Post-closure mine hydrology and its impact on underground tailings disposal at the Thalanga mine, Queensland, Australia

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Abstract

The use of tailings slurry as underground backfill and the rapid flooding of underground workings are commonly thought to be beneficial for mine operators as well as for the environment. Controlled underground placement of tailings behind bulkheads reduces the need for costly surface tailings impoundments and hence the creation of potential long term environmental liabilities. The discharge of excess mine water runoff into underground workings during high rainfall events reduces the risk of mine water dam failure. It also increases the flooding rates of underground workings, thereby decreasing potential sulphide oxidation in the wall rocks.

The Thalanga Cu-Pb-Zn VMS deposit in Queensland Australia was mined by open pit and underground methods until 1998. Today the open pit is partly backfilled with waste rock. Underground tailings disposal behind bulkheads was a common practice during the mine operation. Recent years have seen additional discharges of excess mine surface runoff water into the underground workings.

Groundwater levels during 1998 were at approximately 450m below surface, but later measurements indicated rapidly recovering water tables. By December 2001, groundwater levels measured at a number of exploration drill holes, indicated a groundwater table between 35 and 40m. This groundwater table was approximately 30 to 35m above the floor of the remaining pit void. Prior to backfilling, the crown pilar at the floor of the open pit collapsed, opening a direct pathway to underground workings below, which were previously filled with tailings slurry.

In August 2002, alkaline tailings water rapidly flooded the remaining pit void to the height of the previous measured ground water levels. The appearance of tailings water in the surface mining void is thought to be the result of increased hydraulic head and consequent bulkhead failure. The observed stability limitations of bulkheads, and the consequent mobility of tailings, raises serious questions about the physical, and subsequently chemical, stability of underground tailing disposal.

1 Introduction

Mining of mineral deposits creates underground and surface voids, which can be suitable repositories for mine process and metallurgical wastes. Backfilling of underground mining voids with mine waste materials has the advantage of reducing the long-term maintenance costs for waste rock dumps and tailings dams. Thus, backfilling of underground workings is often regarded as best practice for the rehabilitation of mining voids (e.g., MEND, 1995). Such backfilled waste is often regarded to be as chemically and physically secure as the original mined ore. In particular, the disposal of tailings below the groundwater table reduces the amount of reactive material that would be available for oxidation. Nevertheless, if the tailings are stored above the groundwater table without a dry or wet cover, oxidation may generate metal-rich acid leachate (Morin and Hutt, 1997). The leachate in most cases will be transported in the saturated zone of surficial aquifers where the prevailing groundwater flow will produce metal and metalloid rich plumes down gradient from the mine workings (e.g., Warren et al., 1997; Younger, 2000). This study is based on seasonal groundwater measurements and sampling and the results of kinetic leaching experiments in combination with hydrological modelling. The results explain the appearance of an alkaline lake in an open pit at the Thalanga base metal mine, Australia.

2 Site description

The Thalanga copper-lead-zinc VMS deposit is located 60 km west of Charters Towers, north Queensland. The deposit is positioned in the Ordovician Mount Windsor Volcanics and comprises massive sulphides of Kuroko style (Gregory et al. 1990). The mine operated from 1988 until 1998 and is located in an area with a subtropical climate of distinct dry and wet seasons and an average annual rainfall of 680mm. The mining operations resulted in extensive underground workings (~1.6 million m^3) and a large open pit (600 m x 150 m x 70 m). The underground workings were used for the disposal of ~290000 m^3 of tailings. The thickened tailings slurry was pumped into selected underground voids behind constructed bulkheads. The construction of bulkheads allowed underground operations to continue safely while adits were filled with tailings slurry. These bulkheads, however, may cause problems when loaded hydrostatically. Constructed with impervious bricks, they were likely to fail (Cowling and Dugan, 1998), thus re-opening pass ways for underground water flow. The pumping of tailings into the underground workings was thought to stabilise active subsidence areas associated with the more intense mined underground sections. The mined section directly below the open pit was one of the underground tailings backfill areas.

In addition, upon mine closure about 80 % of the surface mining void was backfilled with acid producing sulfidic waste rock, leaving a small void, of approximately 70 m depth, at the western end of the pit. The collapse of the crown pilar during the backfill operation opened the backfilled pit floor in the east section of the open pit to the underground workings. Subsequent settling of the backfill repeatedly produced large tension cracks at the backfill surface that required additional backfilling. Furthermore, the pit serves as a sink for acidic runoff from adjacent waste rock piles and mine workings. Evaporation leads to the precipitation of abundant mineral efflorescences. For most of the dry season, the surface of the backfill is covered by a 2cm thick salt layer. During the dry season, in August 2002, a slight alkaline water body appeared in the open pit, which within weeks reached a level equivalent to previously measured local groundwater heights.

