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# Acid Drainage Potential of Rocks in South-Western Ghana

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**Abstract:** The generation of acid in reactive sulphide-containing rocks is a major global problem confronting advanced countries, and serving as a wake-up call for developing countries like Ghana. South-western Ghana hosts two major gold belts, which house ten large-scale mining companies, several small-scale mining companies, farms and other activities. The presence of sulphur in the rocks, coupled with the land disturbances stemming from the activities mentioned above, suggests the potential for uncontrolled acid generation. These have thus generated interest in studies on mapping out the acid generating potential of these areas, so that proactive steps can be taken to prevent acid mine drainage. In this study, several samples were taken from mine waste, mineralised waste and ore from a mine concession in Ghana, and subjected to mineralogical, geochemical and Acid-Base Accounting (ABA) studies. Mineralogical studies reported about 75% quartz while carbonates, feldspars, pyroxene, sericites and chlorites accounted for 25% of samples tested. Polish sections showed pyrite content of up to 5% while arsenopyrite accounted for 1%. The results from geochemical and Acid-Base Accounting (ABA) passed 31% of the samples as non-sulphidic, whereas 20% had sulphur content above 0.5%. The sulphur content in excess of 0.5% gives an indication that the rock can generate acid. Analysis of paste pH confirmed that about 80% of the samples were neutral to basic (i.e. pH 6.5-8.5). Further analysis using Net Neutralising Potential (NNP) and ratios of Maximum Neutralisation Potential to Acid Production Potential (NP: AP) placed 35% of the samples as having the potential to generate acid since the NNPs were negative, while the NP: AP had values less than 1. This 35% had the capacity to significantly deteriorate natural water quality. The study concludes that there is a great potential for AMD generation in south-western Ghana, and this calls for periodic monitoring and development of proactive neutralising strategies to arrest the situation.

**Keywords:** Geochemical Analysis, Acid Base Accounting, Neutralisation Potential, Acid Production Potential

## 1. Introduction

Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) occurs when sulphide-containing rocks are exposed to weathering activities leading to the release of acidic waters. The major causative agents for acidic water generation are reactive sulphide minerals such as pyrite and arsenopyrite, oxygen, water and sulphur-oxidising microbes [1-5]. In areas where the acidic water drainage is caused by the presence of a mine, it is referred to as Acid Mine Drainage. Acid rock drainage may occur naturally in sulphide-prone environments but may intensify due to large-scale disturbances and/or during periods of heavy rainfall. Acid can be generated from many sources on a mine including surface runoff from open pit mine faces and pit workings, underground workings, waste rock dumps, ore stockpiles and spent heaps, tailings and process residue storages [4-7].

The generation of acid in reactive sulphide-containing rocks is a major global problem that requires proactive measures to arrest the situation. Acid generation usually results in dissolution and migration of heavy metals which contaminate water bodies and cause ecological destruction adversely affecting flora and fauna. The cost implications are extremely high with regards to the long term devastating effect beyond the life of the excavation project [4-5]. Until the late twentieth century, acid generation and drainage issues were not given much attention due to no clear policies previously in place. Several countries like South Africa, Canada, Australia, USA and Europe have abandoned mine sites which are experiencing environmental challenges due to acid mine drainage problems [5, 8], and huge sums of dollars are being used to clean up such environments [6-7]. Developing countries like Ghana should take a cue and consider the long term social, economic, environmental and political implications.

### *1.1. Rock Systems and Gold Mineralisation*

Ghana has several gold belts which include the Ashanti, Sefwi-Bibiani, Bui-Banda and the Kibi-Winneba as shown in Figure 1. The two most prominent belts; the Ashanti and Sefwi-Bibiani host ten (10) large-scale gold mines and over 500 small-scale gold mines found within south-western Ghana. The Ashanti Belt is primarily composed of palaeoproterozoic metavolcanic and metasedimentary rocks which are divided into the Birimian Supergroup (Sefwi and Kumasi) and the Tarkwa Group, which are both intruded by abundant granitoids [9]. The Birimian stratigraphy comprises metavolcanic rocks and metasedimentary rocks. The Birimian metavolcanic rocks contain mostly metamorphosed basaltic and andesitic lavas, hornblende-actinolite schists, amphibolites, conglomerates, tuff, carbonate-chlorite schists, quartz-sericite-schist, and mica schist [10-11]. The Birimian metasedimentary rocks are primarily phyllites, metagreywackes and schists. Figure 2 presents a part of the Geological map of Ghana showing the location of the Birimian and Tarkwaian rocks [10].

