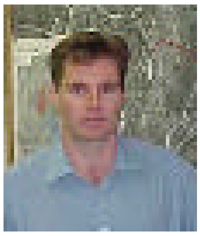
WATER POLLUTION FROM AND REHABILITATION OF AN EXPLORATION SITE IN THE BARBERTON AREA OF SOUTH AFRICA



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ABSTRACT

In the 1977 Anglo American Prospecting Services commenced exploration in the Barberton area of Mpumalanga, South Africa. Exploration drilling delineated a sulphide ore body, which was accessed for bulk sampling purposes, via a 600 m long adit. The waste rock from the adit was deposited on a steeply dipping hill slope, immediately above a non-perennial tributary to the Kaap River. This rock contained sulphide minerals including, *inter alia*, pyrite, sphalerite, chalcopyrite, galena and tracers of arsenopyrite. The sulphide minerals began to oxidise when exposed to atmospheric conditions, resulting in typical acid rock drainage (ARD). Metals released during oxidation, included iron, zinc, copper, cadmium and arsenic. In 1989 during a severe storm event low pH, metal rich waters were washed into the local stream causing fish and other aquatic life kills in a local farmer's reservoir. The farmer brought damage claims against Anglo American. Water sampling revealed that the pollution had originated from the waste rock. A number of rehabilitation options were investigated before it was decided to remove all waste rock from the hillside and encapsulate it in a specifically engineered repository. Along with other remedial measures, the adit was sealed off and all waste rock that had been eroded into the stream removed. These measures were implemented at a cost of approximated R2,5 million in 1994 terms. Prior to rehabilitation and remediation water qualities in the stream showed typical concentrations of zinc at 160 mg/l, sulphate at 1281 mg/l, pH values in the order of 2,8 and TDS values at 2238 mg/l. Following rehabilitation the water quality has improved to what is believed to be its original state with zinc concentrations at less than 0,8 mg/l, sulphate at 27 mg/l, pH values of 6,5 and TDS at 80 mg/l.

From this incident Company exploration staff have learnt to evaluate the environmental impacts of their activities as part of their day to day operations. Furthermore, water quality data are proof that rehabilitation and remedial techniques can improve environmental conditions and minimise pollution from exploration and mining sites.

1. INTRODUCTION

Bien Venue exploration site is located in the Barberton area of Mpumalanga, South Africa and is approximately 30km north, north east of the town of Barberton and approximately 40km south east of Nelspruit (Figure 1). The exploration site takes its name from the farm on which the site is located. Small to medium size gold mining has occurred in the Barberton area for more than a 100 years and some gold mines are still profitable concerns to this day.

Figure 1:- Locality map showing the location of the Bien Venue exploration site on a regional scale.

In 1977 Anglo American Prospecting Services commenced exploration at Bien Venue. An adit was excavated into the ore body during the mid 1980's as part of the exploration program and the waste rock from the adit excavation was deposited on a steeply dipping hill slope, immediately above a non-perennial tributary to the Kaap River. The oxidation of sulphide minerals led to the formation of acid rock drainage. In 1989 a severe storm led to the release of a significant quantity of ARD into the local stream, resulting in fish kills in a farmers reservoir.

Consequently Bien Venue exploration site has become an interesting learning ground for mine environmental control. Initial water quality data revealed the stream had in fact been affected by ARD. Had exploration staff realised that the waste rock had ARD tendencies they would never have located the dump where they did. Rehabilitation options that were assessed initially focused on containment of ARD and pollution, and not elimination. It was latter decide that the only way to obtain a lasting solution to the pollution problem was to remove the source of the pollution and prevent the generation of ARD. By looking at water quality data in the local stream before and after rehabilitation it is evident that rehabilitation has been successful.

2. EXPLORATION

Geological exploration by the then New Mining Business Division of Anglo American Prospecting Services commenced in 1977. The exploration programme included a surface exploration phase followed by an underground exploration phase.

2.1. Surface Exploration

Surface exploration on the farm Bien Venue commenced in September 1977. An extensive stream sediment sampling programme was initiated. This programme delineated a series of stream sediment anomalies with elevated concentrations of zinc, copper, lead and arsenic being detected. The identification of these anomalies led to further exploration. In February 1978 a detailed surface exploration programme commenced. This involved digging 1450m of trenches and 275 pits across Bien Venue. The trenches and pits were sampled extensively. Sampling results were encouraging and a decision was taken to commence with surface drilling. A total of 29 diamond drilling boreholes were drilled with the total drilling meterage reaching 8050m. 82 percussion holes were also drilled with a total drilling meterage of 525m. The drilling programme indicated an ore-body grading 1,35g/t gold, 152g/t silver, 3,15% zinc, 0.49% lead and 0,2% of copper over an average width of 4,4m.

