

Leaching of Sulfidic Backfill at the Thalanga Copper-Lead-Zinc Mine, Queensland, Australia

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ABSTRACT

The placement of sulfidic waste below the groundwater table ensures limited interaction with the hydrosphere and suppression of sulfide oxidation. However, if sulfidic waste is placed above the groundwater table and remains uncovered, the backfill becomes part of the unsaturated zone and is exposed to atmospheric oxygen and leaching. This study aims to establish the leaching behaviour of sulfidic waste placed above the groundwater table and the impact of such leachate on the local aquifer at the Thalanga base metal mine. Mining of the Thalanga copper-lead-zinc deposit resulted in a large final mining void (600 m × 150 m × 70 m) and extensive underground workings. The underground workings were partly filled with tailings and the open pit was partly backfilled with acid producing sulfidic waste rock. In addition, the pit serves as a sink for acidic run-off from adjacent waste rock piles and mine workings. To date, the backfill of sulfidic waste rock placed into the pit has not been capped with benign materials and for most of the dry season, the surface of the backfill is covered by melanterite-type efflorescences. Results of kinetic column leach experiments conducted on the sulfidic waste indicate that Cd, Cu, Zn and SO₄ rich waters migrate from the backfilled sulfidic waste into the local unconfined aquifer. However, the seepage of alkaline (pH 7.3 - 8.0), high conductivity (>10 000 µS/cm) tailings waters into the remaining pit void clearly shows that the acid leachate originating from the sulfidic waste rock does not impact beyond the waste repository and its immediate environment. Geochemical modelling implies that minimal or no mixing occurs between the acid waste rock leachate and the alkaline tailings waters.

INTRODUCTION

Mining of mineral deposits creates underground and surface voids, which can be suitable repositories for mine process and metallurgical wastes. Backfilling of surface and 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 open pits and underground workings is often regarded as best practice for the rehabilitation of mining voids (eg 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 sulfidic waste rock and tailings below the groundwater table reduces the amount of reactive material that would be available for oxidation. Nevertheless, if the backfill is 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 reach the saturated zone of surficial aquifers where the prevailing groundwater flow will produce metal and metalloid rich plumes down gradient from the mine workings (eg Warren *et al.*, 1997; Younger, 2000). This study uses kinetic leaching experiments and groundwater sampling in combination with detailed waste rock characterisation and hydrological modelling to predict the concentrations of metals and metalloids in backfill leachate and its impact on the local groundwater quality at the Thalanga base metal mine, Australia.

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 sulfides of Kuroko style (Gregory, Hartley and Wills, 1990). The mine was operating 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 680 mm. The mining operations resulted in extensive underground workings (~1.6 million m³) and a large final mining void (600 m × 150 m × 70 m). The underground workings were used for the disposal of ~290 000 m³ of tailings. This hydraulic fill was stored behind bulkheads at various depths. The mined-out section directly underneath the open pit was one of these repositories. In addition, upon mine closure about 80 per cent of the open pit was backfilled with acid producing sulfidic waste rock, leaving a small approximately 60 m deep void at the western end of the pit. The collapse of the crown pillar during the backfill operation opened the backfilled pit floor to the underground workings and repeatedly produced large tension cracks that required additional backfilling. Furthermore, the pit serves as a sink for acidic run-off 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 2 cm thick salt layer.

METHODS

Groundwater sampling from 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, SiO₂ and Zn as well as TDS, nitrogen, sulfate, chloride, bicarbonate, carbonate, alkalinity, hardness, pH and conductivity at the Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University (JCU), Townsville.

The mineralogy of selected precipitates and 27 backfill samples (18 surface samples and nine 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 HNO₃ 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 ten-year climatic records from the mine site, the average daily rainfall was calculated for 1.5 years and used for the conduct of a 200-day accelerated column leach experiment. Water to the first column was adjusted with H₂SO₄ to a pH value of 3.7, mimicking the pH conditions of waters accumulating on the backfill during the wet season. Leachate from the first (2 m) column was applied to the second (4 m) column, and leachate from the second column was the input to the third (6 m) column. 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,

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JCU Townsville). The geochemical modelling tool PHREEQC 2.3 was used to simulate the mixing of alkaline tailings waters and acid waste rock leachate.