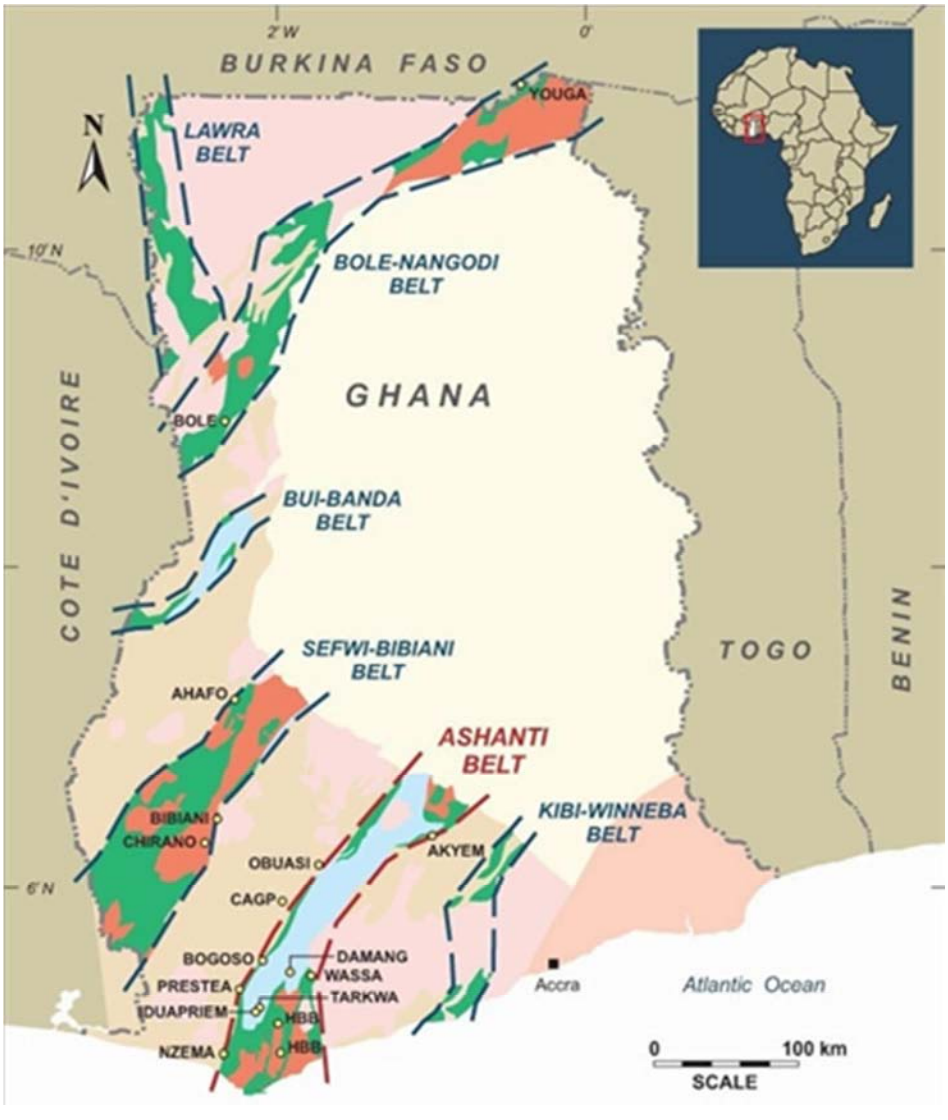


***Figure 1.*** *Geological map of Ghana showing the key gold belts (After [10]).*

In the Birimian rock system, gold is mainly hosted in pyrite and arsenopyrite whereas gold-bearing minerals in the Tarkwaian rock system are predominantly oxides [9-11]. Though the sulphide minerals present in the Tarkwaian rock system are generally not mineralised with gold, they are a potential precursor for acidic water generation. Due to the presence of sulphides in the Tarkwaian and Birimian rocks, any excavation has the potential to expose sulphide minerals. Thus both farming and mining activities which are prominent in the area have the potential to expose sulphide minerals and generate acidic water leading to environmental challenges. Since the Tarkwaian and the Birimian rock systems cover virtually the whole of south-western Ghana [10] (Figure 2), and they contain sulphide minerals, it is prudent to map out the acid generating potential of these areas, for possible proactive strategies in dealing with the problem.