The relatively high gold content of the ore led to this project being passed on to the then Gold and Uranium Division of Anglo American Prospecting Services (now AngloGold) for future exploration. Surface exploration ceased in July 1983.

2.2. Underground Exploration

In September 1983 it was recommended that underground development be carried out to delineate the ore-body for detailed evaluation, metallurgical test work and to facilitate the underground drilling to determine the depth extensions of the ore-body. The development of an adit into the ore-body commenced in August 1985. The adit and its associated cross cuts and drill chambers entailed 768m of underground development. Approximately 8000m^3 of waste rock from adit development was discarded down dip of the adit on the hill slope. (Figure 2). It was the geochemistry of this waste rock that led to ARD forming and the associated water pollution.

Figure 2:- Photograph showing the extent of the waste rock dumped down slope of the adit portal.

The rock dump was made up of two portions. The eastern portion of the dump extended down the N.E. slope of the hill at an inclination of about 33° for a vertical distance of 55m and with a surface length of at least 90m. This portion of the dump covered an area of approximately 1400m^2. The western portion of the dump extended down the N.E. slope at a 35° angle and covered a surface area of approximately 2100m. The toe of the western portion of the rock dump was at one point in time in the streambed. The total surface area of the rock dump was 3500m^2. Assuming an annual rainfall of 1000m and 70% runoff, then the total estimated runoff from the rock dump would be 2000m^3/annum.

Underground diamond drilling, consisting of 6 boreholes, commenced in September 1986 with a total of 412m being drilled. By November 1986 all underground operations ceased. In March 1988 all underground equipment was dismantled and removed and the adit portal was sealed after an economic evaluation concluded that it would be sub-economic to mine the ore-body.

3. GEOLOGY

3.1. Regional Geology

Bien Venue is situated on the northern flank of the Barberton greenstone belt, which forms part of the Archaean Barberton Sequence. The Barberton Sequence consists of a predominantly volcanic succession

(Onverwacht Group), which is overlain by an argillaceous sedimentary unit (Fig Tree Group), which, in turn is overlain by an arenaceous assemblage (Moodies Group).

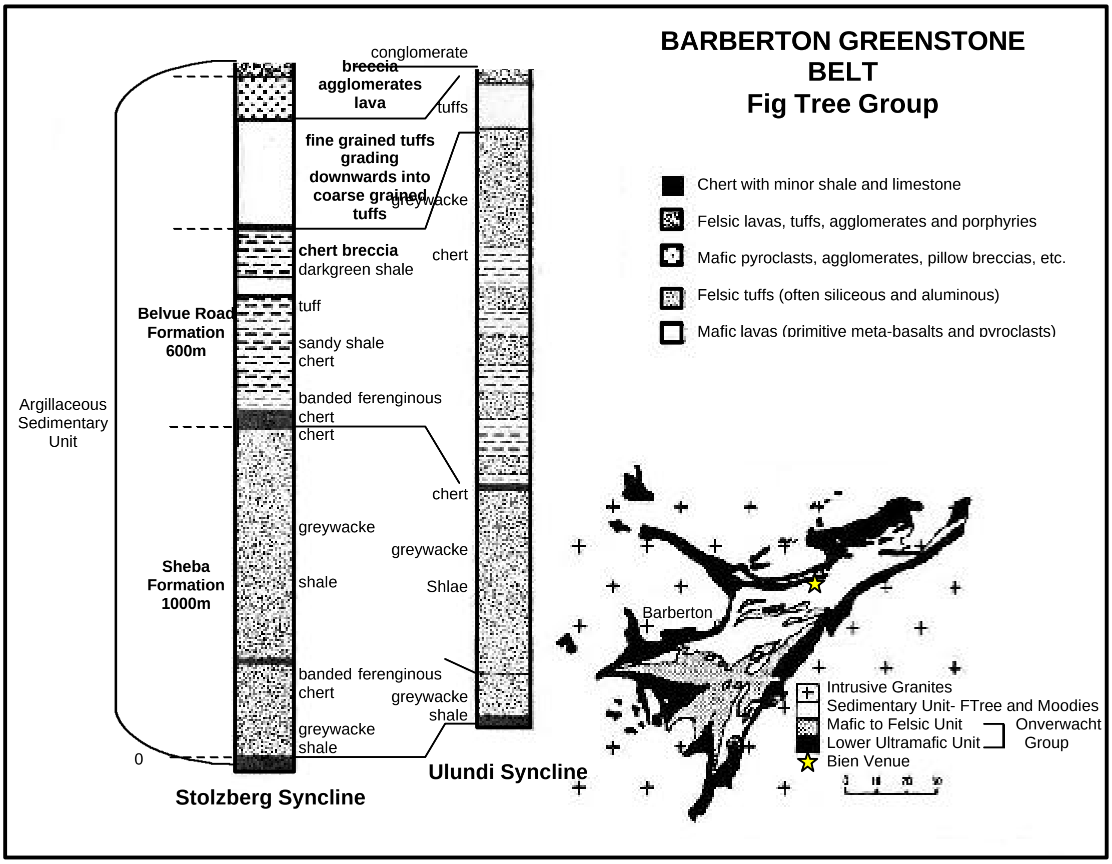
The northern flank of the Barberton greenstone belt is made up of a wide variety of rock types forming part of the upper Fig Tree and lower Moodies successions (Figure 3). The prevalent Fig Tree Group consists essentially of formations with a sedimentary character (greywacke, shale and chemical precipitates), as well as subordinate volcanic and pyroclastic members (Anhaeusser, 1986b).

