Cost effective integrated assessment of mine waste and practical management solutions

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Abstract

Effective management of mine waste represents a high risk for many mining projects, with risks including geochemical composition, physical stability and revegetation performance. Investigations to develop mine waste management recommendations are typically reliant on large amounts of testwork by study teams who often work in isolation, have little geological understanding and lack practical mining experience. This can result in expensive studies that fail to identify issues or develop practical solutions.

Mine Earth have supported Norton Gold Fields in developing practical solutions to manage mine waste for existing and proposed projects in the Goldfields region of Western Australia. The approach consisted of identifying keys risks and data gaps through deposit scale geological assessment and review of existing data. Collaboration within a specialised team enabled targeted investigation and testwork to be undertaken, based upon a sound geological understanding of the projects. A multi-disciplinary workshop was also used to address key risks, identify opportunities and integrate recommendations.

This approach has been implemented at several Norton projects, including Natal and Enterprise. For Enterprise, a number of significant risks were identified including the presence of potentially acid forming and erosive waste rock that had not been identified during previous investigations. These findings have led to considerable adjustments for the management of mine wastes. For Natal, recommendations for final landform design were developed from geological mapping, targeted testwork and collaboration within a multi-disciplinary team.

Practical solutions were developed for each of these projects that addressed key risks whilst capitalising on opportunities to contribute to better closure outcomes and cost efficiencies.

Introduction

Mine waste including waste rock is an inevitable by-product of mining. Management of waste rock generated during mining can present a significant risk to mining companies during operation and after mine closure. Poor management of waste rock during mining can result in a number of undesirable outcomes, including:

- Environmental impacts from inadequate management of geochemically reactive waste types.
- Increased levels of erosion.
- Impacts to the surface water regime.
- Inability to meet mine closure objectives and criteria.
- Increased rehabilitation and earthworks costs.
- The need to double handle waste.
- Increased ongoing maintenance requirements.
- Increased safety risks.

Development of effective mine waste management strategies requires input from a range of disciplines. Geochemical and physical waste characterisation underpins the design of waste rock dumps (WRDs) and other mine waste structures. WRD design is further influenced by the mining schedule, local and regional hydrology, local topography, the location of mine infrastructure, the zone of instability associated with open pits, exclusion zones and environmental or social constraints.

Waste rock properties can vary markedly between projects, and within the different geological zones at a project. Characterisation of waste rock prior to mining can be challenging, time consuming and financially demanding, however it provides the greatest opportunity to manage risks related to waste rock handling. Assessment of waste rock following the commencement of mining also allows for an enhanced understanding of waste rock properties and for the refinement of pre-mining findings and projections, however at this point there may be reduced opportunities to influence procedures for managing waste rock.

Common failings related to mine waste characterisation and management studies include a reliance on large quantities of testwork without obtaining a thorough understanding of deposit geology; the failure to relate sampling and analysis results back to the geological setting and scale of the deposit; and a focus on discrete elements of waste characterisation without broader consideration of other waste management constraints. Often waste rock management strategies are developed without consideration of the waste rock available to achieve the relevant WRD design specification.

Mine Earth utilise an approach to mine waste characterisation that consists of the following:

1. Develop a sound understanding of the project

Obtain a sound understanding of the project, with a focus on the geological setting of the deposit. The individual tasks will vary between greenfield and brownfield projects, but would typically include liaison with internal stakeholders such as project geologists, mine planners and environmental staff; review of drill samples; review of the geological model; review of the mine plan; observations of pit walls; and geological assessment and mapping of WRDs.

2. Interpretation of the geological setting

Geological interpretation based upon waste rock lithology, mineralogy, alteration, structure and weathering characteristics to screen likely geochemical and physical attributes and make *preliminary observations (identify geozones) and identify risks and opportunities. Prepare a plan for targeted sampling and analyses.*

3. Investigations

Targeted sample collection and testwork, using practitioners with significant local experience. Investigations are targeted on validation of the geological observations rather than relying solely on large quantities of testwork in isolation.

4. Develop recommendations

Develop waste rock management recommendations based upon integrated study findings and input from key internal stakeholders, typically in a workshop forum. The recommendations should be closely linked with the geological setting and in consideration of the mine plan.

