Acid Rock Drainage Generation Characterization of Rock Samples from Open Pit mine using Acid Base Accounting and Column Test Prediction Procedure

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Abstract—The gold mineralizations in most of the concessions in Ghana are associated with sulphide minerals. The oxidation of these sulphide minerals has the potential to generate Acid Rock Drainage (ARD). Acid Base Accounting test was conducted on 20 grab samples made up of basalt and felsic porphyry (FPO) obtained from Subriso East and Subriso West pits of Huni-Butre Benso (HBB) concession of Golden Star Wassa limited, Ghana. The samples were tested for CO_2 and % total sulphur. The MPA was calculated based on the % total sulphur obtained. The neutralization potential was determined using the EPA (Sobek) method. The NNP was calculated and the NNP results were used to classify samples as acid generating or non-acid producing. Other classification plots such as NPR vs % total sulphur and NP vs MPA were also used to classify the samples. The ABA test results showed that the basalt and the felsic porphyry all have a potential to generate acid. As a confirmation test for the static test column test, a type a kinetic test was conducted on both lithological units. The result after one month of testing showed that the water quality parameters that were measured were all within accepted limit**.**

Index Terms—Acid-Base accounting, Acid Rock Drainage, Neutralization Potential, Maximum Potential Acidity, total Sulphur, Column test, water quality, heavy metals

1 Introduction

Aside the numerous benefits of mining in Ghana, some negative impacts are inherent. One such inherent problem is acid rock drainage perceived to be the largest single environmental problem facing the mining industry today [1], [2], [3], [4]. Acid rock drainage (ARD) often referred to as acid mine drainage (AMD) occurs as a result of the oxidation of sulphide minerals when they are exposed to air and water. This is a natural activity but certain human activities such as mining and construction speed up the phenomena. In most metal mine areas the sulphide minerals are mostly associated with the mineral of interest. The onset of ARD is a dynamic process which is influenced by many factors such as geological and environmental factors. It could happen instantaneously or after many years after the available neutralization has been exhausted [5]. It may take many years before the biological, physical and chemical threshold necessary for a negative effect to be felt as a result of ARD hence observation that ARD has not yet occurred does not guarantee it cannot occur in the future. ARD leads to the dissolution of other minerals contributing to an increase in the contaminant load in the acid drainage [3]. Among factors affecting the total capacity of a material to generate acid are amount of acid generating (sulphide) minerals present, amount of acid neutralizing minerals present, amount and type of potential contaminants present. The rate of acid generation is also influenced by the following factors type of sulfide mineral present (including crystal form), type of carbonate mineral present and other neutralizing minerals, mineral surface area available for reaction, particle size, available water and oxygen, bacteria.

As mineralogy and size variables changes, the ability to accurately predict the acid potential becomes quite difficult [6]. Coarse grain material allows air circulation; however, fine grain material exposes more surface area to oxidation [3]. Acid rock drainage prediction tests are increasingly relied upon to assess the long-term potential of acid generation. This concern was developed because of the lag time at existing mines between waste emplacement and observation of an acid drainage problem [7]. ARD prediction tests are aimed at determining discrete volume of material that will generate acid and to predict the quality of the drainage based on the rate of acid formation measured [8]. The prediction test for ARD is categorized into static and kinetic test. Static tests predict drainage quality by comparing the sample's maximum acid production potential (AP) with its maximum neutralization potential (NP). The most common neutralizing minerals are calcite and dolomite. The term static is used since the tests do not consider the relative rates of acid production and consumption. The Kinetic tests are intended to mimic the processes found at mining sites, usually at an accelerated rate.

