Mount Isa Mines Rehabilitation Material Sampling and Analysis Program for Closure Planning

Matt Landers[1], Greg Maddocks[1], Candice Nucifora[2], Kristian Mandaran[2], Jason Jones[2], Amanda Forbes[3], Ward Wilson[4], Steven Newman[5]

[1]*RGS Environmental Pty Ltd, PO Box 3091, Sunnybank South, Queensland, Australia, 4109, matt@rgsenv.com*

[2]*Mount Isa Mines, Glencore Pty Ltd, Australia*

[3]*Deswik Mining Consultants Pty Ltd, Level 22, Riparian Plaza, 71 Eagle St, Brisbane, QLD 4000, Australia*
[4]*Unsaturated Soils Engineering Ltd., 960 Massey Court NW, Edmonton, AB, Canada, T6R 3S8*

[5]*Newman Engineering Pty Ltd, Melbourne, Australia*

Abstract

Glencore's Mount Isa Mines Limited (MIM) has completed the second phase of the rehabilitation materials sampling and analysis plan (RMSaAP) to identify and quantify potential materials that can be used to rehabilitate the large tailings storage facility (TSF) with an earthen cover system sourced from adjoining hills. Samples, collected from a test pit/ drilling program, were analysed to evaluate chemical/ physical properties of regolith within major rock/ soil types. Results were used with Deswik software to develop a stratigraphic 3-D overburden model to delineate rehabilitation borrow sources and schedule the TSF cover placement, and to undertake unsaturated zone modelling to evaluate the cover performance.

Keywords: Soil Cover | Deswik | Mount Isa Mines | Rehabilitation | TSF | AMD | Mine planning

Introduction

Glencore's Mount Isa Mines Limited (MIM) operates the Mount Isa open cut and underground copper (Cu) and zinc-lead (Zn/Pb) mines near Mount Isa in Queensland, Australia. Tailings from processed Cu and Zn-Pb ore is contained in a 1,315 ha shallow (< 35 m deep) multi-cell valley fill tailings storage facility (TSF).

Static geochemical testing conducted by MIM over the life of mine (LoM) verifies that the Cu, and Zn-Pb tailings have variable sulfide content and diverse mineralogy with significant acid neutralising capacity (ANC) in some samples. The tailings are predominantly classified as potentially acid forming (PAF) using static analytical methods. Kinetic leach testing using free draining columns and humidity cell tests simulating tailings placed on the surface of the TSF suggest that the tailings samples are likely to remain non-acid forming (NAF) for ≈7 years under aerial exposure, and much longer than this under anoxic saturated conditions within the TSF. During this period of weathering, as ANC is depleted, the neutral pH drainage may contain elevated concentrations of some elements including sulfate, manganese and zinc. Only when the ANC is depleted would the tailings then begin to produce acid drainage.

The main environmental risks posed by the tailings are the potential for (i) the physical movement of tailings or surficial efflorescent salts by aeolian processes, and (ii) the release of acid, major ions, metals and metalloids from the tailings solids and the percolation of these elements in solution into and through the surrounding regolith, and to a lesser degree through the tailings that may result in surface seeps, percolation to basement regolith below the TSF and/or deeper percolation to bedrock. It is assumed tailings solids and solutes would not be released from the TSF in surface water as the TSF is designed with sufficient storage capacity.

The overall management goal for the TSF is to maintain ongoing tailings deposition on the tailings beach and then implement rehabilitation strategies after the final placement of tailings before surficial ANC is depleted in the tailings. This management approach should ensure that potential adverse environmental impacts are minimised as the PAF tailings will continue to produce neutral pH drainage. In practice the decommissioning and rehabilitation of the TSF will occur progressively as TSF cells reach maximum design storage capacity.

Therefore, the current rehabilitation objectives for the TSF are to cover the tailings with an earthen cover system which is (i) safe to humans and wildlife (ii) non-polluting (iii) stable, and (iv) able to sustain native vegetation. The earthen cover system design currently proposed for the TSF comprise the placement of a 1.5 m thick geochemically inert borrow material layer directly on the tailings with a 0.5 m growth media layer overlying the borrow material.