Mine Earth have applied this approach to streamline the development of waste rock management strategies at three of Norton Gold Fields' (Norton) projects in the Goldfields of Western Australia, including Natal (*ex situ* waste rock) and Enterprise (combined *in situ* and *ex situ* waste rock). A multidisciplinary team with specialist skills including geology, geochemistry, physical characterisation, mine closure planning and engineering was assembled. The key findings from the Natal and Enterprise studies are described below.

Natal

Mine Earth led a study team to develop closure recommendations for the Natal gold mine (Natal) WRDs. The study team consisted of Mine Earth, Norton staff, Graeme Campbell and Associates, Trajectory and Outback Ecology. The study objectives were to investigate the geology of the Natal WRDs, investigate potential sources of cover rock / armour, determine the geochemical properties of select geological units and develop closure recommendations for the Natal WRDs.

Project review and geological setting

Natal is located 25 km northwest of Kalgoorlie. Mining commenced at Natal in December 2004 and ceased in April 2008. Natal consists of one open pit mine and two WRDs (Natal WRD1 and Natal WRD2).

Local stratigraphy consists of three distinctive lithological packages, with the Victorious Basalt at the base, overlain by a sequence of felsic volcanics with discontinuous bands of black shale. This is in turn overlain by a thick sedimentary package consisting of inter-bedded siltstones and shales.

Initial geochemical investigations had shown the black shale to be potentially acid forming (PAF) with no acid neutralising capacity (ANC) and rapid onset of acidification when exposed to oxidising conditions. The black shale was observed to have elevated concentrations of arsenic. The basalt bedrock was also identified as PAF (long lag), with elevated concentrations of arsenic. The initial investigations had advised that mining not proceed until a comprehensive management plan had been prepared for the PAF, saline and sodic varieties of waste rock.

A subsequent assessment of the geochemistry results determined that the initial assessment failed to take into account surface reaction processes which would limit the extent to which the basalt generated acid rock drainage (ARD). The review determined that in a water limited setting, the basalt was likely to be NAF, and recommended additional testing to refine the acid-base accounting for the Natal WRDs (GCA, 2007). Additional testing of the basalt determined that it typically contained only minor amounts of sulphide sulphur and had sufficient ANC to neutralise all acidity generated, meaning that ARD was unlikely to be generated by the basalt (SWC, 2007).

Existing closure commitments for Natal required a one metre cover consisting of competent, inert rock to be applied to the WRDs. One of the objectives of the investigation was to refine the cover strategy for the WRDs.

Investigations

Geological investigations

An investigation was undertaken by Mine Earth to inspect the two WRDs at Natal to visually assess *ex situ* waste rock behaviour and performance, identify potential sources of cover rock, and develop and implement a sampling and testwork program to verify geological observations. The investigation included geological assessment and observations from additional waste rock and soil stockpiles: Natal WRD1 rock stockpile, Natal WRD2 rock stockpile, Homestead WRD and stockpile and Natal soil stockpiles.

The key observations from the geological investigation of the WRDs are summarised in Table 1. Of the three rock stockpiles inspected, the WRD2 stockpile contained moderately weathered porphyry which had potential to provide a useful source of cover rock, and the Homestead WRD and stockpile consisted of fresh to moderately weathered basalt which had the potential to provide a useful source of cover material for PAF exposures on Natal WRD2.

Table 1 Key WRD observations

Area	Description
WRD1	• Constructed in two lifts separated by an inter-slope berm. • Outer slopes had been reprofiled; 35% of batters were covered with 0.5 – 1 m of competent waste rock consisting of basalt and porphyry. • Uniform waste lithology of weathered sandstone, massive competent basalt and competent felsic porphyry. • Poor surface water control from the top surface of the WRD, resulting in erosion at the northern crest. • Relatively poor standard of closure earthworks.
WRD2	• Constructed in a single lift; outer slopes predominantly at the angle of repose. • WRD constructed of heterogeneous waste rock, including some black shale (PAF). • Inadequate surface water control on and around WRD2. • Key issues needing management were the formation and discharge of ARD, surface stability and drainage control.

Based upon the outcomes of the geological investigation a sampling program was developed. Sampling at WRD1 and WRD2 was targeted to identify potentially problematic and useful geological units and to assist in the development of WRD closure recommendations. Sampling of the WRD rock stockpiles, the existing WRD1 cover and Homestead WRD aimed to identify suitable armouring cover for the Natal WRDs. The sampling of the Natal soil stockpiles was targeted at identifying soils suitable for use as a rehabilitation resource. Samples were typically analysed for a range of geochemical and physical properties as well as clay mineralogy.

