

# Passive Treatment of Toe Drain Discharges from a Tailings Storage Facility using an Oxic Granite Bed

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## ABSTRACT

PanAust Limited (PanAust), through its Laos-registered subsidiary Phu Bia Mining (PBM), owns and operates the Phu Kham Copper-Gold Operation in the Lao Peoples Democratic Republic (Laos). The operation includes a flooded tailings storage facility that discharges through two toe drains installed in the facility's earthen dam. The toe drain discharges are alkaline with pH 6-7 and contain 2-10 mg/L iron and manganese. In May 2013, a passive system was installed to treat the toe drain discharges. The system consists of an oxidation pond followed by an oxic aggregate bed that is constructed with granite aggregate manufactured on-site. The system has treated, on average, 187 m<sup>3</sup>/hr of flow to an effluent containing pH 7.2, 6.5 mg/L dissolved oxygen, 176 mg/L alkalinity (CaCO<sub>3</sub>), 0.01 mg/L dissolved iron, and 0.14 mg/L dissolved manganese. The project demonstrates the feasibility of treating large toe drain discharges passively and the suitability of non-calcareous aggregate as a reactive media where the mine water is alkaline and contaminated with moderate concentrations of iron and manganese.

**Keywords:** copper mining, tailing storage facility, acid rock drainage, passive treatment

## INTRODUCTION

The management of mine tailings in wet climates often includes their permanent subaqueous disposal in constructed storage reservoirs. The earthen dams that create the storage reservoirs are typically constructed with one or multiple internal seepage collection systems that collect infiltration into the dam and discharge through toe drains. During the years or decades over which the dam is raised and tailings are disposed of in the tailings disposal facility (TSF), the primary discharge is through the toe drains. As the toe drain effluent is often a final discharge point from the TSF, its quality is subject to discharge criteria defined in the mine permit. Mine operators typically attempt to maintain good quality water in the tailings reservoir (alkaline with low metals) so that the toe drain discharges are also good quality. Not uncommonly, however, the toe drain discharges contain elevated concentrations of iron (Fe) and manganese (Mn) that exceed the permit limits, requiring treatment during and after the mine's operation.

The Phu Kham Copper-Gold Operation in Laos includes a TSF created by a large earthen dam that contains two toe drains. The toe drains discharge alkaline water with concentrations of Fe and Mn ranging between 2 and 10 mg/L. In 2013, a passive treatment system was installed that receives the full flow from the toe drains. The system's construction is innovative in its use of granite aggregate instead of limestone aggregate for removal of Mn. This paper describes the construction of the treatment system in 2013, an investigation of the condition of the aggregate in 2014, and its treatment performance over its first 1.5 years of operation.

## METHODOLOGY

Water samples were collected by PBM staff. Flow rates were measured at V-notch weirs located 10-20 metres below each of the two toe drain discharges. Water samples were collected at the weirs, within the treatment system, and at the final effluent channel. Analyses were made in the field for pH, DO, temperature, specific conductivity, and oxidation-reduction potential. Water samples were collected daily and transferred within 4 hours to the on-site laboratory where alkalinity was measured by titration, and concentrations of dissolved (<0.45 micron) Ag, As, Cu, Fe, Pb, Ca, Mg, Mn, Mo, Ni, Na and Zn were measured by atomic emission spectroscopy. A separate set of samples were collected approximately monthly from the toe drains and submitted to ALS Environmental laboratory in Bangkok for analysis of total concentrations of a much wider suite of elements.

### Project site

The Phu Kham Copper-Gold Operation in Xaysomboun Province in Laos is located in a challenging mountainous environment subject to high monsoonal rainfall. The main rock types in the project area are red bed (korat group), limestone, andesite ash flow tuff (metamorphosed to schist), cataclastite and granite. The host sequence forms the upper plate of a thrust fault with red bed siltstone making up the foot wall. The Phu Kham deposit is sericitic-altered porphyritic igneous and magmatite - chalcopyrite skarn clasts. The mineralisation shows a trend along north-north-west which is mainly hosted in highly foliated schist between red bed as the foot wall and cataclastite, limestone and granite as the top of the hanging wall. The sulphide mineral assemblage is predominantly pyrite, chalcopyrite, chalcocite, bornite, and covellite.

