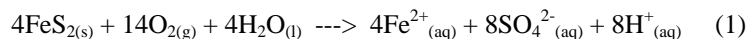


## OVERVIEW OF AMD AND RECENT GOVERNMENT ACTIVITY

- The Witwatersrand has been mined for more than a century. The Witwatersrand Mining Basin is composed of the Far East Basin, Central Rand Basin, Western Basin, Far Western Basin, KOSH (Klerksdorp, Orkey, Stilfontein and Hartbeestfontein) and the Free State gold mines.
- It is the world's largest gold and uranium mining basin with the extraction, from more than 120 mines, of 43 500 tons of gold in one century and 73 000 tons of uranium between 1953 and 1995.
- The basin covers an area of 1600 km<sup>2</sup>, and led to a legacy of some 400 km<sup>2</sup> of mine tailings dams and 6 billion tons of pyrite tailings containing low-grade uranium.
- The mineral pyrite (FeS<sub>2</sub>) and other sulfur containing minerals are common. Mining gold inevitably involves exposing these pyritic materials to oxygen and water. In the deep gold mines, these materials are exposed in the voids created by the mining process. They also are brought to the surface as an unwanted waste product along with the gold, where they and other unwanted materials were separated from the gold and historically put in huge refuge piles known as tailings dams. Here too the pyritic materials were exposed to oxygen and water.
- Wherever pyrite can come into contact with oxygen and water a potential problem exists. This trio of pyrite, oxygen and water causes in the formation of AMD<sup>1</sup>.

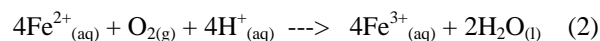
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<sup>1</sup> When pyrite is initially exposed to oxygen and water the following reaction can occur



This can be stated as pyrite, oxygen, and water react to form dissolved ferrous ions (a.k.a. iron II), dissolved sulfate ions and acidity. Thus ferrous ions and acidic hydrogen ions are released into the waters that runoff through the mine tunnels or refuge piles. The pH of the water will likely go down depending on just how often this reaction occurs. While dissolved, ferrous iron (Fe<sup>2+</sup><sub>(aq)</sub>) and sulfate ions (SO<sub>4</sub><sup>2-</sup><sub>(aq)</sub>) are colorless and the water may actually look crystal clear. In some AMD discharges, this is the condition of the water as it makes its way to the surface. Also note that this is not a particularly fast reaction just as the formation of rust takes a while to happen.

The next step in the process is for the ferrous iron to be oxidized to ferric iron as shown in the following reaction



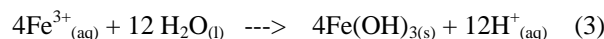
Aqueous ferrous (Fe<sup>2+</sup>) ions react with oxygen and acidic hydrogen ions to form ferric (Fe<sup>3+</sup>) ions and water. Note that oxygen needs to be present for this reaction to happen. Often this reaction doesn't happen to any great extent

- Tailings dams and waste rock dumps can never be maintained in completely reducing environment. It logically follows that there will be long term water risks.
- Waste from gold mines constitutes the largest single source of waste and pollution in South Africa.
- Acid Mine Drainage (AMD) is responsible for the most costly environmental and socio-economic impacts. This water has a low pH and a high acidity and contains toxic and radioactive heavy metals.
- Production of AMD may continue for many years after mines are closed and tailings dams decommissioned.

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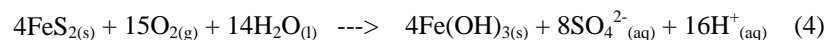
underground because of limited available oxygen. Also note that acidity is consumed in this process. This reaction rate is pH dependant with the reaction proceeding slowly under acidic conditions (pH 2-3) with no bacteria present and several orders of magnitude faster at pH values near 5. This reaction is referred to as the "rate determining step" in the overall acid-generating sequence.

Equation 3 describes the next reaction where the ferric ions now hydrolyze in water to form ferric hydroxide. (Hydrolysis is a reaction in which water reacts with another reactant and which a hydroxyl group and a hydrogen ion are formed.)



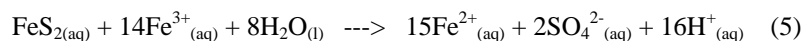
This process releases even more hydrogen ions into the aquatic environment and further reducing the pH. The ferric hydroxide formed in this reaction is also called "yellow boy", a yellowish-orange precipitate that turns the acidic runoff in the streams to an orange or red color and covers the stream bed with a slimy coating. Aquatic life dwelling on the bottom channel of the stream is soon killed off. If the pH is greater than 3.5 this precipitation reaction will occur.

Often the net effect of equations 1 through 3 is summarized in the following equation



Overall pyrite is oxidized releasing acidic hydrogen ions into the water and coating the stream bed with "yellow boy".

These reactions give a fair representation of how pyrite reacts to form pollution. However, a number of other reactions are also possible, mostly leading to the same kind of products. For example



involves pyrite reacting with ferric ions and water producing ferrous ions, sulfate ions and acidity. What happens in any particular environment is largely dependant on the conditions existing in that environment. One such factor is the presence of a bacteria known as *Thiobacillus ferroxidans* which likes acidic conditions and can greatly enhance the rate of oxidation of iron and sulfur containing compounds.