Methods

To achieve the rehabilitation objectives, MIM is implementing a progressive RMSaAP. The work described in this study (Phase 2 of the RMSaAP) aims to identify and quantify the potential materials that can be used for rehabilitation and landform design at MIM: at a broad scale within the project area. The earthen cover system requires soil and regolith to be sourced from adjoining hills that include volcanic, sedimentary and metamorphic units overlain by ferrosol, rudosol and chromosol soil profiles. A test pit and drilling program was undertaken to collect samples to (i) evaluate the variability of the chemical and physical properties of the regolith within the major rock and soil types, and (ii) establish the depth and degree of weathering in the hills (iii) used as input to numerical unsaturated zone modelling to evaluate probable cover performance (iv) map-out potential borrow areas (shallow areas to strip soil) and borrow pits to mine deeper regolith, and (v) to schedule the movement of the soil and regolith onto the TSF.

The drilling and test pit program included 30 test pits and five PQ diamond core drill holes placed within each of the major material types or potential borrow areas. Samples were collected (nominally) from the O, E and A soil horizons for each test pit, and select intervals from the core.

The geochemical analytical methods included continual downhole hyperspectral mineralogy by HyLogger^{TM}, pH/ EC, NAPP, CEC/ ESP, metal(loid)s analysis and nutrient and organic carbon content. Physical analytical methods included texture, porosity, density, particle-size-distribution (PSD), point load and abrasion testing, Emerson aggregate analysis, Atterberg limits, hydraulic conductivity and soil water characteristic curves.

The results from physical testing (particle-size-distribution, soil water characteristic curves [SWCC] and saturated hydraulic conductivity) for the material types within the borrow areas were used to undertake finiteelement unsaturated flow modelling using SEEP/W (formerly VADOSE/W) (GEO-SLOPE International, 2016; GEO-SLOPE International, 2008a, b). The SWCC used in the modelling were corrected for particle size according to the Bouwer-Rice correction procedure (Bouwer and Rice, 1984) and fitted with the equation by Van Genuchten (1980). The hydraulic conductivity function (suction [kPa] versus hydraulic conductivity [m/s]) was estimated using the measured ksat and extrapolated using the Fredlund method (Fredlund et al., 1994). A two-dimensional (2-D) slice through the TSF with overlying cover system, including growth medium (Fig. 1), was simulated under transient conditions. The models comprise a climatic flux-boundary on the surface which allows true climatic conditions to be applied (rainfall, evaporation and evapotranspiration), with several flux boundaries within each cover layer (and within the tailings) to determine infiltration (and capillary rise) rates. Since the tailings are de-watered there is no water table within the TSF; therefore, the lower boundary condition of the models was simulated with unit hydraulic gradient. Similarly, lateral interflow of water above the tailings was allowed to exit the model via seepage face. As part of the assessment, the cover material thickness and texture were varied, and runoff and infiltration values provided as performance indicators.

Deswik.CAD software (Deswik.CAD v2017.2) was used to develop a concept level

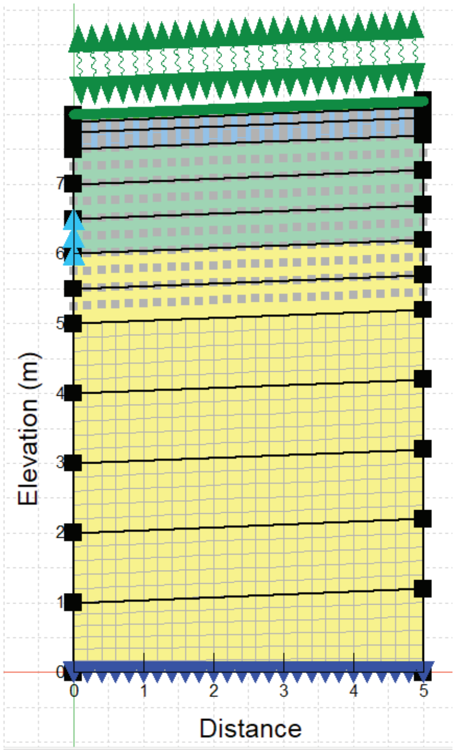

***Figure 1** VADOSE/W model geometry and mesh.*

stratigraphic 3-D overburden model incorporating a 2 m deep soil profile and underlying regolith. Mining of soil and regolith from borrow areas and borrow pits and scheduling options for placement onto the TSF were evaluated with varying plant and equipment using Deswik.LHS.

Results and Discussion

Geochemical and physical properties of soil and regolith

The results of the analytical program have indicated that there are no fatal flaws related to the chemical and physical properties of the upper profile of the regolith (comprising soil and sub-soil to ≈ 2 m bgl) or the ability to win extremely weathered to weathered material from borrow pits that could extend from the surface of the hills down to ≈ 420 m ASL (nominal elevation selected for the base of the borrow areas as it would be above the final tailings beach and TSF embankments).