Before the Phu Kham operation commenced, acid rock drainage (ARD) was identified as the single most significant environmental risk. Potentially acid-forming waste rock and tailings were identified as by-products of the mining and processing of ore as part of the Environmental and Social Impact Assessment process. As a result, a detailed acid rock management plan was formed prior to mining and processing commencing.

PanAust has developed an integrated life-of-mine approach accounting for the entire 182 million tonnes of potentially acid forming (PAF) waste (Miller et al., 2012). The overall objective has been to prevent any ARD legacy from waste rock and tailings during the mine's construction, operation and after closure. To implement the plan, detailed operational guidelines incorporate ARD management practices into daily operating activities.

The ARD management plan is based on the fundamental strategy of isolating sulphidic mine waste from atmospheric oxygen. This essentially places the material within a pH and oxidation regime similar to the original ore body where pyrite is thermodynamically stable. This is the most geochemically secure option for ARD control.

Engineering options for achieving isolation from atmospheric oxygen include placing sulphidic material under a permanent water cover or construction of an engineered seal that essentially reduces oxygen transfer to geological rates. At Phu Kham, both strategies have been adopted with the higher sulphidic acid-generating waste rock and tailings reporting to the tailings impoundment (which maintains a minimum two metres of water cover) and the lower sulphidic acid-generating waste isolated in cells and zones (PAF cells) within the downstream portion of the tailings storage facility embankment.

## RESULTS AND DISCUSSION

### Toe drain characterisation

The primary toe drain (#1) has discharged since 2008. The effluent has always been alkaline. Table 1 shows the average total metal concentrations between 2008 and 2012. Concentrations of all hazardous metals are very low and well below effluent targets. The only metals that exceed effluent targets are Fe and Mn.

**Table 1** Average pH and total metal concentrations for Toe Drain #1, Feb 2008 – May 2012. Analyses by ALS Environmental (Bangkok).

	pH	Al	As	Cd	Cu	Fe	Pb	Mn	Ni	Zn
	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Average	6.8	0.38	<0.01	<0.002	0.007	2.3	0.003	3.0	0.006	0.018
Count	44	50	50	50	50	50	50	49	50	50
Limit	6-9	-	0.1	0.03	0.3	1.0	0.2	0.5	0.2	0.5

### Passive system construction

The design of the treatment system is shown in Figure 1. The system includes a settling pond followed by a bed of aggregate. The design follows US Bureau of Mines guidance provided in 1994 (Hedin, Nairn & Kleinmann, 1994) and more recent advances in the use of limestone aggregate in mine water treatment (Hedin et al., 2013). The intention of the design is to oxidize and settle Fe solids in the pond and to oxidize and trap Mn solids in the aggregate bed. The two toe drains are combined into a single piped flow that discharges into the pond through a horizontal fountain. The Fe pond has a surface area of 1,800 m<sup>2</sup> and a depth of 2 m. The pond contains three geotextile curtains that spread flow across the pond and promote solids settling. Water flows from the pond through a wide shallow channel in to the aggregate bed. The bed has a surface area of 4,200 m<sup>2</sup>, is 2 m deep, and contains 10,100 tonne of material.

The bed was constructed with granite aggregate produced on-site. Limestone, which is commonly used in Mn systems such as this, was not available. Figure 2 shows the particle size distribution of the aggregate used in the treatment system.

The elevation of water in the system is controlled by the final effluent. The design intended that the water elevation in the aggregate bed should be 10-15 cm below the aggregate surface. This feature was expected to minimise short circuiting of flow on top of the aggregate and also limit plant growth in the system.