The acid-base accounting test, a form of static testing, was developed in 1974 to evaluate coal mine waste and was modified by Sobek et al. in 1978 [9]. The acid production potential (APP) is determined from the total sulfur content as follows: APP = 31.25 x percent Sulphur and assumes that two moles of acid will be produced for each mole of sulfur. Units for APP are tons of acidity per ton of rock. Neutralization Potential (NP) is determined first by a simple fizz test to select the acid strength to use in the next step. Based on this information, hydrochloric acid is added to the sample and the sample is boiled until the reaction stops. The resulting solution is back titrated to pH 7 with sodium hydroxide to determine the amount of acid consumed in the reaction. Prediction of drainage quality for a sample based on these values requires assumptions that reaction rates are similar and that the acid consuming minerals will dissolve [10]. This work was aimed at assessing the potential of the samples collected to generate ARD using acid base accounting and column testing to classify materials into either acid generating or non-acid generating.

2 Study Area

The Birimian in Ghana is classified into a two-fold litho-stratigraphic systems consisting of metavolcanic and metasedimetary groups with an overlying younger arenaceous and clastic Tarkwaian group [11]. The Benso deposits are hosted by Birimian metavolcanics into which coarse plagioclase porphyry units have intruded and which are generally conformable with the volcaniclastic units. At Subriso East the metavolcanics host complex quartz vein systems associated with intense shearing and abundant sulphide mineralization. Mineralogy is relatively simple with fine-grained but visible gold disseminated in discrete quartz veins. Pyrite is abundant and associated with the gold in clusters of fine crystals. Zones of intense alteration with chlorite, carbonates and epidote are common.

3 Method

In order to characterize the various rocks types that would be exposed in the course of mining to the agents of weathering consequently causing acid rock drainage for sulphide containing rocks twenty (20) samples were obtained by grab sampling method from Subriso East (SBE) and Subriso West (SBW) pits. The samples from SBW were basalts while five of the samples from SBE were felsic porphyry (FPO) and five were basalt.

The samples taken to the laboratory were crushed and portion of the sample tested for carbon dioxide CO_2 and percent total sulphur (%S). The total sulphur was determined by high temperature furnace combustion (ISO 15178) and the CO_2 too was determined by combustion. The maximum potential acidity (MPA) was also calculated as follows:

$$MPA = 31.25 \times \% \text{ total sulphide} \quad (1)$$

The static test determination of the neutralization potential (NP) was conducted according to EPA (Sobek) protocol. To determine the potential of the rock types to generate acid rock drainage upon weathering the neutralization potential Ratio (NPR) was calculated from the ratio of NP to MPA and the net neutralization potential (NNP) was also calculated as the difference between neutralization potential (NP) and the maximum potential acidity (MPA).

In other to facilitate the classification of samples a plot of NPR versus the %S using NPR threshold of 2 and %S threshold of 0.3 to divide the plot region into four quadrant (I, II, III, IV). Other plots of graph that were carried out include MPA versus %S and neutralization plots such as NP versus MPA, CO2 versus NP.

The static test always provides a quick classification of sample as either acid generating or non-acid producing. Kinetic test was performed for basalt samples from Subriso West pit and felsic porphyry samples form Subriso East pit as they were found to be acid producing based on the static test classification scheme. The column test was the type of kinetic test used. Single lithological units was added incrementally to a 6 inch inside diameter PVC column and leached with rain under natural environmental conditions. Water samples from columns were sampled at the end of one month and analysed for the pH, conductivity, acidity, alkalinity, total dissolved solid (TDS), sulphate and some major and minor constituent of groundwater.

4 Results and Discussions

The acid base accounting test result (Table 1) for samples from SBE and SBW gave MPA values ranging from 0.9 to 80t$CaCO_3$/1000t ore and a NP values also ranging from 5 to 222t$CaCO_3$/1000t ore. According to ABA classification samples with NNP greater than 20 have low potential to generate ARD whiles NNP less than 20 were likely to form ARD but NNP of between -20 and 20 their potential to generate ARD is uncertain [4]. Most of the samples analyzed gave net neutralizing potential greater than 20 tCaCO3/1000 t ore as shown in Table 1 which is indicative that such samples have low potential to generate acid since the total amount of the neutralization component exceed the acid producing potential. It was also observed that four of the samples, SBWARD_003, SBWARD_013, SBWARD_016, and SBWARD_017 had their acid generating potential been uncertain.