Geochemical investigations

The geochemical testwork assessed the AMD potential and the mineralogy of the samples. Analysis included acid-forming characteristics, multi-element enrichment, solubility of relevant elements and clay chemistry and mineralogy. The geochemical investigation determined that (GCA, 2012):

- Metal enrichment for all geological units sampled fell within the range typically observed for mine wastes at local gold mines.
- Dominant clays were micas, kaolinites and chlorites.
- Most samples were NAF. Black shale (identified within WRD2) was PAF and a sample of felsic intrusive with minor porphyry (identified within the WRD2 rock stockpile) was classified as PAF (long lag).
- The basalt within the Homestead stockpile was identified as net acid consuming (NAC).

The black shale lithotype was located within the reach of the seasonal wetting front, and the pH of its rock fines fraction may be as low as pH 3 at an advanced stage of oxidation. Black shale consisted of approximately 10% of the total waste volume extracted from the pit during mining, but was assessed as only representing a minor proportion of the surface of WRD2 overall.

The felsic intrusive with minor porphyry was not observed to comprise a large portion of the WRD2 rock stockpile, however additional testing would be required to confirm the extent of PAF rock through the stockpile prior to use as an armouring rock.

The basalt from the Homestead stockpile was assessed as NAC, which had potential benefits for use as an armouring rock for Natal WRD2. It was determined that circum-neutral conditions would prevail where the Homestead basalt and the WRD2 black shale co-exist.

Assessment of physical properties

An assessment of physical properties was completed to verify geological observations, evaluate the propensity for the different geological units to erode and assess the rehabilitation potential for the samples. The physical assessment determined that (OES, 2012):

- WRD1 consisted of relatively homogenous oxide/transitional waste which was not highly erodible and was relatively benign from a physical and chemical perspective, although very saline.
- The WRD1 rock stockpile was sodic and saline. The samples displayed a moderately slow hydraulic conductivity and a low water holding capacity. The susceptibility to erosion of this unit meant it would not be suitable for use as a rock armour.
- Physical properties varied between the geological units within WRD2. Of note:
    - All geological units were sodic and saline.
    - The siltstone and clays had a very low hydraulic conductivity and a high water holding capacity. These materials would be susceptible to erosion if placed on the outer surface of the reprofiled WRD without adequate rock armour. There was potential to use these materials to form an aquitard above the black shale units.
    - The black shale unit was strongly acidic, and so detrimental to plant growth and water quality overall.
- The WRD2 rock stockpile had a high hydraulic conductivity, was non-sodic and was not dispersive. The majority of the samples were moderately saline and moderately alkaline. The porphyry was identified as a potential source of rock armour for erodible surfaces and vegetation growth in these materials is unlikely to be restricted.

- The Homestead stockpile basalt was strongly alkaline and non-sodic. The clay fraction of the basalt had the potential to disperse upon severe disturbance. The soil fraction of the Homestead basalt had a propensity to hardset. The Homestead basalt was dominated by the coarse fraction, so despite these limitations the Homestead basalt was considered a potential source of rock armour. The Homestead basalt was unlikely to constrain vegetation growth.
- The majority of soils from the Natal topsoil stockpiles were saline, prone to partial dispersion and had a low hydraulic conductivity. The soils were assessed as being prone to erosion if placed on slopes without adequate rock armouring, and should only be placed on flat surfaces such as WRD top surfaces or berms. The salinity of the soils was likely to restrict vegetation programmes to salt tolerant species. The soils were generally moderately alkaline, and the pH was unlikely to impact upon vegetation growth.

Recommendations

A workshop was held between the Norton Environmental Superintendent and the study team to develop closure recommendations for Natal. This enabled the study team to develop recommendations and a WRD closure design that considered and balanced the findings from the technical studies.

WRD1 closure recommendations

The key closure issue to be managed from WRD1 was the improvement of the WRD stability and surface water control. The key recommendations developed for WRD1 were (Mine Earth, 2012a):

- Improvement of surface water management through the construction of an armoured drain, perimeter and cell bunds on the top surface, cross bunds along the berm and reprofiling of the top surface and berms so that they avoid concentrating flows and drain internally.
- Encouragement of rehabilitation of the top surface and berm by placing and treating a layer of select topsoil within the cells on the top surface of the WRD.
- Maintain the existing batter/berm profile but re-trim to achieve concave batters, starting at 18° at the top and reducing to 14° at the base of each batter.
- Sheet slopes and berms with a 500 mm cover of competent porphyry rock sourced from WRD2.
- Cross rip the outer slopes on the contour using a winged tine to improve integration of the WRD cover with the substrate and reduce runoff.
- Construct a graded bund and cross bunds at a 10 m off-set from the toe of the WRD outer slopes.