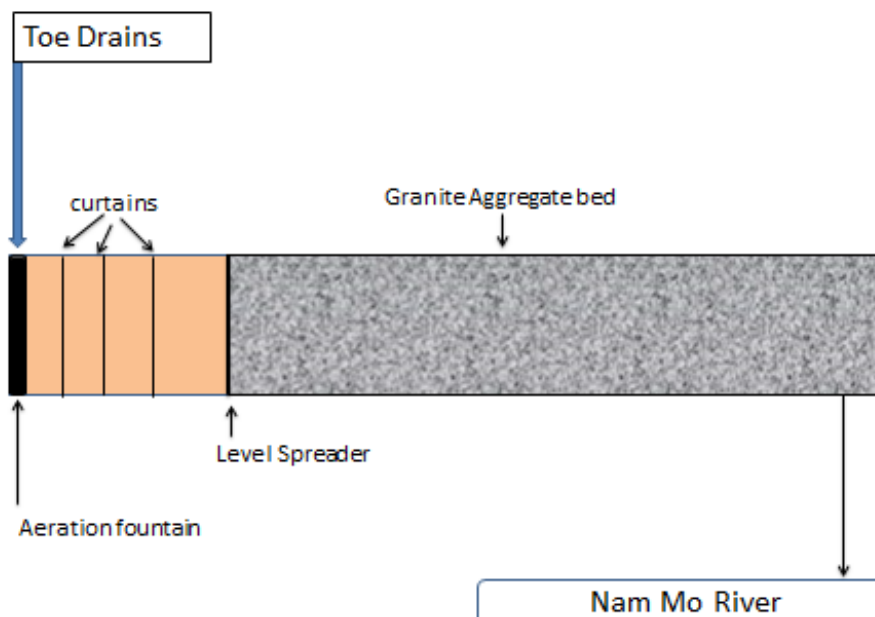


Figure 1 Design of the passive treatment systems

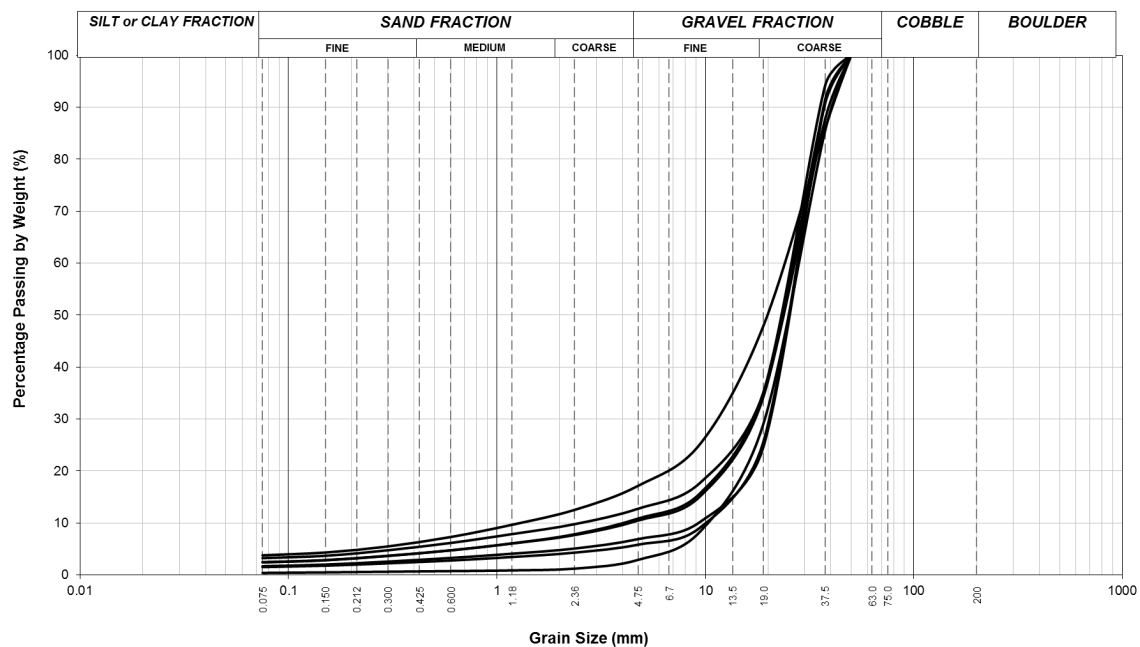


Figure 2 Particle size distribution for aggregate used in the passive system. The lines represent multiple samples collected from the bed after its construction.