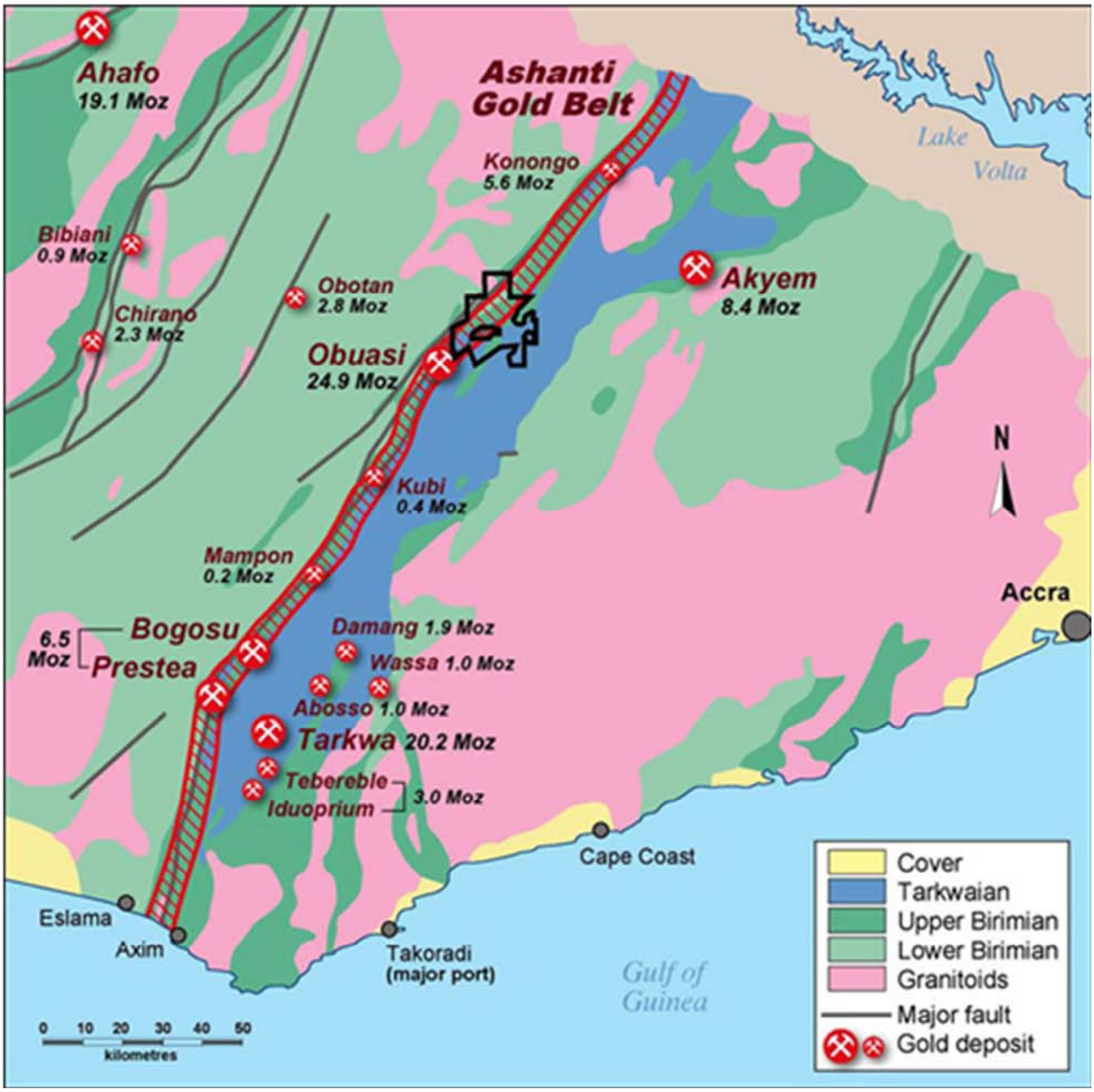


***Figure 2.*** *Geological map of Ghana showing the location of the Birimian and Tarkwaian rocks (After [10]).*

### *1.2. Prediction of AMD/ARD*

The reactive measure of dealing with AMD/ARD is very complex and expensive, whereas the proactive is more effective [12-16]. Developing proactive strategies in dealing with AMD/ARD problem requires prediction using appropriate tools which help to better control AMD/ARD before major excavations. A study of the mineralogy and analysis of the relative percentages of both acidic and basic minerals is used as a predictive tool for AMD [8, 12, 17-18]. Acid-base accounting is used to define the geochemical character of different rocks, which is then utilised to ascertain and predict the likely discharge of acidic waters in ores, mine waste or materials generated after major excavations [6-7, 18-21].

Mining companies go through compulsory acid-base accounting to ascertain the AMD potential before any major excavation so as to develop a proactive strategy to address any possible AMD generation [21-23]. Earlier studies by Ofori-Sarpong *et al*. [3] in the Tarkwaian rock system showed low AMD potential. This paper presents a study aimed at mapping out the acid drainage potential of rock systems (mainly the Birimian rocks) within south-western Ghana. The approach involved subjecting products of a mine excavation; mainly, mine waste, mineralised waste and ores to acid-base accounting so as to identify and quantify minerals with the potential to generate acidic water.