WRD2 closure recommendation

The key closure issues for WRD2 were the management of the PAF black shale unit, WRD stability and surface water control as described below (Mine Earth, 2012a):

- Reprofile outer slopes to a concave profile of 20° at the top of the slope down to 14° at the base.
- Remove areas of black shale and backfill the resultant voids and cover with inert siltstone/clay sourced from WRD2.

- Armour the outer slopes with competent waste rock to a 500 mm thickness using NAC Homestead basalt for areas where black shale is present, and porphyry from the WRD2 rock stockpile in other areas.
- Reduce runoff from the WRD through the construction of a perimeter bund and cell bunds on the top surface and reprofiling to ensure the WRD is internally draining and does not concentrate flows.
- Encouragement of rehabilitation of the top surface by placing and treating a layer of select topsoil within the cells on the top surface of the WRD.
- Cross rip the outer slopes on the contour using a winged tine to improve integration of the WRD cover with the substrate and reduce runoff.
- Construct a graded bund and cross bunds at a 10 m off-set from the toe of the WRD outer slopes.
- Install flood armouring of 1 m thick coarse material at the stream interface up to a 3 m vertical height.

Implementation

The majority of the closure recommendations have been successfully implemented. To date, the WRDs are performing well and no remedial works have been required.

Enterprise

Mine Earth led a team to study develop recommendations for the management of waste rock from the Enterprise gold mine (Enterprise) and closure recommendations for the Enterprise WRD. The study team consisted of Mine Earth, Norton staff, Graeme Campbell and Associates, Trajectory and Outback Ecology. The study objectives were to develop a program to collect representative regolith and primary rock samples from the Enterprise deposit, conduct geochemical and physical analyses on the samples and develop recommendations for waste rock management.

Project review and geological setting

Enterprise is located 2.5 km east of Ora Banda in the Goldfields region of Western Australia. Two stages of open pit mining had previously been completed during the 1980s and 1990s to remove the oxide and transitional ore, as well as the uppermost portion of the sulphide ore. Mining activities had resulted in the development of one open pit and one WRD. An extension to the Enterprise project is proposed and consists of a cutback to triple the size of the existing Enterprise pit, resulting in an additional 12.6 million bulk cubic metres (BCM) of waste rock to be deposited to the existing WRD.

The primary host rock for the ore body is the Enterprise Dolerite which consists of a layered mafic sill that trends 120°/44° south-west. The Enterprise Dolerite is overlain by the Cashman’s Horizon (roughly 20 m thick), which is in turn overlain by the Mt Pleasant Sill (Figure 1). The Cashman’s Horizon is known to be PAF.

Locally, the regolith horizon consists of pedolith and saprolith zones. The saprolith includes upper saprolite, lower saprolite and saprock horizons. A generalised regolith profile is presented in Figure 2.