Table 1: ABA results for the twenty samples

Sample ID	MPA	NP	NNP	NPR
SBEARD_010	80.3	140	60	1.74
SBEARD_024	14.4	169	155	11.76
SBEARD_025	1.3	215	214	172
SBEARD_031	7.2	167	160	23.23
SBEARD_032	12.2	112	100	9.19
SBEARD_004	24.4	135	111	5.54
SBEARD_005	14.1	133	119	9.46
SBEARD_006	61.9	77	15	1.24
SBEARD_008	19.1	108	89	5.67
SBEARD_009	9.4	115	106	12.27
SBWARD_003	5.9	25	19	4.21
SBWARD_004	24.4	86	62	3.53
SBWARD_006	0.9	54	53	57.6
SBWARD_008	15	75	60	5
SBWARD_009	35.9	222	186	6.18
SBWARD_011	49.1	137	88	2.79
SBWARD_013	25.3	7	-18	0.28
SBWARD_016	10.3	5	-5	0.48
SBWARD_017	15.6	5	-11	0.32

*MPA, NP and NNP have their units as t$CaCO_3$/1000t ore

From Fig 1 a plot of neutralization potential ratio (NPR) against percent total sulphur showed that most of the samples were found in quadrant I and IV. Samples that were found in quadrant I and IV have their percent total suphide greater than the threshold which is 0.3 but unlike samples in quadrant IV which have the potential to generate acid, samples in quadrant I have enough neutralizing potential to counter the acid to be generated. Also samples which were found in quadrant II and III have non-acid producing potential. It is observed from the plot that five of the samples analyzed had the potential to generate acid rock drainage according to this classification scheme. These samples comprised of four basalt samples with sample identification of SBEARD_010, SBWARD_013, SBWARD_016, SBWARD_017 and one felsic porphyry sample with sample identification of SBEARD_006.

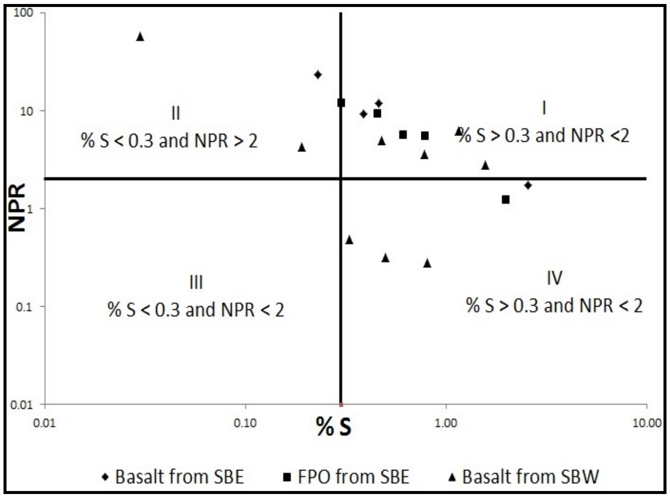

Fig. 1. Categorization of samples into four quadrants using a %S threshold of 0.3 and NPR threshold of 2

Based on the obtained ABA data another classification which could be used is a plot of NP against MPA. Using NP to MPA ratio of 2:1, 1:1 and 1:2, the plot can be divided into four regions ie acid consuming (AC), potential acid consuming (PAC), potential acid generating (PAG) and acid generating (AG) as shown in Fig 2. From this plot it could be seen that most of the samples were non-acid generating since most of the samples were found in the acid consuming category but three of the basalt samples from Subriso West still indicated the potential to generate acid rock drainage.