## 2. Experimental Investigations

The experimental investigations followed a similar protocol as used in Ofori-Sarpong *et al* (2013).

### 2.1. Samples and Sample Preparation

The samples received for analysis included core and weathered materials. Core samples were split longitudinally; one part was used for mineralogical analysis and the other for chemical analysis. In order to capture all lithologies, various units within the cores were sectioned and analysed [3]. Samples for chemical analyses were crushed and pulverised to 80% passing 75 µm, and split using riffles.

### 2.2. Mineralogical and Elemental Investigations

Mineralogical studies were done by megascopic analysis and also by thin and polish section microscopy. Based on the megascopic analysis, samples were classified as A1, B1, C1. in that order. Thin section microscopy was done using a LEICA DMC EP polarising microscope while polish sections were analysed using a Leitz optical microscope. The objective of the study was to identify the suite of both rock-forming and ore minerals that may be present, with emphasis on the presence of carbonates and sulphidic ore minerals. The absence or presence of sulphides and carbonates would be a basis for the generation or otherwise of AMD in the environment. The various rock-forming and ore minerals identified were captured for further studies. Total carbon, carbonates, total sulphur and sulphide sulphur were determined by the combustion volumetric technique using LECO SC-144DR Titrator and chemical procedures presented by [23]. Metals and metalloids were analysed using the Inductively Coupled Plasma-Atomic Emission Spectrophotometer (ICP-AES). Paste pH was obtained by pulping to 50% solids and observing to obtain a stable pH value.

### 2.3. Acid-Base Accounting

All samples received were subjected to Acid-Base Accounting (ABA) testing. The paste pH test was performed according to the ABA protocol [6, 17, 22]. The maximum Acid Production Potential (AP) and the maximum Neutralization Potential (NP) were determined according to the protocols of the United States Environmental Protection Agency [6-8]. AP was calculated by multiplying the percent sulphur by 31.25 while NP, which is a measure of the carbonate materials available to neutralise acid, was determined by adding acid to the sample and back-titrating to find the amount of acid consumed. The acid/base account or Net Neutralising Potential (NNP) was determined by subtracting AP from NP while Neutralisation Potential Ratio was estimated from the ratio of NP to AP.

## 3. Results and Discussions

### 3.1. Mineralogical Study

In general, most of the samples appeared sheared and/or fractured and highly altered due to some degree of metamorphism. Some foliations, microfolds ('kinks') and minor displacements were observed in the structures. The principal minerals observed were quartz (qtz), highly to partially altered feldspars (fsp) and micas, and minor amphiboles (amp), represented by hornblende. The altered feldspars and micas gave rise principally to sericites and chlorites. The presence of carbonates (calcite and dolomite) was confirmed in some samples, and in others, graphitic carbonaceous materials (grp) were detected. The textures and structures observed are shown in Figures 3-6. The mineral assemblages: quartz, feldspars, micas (biotite, muscovite), carbonates and their altered derivatives such as sericites, chlorites and clays are typical assemblages of the Birimian suite of rocks [9-11].

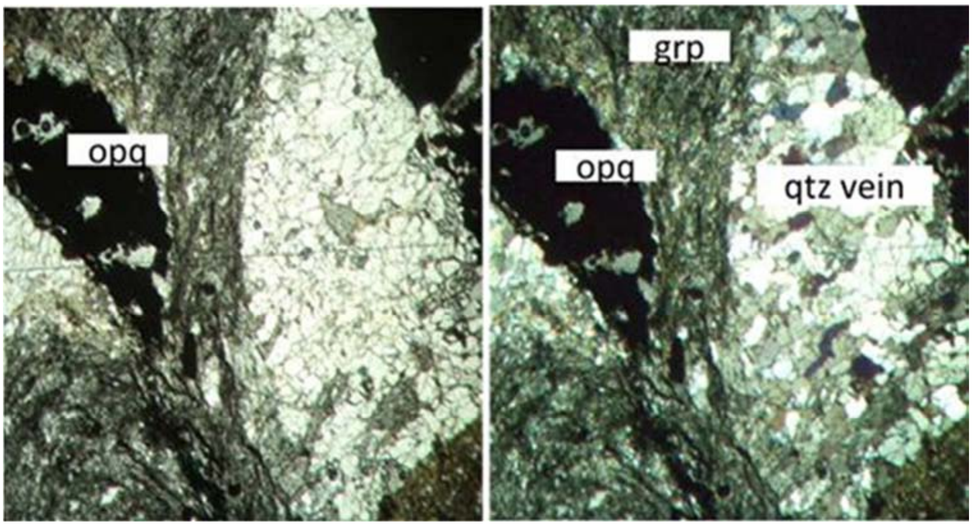


***Figure 3.*** *Photomicrographs of sample A1 showing quartz (qtz) veins, graphitic band (grp) and opaques (opq) minerals. Opaques are ore-forming minerals that are not identified directly in thin section.*

