Understanding Acid Rock Drainage Risk in the West African Shield

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Abstract

The Birimian and Tarkwaian rocks of the Paleoproterozoic West African Shield host some of the most important gold reserves in the world, deposited during successive hydrothermal sulphide alteration events, which were channelled by shear zones and thrusts during the regional Eburnean tectono-thermal deformation event. The hydrothermal fluids were auriferous and sulphide-rich, resulting in two distinct types of mineralisation: (1) Gold-bearing quartz and quartz-ankerite veins, occurring in NNE-SSW trending shear zones or thrust folds, usually in Birimian metasediments, with associated sulphides deposited on the fragmented wall rock. (2) Disseminated gold-bearing pyrite and arsenopyrite, occurring in halos within the same shear zones or thrust folds as the quartz veins.

The sulphidic nature of the gold deposits lead to a high risk of acid rock drainage (ARD). The environmental geochemistry of fourteen mines and deposits in the West African Shield was studied, using a combination of techniques. Weathering profiling, using a model initially developed by Senes, was used to divide rock and saprolite into three weathering zones, distinguishable in borehole core. Mineralogical profiles were used to characterise rock units by the relative abundance of macroscopic sulphide and carbonate minerals. Conventional acid base accounting was also done to provide quantitative acid generation and neutralisation potential. Combined logs were then prepared from these three profiles, showing the geochemical behaviour of the different rock units.

The results of the study show two key drivers of acid rock drainage risk: firstly, the degree of weathering: the Oxide Zone, from which both the acid-generating sulphide minerals and the acid-neutralising carbonate minerals have been largely leached, is non-acid generating. The Transitional Zone, from which the carbonate minerals have been largely leached but the sulphide minerals remain is almost always acid generating. The Fresh Zone, from which neither sulphides nor carbonates have been leached is uncertain and the second key driver of acid rock drainage risk applies: the abundance of acid neutralising carbonate minerals, which varies significantly from deposit to deposit – being at least partially controlled by the host rock mineralogy.

Since the two key drivers relate to the weathering zone classification and the host rock lithological units, this translates to readily-defined blocks and tonnages, giving the opportunity for separation of mine waters of different qualities and the selective handling of waste rock. Given the repeatability of this approach, it is suggested that it can be applied in principle across the West African Shield.

Keywords: Acid rock drainage, West Africa, gold, weathering, sulphide

Introduction

The Birimian and Tarkwaian rocks of the Paleoproterozoic West African Shield host some of the most important gold reserves in the world, deposited during successive hydrothermal sulphide alteration events, which were channelled by shear zones and thrusts during the regional Eburnean tectono-thermal deformation event. The hydrothermal fluids were auriferous and sulphide-rich, resulting in two distinct types of mineralisation: (1) Gold-bearing quartz and quartz-ankerite veins, occurring in NNE-SSW trending shear zones or thrust folds, usually in Birimian metasediments, with associated sulphides deposited on the fragmented wall rock. (2) Disseminated gold-bearing pyrite and arsenopyrite, occurring in halos within the same shear zones or thrust folds as the quartz veins. The sulphidic nature of the gold deposits lead to a high risk of acid rock drainage (ARD).

Methods

The environmental geochemistry of fourteen mines and deposits in the West African Shield was studied, using a combination of techniques. Weathering profiling, using a model initially developed by SENES, was used to divide rock and saprolite into three weathering zones, distinguishable in borehole core. Mineralogical profiles were used to characterise rock units by the relative abundance of macroscopic sulphide and carbonate minerals. Conventional acid base accounting was also done to provide quantitative acid generation and neutralisation potential. Combined logs were then prepared from these three profiles, showing the geochemical behaviour of the different rock units.

Case Studies

Introduction

The West African Precambrian Shield is a tectonic province dominated by two Lower Proterozoic volcano/sedimentary sequences that are important for the occurrence of gold mesothermal mineralization, the Birimian Supergroup and the Tarkwaian Group (Figure 1).