3.2. Local Geology

Mineralisation at Bien Venue occurs within Archean tuffs and rhyolites which form part of the upper Fig Tree Group within the Barberton greenstone belt. Petrological and mineralogical examination indicates that the host rocks are mainly schists, and are relatively low grade regionally metamorphosed lavas of acid and intermediate compositions, tuffaceous rocks and chert/silica-rich sediments. Successive formations are broken into two parts by a number of reverse sinistral faults, and isoclinal folds.

The ore occurs as lenses in a tectonically modified silver-gold-base metal volcanogenic massive sulphide deposit. The host lithology is felsic lapilli tuff. This is underlain by ryolite, which in turn is underlain by oligomictic quartzitic agglomerate, into which the adit portal was developed. The hangingwall comprises a complex unit of rhyolitic tuffaceous material with quartz eyes and clasts (Figure 4).

Figure 3:- Stratigraphic column of the Fig Tree Group within the Barberton Sequence in the Eastern Transvaal and Swaziland. (Condie *et al.*, 1970). The inset geological map shows the distribution of the Onverwacht, Fig Tree and Moodies groups within the Barberton greenstone belt (Anhaesser, 1973), and the position of the farm Bien Venue.



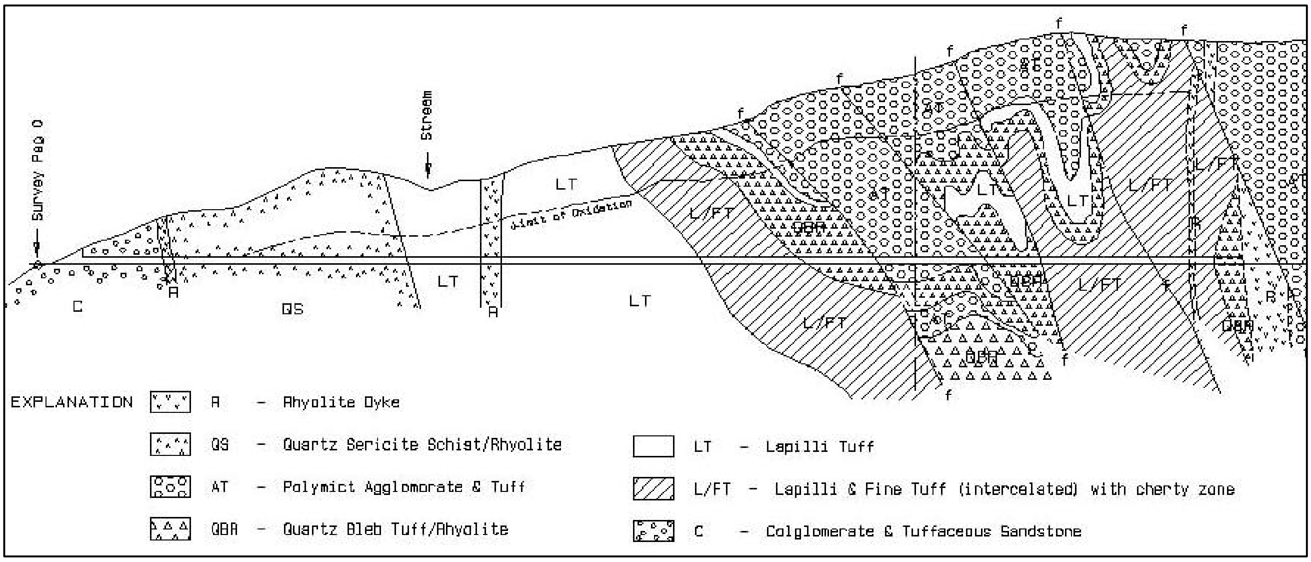


Figure 4:- North west - south east geological cross-section of the Bien Venue deposit.

3.3. Petrology and mineralogy

The petrology and mineralogy of the Bien Venue ore and host rock is mentioned briefly as the mineral composition of the rock has a direct bearing on the ARD generation potential. Non-opaque constituents found in Bien Venue shistose rocks include quartz, chlorite, sericitic mica, chlorite, dolomite, barite and opaque minerals. Smithsonite has been seen in appreciable amounts in some samples. Relatively minor constituents include feldspar, biotitic mica and plumbogummite. Opaque constituents are typified by sulphide mineralization commonly encountered in massive sulphide deposits of volcanogenic-exhalative origin. The most abundant sulphide mineral is pyrite (FeS_2), and