### Passive system treatment effectiveness

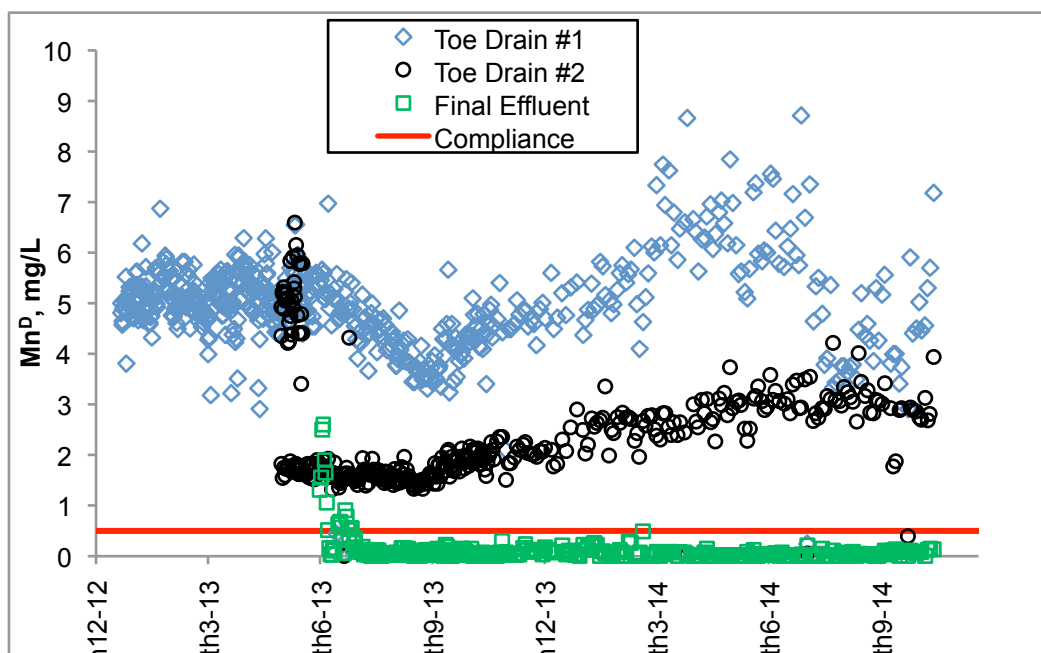
Table 2 shows the average chemistry of the treatment system influents, the calculated influent to the pond, the influent to the aggregate bed, and the final system discharge. All elemental concentrations shown are dissolved. Flow through the oxidation pond decreased Fe<sup>D</sup> to from 2.1 mg/L to less than 0.1 mg/L and Mn<sup>D</sup> from 4.0 mg/L to 2.6 mg/L. Flow through the aggregate bed decreased Fe<sup>D</sup> below 0.01 mg/L and Mn to 0.07 mg/L.

Figure 3 shows concentrations of Mn<sup>D</sup> between June 2013 and October 2014. Final effluent concentrations of Mn<sup>D</sup> did not consistently meet the 0.5 mg/L target until July 9, 2013; 27 days after the system was first put into operation. Since that date, the discharge has contained less than 0.5 mg/L on every sampling occasion.

**Table 2** Average flow and chemistry for the passive treatment system, Jun 2013 – Oct 2014. Flow rates are measured at weirs at Toe Drains #1 and #2. Other stations by addition.

	Flow	pH	DO	Alk	Ca <sup>D</sup>	Mg <sup>D</sup>	Na <sup>D</sup>	Fe <sup>D</sup>	Mn <sup>D</sup>
	m <sup>3</sup> /hr	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Toe Drain #1	34.4	6.4	2.7	142	109	21	7.0	3.0	4.9
Toe Drain #2	17.8	6.5	2.8	244	137	34	8.1	0.3	2.4
Into pond*	52.2	6.4	2.7	177	119	25	7.4	2.1	4.0
Into granite bed	52.2	6.9	6.4	183	122	25	6.5	<0.1	2.6
Final	52.2	7.2	6.5	176	116	25	6.4	<0.1	0.1

\* calculated mixture of Toe Drain #1 and #2



**Figure 3** Concentrations of dissolved Mn at the toe drains (system influents) and the aggregate bed final effluent.

**Table 3** Average loads (kg/d) of major water constituents at the treatment system stations, Jun 2013 – Oct 2014. % removal is the loss between the sum of the two influents and the final.