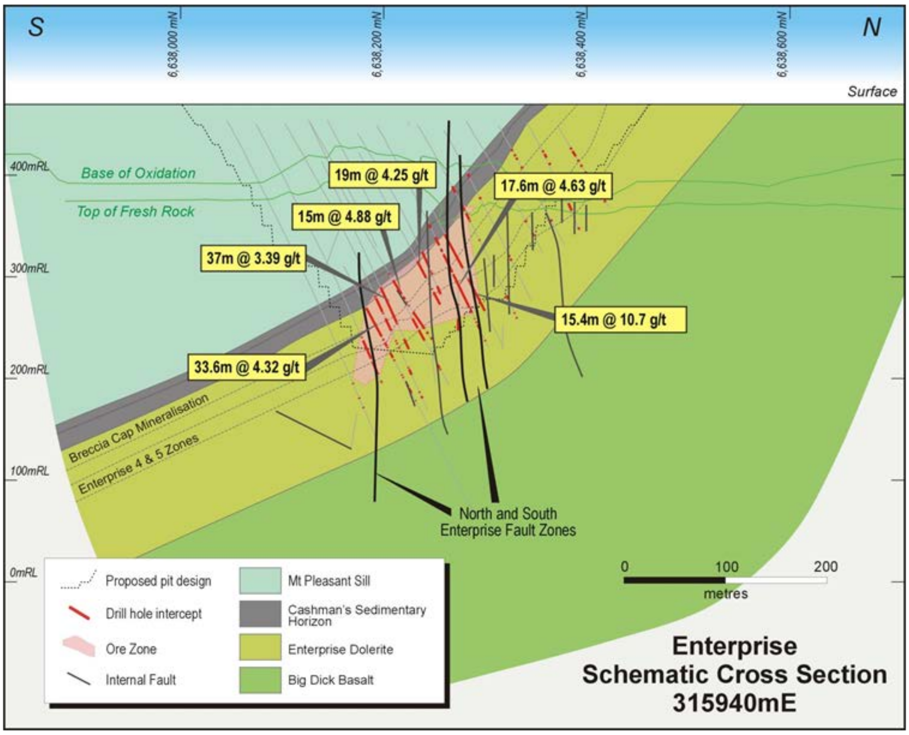

Figure 1 Schematic cross-section of the Enterprise deposit

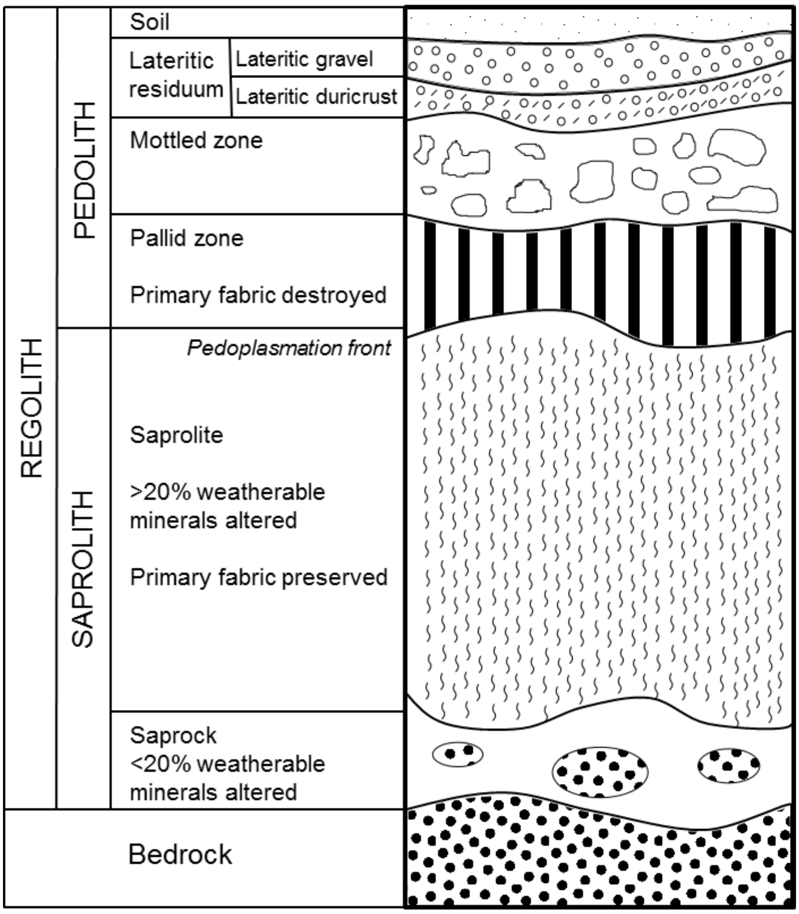

Figure 2 Generalised regolith profile (after McQueen and Scott, 2009)

GCA (2000) conducted a geochemical investigation for a proposed underground decline (i.e. outside of the proposed Enterprise pit shell) and determined that at that location, the Enterprise Dolerite unit was NAF. Subsequent investigations at Enterprise determined that oxidised and transitional samples from the Enterprise Dolerite were NAF, the porphyry was uncertain in terms of acid formation potential, and assumed that fresh samples of the Enterprise Dolerite were NAF based on GCA (2000) (MBS Environmental, 2010).

Investigations

Geological investigations

The geological investigations included a review of previous assessments, meetings with project geologists, engineers and site environmental personnel, and a preliminary geological assessment of the Enterprise WRD, open pit and drill core. The projected waste rock inventory for Enterprise is presented in Table 2.