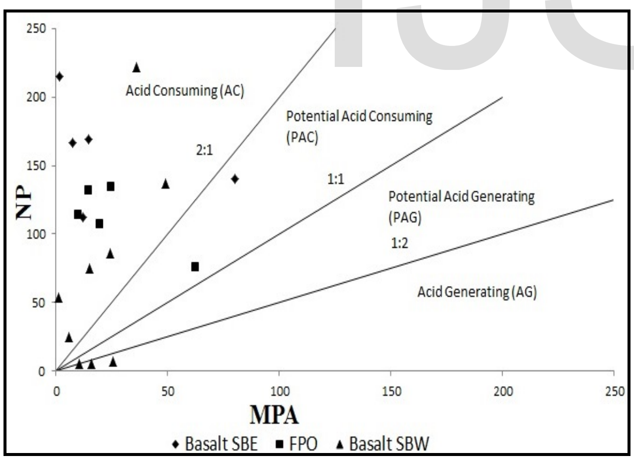

Fig. 2. NP-MPA plot for sample to categorize as acid consuming (AC), potential acid consuming (PAC), potential acid generating (PAG) and acid generating (AG)

A plot of MPA against percent sulphide shows the distribution of sulphate in the samples. The presence of sulphate resulting from prior oxidation of sulphides might exacerbate the ARD problem in the short term due to solubilization and hydrolysis reactions upon further weathering. Samples without sulphate will plot in a straight line if a sample does contain sulphate then that sample will plot below the line. A plot of MPA against percent sulphide (Fig 3) showed that none of the sample plotted below MPA=%total Sulphur line which implies that sulphate was not present in the sample. This implies that oxidation of the sulphide had not began in the sample prior to the test.

In other to identify whether or not the carbonates were the major contributing mineral to the neutralization a plot of CO_2 against neutralization potential (NP) (Fig 4) was analyzed. The graph showed a positive correlation with coefficient of correlation of 0.9779 which tends to indicate that the major neutralizing mineral could be attributed to the carbonates.

As a confirmation test of the data obtained from the static test result, kinetic test was therefore performed for samples that were potential acid generating. These yielded results as presented in Table 2. The pH of the samples was basic which were indicative that the samples which were regarded acid generating by the static test when subjected to similar conditions under which the kinetic test was conducted in the environment by agents of weathering would not be producing acid rock drainage. The measurement of the conductivity gave a value of 24mS/m which falls within the range for safe drinking water of 5-50mS/m. This implies that the release of the ionic substances in water bodies would be accepted for living organisms to survive as well as water from the source rock could be drinkable. The measurement of the major and minor elemental constituents of the affluent that was released was all within the accepted range as shown in Table 2.

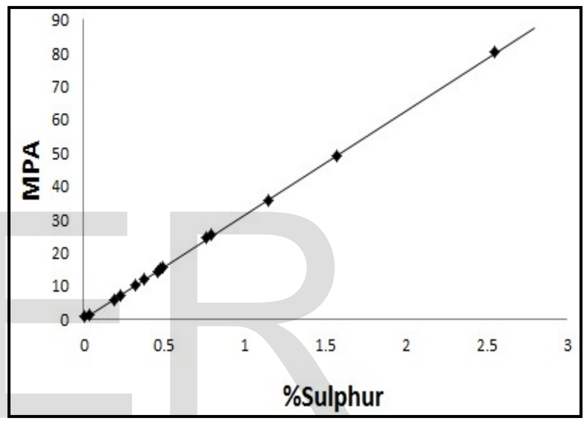

Fig. 3. MPA vs % S to determine the presence of sulphate

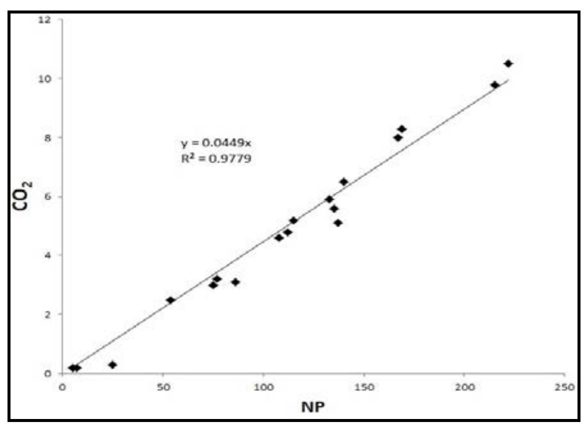

Fig. 4. Neutralisation plot CO_2-NP for determination of the contribution of the carbonate