the major ore mineral is sphalerite (ZnS), followed by chalcopyrite (CuFeS), galena (PbS) and barite ($BaSO_4$). Other sulphide minerals include stromeyerite (CuAgS), jalpaite ($(Ag_{33}CuS_2)_2$), smithsonite ($ZnCO_3$), plumbogummite ($PbAl_3(PO_4)(OH)_5.H_2O$), tetrahedrite ($(Cu,Fe)_{12}Sb_4S_{13}$) and native silver. It is these sulphides that contribute directly to the ARD generation. The foliation in these rocks is well developed and the sulphides have been distributed along this foliation as narrow bands alternating with layers of gangue (Anonymous internal geological report).

The Bien Venue ore body consists of copper rich ore on the western side and barium, silver and zinc rich ores on the eastern side. The gangue minerals are mainly quartz and sericite with subordinate chlorite, dolomite and biotite. These dolomites do offer some neutralising potential against the formation of ARD.

3.4. Geochemistry

The geochemistry of the ore and host rock at Bien Venue has a direct bearing on the acid generating potential of the rock. Chemical analyses of selected Bien Venue rock samples are presented in Table 1. This data represent analyses of samples of a polymict lipillistone, a quartz-bleb tuff, a lapilli tuff, a mineralised lappili tuff and a quartz eye ryolite.

Major Oxides (wt%)					
Sample	**1**	**2**	**3**	**4**	**5**
SiO_2	76,42	77,85	74,50	35,10	82,40
TiO2	0,15	0,13	0,18	0,23	0,19
Al_2O_3	11,62	10,70	13,00	16,10	9,36
Fe_2O_3	0,55	0,54	0,59	0,02	0,01
FeO	1,51	1,15	1,10	4,78	0,36
MnO	0,01	0,01	0,07	0,12	0,02
Mg0	2,32	2,88	3,00	10,44	2,94
Ca0	0,03	0,27	0,58	0,23	0,06
Na_20	0,20	0,20	0,20	0,01	0,20
K_20	3,70	3,10	3,57	2,64	1,91
P_20_5	0,01	0,01	0,02	0,01	0,02
Ba0	-	-	-	0,06	-
$S0_3$	-	-	0,06	3,68	0,01
S	-	-	0,08	6,99	0,01
CO_2	0,06	0,13	0,51	0,44	0,08
H2O+/LOI*	2,22*	2,08*	2,92	5,89	2,91
Total	98,79	99,05	100,38	86,74**	100,48
Minor Constituents (ppm)					
Cu	11	6	34	0,22%	5
Zn	807	137	300	12,8%	22
Pb	9	13	42	0,56%	5
Co	5	3	10	5	10
Ni	2	2	264	-	161
Ba	589	1146	1187	-	635
Zr	253	125	233	-	122
Y	39	97	35	-	-
Rb	120	84	97	-	37
Sr	5	7		-	-
As	8	11	5	-	6
Sn	9	8	10	-	-