Table 2 Enterprise waste rock inventory

Rock type	BCM	Relative volume (%)
Upper saprolite	**8,539,500**	**33.9%**
Mt Pleasant Sill	6,383,500	25.3%
Cashman’s Horizon	217,500	0.9%
Enterprise Dolerite	1,938,500	7.7%
Lower saprolite and saprock	**3,164,500**	**12.6%**
Mt Pleasant Sill	2,453,500	9.7%
Cashman’s Horizon	83,000	0.3%
Enterprise Dolerite	628,000	2.5%
Fresh Rock	**13,504,000**	**53.6%**
Mt Pleasant Sill	10,425,000	41.4%
Cashman’s Horizon	299,500	1.2%
Enterprise Dolerite	2,779,500	11%
TOTAL	***25,208,000***	***100%***

The geological investigation identified several gaps or potential issues (Mine Earth, 2012b):

- The 2010 geochemical testwork was undertaken only on oxidised and transitional dolerite samples. No fresh rock samples were assessed during this investigation. It was unclear if any of the fresh rock samples from the Mt Pleasant Sill had been tested as part of the geochemical investigations for Enterprise. Fresh rock samples present an increased risk regarding ARD.
- Samples were collected outside the anticipated Enterprise pit shell, and may not be accurately reflect *in situ* conditions.
- Drill core samples indicate that the presence of sulphides within the Mt Pleasant Sill and the Enterprise Dolerite increased substantially close to the Cashman’s Horizon, which had not

been identified within the previous geochemical testing. The geological assessment of the Enterprise WRD confirmed an abundance of pyrite.

- No dedicated program had been completed to assess the physical properties of Enterprise waste rock, although the 2010 geochemical investigation had concluded that the transitional dolerite had good physical and chemical properties for use as a WRD cover. This was inconsistent with the observations of the geological assessment completed for Mine Earth (2012b).
- Discussions with the project geologist and engineer indicated that the Mt Pleasant Sill contains numerous ultramafic horizons that are susceptible to erosion. The presence of a significant quantity of weathered mafics and ultramafics was confirmed during the WRD geological assessment. Weathered exposures of the Mt Pleasant Sill in the pit wall appeared unstable and susceptible to erosion. Weathered exposures of the Enterprise Dolerite in the pit wall appeared less susceptible to erosion than the Mt Pleasant Sill.

As a result of the geological investigation, a sampling and analysis program was developed to address knowledge gaps with regards to the geochemical and physical properties of mine waste. Previous investigations had confirmed that the Cashman's Horizon was known to be PAF and was excluded from the sampling and analysis program.

Geochemical investigations

All samples were analysed for total sulphur, total carbon, total carbonate and targeted heavy metals. Regolith samples were assessed for clay mineralogy and three bedrock samples were assessed for rock pulp mineralogy (two from the Mt Pleasant Sill and one from the Enterprise Dolerite). All waste bedrock samples were subjected to acid-base analysis and net acid generation testwork. One sample from the Mt Pleasant Sill and one sample from the Enterprise Dolerite were assessed for their pH buffering properties. The key findings from the geochemical investigations were (GCA, 2013):

- Fresh rock samples from the Enterprise Dolerite and the Mt Pleasant Sill were typically PAF, with five of the seven Enterprise Dolerite samples and five of the eight Mt Pleasant Sill samples classified as PAF. The PAF lag phase was variable, with lag timescales ranging from months to decades. Based upon the available data, there did not appear to be any obvious geological control on the distribution of PAF rock.
- Enterprise waste regolith samples were NAF.
- Heavy metal enrichment was variable, but not high enough to require specific management.

On the basis that fresh rock will compose 54% of the total waste rock volume for the Project, additional, testing was recommended to characterise the distribution of PAF rock within the fresh rock zone. Targeted kinetic testing was recommended once total sulphur and total carbon results had been reviewed to improve the understanding of the geochemical properties of the waste rock. Without additional testing, all fresh rock would need to be managed as PAF.

Assessment of physical properties

An assessment of the physical properties was completed to verify geological observations, evaluate the propensity for the different geological units to erode and assess the rehabilitation potential for the weathered zones of the Enterprise Dolerite and Mt Pleasant Sill. The key findings of the physical investigations were (OES, 2013):

- Sample pH was variable, ranging from very strongly acidic to moderately alkaline. The acidity was generally observed to decrease with depth through the regolith profile.

- Salinity ranged from non-saline to extremely saline and decreased with depth through the regolith profile.
- All regolith samples were assessed as sodic or extremely sodic, prone to hardsetting and typically poor draining.
- Soil samples ranged from dispersive to stable. The transported upper saprolite and the Enterprise Dolerite saprock were the most stable of the tested soils.
- Samples were observed to have a high water retention capacity.