ISSN 2229-5518

Table 2: Kinetic test result after one month of column test

Parameter	Basalt	FPO
pH	8.0	7.6
Conductivity (mS/m)	24	207
Acidity (mg/l)	17	41
Alkalinity (mg$CaCO_3$/l)	83	61
Total Dissolved Solids (TDS) (mg/l	140	1620
Sulphate (mg/l)	14	1120
Lead Pb (dissolved) (mg/l)	< 0.001	<0.01
Chromium Cr (dissolved) (mg/l)	0.04	0.02
Cobalt Co (dissolved) (mg/l)	< 0.05	<0.05
Copper Cu (dissolved) (mg/l)	0.02	0.03
Manganese Mn (dissolved)	<0.02	<0.02
Nickel Ni (dissolved) (mg/l)	0.03	0.02
Zinc Zn (dissolved)	<0.05	<0.05
Nitrate as NO_3 (mg/l)	4.17	<0.06
Nitrite as NO_2 (mg/l)	<0.05	<0.05
Arsenic As (dissolved) (mg/l)	0.12	0.012
Antimony Sb (dissolved) (mg/l)	<0.003	<0.003
Aluminium Al (dissolved) (mg/l)	0.11	0.11
Cadmium Cd (dissolved) (mg/l)	<0.002	<0.002

5 CONCLUSION

Even though results from the static test indicated that basaltic samples from the pits possessed the potential to generate acid rock drainage, the kinetic test proved otherwise within the time frame of the test for the samples. This implies that the type of carbonate present, the reaction rate of the carbonate, and the liberation of the sulphide would determine whether or not samples would produce acid rock drainage. It would therefore be important that samples are continuously monitored.

REFERENCES

[1] Barbour, S L, Wilson, G W and St Arnaud, L C, "Evaluation of the saturated – unsaturated groundwater conditions of a thickened tailings deposit", *Canadian Geotechnical Journal*, 30:935-946, 1993.

[2] USDA Forest Service Acid Mine Drainage from Mines on the National Forests, A Management Challenge. Program Aid 1505, p.12. 1993.

[3] Ferguson, K. D. and P.M. Erickson, "Pre-Mine Prediction of Acid Mine Drainage. In Dredged Material and Mine Tailings," Edited by Dr. Willem Salomons and Professor Dr. Ulrich Forstner. Copyright by Springer-Verlag Berlin Heidelberg 1988

[4] Lapakko, K, "Mine Waste Drainage Quality Prediction: A Literature Revie," Draft Paper, Minnesota Department of Natural Resources, Division of Minerals, St. Paul, MN. 1993.

[5] Morin, K. A and Hutt N.M, "Environmental Geochemistry of Minesite Drainage: Practical Theory and Case Studies," Minesite Drainage Assessment Group, 1997.

[6] Brodie, M.J., L.M. Broughton, and Dr. A. MacG. Robertson, "A Conceptual Rock Classification System for Waste Management and a Laboratory Method for ARD Prediction from Rock Piles," *In Second International Conference on the Abatement ofAcidic Drainage*. Conference Proceedings, Volumes 1- 4, Montreal, Canada, 1991

[7] Univ. of California, Berkley Mining Waste Study: Final Report. Prepared for the California State Legislature. 1988.

[8] California Mining Association, Mine Waste Management. Edited and Authored by Ian Hutchison and Richard D. Ellison. Sponsored by the California Mining Association, Sacramento, CA, 1991.

[9] Sobek, A.A., Schuller, W.A., Freeman, J.R. and Smith, R.M., "Field and Laboratory Methods Applicable to Overburdens and Mine soils," EPA 600/278-054, 203pp, 1978

[10] Lapakko, K., "Evaluation of Tests for Predicting Mine Waste Drainage pH," Draft Report to the Western Governors' Association, May 1992.

[11] Kesse, G.O., *The Mineral and Rock Resource of Ghana*, A. A. Balkema/Rotterdam/Boston, 610p, 1985