*Loss of ignition **Total =100.31 if Cu, Pb and Zn is added as metals to oxide data

Table 1:- 1. Polymict Agglomerate, 2. Quartz-Bleb Tuff, 3. Lapilli Tuff 4. Mineralised Chloritized Lapilli Tuff, 5. Quartz Eye Rhyolite

4. THE IMPACT OF EXPLORATION ON WATER QUALITY

As already mentioned, during the excavation of the adit, approximately 8000m^3 of waste rock was generated. The waste rock was tipped down the hillside at a maximum inclination of 35^o, with the toe of the dump encroaching on the local stream. With time it was noticed that the dump turned an overall yellow-ochre colour (See Figure 2). This yellow colouring is a typical indication that ARD is occurring and in this instance was due to the oxidation of the primary sulphide minerals pyrite (FeS_2) and chalcopyrite (CuFeS). It was also noticed that a dark reddish brown water with a pH of 2.5 was seeping from the dump. Both these phenomenon are attributed to ARD which had a significant impact on water quality in the local stream. ARD will be discussed in more detail.

4.1. Acid rock drainage

The acidic and sulphate–rich leachate that was generated from waste rock at Bien Venue is commonly termed ARD(ARD). ARD at Bien Venue formed when the sulphide minerals in the waste rock-dump were weathered under oxidising conditions in the presence of water and oxygen. Without oxygen and water ARD would not occur. According to Simmons*, et al.* 1997, pyrite plays an important part in the process of ARD generation as ARD derives part of its acid character from hydrated iron. Hydrated iron is formed during the initial oxidation of pyrite. Fe^{3+} promotes the additional oxidation of fresh pyrite and other minerals (Kleinman, *et al.*,1981; Leathen *et al*., 1953). The primary chemical factors which determine the rate of acid generation include pH value; temperature; oxygen content of the gas phase if saturation is less than 100%; concentration of oxygen in the water phase; degree of saturation with water; chemical activities of Fe^{3+}; surface area of exposed metal sulphide and the chemical activation energy required to initiate acid generation. In addition, the chemolithotropic bacteria *Thiobacillus ferrooxidans* may accelerate the reaction by its enhancement of the rate of ferrous iron oxidation. It also may accelerate reaction through its enhancement of the rate of reduced sulphur oxidation. *Thiobacillus ferrooxidans* is most active in waters with a pH value around 3.2.

The initial reaction for direct oxidation of pyrite, either abiotically or by bacterial action, according to Lundgren & Silver (1980) is:-

$$2FeS_2 + 7O_2 + 2H_2O \dashrightarrow 2\,FeSO_4 + 2H_2SO_4 \qquad (1)$$

Subsequent biotic and abiotic reactions which lead to the final oxidation of pyrite by ferric ions (direct oxidation mechanism), can be represented as follows:

$$4FeSO_4 + 2H_2SO_4 + 2O_2 \dashrightarrow 2Fe_2(SO_4)_3 + 2H_2O \qquad (2)$$
$$Fe_2(SO_4)_3 + 6\,H_2O \dashrightarrow 2Fe(OH)_3 + 3\,H_2SO_4 \qquad (3)$$
$$4Fe^{2+} + O_2 \rightarrow 4Fe^{3+} + 2H_2O \qquad (4)$$
$$FeS_2 + 14\,Fe^{3} + 8\,H_2O \dashrightarrow 15\,Fe^{2+} + 2SO_4^{2-} + 16H^{+} \qquad (5)$$

Reaction (1) shows the initiation of pyrite oxidation in the presence of water and oxygen, either abiotically or biotically. *Thiobacillus ferrooxidans* converts the ferrous iron of pyrite to its ferric form. The formation of sulphuric acid in the initial oxidation reaction and concomitant decrease in the pH make conditions more favourable for the biotic oxidation of the pyrite by *Thiobacillus ferrooxidans*. The biotic oxidation of pyrite is four times faster than abiotic reaction at pH 3.0. The development of ARD is a complex combination of inorganic and sometimes organic processes and reactions. In order to generate severe ARD(pH<3), as in Bien Venue's case, sulphide minerals must create an optimum micro-environment for rapid oxidation and must continue to oxidise long enough to exhaust the neutralisation potential of the rock.