3 Methods

Groundwater sampling of former exploration drill holes was conducted in April and November 2001. Field water quality parameters were measured at 13 separate sites (up gradient from the pit) and included sample depth, temperature, pH and conductivity. Groundwater samples were analysed for Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, SiO_2 and Zn as well as TDS, nitrogen, sulphate, chloride, bicarbonate, carbonate, alkalinity, hardness, pH and conductivity at the Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University (JCU), Townsville.

Chemical data for the pit lake water body and initial tailings backfill were supplied by Thalanga Copper Mines. Analysed parameters included pH, conductivity, TDS, carbonate, bicarbonate, sulfate, Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Pb, Zn and total cyanide.

The mineralogy of selected precipitates and 27 backfill samples (18 surface samples and 9 samples from three 6 m deep test pits) was determined by X-ray diffraction (XRD; Siemens D5005) in conjunction with the quantitative evaluation program Siroquant at the Advanced Analytical Centre (AAC), JCU Cairns. Backfill samples were also investigated for their total Al, As, Ba, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Pb, S, Sb, Se, Si and Zn contents using inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (microwave oven-assisted HNO_3 extraction) (JCU AAC, Townsville).

The material collected from the three test pits was used for three leaching experiments. For each experiment, backfill collected from different depth (2 m, 4 m, 6 m) was placed into 50 cm plastic columns. Utilising the 10-year climatic records from the mine site, the average daily rainfall was calculated for 1.5 years. This figure was then used to determine the daily rainfall volumes used for a 200-day accelerated column leach experiment. Water to the first column was adjusted with H_2SO_4 to a pH value of 3.7 to simulate the pH conditions of waters accumulating on the backfill during the wet season. Leachate from the first column (2 m deep) was fed to the second column (4 m deep), and leachate from the second column was the fed to the third column (6 m deep). The final leachate from the third column, representing water percolating through the entire test pit profile, was analysed by ICP-MS and ICP-AES for Al, As, Ba, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Pb, S, Sb, Se, Si and Zn (AAC, JCU Townsville). The geochemical modelling tool PHREEQC 2.8 was used to simulate the mixing of alkaline tailings waters and acid waste rock leachate.

4 Results and discussion

4.1 Waste rock backfill

The upper 6 m of the backfilled sulfidic waste is composed of diverse materials, ranging from silty particles of less than 2 mm to boulders 2 m across. 35 wt% of the total waste material has a grain size < 2mm. Also, whilst the quantitative mineralogical composition of the waste rock material varies considerable, the mean mineralogy comprises major quartz (59 %), chlorite (17 %) and muscovite (16 %), minor amounts of pyrite (5.8 %) and albite (1.5 %), traces of barite, and a range of post-mine oxidation products, particularly gypsum (1.8 %) and jarosite (2.2 %). Salt precipitates on the backfill surface were identified as melanterite ($Fe^{II}SO_4$ $7H_2O$) and siderotil ($Fe^{II}SO_4$ $5H_2O$). Other minor phases include rozenite ($Fe^{II}SO_4$ $4H_2O$), szomolnokite ($Fe^{II}SO_4$ H_2O), römerite ($Fe^{II}Fe^{III}_2(SO_4)_4$ $14H_2O$), halotrichite ($FeAl_2(SO_4)_4$ $22H_2O$), alunogen ($Al_2(SO_4)_3$ $18H_2O$), hexahydrite ($MgSO_4$ $6H_2O$), epsomite ($MgSO_4$ $7H_2O$) and chalcanthite ($CuSO_4$ $5H_2O$). Dissolution of these secondary minerals and sulfide oxidation resulted in the generation of a low pH, high TDS metal rich leachate.

4.2 Local hydrology and hydrochemistry

Groundwaters up gradient from the pit have pH values ranging from 6.1 to 7.4. The TDS, $CaCO_3$, SO_4, Ca and Cl concentrations in these waters progressively increase towards the backfilled pit. Groundwater closest to the pit has the highest values for most parameters tested. Considering that water levels were on the rise during this short period, evapoconcentration of the groundwater cannot be the reason for the higher constituent values. Therefore, it is possible that leachate from the backfill enters the surrounding unconfined aquifer. Kinetic column leach experiments illustrate this process. The leachate of the sulfidic waste rock as determined by the kinetic column experiments has concentrations of Cd, Cu, Fe, SO_4 and Zn that are 2 to 3 orders of magnitude higher than those of groundwater up gradient of the backfilled pit. Therefore, limited migration of the backfill leachate into the local aquifer might lead to rising Cd, Cu, Fe, SO_4 and Zn concentrations in local groundwaters. However, the column experiments also showed that a significant amount (40 %) of the simulated rainfall was retained as porewater in the column material. Hence, significant flow through the backfill should only occur after prolonged rainfall periods and may be restricted to tension cracks.