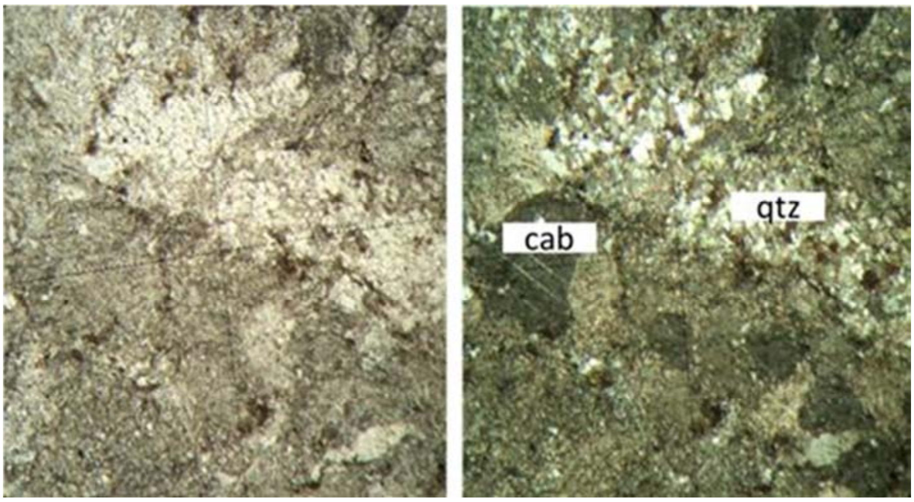


***Figure 4.*** *Photomicrographs of sample B1 showing carbonate (cab) and quartz (qtz).*

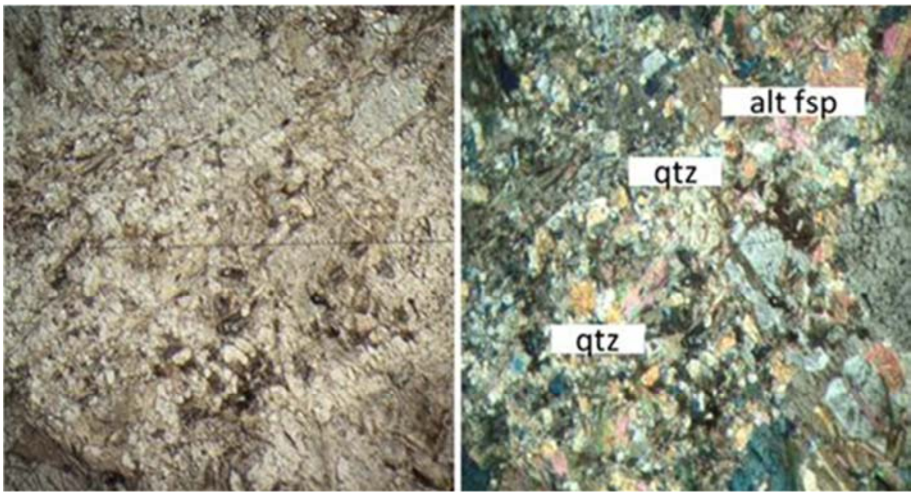


***Figure 5.*** *Photomicrographs of sample C1 showing high level of alteration with altered feldspars (alt fsp) and quartz (qtz).*