There are no geochemical constraints (pH, EC, TS, ANC and soluble and total metal(oids) to using test pit or borrow material for rehabilitation, and no substantial differences in the pH, EC, NAPP or metal(loid) content in topsoil (0 to 0.5 m bgl), subsoil (0.5 to 2.0 m bgl) or deeper soil and regolith below 2.0 m.

There may be issues in the soil cover system relating to chemical imbalances (e.g. CEC) and biological aspects such as nutrient deficiencies, particularly if the upper topsoil layer is diluted with subsoil. Samples that were composited prior to analysis had the following results:

- Soil from 0.to 0.5 m bgl had the following averages pH 6, EC 45 µS/cm, CEC 5.4 meq/100g, ESP 0.5%, TKN 197 mg/kg, Bray P 2.2 mg/kg and TOC 1,283 mg/kg.
- Soil from 0.5 m to 3 m bgl had the following averages pH 7.5, EC 62 µS/cm, CEC 4.9 meq/100g, ESP 0.3%, TKN 78 mg/kg, Bray P 0.8 mg/kg and TOC 766 mg/kg.
- Regolith > 3 m bgl had the following averages pH 8.3, EC 53 µS/cm, CEC 1.3 meq/100g, ESP 0% (n=7) and 25% (n=1), TKN was BDL, Bray P was BDL and TOC was BDL (n=7) and 400 mg/kg (n=1).

From the perspective of the physical material properties, the surface material in all borrow areas is mostly non-dispersive and is dominated by material with low clay content. The fines content decreases substantially with depth in drill core. The physical sampling and analytical program verifies a wide range in measured PSD in the test pit samples. The PSD on the crushed drill core samples provides some qualitative comparison between sample types and was not intended to define the PSD of as-mined rehabilitation units. Whereas it is probable the surficial test pit samples would yield material with a suitable fines content this may not be attained from deeper regolith units. However, because of the low permeability of the underlying tailings water that does percolate through the cover will be stored there in the pore voids. The deeper regolith sampled from drill core may be amenable to use as "general fill" that comprises the 2.0 m layer of geochemically inert material in the concept cover system: the general fill may yield clay, slit and sand to cobble size material in a soil cover system when blasted. This is assumed because of the highly fractured nature of the regolith, low rock strength and measured permeability.

One aspect of the evaluation of the proposed soil cover system which is not able to be modelled is that the soil cover will undergo continual physical and chemical weathering, and a soil profile with increasing fines content will develop within the soil cover over the tailings as fines are leached through the soil cover.

The volume of soil from the designated borrow areas (≈ 485 ha) is in the order of 3 Mlcm (short of the required 9 Mlcm) but this could be increased to the desired 9 Mlcm by increasing the stripping depth from 0.5 m to 1.5 m bgl. Bgl. This would result in "dilution" of the chemical, physical and biological parameters, and functions, of the as-placed soil (as outlined in the above bullet points).

Earthen Soil cover modelling

The placement of a soil cover comprising soil and regolith sourced from borrow pits around the perimeter of the MIM will shed runoff during the large rainfall events (e.g. > 25 mm/day rainfall events) but will generally allow rain to percolate into the soil cover due to the sandy / loam texture soil and the coarse particle size distribution of the weathered to heavily weathered regolith present to a depth of 30 m bgl within the hills around the MIM TSF. The variable surface runoff from the soil cover ranges from: 0% for rainfall events < 10 mm per day; 16.5% for rainfall events > 10 mm and < 30 mm per day; and, 42% for rainfall events > 30 mm per day.

The modelling results verify that the amount of runoff is reduced substantially if the slope of the soil cover is reduced because ponding of water on a flat surface allows more water to percolate into the soil cover. Since average annual evaporation (≈3 m/ yr) exceeds average annual rainfall (≈430 mm/ yr) by a factor of > 7 and since the tailings have very low permeability almost all rain entering the soil cover will leave the cover system as evaporation and or transpiration.

The coarse and blocky nature of the deeper regolith material may act in part as a capillary break reducing upward migration of soluble weathering products but may also allow some lateral movement of water within the cover during large rainfall events.