Groundwater measurements up gradient of the backfilled pit indicate that groundwater levels have recovered to a height of ~40 m below surface. Recovery rates in the vicinity of the pit are slower resulting in a groundwater level gradient. In fact, water level monitoring has indicated that the local groundwater table is still recovering to pre-mining conditions of around 30 m below surface. In December 2001, the potentiometric surface up gradient of the pit was approximately 15 m to 20 m higher than the floor of the remaining pit void. Increased underground pumping of excess mine water during the following month increased the gradient and probably led to the complete flooding of the underground workings.

4.3 Bulkhead failure and formation of the pit lake

The increase of hydraulic pressure and subsequent bulkhead failure led to the formation of a slightly alkaline water body in the remaining pit void. The chemistry of the new water body in the pit was similar to the chemistry of the original tailings water prior to underground disposal (pH: 8; EC: ~10000 µS/cm). The composition of the lake was in stark contrast to the results of the leaching experiments (Table 1), which suggested that the eventually forming pit lake would be particularly acid and metal rich. However, the water body in the pit exhibited distinctly higher Cd, Mn, Zn and SO_4 concentrations than the original tailings waters.

Table 1 Mean composition of the water body in the pit in comparison to the results from the leaching experiment and tailing backfill composition

		Mean pit lake composition	Tailings water sample UG-2	Tailings water sample UG-3	Mean leachate composition
pH		7.74	7.8	8.04	3.54
Conduct	µS/cm	10700	9950	6860	
T.D.S.	mg/L	11450	7470	6350	
Ca	mg/L	718	497	545	341
Mg	mg/L	1025	420	529	385
HCO_3^-	mg/L	<1	<1	<1	-
CO_3^{2-}	mg/L	148	223	316	-
SO_4	mg/L	7950	2500	3930	6624
Al	mg/L	<1	<1	1	123
Cd	mg/L	0.16	0.05	<0.05	2.5
Cu	mg/L	<1	<0.1	<0.1	473
Mn	mg/L	77	4.4	7.2	69.3
Zn	mg/L	53.5	13	6.2	453
As	mg/L	<1	-	-	0.032
Pb	mg/L	<1	0.746	0.003	0.41
Fe	mg/L	0.575	<1	<1	8.6
Total Cyanide	mg/L	0.152	-	-	-

Geochemical modelling using PHREEQC 2.8 indicated that the mixing ratio of the experimental acid waste rock leachate and alkaline tailings was below 1:1000. Therefore the initial influence of the backfilled acid waste rock on the lake chemistry was minimal. Considering the strongly acid generating potential of the sulfide backfill, the slightly alkaline character of the pit lake at first seems surprising. However, the collapse of the crown pilar and the method used for backfilling the open pit provided these alkaline waters with a relatively unhindered passage through a coarse boulder layer at the bottom of the pit. The rate of the filling would initially have resulted in only limited contact between the backfill and the alkaline water. Nevertheless, as the backfill becomes saturated in the future, dissolution of accumulated secondary metal sulfates and subsequent acidification of the pit lake water body cannot be discounted.

5 Conclusion

The Thalanga mine workings have been partly backfilled with tailings and sulfidic waste rock. Unconstrained oxidation of sulfidic waste rock generates a highly concentrated Cd-Cu-Fe-SO_4-Zn leachate in the backfilled pit. In addition, re-dissolution of secondary acid producing salts on the waste rock surface lowers the initial pH of the leachate aiding further weathering of the waste rock in the mining void. The permeability of the bulk waste rock is low and water flow through the backfill is aided by numerous tension cracks which act as conduits for atmospheric oxygen and water, facilitating sulfide oxidation at depth.

The placement of tailings behind bulkheads initially acted as a barrier to underground water flow and prevented the rise of water into the open pit. However, breaching of these bulkheads, due to increased hydraulic head conditions up-gradient from the open pit, resulted in rapid flooding of the remaining pit void with tailings pore water. The technique used to backfill the open pit aided the flow of the tailings pore water and resulted initially in only limited contact with the acid generating waste rock. As saturation of the waste rock backfill proceeds, acidification of the water in the pit void is anticipated.

The results of this study raises questions about the stability of bulkheads and the long-term physical and chemical confinement of underground tailings backfill following uncontrolled flooding of underground mines. Alternative, controlled flooding techniques need to be developed in order to prevent bulkhead failure.

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