The Birimian, a dominantly marine turbidite series, is composed largely of phyllites, schists, meta-greywackes and, in places, is inter-bedded with meta-volcanic rocks including lavas, and volcanoclastic rocks (Hammond and Tabata, 1997). Non-conformably overlying the Birimian are the continental clastics of the Tarkwaian Group (Oberthür et al., 1997). These clastics were derived from the weathering of Birimian rocks and granitic batholiths (Dampare et al., 2005). The Birimian and Tarkwaian were subjected to regional deformation in the 2.0-2.2 Ga Eburnean orogeny, resulting in major thrusts and shear zones (Blenkinsop et al., 1994; Oberthür et al., 1997). Birimian rocks are intensely folded (mostly isoclinals) and faulted, whereas the Tarkwaian units display a more broad-scale folding and less tectonic disturbance. Both the Birimian and Tarkwaian display greenschist regional metamorphism, and the mafic dykes have been carbonate-altered (Mumin et al., 1994).

Shear Zone Gold Deposits

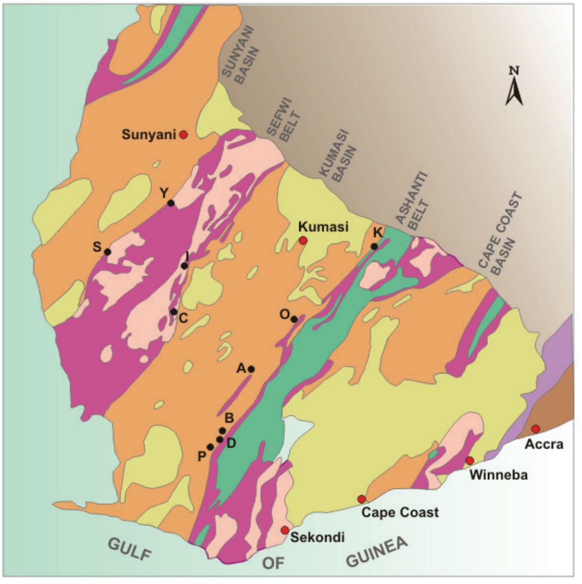
The majority of the gold deposits studied (11/14) are hosted on northeast-southwest trending shear zones (Allibone et al., 2002). These shear zones form the boundary between the volcano-sedimentary Birimian belts and the Tarkwaian sedimentary basins. They are a few metres to hundreds of metres wide and display different styles of deformation, probably related to varying competencies of the different rock units. The shear zones are frequently intruded by granitoids and less frequently by mafic (dolerite) to ultramafic dykes.

The hydrothermal gold occurs in quartz-carbonate veins, with large pyrite crystals, minor arsenopyrite at some sites, minor to accessory chalcopyrite and accessory pyrrhotite, galena and sphalerite. The carbonates in the veins are mainly dolomite and ankerite. Beyond the veins, gold-bearing pyrite and arsenopyrite crystals occur disseminated in halos around the shear zone.

Thrust Fold and Placer Gold Deposits

The Banket series of the Tarkwaian Group host the remaining deposits (3/14). The Bankets comprise quartz pebble conglomerates of the Tarkwaian Group, and carry detrital gold, magnetite and haematite (Oberthür et al., 1997). They were formed as alluvial fan deposits with braided stream channels reworking the fans. The braided rivers concentrated gold particles within the coarse, high-energy channel conglomerates. The sediments were ultimately derived from the erosion of Birimian rocks. The Eburnean orogeny resulted in major thrust folds (Blenkinsop et al., 1994), which have folded the Banket series in mainly north-south trending, northwards plunging synclines and anticlines, with the reefs often thickened in the fold noses.

The Bankets are dominated by oxide and silicate minerals, with few sulphides present.



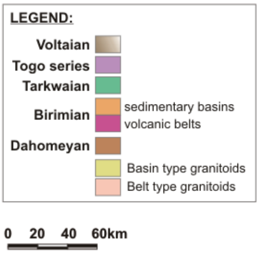


Figure 1: Geological map of Western Ghana, some major mines: A=Ayanfuri, B=Bogoso, C=Chirano, D= Dumasi, I=Bibiani, K=Konongo, O=Obuasi-Ashanti, P=Prestea, S=Sefwi, Y=Yameo), adapted from Oberthür et al. (1997)

The same applies to the thrust folds, where sulphides have been removed by silicification during folding.

Geochemical Model

Weathering zones

SENES (1999) proposed a weathering model for the environmental mineralogy of a Ghanaian gold deposit, and this has proved quite robust and have been adapted through observations from other sites over the years:

- The upper oxide zone comprises a 40 to 200 m thick heavily weathered zone, comprising an uppermost layer of either clay or laterite, and a thick saprolite layer. Typically, all carbonate and sulphide minerals have been leached from both zones. The rocks are heavily oxidised, with frequent iron oxide alteration, and is typically non-acid generating, due to the absence of both sulphide minerals and carbonate minerals. Where the uppermost layer is laterite, a mottled zone often forms at the base of the laterite, where metals and semimetals leached out of the laterite are concentrated. This can lead to quite high concentrations, but the elements are typically in oxide form and with low solubility.
- The transition facies is 5 to 20 m thick weathered rock, from which carbonate minerals have been removed by dissolution weathering. Sulphide minerals are still present and unoxidised. This is typically acid-generating, due to the presence of sulphide minerals and absence of carbonate minerals.
- Below the transition facies is the fresh facies, where both sulphide and carbonate minerals have not been oxidised and leached out. This may be acid-generating or not, depending upon the balance between sulphide minerals and carbonate minerals.

This model is summarised in Figure 2.

Acid base accounting

Putting together the acid base accounting data for the fourteen deposits, by comparing the sulphur content of the rock materials (which shows the potential to generate acid) and the neutralisation potential ratio (which shows the balance between acid-generating minerals and acid-neutralising minerals) showed a number of trends – Figure 3.

The oxide rocks are almost entirely non-acid generating, largely due to the absence of sulphide minerals. The fresh rocks have variable sulphide content, often quite high, but over half of such materials have sufficient acid-neutralising material (mainly carbonates) to balance the acid generation. Much, but not all, of the transition material, is acid-generating,

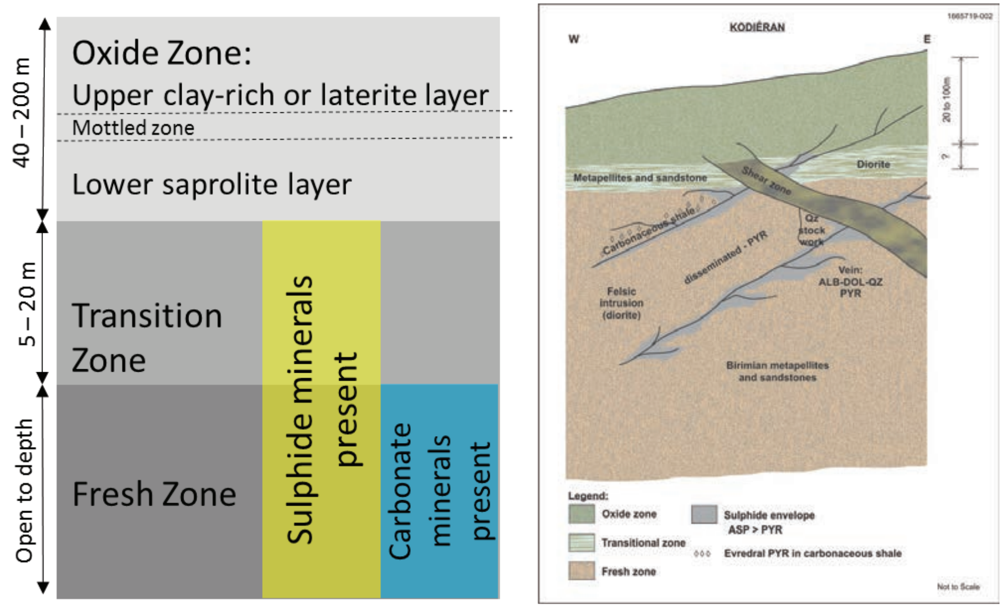


Figure 2: Summary of the weathering and acid rock drainage generation model of West African gold deposits: (left) conceptual overview, (right) example showing shear zone and mineralogy

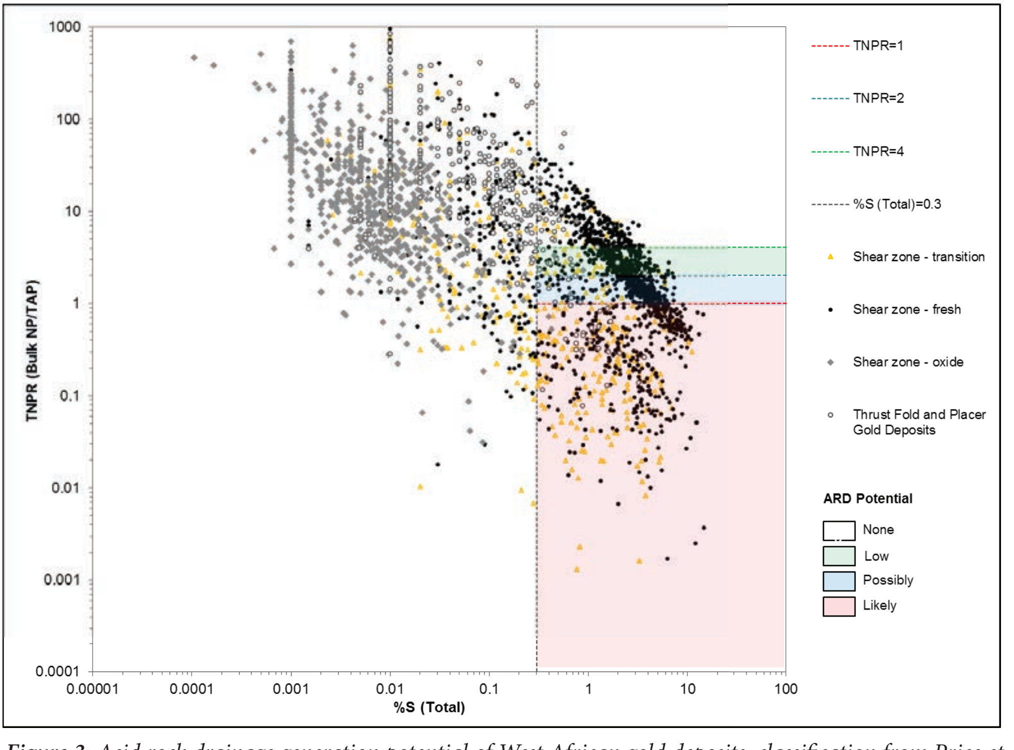


Figure 3: Acid rock drainage generation potential of West African gold deposits, classification from Price et al. (1997) and Soregaroli and Lawrence (1997)

with moderate to high sulphide content which is not balanced by neutralising minerals.

The thrust fold and placer deposits, being dominated by silicate mineralogy, are mainly non-acid generating.

Combined logs

An example of a combined log is shown in Figure 4. The preponderance of acid-generating material in the transition zone is clear. In Figure 5, at a second site, it can be seen that the acid-generating material occurs mainly within a specific depth band.

Discussion

The results of the study show two key drivers of acid rock drainage risk: firstly, the degree of weathering: the Oxide Zone, from which both the acid-generating sulphide minerals and the acid-neutralising carbonate minerals have been largely leached, is non-acid generating. The Transitional Zone, from which the carbonate minerals have been largely leached but the sulphide minerals remain is almost always acid generating. The Fresh Zone, from which neither sulphides nor carbonates have been leached is uncertain and the second key driver of acid rock drainage risk applies: the abundance of acid neutralising carbonate minerals, which varies significantly from deposit to deposit – being at least partially controlled by the host rock mineralogy.

Conclusions

Since the two key drivers relate to the weathering zone classification and the host rock lithological units, this translates to readily-defined blocks and tonnages, giving the opportunity for separation of mine waters of different qualities and the selective handling of waste rock. Given the repeatability of this approach, it is suggested that it can be applied in principle across the West African Shield.