Rehabilitation scheduling

The material balances for the borrow sources, derived using Deswik.CAD, are presented in Tab. 1. The key results are that approximately 500 ha of borrow areas were identified in the study (Fig. 2), but approximately 1,500 ha of area is required to be rehabilitated. This means that the topsoil (specifically) and underlying subsoil recovered from the 500 ha will need to be diluted i.e. if 60 cm of topsoil is stripped from the borrow areas it would be spread at a depth of 20 cm and it is uncertain if this would enable sustainable growth of vegetation without amendment of the as constructed soil cover. The rehabilitation schedules (in respect to the time over which the cover could be placed) are based on assumptions needing testing and verification, for example the:

- geotechnical properties of the tailings are not known and there are major (untested) assumptions related to the time it will take for the tailings to consolidate so a soil cover can be placed on the TSF; and,
- the time it will take to construct the soil cover (and therefore financial cost) is a function of gaining access to tailings and the fleet that is used, therefore it is necessary to understand the physical properties of the tailings and TSF and determine what type of equipment can (cannot) be used to construct a soil cover on the tailings.

Equipment for sourcing and placing soil and regolith is assumed to include 1 x Komatsu 1250 excavator and CAT 725G (20 t capacity) trucks and requires 14 to 15 years to complete placement of the cover system. The Deswik landform haulage scheduling verifies there are differences in the order of 20,000 to 30,000 hours truck time for the two borrow pit location options (Fig 2) but substantial differences in the order of 200,000 hours for the two sequencing options (Fig 3). The Deswik model can be used to evaluate additional scheduling options including changing borrow area locations, configurations, haul routes, equipment specifications and placement strategies. Similarly, the financial aspects of the current Deswik scheduling model can also be built-in to the model.

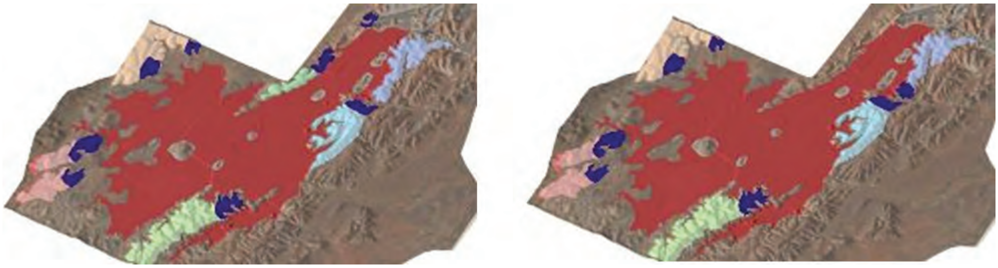

Figure 2 *proposed borrow pit locations and scheduling options: Option 1 all borrow areas (left) Option 2 N1 and N2 excluded (right).*

Figure 3 *Scheduling variations: strip sequence north to south (left) versus no sequence (right).*

Conclusions

The findings of the RMSaAP work program informed the work that is scheduled for 2018 and 2019 that includes additional test pits and drill holes in each borrow pit to enable the development of a 3D regolith model that will quantify the volume of each major rehabilitation unit from topsoil through to the partially weathered regolith that could be mined from each borrow pit. When all borrow pits have been drilled, sampled and analysed the detailed regolith models for each borrow area will be used to develop a detailed earthen soil cover system construction schedule to be completed with optimisation around the placement of materials and equipment fleet used to construct the cover system.

The approach being implemented by MIM will provide a robust, reliable and transparent method of calculating the timing and cost of construction and the probable performance of the earthen soil cover system. The overall conclusion of this work is that the soil, sub-soil and extremely weathered to partially weathered regolith in the hills adjacent to the MIM TSF would be suitable to encapsulate the tailings and should support a vegetative cover. Additional detail to support the general conclusion of the work and limitations around this statement are summarised below.

Acknowledgements

The authors thank Tshwane University of Technology (TUT) for hosting the ICARD | IMWA | MWD 2018 Conference.

References

Bouwer H, Rice R (1984). Hydraulic Propertiesof Stony Vadose Zones. Ground Water, 22(6).

Deswik Mining Consultants Australia Pty Ltd (2017) Deswik.CAD v2017.2 software https://www.deswik.com/

Fredlund DG, Xing A, Huang S (1994) Predicting the permeability function for unsaturated soils using the soil-water characteristic curve. Canadian Geotechnical Journal, 31, p 533 - 546

Geo-Slope International Ltd. (2008a) Seepage Modeling with SEEP/W 2007 – An Engineering Methodology. Third Edition, GEO-SLOPE International Ltd., March.

Geo-Slope International Ltd. (2008b) Vadose Zone Modeling with VADOSE/W 2007 – An

Engineering Methodology. Third Edition, GEO-SLOPE International Ltd., March.

Geo-Slope International Ltd. (2016) GeoStudio 2016. Version 8. Online. www.geo-slope.com

van Genuchten M (1980) A Close-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils.