burnt and old unburned materials. The volume and surface area of the dump have been defined as 520 000m^3 and 65 000m^2, respectively. The data were calculated using Surfer© 8.2 based on the survey data (x,y,z) provided by the mine. The maximum height is 1 351.7m and the minimum height is 1 322.4m in the surveyed area. Based on contour and surface maps, 1 330m was taken as the ground level, which is about 8m higher than the minimum point in the surveyed area. The height of the dump is approximately 21m. The soil cover, proposed by Durnacol, comprises two layers: 150 mm topsoil on top and 400 mm compacted clay on the dump.

The Dump No. 2 node consists of old burnt and unburned material and topsoil (a layer of approximately 30 cm covering approximately a third of the dump). The volume and surface area of the dump have been defined as 1 600 000m^3 and 114 000m^2, respectively based on the similar estimation as shown for Dump No 1. The maximum height is 1 369.7m and the minimum height is 1 318.0m in the surveyed area. Based on contour and surface maps, 1 334m was taken as the ground level, which is about 16m higher than the minimum point in the surveyed area. The height of the dump is approximately 35.7m.

Rainfall infiltration rate for the intermediate cover for Dump No 1 is 14.8% based on the SoilCover model for Dump No 7 (PHD, 2003). For Dump No. 2, rainfall infiltration rate for the base case is 20% based on the study for Dump No. 7 (PHD, 2003, pers. comm.). This number is only correct for the unburned coal discard (30%). 70% of the coal discard was burnt, with some of it currently burning. In this case, 10% water infiltration is used for the dump as a whole based on 30% (30% multiply by 20%) unburned material and 70% (multiply by 5%) burnt material. The infiltration rate difference between unburned and burnt materials is due to different temperatures. This approach is assumed that the burnt materials are not reactive in terms of AMD. The difference of the two portions of burnt and unburnt materials is noted and may be considered as different nodes in future.

For Dump No. 1 coal combustion is assumed to be extinguished after the placement of a soil cover. For Dump No. 2, it is still hot and still partially actively burning, which strongly affects the evapo-transpiration process. If 20% of normal infiltration for the unburned area (30%) and 5% for the hot and burnt area (70%) are used, the weighted average rainfall infiltration will be approximately 10%. It is important to characterise the reactive materials in the dumps. Half of Dump No. 1 is unburned material and only 64 % of this material (< 4.75 mm) is regarded as reactive, the other half is burnt material and only 40 % (< 4.75 mm) of this material is regarded as reactive. Dump No. 2 has 30% unburned material of which only 78% of the material (< 4.75 mm) is regarded as reactive while the other 70% of the dump is burnt material, of which only 43% of the material (< 4.75 mm) is regarded as reactive.

Surface areas for individual minerals were estimated based on the size fraction of <2mm that is reactive. This is useful for kinetic geochemical modelling. For unburned material in Dump No. 1, 1 733 cm^2/g for pyrite; 3 019 cm^2/g for calcite and 3 111 cm^2/g for quartz and others based on the averaged grain size (0.91mm), roughness (125) and specific mineral gravity. For burnt material 2 065 cm^2/g for pyrite; 3 599 cm^2/g for calcite and 3 708 cm^2/g for quartz and others based on the averaged grain size (0.86mm), roughness (125), and specific mineral gravity. The surface area of burnt material is used for modelling and 37% of the coarse material (> 4.75mm) will be deducted from the reactive material, *i.e.* 20.6% (55% * 37.5%).

For unburned material in Dump No. 2, surface area is 1 646 cm^2/g for pyrite; 2 868 cm^2/g for calcite and 2 955 cm^2/g for quartz and others based on the averaged grain size (0.96 mm), roughness (125) and specific mineral gravity. For burnt material 2 675 cm^2/g for pyrite; 4 661 cm^2/g for calcite and 4 803 cm^2/g for quartz and others based on the averaged grain size (0.59 mm), roughness (125) and specific mineral gravity. The surface area of burnt material is used for modelling and 23% of the coarse material (> 4.75mm) will be deducted from the reactive material, *i.e.* 6.9% (30% * 23%).

The Modelling data inputs include annual rainfall, recharge rate, initial pore water quality data, mineralogical data, *e.g.*, mineral concentrations, specific surface areas of different minerals are dump specific, moisture contents, porosity, kinetic rate data, boundary conditions, O_2 availability, the heights, water retention time, and individual mineral surface areas.

For Dump No 1, The water quality modelling results for potential seepage can be summarised and generalised for the medium (10 years) to long term (100 years) as follow: 1) Turns slightly acidic (pH about 5.6-6.0); 2) 3 500 mg/ℓ TDS; 3) 70-75.8 kg/day TDS load; 4) 2 100 mg/ℓ SO_4; 5) 505 mg/ℓ alkalinity as HCO_3; 6) 800 mg/ℓ Ca; 7) Close to 0 mg/ℓ Mg; and 8) Below 10 mg/ℓ Na. The major modelling results are also summarised in terms of: 1) 0 – 5 years; 2) 5 – 10 years; 3) 10 – 50 years; and 4) 50 – 100 years. The results can be generalised and summarised as follows: 1) pH turns acidic at the beginning and also in the first five years, but improves in the longer term (pH 5 - 6); 2) TDS and SO_4 concentrations are high in the first five years, but improve and are stabilised in the longer term; 3) Ca concentration is high, but alkalinity as HCO_3^-, Mg and Na is generally low; and 4) Potential seepage volume of 20.8m^3 per day.

For Dump No 2, The water quality modelling results for potential seepage can be summarised and generalised for the medium (10 years) to long term (100 years) seepage from Dump No 2 as follow: 1) pH turns and remains acidic in the first 10 to 20 years, and then it increases to about 6; 2) 2 700 mg/ℓ TDS; 3) 42.8 to 43.2 kg/day TDS load; 4) 2 000 mg/ℓ SO_4; 6) 59 mg/ℓ alkalinity as HCO_3^-; 7) 800 mg/ℓ Ca; 8) Mg drops quickly in the first five years, and remains close to 0 mg/ℓ in the long term; and 9) Below 10 mg/ℓ Na. The major modelling results are also summarised in terms of: 1) 0 – 5 years; 2) 5 – 10 years; 3) 10 – 50 years; and 4) 50 – 100 years. The results can be generalised and summarised as follow: 1) pH turns acidic at the beginning and remain as such in the first five years, but improves in the longer term (pH 5-6); 2) TDS and SO_4 concentrations are close to 9 000 mg/ℓ in the first five years, but improve and are stabilised at about 2 000 mg/ℓ in the longer term; 3) Ca concentration is high, but alkalinity as HCO_3^-, Mg and Na are generally low; and 4) Potential seepage volume of 23.7m^3 per day.

7. DISCUSSION AND CONCLUSIONS

The static tests including ABA and sulphide sulphur concentration show that both Dumps Nos. 1 and 2 will have a negative impact on the surrounding environment, i.e., acid generation, but it is qualitative. This includes sulphide-sulphur >0.25% and NP:AP ratios. The results are quite similar to the environmental impact assessment for other dumps such as Dump No. 7 (PHD, pers. comm.)

The research results also indicated that the burning of discard materials does reduce the acid generation risk since part of the sulphide and calcite can be reduced. For example, two burnt samples from Dump No 2 fall in Type III, i.e. no acid generation. It indicates that the combustion process did reduce the bulk sulphide-sulphur (pyrite) concentration, but bulk calcite concentration may be reduced, too.

The kinetic geochemical modelling results provide similar results as ABA and sulphide sulphur results, but also provide more quantitative indicators for the impact on the environment. For example, the geochemical modelling results indicate the water quality may have pH above 5.5 for Dump No1 and have pH below 5 for at least 20 years for Dump No. 2. The geochemical results also indicate the water quality from the two dumps would have high TDS between 3000 and 8000 mg/l, SO4 between 2500 and 7000 mg/l. However, the fact that no proper validation that can be made, place limitations on the potential use of the technology.

Although, the research results did indicate that the two dumps will have negative impacts on the environment, it should be recalled that overall the two dumps (Nos. 1 and 2) are indeed small in area and volume and also that no clear toe seepage was observed. In addition, they are also old and stopped operating as disposal sites for quite a long period of time. Therefore, it is not recommended to design, plan or carry out a comprehensive water-monitoring programme. It is however recommended that the mine continue to monitor the boreholes in the vicinity of Dump No. 2 to establish the potential development and migration of a pollution plume around the dump in future.