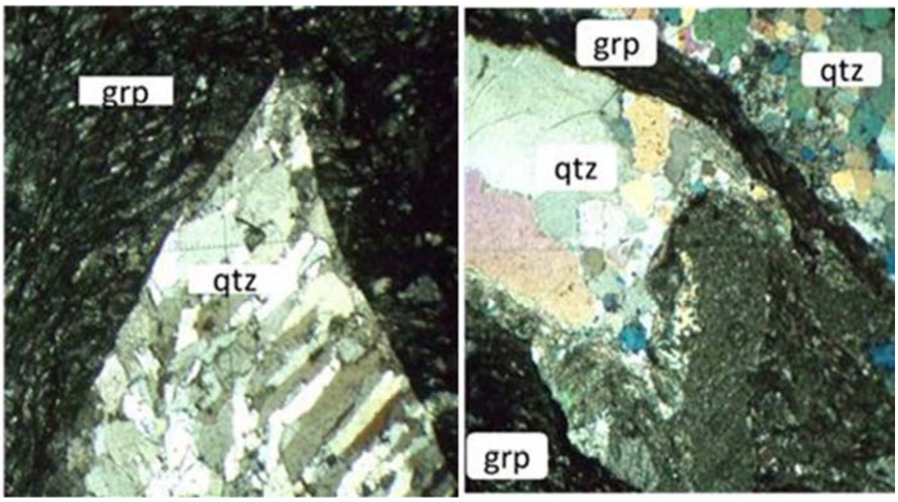


***Figure 6.*** *Photomicrographs of sample D1 showing sheared quartz (qtz) and graphitic bands (grp).*

Polish section studies showed that pyrite (py) was present in almost all the sections observed, and these were disaggregated or fractured. The sulphides were generally euhedral to subhedral and appeared to be associated with quartz veinlets within which they are present. There were variations in the quantities of observed pyrites with a maximum content estimated to be five percent (5%). Arsenopyrite (asp), also observed in some of the samples, was estimated to be a maximum of one percent (1%). Some of these sulphides had undergone oxidation to hematite (hmt). The photomicrographs in

Figures 7 and 8 show the various minerals and their textural relationships observed in the polish sections. The presence of these sulphides suggests the potential for AMD generation.

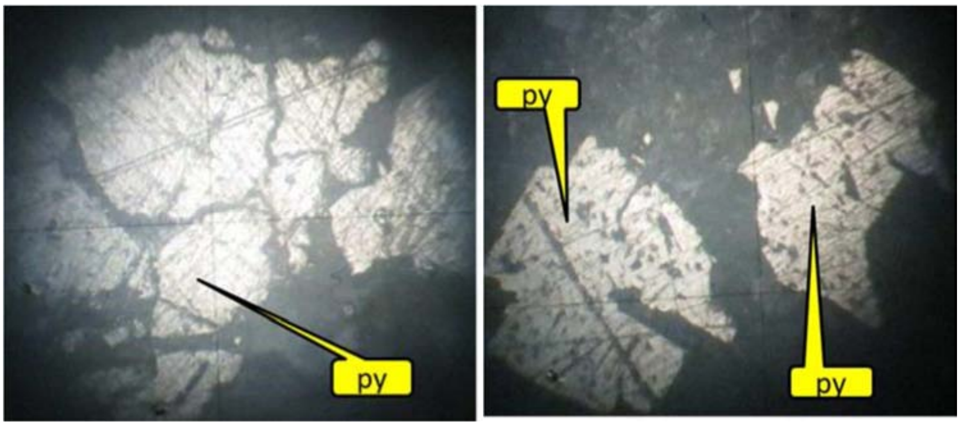


***Figure 7.*** *Photomicrographs of sample A1 and B1 showing fractured and 'pitted' surface of pyrite (py) grains.*

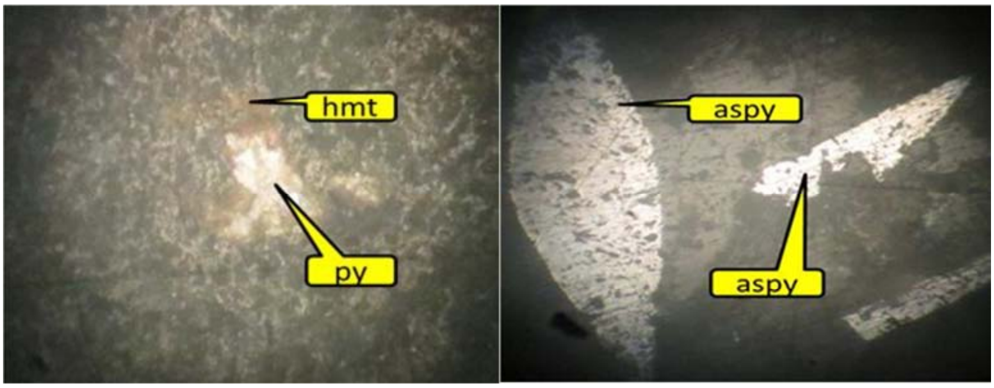


***Figure 8.*** *Photomicrographs of sample C1 and D1 showing alteration of the pyrite (py) grain to hematite (hmt) (a) and arsenopyrite (aspy) (b).*

### *3.2. Acid-Base Accounting*

Waste rock from mining and mineral extraction processes have to be disposed of in a way that they will not harm the environment. To do this proactively, Acid-Base Accounting (ABA) is used to generate values to help ascertain the acid-producing and acid-neutralising potential of rocks, prior to mining and other large-scale excavations. ABA assists in predicting post-mining water quality by comparing the amount of acid-producing rock with the amount of acid-neutralising rock at the location from which they are obtained. Table 1 shows data obtained from geochemical analysis and Acid-Base Accounting of the waste rock, mineralised waste and the ore.