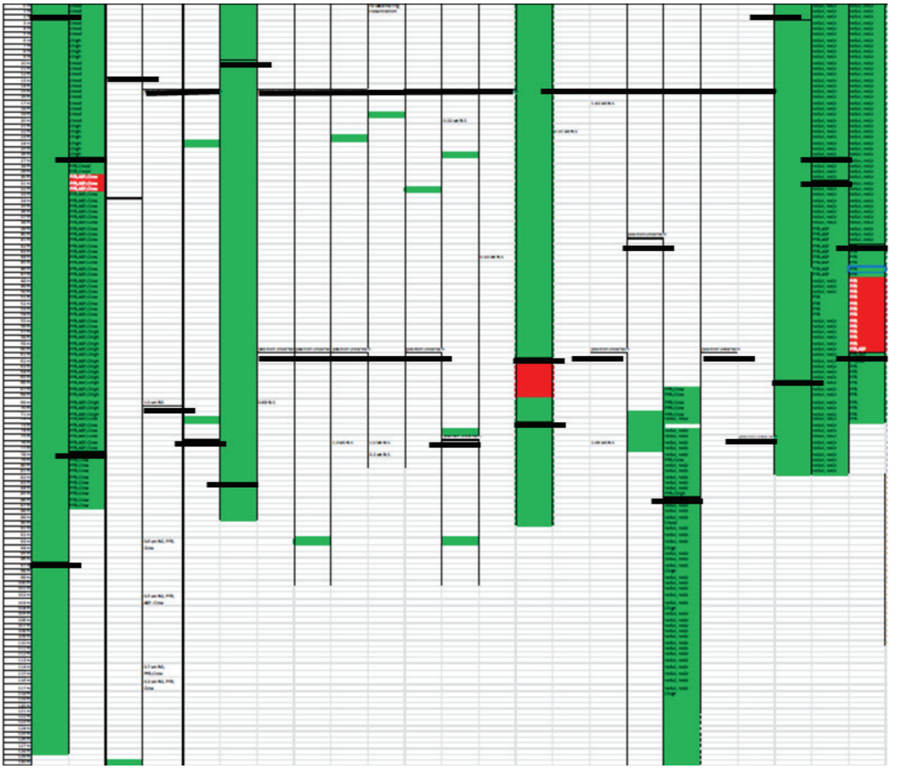


Figure 4: *Example of twenty-three combined logs for a site, with observations arranged by depth (y-axis), thick black lines showing top and bottom of transition zone, red for acid-generating material and green for non-acid generating material*

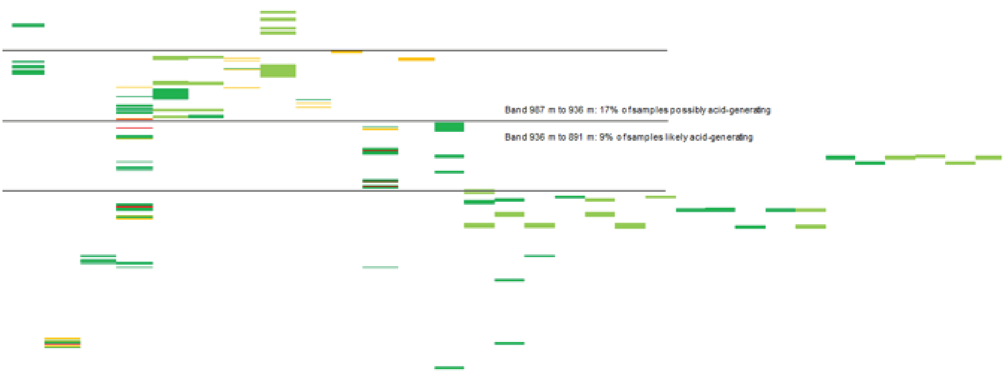


Figure 5: *Example of thirty-one combined logs for a site, showing the occurrence of acid-generating material in a band, thick black lines showing top and bottom of transition zone, red for acid-generating material and green for non-acid generating material*

Acknowledgements

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