At Bien Venue ARD generation was further compounded by the presence of a powdery crystalline, yellow effloresçing mineral which was found on oxidised sulphide minerals in the waste rock dump. This efflorescent mineral was analysed by the Council for Scientific and Industrial Research (CSIR) and identified as aluminium copiapite (hydrous ferric sulphate). Aluminium copiapite is a secondary mineral, formed during the oxidation and leaching processes of the sulphide minerals (Kleinman, *et al.*,1981.). One of the properties of aluminium copiapite is that it readily dissolves in water, providing aluminium and magnesium ions in solution. Aluminium salts are acidic, again catalysing the oxidation and metal-leaching processes resulting in the formation of further ARD.

All of the above-mentioned factors, served to lower the rock-dump's seepage pH to 2.4. These low pH waters then dissolved metals in the waste rock dump and surround rocks, resulting in a final leachate containing high concentrations of aluminium, zinc, iron, copper, lead, arsenic, cadmium, nickel and magnesium.

4.2. Leachate quantity and quality

The waste rock-dump had a volume of 8000m^3, an average thickness of 1.5m and surface area of 3500m^2. The estimated run-off from the rock-dump was calculated to be in the order of 2000m^3 per annum. This volume disregards under-dump seepage from up slope. Pollution of the stream was caused by metal ions and salts, released through oxidation, and leached from ore minerals like pyrite, chalcopyrite, sphalerite, plumbogummite and minor arsenopyrite. The typical chemical composition of leachate run-off sampled over a period of time is detailed in Table 2.

Average leachate analysis results	
pH	2.41
Conductivity	549 mS/m
Total Dissolved Solids	5 224 mg/l
Sulphate	2 965 mg/l
Aluminium	124 mg/l
Zinc	546 mg/l
Cadmium	1.88 mg/l

Table 2:- Typical leachate quality
No. of samples = 15

4.3. Stream water quality

A severe storm event in November 1989 washed a large amount of contaminated leachate, and approximately 1000 tons of waste rock material, into the nearby stream. A number of fish in Mr R.F.B. von Johnstone's (a local nature conservancy operator) dam, situated approximately 1km downstream of the rock dump, were killed. Closer inspection revealed yellow stains on the rocks in the streambed and some dead vegetation downstream of the rock dump. This was a visual indication that pollution of the stream had occurred. Water samples were taken from the stream and typical average water qualities immediately downstream of the rock dump are shown in Table 3. The water quality data confirmed that ARD from the waste rock dump had impacted on stream water quality.

Variable	Value	SABS Permissible Stds
pH	2.2	5.5 – 9.5
Conductivity	185 mSm	300 mSm
TDS	2388 mg/l	-
Total Hardness	734 mg/l $CaCO_3$	650 mg/l
Calcium	96 mg/l	200 mg/l
Magnesium	120 mg/l	100 mg/l
Sodium	13 mg/l	400 mg/l
Sulphate	1281 mg/l	600 mg/l
Zinc	146 mg/l	5 mg/l
Chlorides	12.4 mg/l	600 mg/l
Cadmium	0.7 mg/l	0 mg/l
Iron	5.8 mg/l	-
Aluminium	32 mg/l	0.5 mg/l

Table 3:- Typical water quality before rehabilitation.

Extensive negative media coverage and court action against Anglo American ensued, resulting in a R10 000 fine, suspended for 5 years, being issued in 1991. During this period, thorough investigations were conducted by Anglo American and these culminated in Mr von Johnstone receiving compensation from Anglo American for loss of income, as he was unable to operate his lodge because of the water pollution. Anglo American also undertook to rehabilitate the site to prevent future pollution incidents.

5. REHABILITATION

Anglo-American realised that the Bien Venue site needed to be rehabilitated to improve stream water quality and to prevent future pollution incidents. Three remedial options were considered to either control or eliminate the seepage of polluted water from the waste rock dump.

5.1. Option 1 - The gabion option

Option 1 considered cutting back the western portion of the waste rock dump, thereby removing the toe of the dump from the stream. Thereafter a series of gabions would be anchored to the bedrock, up slope of the streambed, with a vertical concrete wall set adjacent to the gabions. Seepage water from beneath the waste rock dump would be collected in a catchment dam constructed below the eastern portion of the rock dump. To stop infiltration into the waste rock dump, it was proposed to gunite the entire surface of the western portion of the dump. Below the eastern portion of the dump it was proposed that a series of gabions would be constructed to prevent the eastern portion of the dump eroding. A $20m^3$ catchment dam would be constructed on the eastern toe of the rock dump to contain and evaporate seepage.

This option was not implemented, as it was not acceptable to interested and affected parties and Anglo American did not see it as a permanent 'walk-away' solution. Furthermore, it did not take cognisance of flood conditions. In flood conditions waste rock behind the gabions would have eroded into the stream. Furthermore, the proposed catchment dam with a capacity of only $20m^3$ would have had to contain runoff in the order of $60m^3$. Therefore it was agreed not to pursue this option as a 'walk-away' solution.

5.2. Option 2 – The culvert option

In order to prevent further contamination of the stream, a culvert having an approximate cross-section of $2m^2$ could be constructed in the riverbed along the western portion of the rock dump. The culvert would follow the existing river course for 200m. The 2 m^2 culvert would accommodate the 1 in 50 year storm. In order to cater for the natural slope of the river bed and hence the final slope of the waste tip surface, a series of terraces using gabion walls would be constructed transverse to the flow of the water. An under-drainage system would be placed on either side of the culvert section to collect leachate from the waste rock dump. The contaminated rock material would be pushed down slope and placed over the culvert and sealed with an impermeable liner. The sealed dump would be covered with a geofabric lining, top soiled and vegetated with indigenous grasses. In addition to the geofabric an “armaflex” cover would be installed to minimise damage during severe flood conditions.

The eastern portion of the contaminated dump would either be pushed down the slope against a gabion wall to form a platform or would be uplifted and placed together with the western spoil over the culvert. In the case where the material is pushed against the gabion wall the reshaped dump platform would be sealed with an impermeable liner covered with geofabric, topsoiled and vegetated with indigenous grasses. An under-drainage system would be provided to intercept leachate. Cut-off trenches would divert clean stormwater around the platform. Contaminated seepage from the encapsulated material (east and west) would be captured within the drainage systems and piped via an HDPE pipeline to a lined evaporation dam located in the most suitable terrain downstream of the site. The pipeline would be buried to prevent damage by fire and would follow a cross contour route to the evaporation dam. The evaporation dam would be lined with an impermeable liner and bounded with a security fence. The evaporation dam would be sized to cater for a leachate flow rate of 0.25 l/s.

Again this option was not considered to be a walk away solution and the presence of an evaporation dam meant that Anglo American would have had a long term maintenance responsibility at the site.

5.3. Option 3 - The removal option

The removal option considered the removal of all waste rock from the eastern and western sections of the rock dump and disposing of it in an encapsulated waste depository. This option offered a permanent “walk away” solution to Anglo-American and was acceptable to all interested and affected parties. Therefore it was the chosen method of rehabilitation.

Waste rock was removed from the hillside via a cable and rail transportation system. This system included the use of hand labour and mechanical grabs to lift waste rock into rail hoppers. The hoppers were then hauled up slope via the cable system to the terrace above the waste rock dump. From the terrace the waste rock was loaded into dumper trucks and transported to the disposal site, approximately 1.7 km from the adit. The final clearing of the hillside was done by hand and consisted of a "broom and spade" operation. Thereafter, the rock dump footprint area was washed down and a hydroseeded mulch and an indigenous seed cocktail applied to the area. Figure 5 shows a photograph of the hillside after all the waste rock was removed and rehabilitation of the area completed.

Figure 5:- Photograph of the rehabilitated foot print area.

The waste repository area was designed in detail by professional civil engineers to ensure no further ARD generation would occur. The base of the depository was sealed with a compacted bentonite clay and soil mixture and lined with a HDPE liner. The waste rock was placed in layers on this seal and compacted. Special care was taken not to puncture the lining. The outer walls of the waste repository consist of a compacted earth bund. Stormwater diversion trenches have been constructed up slope of the repository to divert stormwater. Once all the waste rock had been dumped into the repository an impermeable HDPE liner was used as a seal. Topsoil was then placed over the liner and the repository vegetated with indigenous grasses. Figure 6 shows a photograph of the waste repository taken 6 years after completion of rehabilitation.

Figure 6:- Photograph of the waste repository taken 6 years after rehabilitation.

