

# Backfilled Pits – Laboratory-scale Tests for Assessing Impacts on Groundwater Quality

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## Introduction

Closure options under consideration at some sites include backfilling mined-out pits with waste rock. Backfill may include mineralised and non-mineralised waste rock. Following groundwater rebound, flow-through conditions may develop in the pit post-closure. The backfill located in the saturated zone below the water table may release solutes under such conditions. It is therefore important to understand the potential impacts that backfilled pits could have on post-closure groundwater quality.

Geochemical characterisation programs are the foundation for assessing the potential chemistry of water that has contacted mined wastes. Such programs must be designed to obtain data relevant to the closure options under consideration. To complement standard testing techniques, SRK utilises saturated column testing designed to generate data on leaching rates under anoxic conditions that could be encountered within submerged backfill.

This paper presents the findings of saturated column test work carried out on waste rock samples from an iron ore mine in the Pilbara.

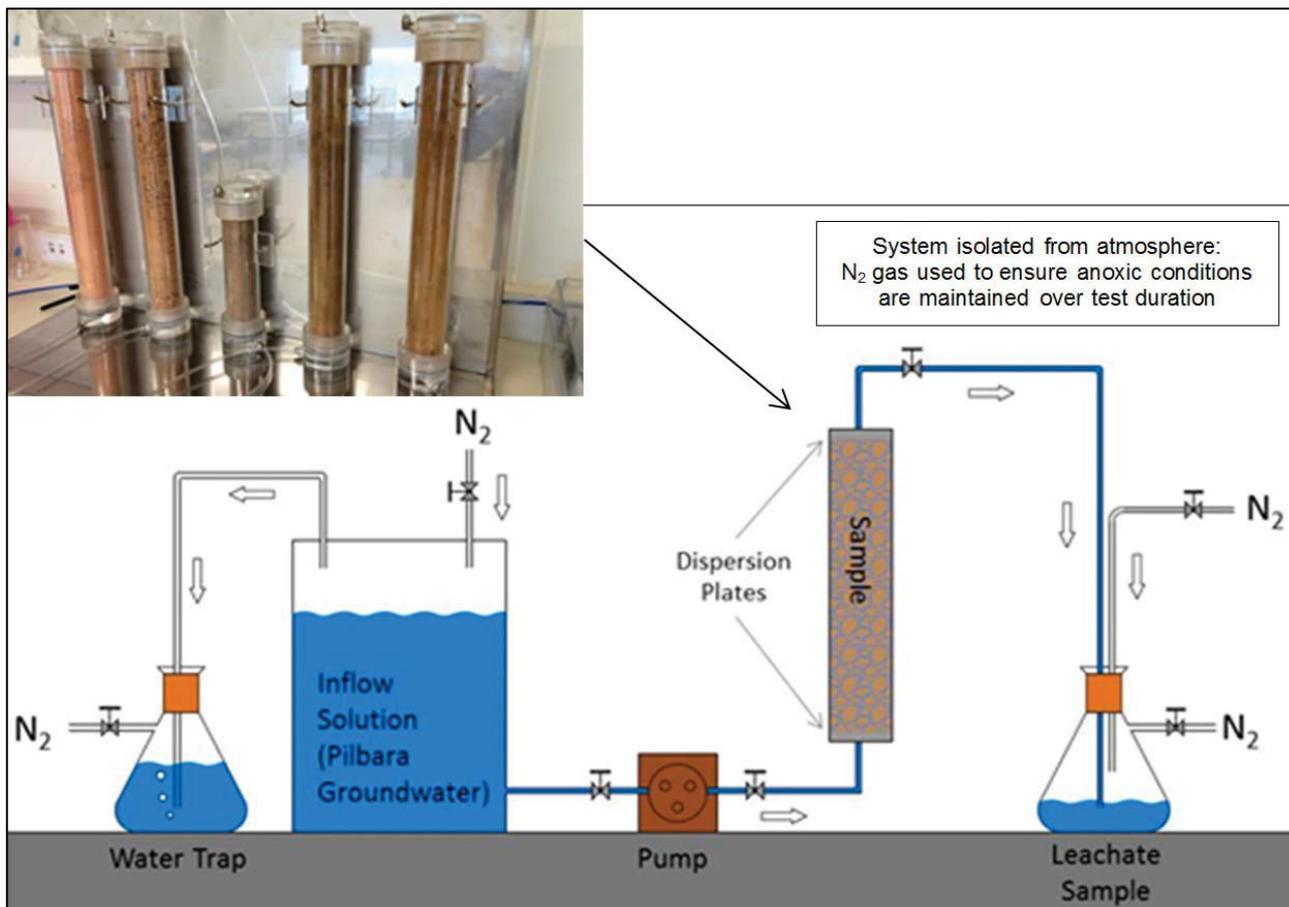
## Method

Up to 2 kg of sample was loaded into a sealed column. Column inflow was Pilbara groundwater, which was collected from the site under anaerobic conditions to ensure that it remained representative of the in situ groundwater. Column pore volumes were exchanged on a weekly basis and the sample remained saturated at all times. Figure 1 illustrates the test set-up. To maintain deoxygenated conditions, head space in sample collection vessels and within the initial groundwater reservoir was filled with nitrogen gas. The columns were operated for 10 to 13 weeks.

Outflow from the columns was analysed for a range of parameters including pH, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO), major cations and anions and a suite of over 20 trace elements.