***Table 1.*** *Acid-base accounting data for the various groups.*

| Material (M) | Fraction of M (%) | Range of $CO_3$ (%) | Range of sulphide S (%) | Paste pH |
|---|---|---|---|---|
| Mine Waste | 48 | 0.05 – 12.50 | 0.00 – 0.4 | 5.2 – 7.8 |
| Mineralised Waste | 10 | 1.45 – 7.95 | 0.00 – 0.9 | 5.1 – 8.5 |
| Ore | 42 | 2.85 – 6.55 | 0.74 – 4.0 | 7.2 – 8.5 |

According to Table 1, 48% of the samples were classified as mine waste, 42% represented the ore and the difference of 10% was mineralised waste. All the groups considered had some samples that contained sulphides. The results from geochemical and Acid-Base Accounting (ABA) analysis passed 31% of the samples as non-sulphidic and 20% had sulphur content above 0.5% which shows that there is the possibility of AMD generation. The acidity status of the samples as given by the paste pH showed 80% of the samples as being neutral to basic (i.e. pH 6.5-8.5). The remaining 20% had acidic pH between 6.5 and 5, suggesting products of sulphide oxidation. These were either mine waste or mineralised waste.

Plots of Maximum Neutralisation Potential (NP) against percentage sulphide sulphur is presented in Figure 9. Figure 9 shows varied amounts of carbonate available for neutralization with respect to sulphide sulphur available to generate acid. The Net Neutralising Potential (NNP) against % sulphur sulphur is presented in Figure 10. In Figure 10, several samples are shown to be below the zero line on the vertical axis. All such samples (35%) may be classified as potentially acid-generating. In ABA studies, samples with NP to AP ratios less than 1 (<1) should produce acid drainage, those between 1 and 2 can produce either acid or alkaline water conditions, while those with ratios greater than 2 (>2) should produce alkaline water. For samples with ratios between 1 and 2, kinetic studies would be necessary to confirm their AMD potential [7-8, 21].

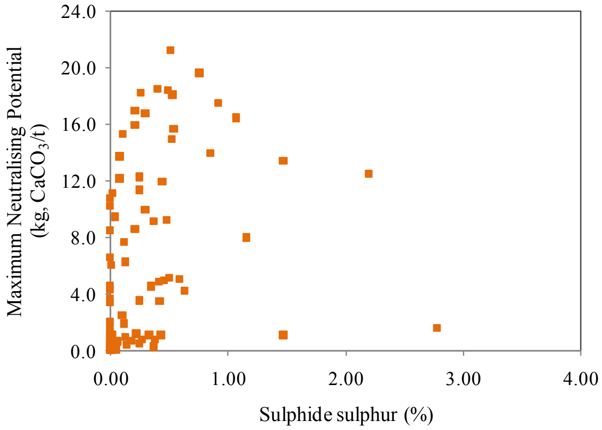


***Figure 9.*** *A plot of Maximum Neutralising Potential against % sulphide sulphur.*

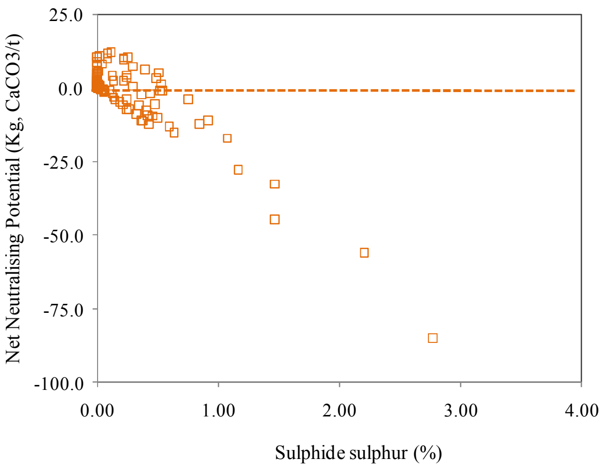


***Figure 10.*** *A plot of Net Neutralising Potential against % sulphide sulphur for the samples.*

Of the 35% that had negative Net Neutralising Potential and hence will generate AMD, 60% were ore samples, 25%, mineralised waste and 15%, waste samples. Ore samples will be leached at pH above 10.5 by the addition of lime to neutralize the acidity and discharged at a similar pH. Thus, it will enter the tailings impoundment in the neutralised state and will not generate acid. The mine waste which is known to be barren will generally be encapsulated between layers of material with no acid generation potential during deposition, as is the current practice [3]. The upper layer will serve as a soil cover and create an anaerobic condition that will not promote AMD [13, 22]. The challenge in many cases, is the mineralised waste which will be kept for future extraction, pending anticipated improvement in metal prices and/or technology. Although it has to be encapsulated to prevent the generation of AMD and pollution of surrounding water bodies, the anticipated usage normally poses impediments.