6. STREAM WATER QUALITY AFTER REHABILITATION

Water quality data from stream water samples show clearly that the rehabilitation at Bien Venue has been successful. Typical post rehabilitation in stream water quality averages are listed in Table 4. By removing the source of pollution from the stream banks Anglo-American have successfully ensured water quality in the stream has returned to its pre-exploration state. Furthermore, by encapsulating the waste rock in the waste repository the potential for further generation of ARD has been eliminated. This is due to the fact that both oxygen and water, two of the fundamental requirements for the generation of ARD, have been eliminated. Figures 7, 8 and 9 show a series of water quality graphs showing how the river quality in the stream has improved with time since rehabilitation was completed.

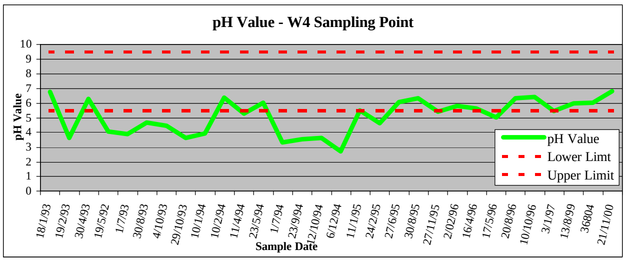


Figure 7:- pH readings subsequent to rehabilitation

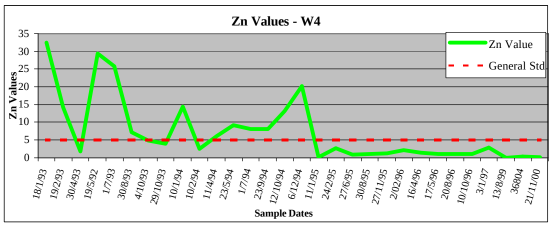


Figure 8:- In stream zinc concentrations.

pH-Value	6.03
Conductivity	6.75
Total Dissolved Solids	44
Total Hardness as CaCO3	18
Total Alkalinity as CaCO3	4
Total Acidity	3.7
Suspended Solids	0.4
Calcium as Ca	2.6
Magnesium as Mg	2.7
Sodium as Na	2.4
Aluminium as Al	0.10
Bicarbonate	4
Carbonate	0.00
Chloride as Cl	10
Sulphate as SO_4	11.3
Nitrate NO_3 as N	<0.1
Arsenic	<0.01
Lead as Pb	<0.01
Boron as B	0.03
Zinc as Zn	0.34
Total Iron as Fe	<0.01
Copper as Cu	<0.01
Cadmium as Cd	<0.01
Ferrous Iron as Fe	<0.01
Ferric Iron as Fe	<0.01
Chemical Oxygen Demand	1.4
Free and Saline Ammonia	0.03
Nickel as Ni	0.03

Table 4:- Typical water quality after rehabilitatior
No of samples = 5

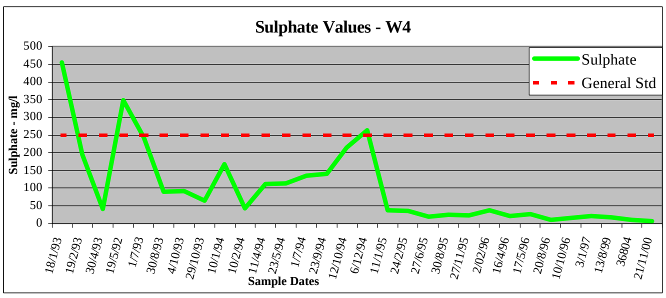


Figure 9:- In stream sulphate values post rehabilitation.

7. CONCLUSION

In stream water quality data and visual inspections showed that Anglo-American's exploration activities in the Bien Venue area had had an impact on the aquatic environment. Various rehabilitation options were considered before it was decided that the best option would be to obtain a walk away solution. This involved the removal of the source of the pollution; the waste rock; to an encapsulated waste repository. Isolating the sulphide bearing waste rock from the two essential requirements for the generation of ARD, water and oxygen meant that no pollutants would in fact be generated. This has been confirmed by post rehabilitation in stream water quality data.

The Bien Venue case study has shown how exploration activities can impact negatively on the aquatic environment if they are not conducted responsibility. It has also shown us that rehabilitation options are available to successfully mitigate negative environmental impacts that originate from exploration and mining activities.

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