## Sample Properties

Five samples were selected from four lithological units at the site. The sample properties are summarised in Table 1. The samples selected contained low sulfur and were enriched with a range of elements (i.e. elements were present at concentrations that resulted in calculated global abundance indicators, GAIs, of three or greater).



**Figure 1: Schematic of saturated column design (inset: photograph of actual set-up)**

## Results and Interpretation

In general, the column leachate (outflow) pH was similar to that of the inflow over the duration of testing (between 6.7 and 7.7), suggesting no significant release of acidity from the materials contained in the tests.

Leachate water quality results are illustrated in Figure 2 for selected parameters (DO, sulfate, arsenic, manganese and selenium). The results for DO concentration indicated that the column discharge was consistent with the groundwater inflow at around 1 mg/L for most of test duration. Small increases in DO occurred during the pore water exchanges on test initiation (week 1) and week 6, probably due to incomplete purging of the apparatus with N<sub>2</sub> prior to leachate collection. The results show that the samples did not consume any oxygen and therefore are void of reactive sulfide minerals, for example.

In many tests, the concentration of a number of major components (e.g. calcium, sodium, sulfate) decreased for successive pore volume exchanges, stabilising in later pore volumes at concentrations equivalent to the inflowing groundwater. This trend is indicative of progressive leaching and depletion of readily soluble salts from the sample. Selenium showed an analogous trend for the Mount Sylvia material (sample 2, which had the highest total sulfur content and enrichment of selenium - Table 1). Selenium is likely present as an impurity in a sulfate mineral phase and leached proportionally as the test progressed. Selenium was not detectable in the leachate from any other samples.

Arsenic release occurred from three of the samples as follows:

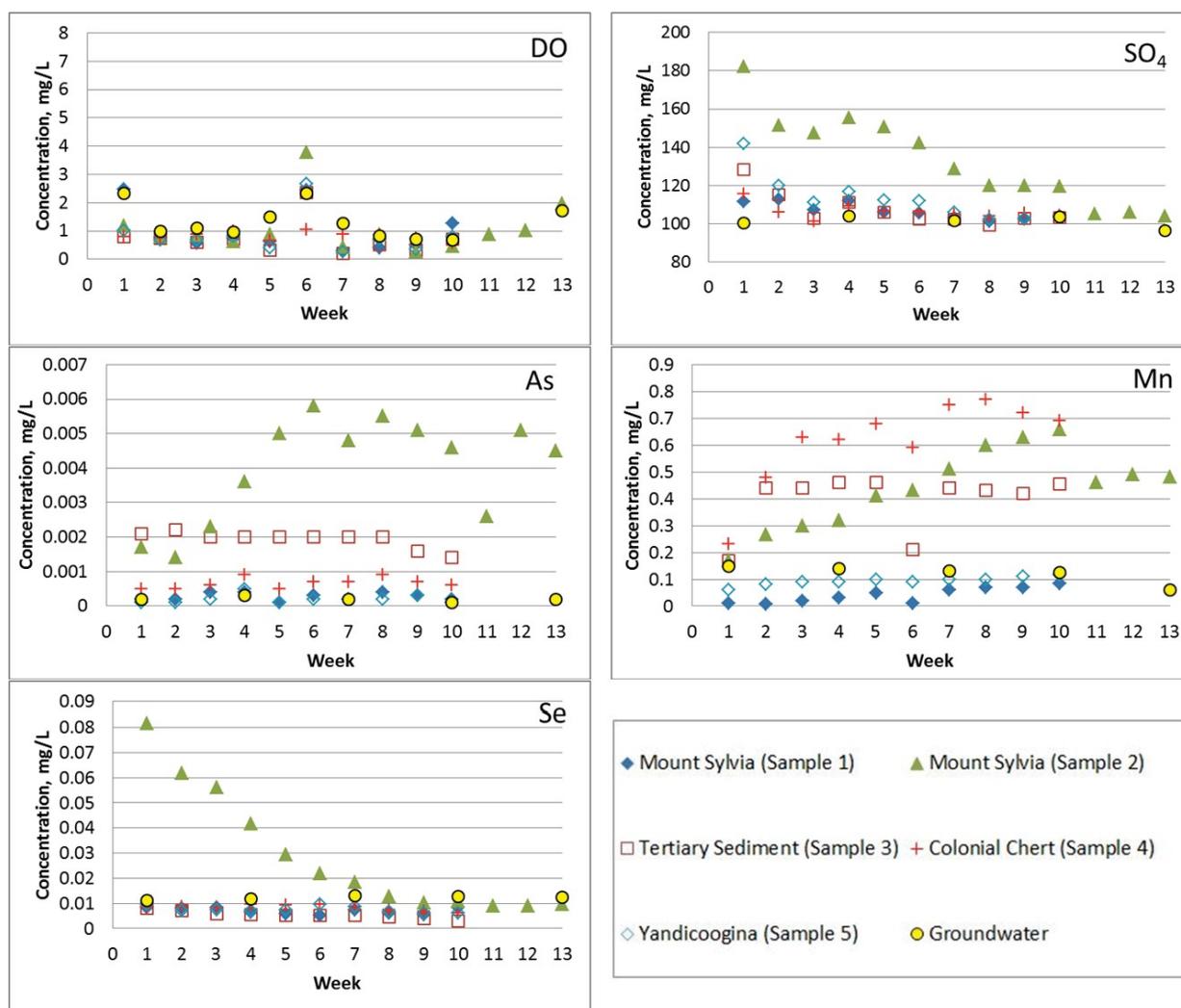
- Tertiary Sediment (sample 3) and Colonial Chert (sample 4) material showed a constant release at low dissolved concentrations over the duration of the test.
- Mount Sylvia material (sample 2) showed an increase in concentrations during the early stages of testing and then stabilised at a relatively constant concentration of around 0.005 mg/L.

**Table 1: Sample details**

Group	Parameter	Units	Sample number and lithology					
			1	2	3	4	5	
			Mount Sylvia	Mount Sylvia	Tertiary Sediment	Colonial Chert	Yandicoogina	
Acid base account	Total sulfur	%	0.03	0.06	0.03	0.01	0.01	
	ANC	kgH <sub>2</sub> SO <sub>4</sub> /t	15.6	105	69	7.5	1.8	
Trace element content	As	mg/kg	23.2	102	20.3	106	276	
	Bi		1.63	0.47	0.27	0.11	1.25	
	Cd		0.04	0.02	0.09	1.39	0.03	
	Mn		198	341	386	84 800	3440	
	Sb		15.9	9.45	1.78	0.87	5.22	
	Se		1.0	8.0	1.0	1.0	1.0	
Global abundance indicator values	As	-	3	5	3	5	6	
	Bi	-	4	-	-	-	4	
	Cd	-	-	-	-	3	-	
	Mn	-	-	-	-	5	-	
	Sb	-	5	4	-	-	4	
	Se	-	3	6	3	3	3	
Mineralogy	Calcite	Carbonates %	ND	1	ND	ND	ND	
	Aragonite		ND	9	ND	ND	ND	
	Dolomite		1	ND	4.5	ND	ND	
	Quartz	Silicates %	1	47	17.1	9	28	
	K-feldspar		2	ND	ND	ND	ND	
	Kaolin		50	11	5.4	1	ND	
	Illite/muscovite		6	5	ND	1	ND	
	Palygorskite		ND	ND	20.6	ND	ND	
	Hematite		Oxides and hydroxides %	15	6	12.2	7	51
	Goethite			17	3	19.5	54	18
	Gibbsite	2		ND	ND	ND	ND	
	Cryptomelane	ND		ND	ND	13	ND	
	Non-diffracting/unidentified	%	16	ND	4	15	17	