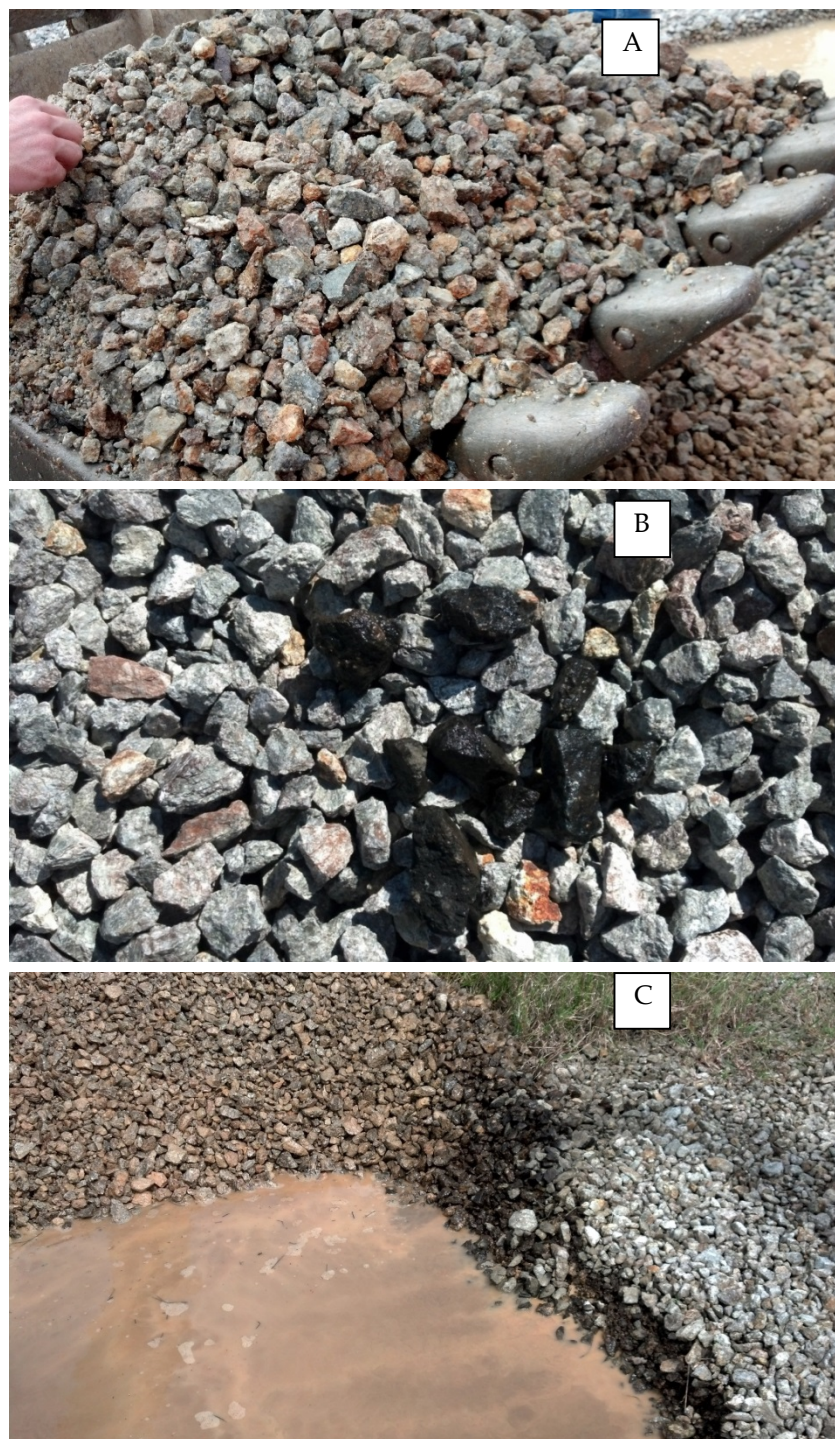
	Alk	Ca <sup>D</sup>	Mg <sup>D</sup>	Fe <sup>D</sup>	Mn <sup>D</sup>	Na <sup>D</sup>
	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d
Toe Drain #1	422	324	62	8.9	14.6	21
Toe Drain #2	375	211	52	0.5	3.7	12
Into granite bed	825	550	113	0.2	11.6	29
Final	794	523	113	0.0	0.6	29
% removal	0%	2%	2%	99%	96%	13%