The gold belts in south-western Ghana stretch beyond the mining concessions currently in operation, and rocks which are not mineralised with gold may have similar mineralogical characteristics as the mine waste [9-11]. Thus, if the mine waste contains sulphides, then it is possible that within non-mining areas, rocks may contain sulphides with the potential to cause AMD when exposed.

### *3.3. Presence of Heavy Metal Ions*

The 32-element test indicated the presence of several metals. Those of major concern are the heavy metals such as lead, manganese, iron, nickel, cadmium, mercury and the metalloid arsenic. A graph of the arsenic content of all samples is presented in Figure 11, and it shows arsenic concentrations between 1 mg/l and 14,000 mg/l. This will not pose any danger unless it is solubilised and become bioavailable. However, the fact that arsenic is present at such high amounts in the soils is an indication that extra care should be taken to prevent AMD generation and solubilisation of arsenic [6].

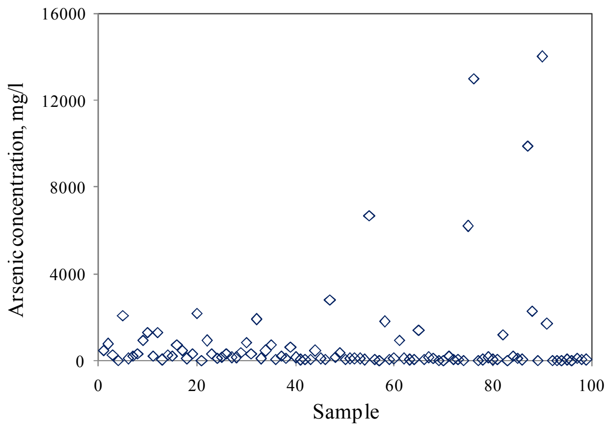


***Figure 11.*** *Arsenic concentration of the samples tested.*

### *3.4. Handling the Acid Generation Problem*

In all the materials tested (ore, mine waste and mineralised waste), some samples have the potential to generate AMD. It could thus be inferred that most zones within south-western Ghana could have acidic water drainage potential. For this part of Ghana, due diligence is therefore required when any major excavation or land disturbance activity is to be embarked upon. Regulatory bodies like EPA should extend monitoring beyond mining companies to cover other major excavation activities to prevent possible generation and mobilisation of acidic waters.

The most effective and sustainable way of dealing with acidic water drainage is to prevent it. Prevention will require identification of the potential areas and quantification of the problem. Static and dynamic methods are necessary for effective prediction [7, 19]. All these will be possible if resources are available to map out these potential areas. Further studies should therefore be undertaken to map out the whole of south-western Ghana for potential acidic water generation.

## 4. Conclusions

Some areas in south-western Ghana have been studied for their acid mine drainage potential. Mineralogical studies show that samples contain quartz, carbonates, feldspars, pyroxene, sericites and chlorites. The pyrite content was up to 5% and arsenopyrite was 1%. The results from geochemical and Acid-Base Accounting (ABA) analysis passed 31% of the samples as non-sulphidic and 20% had sulphur content above 0.5% which is an indication of the ability to generate AMD. The acidity status as illustrated by the paste pH showed about 80% of the samples as being neutral to basic (i.e. pH 6.5-8.5). The remaining 20% with pH below 6.5 suggests some degree of sulphide oxidation.

Further analysis using Net Neutralising Potential (NNP) and ratios of Maximum Neutralisation Potential to Acid Production Potential (NP:AP) placed 35% of the samples as having the potential to generate acid. Of the materials that had the potential to generate AMD, 60% were ore samples, 25%, mineralised waste and 15%, waste samples. Tailings of ore samples are normally discharged at pH above 10.5, and thus, will not generate AMD. Mine waste will generally be encapsulated but mineralised waste may stay much longer without encapsulation due to the potential for future processing. Such mineralised waste materials may easily generate AMD. The study therefore concludes that there is a high potential of AMD generation in both mining and non-mining areas of south-western Ghana.

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