- AMD is not only associated with surface and groundwater pollution, degradation of soil quality, for harming aquatic sediments and fauna, and for allowing heavy metals to seep into the environment.
- Radionuclides are concentrated in sediments downstream of their sources. Sequential extractions showed that these radionuclides are distributed in multiple phases within the sediments bodies of the Witwatersrand goldfields and that they may be remobilised by Acid Mine Drainage.
- Long-term exposure to AMD polluted drinking water may lead to increased rates of cancer, decreased cognitive function and appearance of skin lesions.
- Heavy metals in drinking water could compromise the neural development of the fetus which can result in mental retardation.
- If indeed the extent of “... *problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk*” (EEB, 2000), then the Witwatersrand gold mining area of South Africa is at serious risk.
- In 2002 in the Krugersdorp-Randfontein area water has started to decant from the flooded West Rand Mine Basin, the smallest of the Mine Basins within the Witwatersrand goldfields, into the Tweelopiespruit and the Wonderfonteinspruit. An unqualified volume of AMD furthermore escapes downstream into the Zwartkrans compartment via the Tweelopiespruit, mostly subsurface. The Zwartkrans compartment hosts the very sensitive Cradle of Humankind World Heritage site.
- Groundwater contamination with the chemical characteristics of West Rand Goldfield mine water has been detected at a number of sites in the dolomitic aquifer of the Zwartkrans Compartment. 11 491 people use the groundwater in the Zwartkrans Compartment for domestic use; 2 654 Ha are under irrigation using borehole water and 458 Ha are under irrigation using river water.
- The combination of the pH and redox driven reactions resulted in a measured uranium concentration of 16mg/l of the Robinson Lake, the source of the Tweelopiespruit and resulted in the NNR declaring the lake a radiation area. It furthermore resulted in the Tweelopiespruit being classified as a Class V River, that is, an acutely toxic river.
- The Department of Water Affairs and Forestry issued a Directive on 29 March 2005 to the three mining companies operational within the West Rand. The Mines failed to

comply with the terms and conditions of the Directive and semi-toxic water continued to be discharged into the Tweelopiespruit from 2005 to 2010. 100 tons of salt are discharged daily into the Tweelopiespruit.

- Results indicate that U-levels in water resources of the whole Wonderfonteinspruit catchment increased markedly since 1997 even though U-loads emitted by some large gold mines in the Far West Rand were reduced. This apparent contradiction is explained by the contribution of highly polluted water decanting from the flooded mine void in the West Rand.
- Of particular concern is the fact that U-levels in the Wonderfonteinspruit are comparable to those detected in the Northern Cape which had been geostatistically linked to abnormal haematological values related to increased incidences of leukaemia observed in residents of the area.
- Since the 21<sup>st</sup> of January, 2010 between 12 and 30 Mega Litres of untreated AMD are decanting uncontrolled into the Tweelopiespruit and seeps into the Wonderfonteinspruit. 12.5 Mega Litres of semi-treated AMD are discharged into the Tweelopiespruit.
- The chronic effects of AMD on humans, such as mutagenicity, teratogenicity and estrogenicity, have not been assessed.
- **The R6.9 million that the honourable Minister of Water and Environmental Affairs has recently donated to address the environmental emergency within the West Rand Mine Basin is currently being used, grounded upon physical (real) evidence, to purchase masses volumes of lime, which is added where the untreated AMD (the current volume is 30 Mega Litres) is flowing into the Krugersdorp Game Reserve. This results in the heavy metals, including U, precipitating in the Hippo Dam (the first receptor in the Krugersdorp Game Reserve). Since the iron is not removed, it results in secondary chemical reactions with resultant pH shocks. The acidification causes these heavy metals in the Hippo Dam to become mobilized and solubilized. The pH of the last dam in the Krugersdorp Game Reserve, namely the Aviary Dam, after the water has flowed through wetlands, is 4.**
- There are opposing academic views regarding the impact of the AMD on the dolomite in the Zwartkrans Compartment which hosts the Cradle of Humankind World Heritage Site. Garfield Krige, an expert, found that:

*It has been calculated that the sulphuric acid in each 1 Ml of mine void water will dissolve a volume of dolomite (carbonate rock) of approximately 317 litres. In April 2009 the mine void water, containing sulphuric acid, will have been flowing into the Zwartkrans compartment for 8 years. The corresponding void in the dolomite that has been formed so far, amounts to a staggering 16.7 Ml (i.e. 16 700 m<sup>3</sup>). Although this void space will be spread over a large area, most of it will be concentrated in the area where the water in the Tweelopiespruit first comes into contact with the dolomite. This is also the area where the N14 road crosses the Tweelopiespruit. This road is in serious danger of collapse due to sinkhole formation! A gravity survey and drilling/grouting (if needed) operation should be implemented immediately to safeguard the lives of people using this section of the N14 road.*

*Over the last 8 years the sulphate concentration in many of the boreholes in the Cradle of Humankind World Heritage Site has also increased significantly, indicating that the plume of pollution is spreading rapidly through the groundwater aquifer. Sulphate concentrations in excess of 1 500 mg/l have been recorded in boreholes used for domestic purposes. These water users are presently unaware of the potential poisoning of their water supply and should be provided with a clean source of water before people/animals using this water become ill. In 2006 the pollution plume was already recorded in boreholes well beyond the Sterkfontein caves along the Blaauwbankspruit valley (also referred to as the “Valley of the Ancestors”).*

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