Table 3 shows calculated loads of major constituents through the passive system. The system has negligible effect on alkalinity, calcium (Ca) and magnesium (Mg). A modest removal of sodium (Na) is indicated. The major effect of the system is removal of 96-99% of the Fe and Mn loading.

In mid-2014 water was observed flowing on top of a portion of the aggregate bed. In October 2014 an excavator was mobilised to investigate the change in hydraulics and also to investigate the condition of the aggregate. Flow on the top of the aggregate was limited to the first 25% of the bed. The investigation found algal growth on top of the stone that had created a dense biofilm that promoted flow of water on top of it. When the algal growth was disrupted by mixing the stone, water flowed into the aggregate and no longer flowed on the surface. The cause of the algal growth was suspected to be due to settling of the stone in the first portion of the bed, which allowed water on the surface during high flow conditions. During these conditions, algae growth was enabled. As a result of this observation, the effluent of the bed was lowered by 50 cm so that water would never flow on the surface and growth of algae would be inhibited.

The aggregate in the bed was inspected for signs of Mn removal. The raw granite is grey. Mn oxides form a black coating on the rocks. The aggregate in the final 25% of the bed did not have any black coloring, indicating that little Mn removal is occurring in this section (Figure 4a). As the investigation moved forward into the bed, stones stained black became visible (Figure 4b). In the first quarter of the bed, most of the stone in the top 30 cm was black (Figure 4c). The Mn staining was limited to the top 50 cm of the bed. Beneath 50 cm the aggregate retained its original grey color. These observations indicate that little Mn removal is occurring in the bottom 1.5 m of aggregate. When combined with the observations from the end of the bed, it was apparent that only 15% of the aggregate was involved in Mn removal. This condition likely has two explanations. First, removal of Mn is so effective in the first half of the bed that there is little Mn left for removal in the second half of the bed. This explanation suggests there is a large excess capacity for Mn removal in the second half of the bed which will be useful should Mn loadings increase. The observation that there is little visible Mn removal occurring below 50 cm suggests that flow is not well distributed through the bed. As the influent and effluent structures are both at the surface, there is an apparent preference of flow in the top 50 cm of the bed. This condition could be partially corrected by reconstructing the effluent as a perforated pipe placed on the bottom of the bed. There are no plans to make this change at this time.





**Figure 4** Aggregate encountered during system investigation. A) clean granite aggregate at the end of the system. B) black Mn-coated granite placed on clean stone to show contrast; C) layer of Mn-coated stone found in the first half of the bed.

This project demonstrates the feasibility for passive treatment of toe drain discharges when their chemistry is alkaline and the contamination is limited to moderate concentrations of Fe and Mn. These conditions are not uncommon as the primary author has observed similar chemistry at

tailings facility toes drains in Brazil and Tasmania. Mine planners should recognise that toe drains may need long-term treatment and reserve adequate land for placement of passive treatment systems below the toe drain discharges.

This project demonstrates that the passive removal of Mn from alkaline mine water does not require a limestone substrate. In the coalfield of eastern USA, where passive treatment technologies have been developed, limestone aggregate is preferred because it is readily available and its acid-neutralising capacity is considered a benefit. The very effective Mn removal in this system suggests that the removal of Mn is dependent on physical aspects of the substrate, not chemical aspects. This finding should be of benefit in areas where mine waters are naturally alkaline and limestone aggregate is not available.

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