RESULTS AND DISCUSSION

Backfill

The backfilled sulfidic waste is composed of diverse materials ranging from silty particles of less than 2 mm to boulders 2 m across whereby 35 wt per cent of the total waste material has a grain size below 2 mm. The material comprises major quartz (59 per cent), chlorite (17 per cent) and muscovite (16 per cent), minor amounts of pyrite (5.8 per cent) and albite (1.5 per cent), traces of barite, and a range of post-mine oxidation products, particularly gypsum (1.8 per cent) and jarosite (2.2 per cent). Salt precipitates on the backfill surface were identified as melanterite ($\text{Fe}^{\text{II}}\text{SO}_4 \cdot 7\text{H}_2\text{O}$) and siderotil ($\text{Fe}^{\text{II}}\text{SO}_4 \cdot 5\text{H}_2\text{O}$). Other minor phases include rozenite ($\text{Fe}^{\text{II}}\text{SO}_4 \cdot 4\text{H}_2\text{O}$), szomolnokite ($\text{Fe}^{\text{II}}\text{SO}_4 \cdot \text{H}_2\text{O}$), römerite ($\text{Fe}^{\text{II}}\text{Fe}^{\text{III}}_2(\text{SO}_4)_4 \cdot 14\text{H}_2\text{O}$), halotrichite ($\text{FeAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$), alunogen ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$), hexahydrite ($\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$), epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) and chalcantite ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$). Dissolution of these secondary minerals and sulfide oxidation result in the generation of a low pH, high TDS metal rich leachate.

Local hydrology and hydrochemistry

Groundwaters up gradient from the pit possess 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 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 two to three orders of magnitude higher than those of groundwater up gradient from the backfilled pit. Therefore, limited migration of the backfill leachate into the local aquifer leads to rising Cd, Cu, Fe, SO_4 and Zn concentrations in local groundwaters. However, the column experiments also showed that a significant amount (40 per cent) 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 from the backfilled pit indicate that groundwater levels have recovered to the height (~40 m depth) of the pre-mining watertable. 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. In December 2001, the potentiometric surface up gradient from the pit was approximately 15 m higher than the floor of the remaining pit void. Increased rainfall and recharge during the following month increased the gradient and led to the complete flooding of the interconnected underground workings. This flooding event resulted in the emergence of tailings porewaters in the remaining pit void. The chemistry of the emerged water body in the pit is similar to the chemistry of the original tailings water prior to underground disposal (pH: 8; EC: ~10 000 $\mu\text{S}/\text{cm}$; Ca: 550 mg/L; Mg: 530 mg/L; low metal concentrations, eg Cd: <0.05 mg/L, Zn: ~10 mg/L). However, the

water body in the pit exhibits distinctly higher Ca, Mg, Cd, Zn and SO_4 concentrations than the tailings waters. Geochemical modelling using PHREEQC 2.3 indicates that the mixing ratio of acid waste rock leachate and alkaline tailings is below 1:1000. Therefore vertical percolation of acid waste rock leachate is minimal and increased Cd, Cu, Fe, SO_4 and Zn concentrations in local groundwater are most likely due to lateral seepage/dilution of acid waste rock leachate along the weathering boundary.

CONCLUSIONS

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. Permeability of the bulk waste rock is low and water flow through the backfill is aided by numerous tension cracks which acts as conduits for atmospheric oxygen and water facilitating sulfide oxidation at depth. Furthermore, the presence of a Cd-Cu-Fe- SO_4 -Zn plume in the groundwater 200 m up gradient from the pit implies that the leachate migrates via interflow processes into the local aquifer. The leachate reaches the local aquifer via lateral drainage, interflow processes and preferential fluid flow along tension cracks. Yet, migration of this plume is localised and limited to the immediate environment of the backfilled pit. Tailings placed as backfill below the sulfidic waste rock and hence below the former open pit generate alkaline groundwaters that have emerged at the pit floor. The rise of these waters into the lower part of the backfill is aided by the hydraulic connection of the pit with the underground workings and the rapid rise of groundwaters upgradient from the open pit. While such alkaline groundwater may prevent acidification of the local aquifer, the mobilisation of Cd, Zn and SO_4 into local groundwaters appears to be likely.

ACKNOWLEDGEMENTS

This research has been funded by Thalanga Copper Mines. Manfred Thienenkamp is recipient of a JCU Earth Sciences postgraduate scholarship.

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