Notes: calculation of global abundance indicator values is described in Förstner, Ahlf and Calmano (1993), and average crustal abundances used are documented in Bowen (1979); '-' indicates values less than three (not enriched); ANC – acid neutralising capacity; ND – not detected (detection limit = one per cent).

The observed arsenic leaching behaviour is indicative of release from a sparingly soluble source mineral phase. The results suggest that the source mineral may be more soluble under the less oxic conditions of the saturated column test when compared to conventional static deionised water leach testing, where arsenic concentrations were at or below detection limit for neutral pH leachates. A possible source mineral could be a sparingly soluble iron oxy-hydroxide; strong associations between arsenic and iron have been observed in analogous low sulfur materials from the Pilbara (Linklater et al, 2014).



**Figure 2: Examples of column output – dissolved oxygen (DO), sulfate, arsenic, manganese and selenium. Note: the pH of all leachates was near neutral (ranging between 6.7 and 7.7 over the test duration).**

Manganese release is observed to occur from the Mount Sylvania, Tertiary Sediment and Colonial Chert material (samples 2, 3 and 4 respectively); dissolved concentrations are relatively constant for the Tertiary Sediment and Colonial Chert material. These trends suggest ongoing release from a sparingly soluble source mineral (possibly an iron or manganese oxide). Lower dissolved manganese concentrations were coincident with increased DO during the week 1 and week 6 pore volume exchanges, which suggests the source mineral could be redox dependent. In contrast the concentration in the leachate from the Mount Sylvania material (sample 2) increased over time; this suggests that the source mineral phase in this material is slightly different to that in Tertiary Sediment and Colonial Chert material (or test conditions within this test set-up may have varied slightly over time).

Concentration trends for the Mount Sylvania and Yandicoogina material (samples 1 and 5) showed evidence of manganese sorption, with the effluent concentrations lower than the influent concentrations. The results further suggest that the available sorption capacity was exhausted by around the seventh pore volume exchange.

### Conclusions

Saturated column testing indicated that predominantly the Mount Sylvania, Tertiary Sediment and Colonial Chert materials could release contaminants (e.g. arsenic and manganese) on an ongoing basis. The results further suggest that redox conditions may influence the concentration of some parameters, with increased leaching observed for less oxic conditions. The results also indicated that multiple pore volume displacements are required to completely remove both readily and sparingly soluble mineral phases.

In the context of backfilled materials that will be inundated post-closure, as conditions become progressively more anoxic, there is the potential that dissolved concentrations of manganese and arsenic could increase to levels above those observed in baseline groundwater.

## References

- Bowen, H J M, 1979. *Environmental Chemistry of the Elements* (Academic Press: London).
- Förstner, U, Ahlf, W and Calmano, W, 1993. Sediment quality objectives and criteria development in Germany, *Water Science and Technology*, 28(1993):307-316.
- Linklater, C M, Chapman, J T, Brown, P L, Green, R and Leake, S, 2014. Assessing metal leachability from low sulfur wastes - sequential extraction methods, in *Proceedings Eighth Australian Workshop on Acid and Metalliferous Drainage* (eds: H Miller and L Preuss), pp 325-338 (JKTech Pty Ltd: Brisbane).