The regolith samples at Enterprise had the potential to be structurally unstable and susceptible to erosion. Samples were observed as typically having high salinity, high sodicity, dispersive behaviour, susceptibility to hardsetting and low hydraulic conductivity, and were generally not considered suitable for placement on sloped surfaces of the WRD.

The Enterprise Dolerite lower saprolite and saprock units were identified as the most durable and considered to be the most suitable for placement on the outer slopes of the WRD, which confirmed the observations of the preceding geological investigation.

The high water storage capacity and low hydraulic conductivity of the remaining regolith units indicates they may be suitable for covering PAF waste rock.

Recommendations

A workshop was held between the Norton Environmental Superintendent and the study team. During the workshop, the key management issues were identified and agreed management actions were developed into a mine waste management strategy.

Key management issues

The key waste rock management issues for Enterprise were identified as:

- Management of PAF rock from the fresh rock zone and the Cashman's Horizon.
- Controlling erosion from the outer slopes of the WRD. Regolith samples had the potential to be structurally unstable and susceptible to erosion.
- Determining the distribution of PAF rock within the Enterprise Dolerite and Mt Pleasant Sill fresh rock zone.

Waste rock management recommendations

The waste rock management recommendations for the Project were (Mine Earth, 2013):

- Complete additional geochemical investigations to delineate the distribution of PAF waste rock within the Mt Pleasant Sill and Enterprise Dolerite fresh rock zone.
- Selectively handle all PAF waste rock for isolation within the WRD.
- NAF fresh waste rock from the Enterprise Dolerite may be the best source of durable rock that might be deployed as a WRD armour layer over the regolith to enhance stability. The outcomes of the geochemical assessment will determine whether NAF fresh rock is available.
- Fresh rock from the Mt Pleasant Sill may not be suitable for use on WRD surfaces because of erosion potential associated with ultramafic influences.
- The Enterprise Dolerite lower saprolite and saprock units are likely to be the most durable of the regolith horizon and as such were considered to be the most suitable for placement on the

outer slopes of the WRD. These materials comprise approximately 2% (628,000 BCM) of the total waste rock volume, so careful management of this resource will be required. The physical properties of the as-mined Enterprise Dolerite lower saprolite and saprock units are unknown, and these should be verified during mining.

- It will be important to avoid rehandling armouring rock where possible, to maintain the structural integrity of this resource.
- The high water storage capacity and low hydraulic conductivity of the remaining regolith units (44% of the total waste volume) indicates they may be suitable for covering PAF waste rock. These more erosive regolith units should not be applied to the outer surface of the WRD.

It should be noted that there will be competing requirements for durable waste rock including abandonment bund construction.

WRD conceptual design

Careful management will be required to minimise potential impacts associated with PAF primary rock and erosive regoliths on the Enterprise WRD. The following key recommendations were made in relation to WRD design (Mine Earth, 2013):

- PAF waste rock should be isolated within the WRD to avoid exposure to seasonal wetting and drying cycles (Figure 3 and Figure 4).
- Within the WRD, PAF waste rock should be encapsulated within the high water storage capacity and low hydraulic conductivity regoliths (i.e. upper saprolite from both the Mt Pleasant Sill and the Enterprise Dolerite, as well as lower saprolite and saprock from the Mt Pleasant Sill) (Figure 3 and Figure 4).
- The upper saprolite from both the Mt Pleasant Sill and the Enterprise Dolerite, as well as fresh rock, lower saprolite and saprock from the Mt Pleasant Sill, should not be exposed on final WRD surfaces because of erosion potential.
- The Enterprise Dolerite lower saprolite and saprock units should be used as an outer cover over the more erosive regoliths, if their as-mined physical properties are favourable (Figure 3 and Figure 4).
- NAF fresh waste rock from the Enterprise Dolerite may be the best source of durable rock that might be deployed as a WRD armour layer over the regolith to enhance stability (Figure 3 and Figure 4).

In aiming to achieve adequate surface stability on the WRD there may be limitations on what level of revegetation success can be achieved.