Based on the discussion in the above section, it is concluded that: 1) Both dumps do have acid generation potential that will pose a negative impact on the environment based on both static tests and kinetic geochemical modelling; 2) The combustion process reduced the sulphide (pyrite) - sulphur concentration of the major acid generation mineral and at the same time, also the neutralising mineral calcite. Overall, the burning process may reduce acid generation potential and potential risk of AMD; 3) Due to no major toe seepages being observed around the dumps, their small size and volume, linked to a slow burning process without major smokes, it is not recommended to design, plan or carry out a comprehensive water monitoring programme for the two dumps. It is however recommended that the mine continue to monitor the boreholes in the vicinity of Dump No. 2 to establish the potential development and migration of a pollution plume around the dump in future; and 4) This integrated study using both static tests and kinetic geochemical modelling may provide a protocol of model procedures for environmental risk assessment on coal discard dumps in South Africa.

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9. REFERENCES

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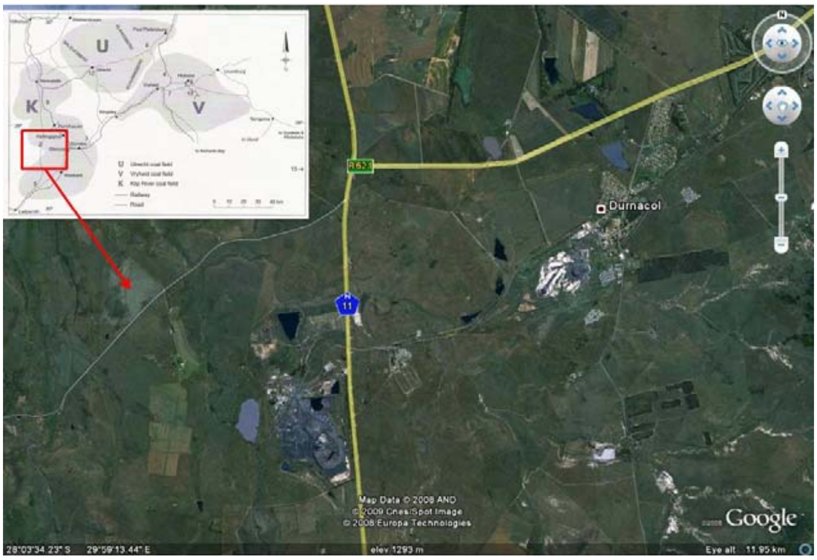

Figure 1. Locality map of Durnacol. (after Google Earth and Snyman, 1998)

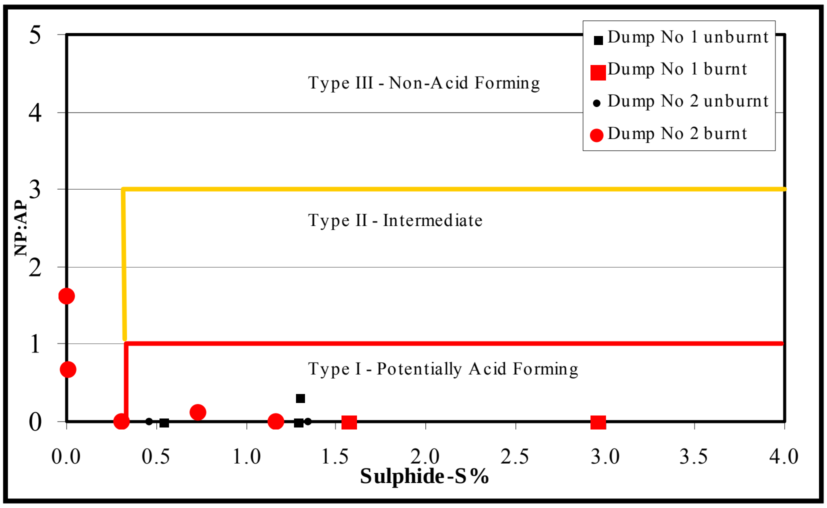

Figure 2. Rock types for AMD based on Sulphide-S (%) vs NP:AP ratio