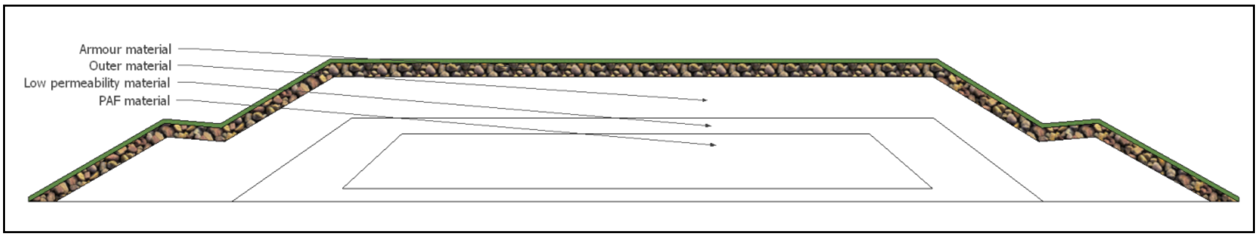

Figure 3 Indicative WRD cross-section (not to scale)

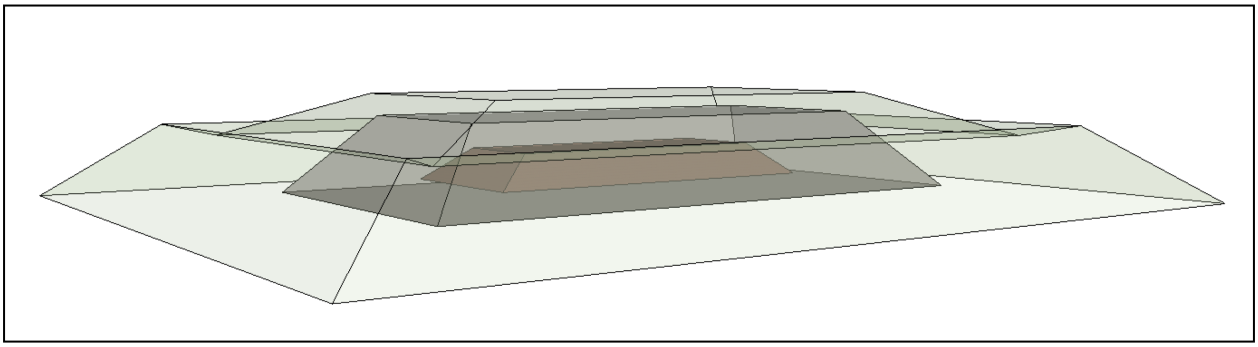

Figure 4 Indicative WRD isometric schematic (not to scale)

Site specific WRD conceptual closure design parameters were developed for Enterprise based upon the workshop and investigations. The design was developed to manage surface water on and around the WRD, encourage rehabilitation and reduce erosion from the WRD.

Implementation

Norton has implemented the waste rock management plan through internal management procedures. The key roles responsible for the implementing the procedure are the Health Safety and Environmental Superintendent, the Mine Geologist and the Area Superintendents. The Mine Geologist (in consultation with the Health, Safety and Environmental Superintendent) is responsible for ensuring that grade control drilling includes the assessment of PAF rock, which informs the weekly dig plan. The weekly dig plan is used to ensure that PAF waste is handled in accordance with the waste rock management plan. To date this approach has proven effective.

Conclusions and further opportunities

The proposed approach to mine waste characterisation has provided an effective and cost efficient tool to develop practical waste rock management plans and WRD designs.

By developing a sound understanding of deposit scale geology prior to commencing investigations, it was possible to develop sampling and analyses plans that were tailored to target zones where the greatest risks and opportunities were anticipated. A good understanding of deposit geology can provide an indication of factors including the likely physical properties of waste rock after mining and potential geochemical risks. Contrastingly, deficiencies identified within previous studies generally occurred as a result of an inadequate understanding of deposit geology, which impacted upon the validity of underlying assumptions. Were these deficiencies not identified, it is likely that the previous waste rock management strategy would have resulted in significant ARD issues and long term erosion issues at both Natal and Enterprise.

The utilisation of a multi-disciplinary and experienced team was an important element in streamlining the assessment process. An understanding of the geological zones from previous studies provided an insight into their potential impacts for mine waste management. Adopting a workshop approach to integrate the findings of the study team and develop an agreed approach ensured that the waste management recommendations were able to balance the risks and opportunities and better inform waste rock management and WRD design.

The focus on understanding and utilising available resources ensured that the recommendations developed for the projects were practical and achievable. Commencing waste rock management investigations earlier during mine life enables proponents to avoid sterilising useful mine waste, optimise mine waste handling and establish realistic and achievable closure plans.

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